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Recommendations for developing space suit integrated food systems and delivering nutrition before, during, and after lunar EVA

Recommendations for In-Suit Nutrition

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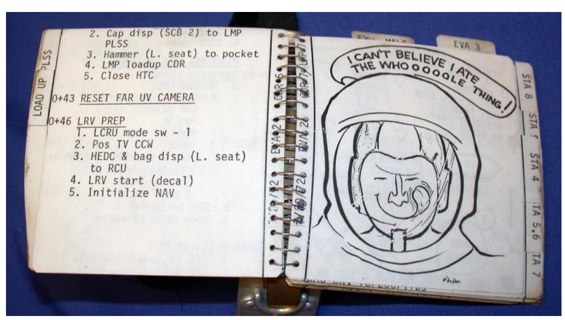

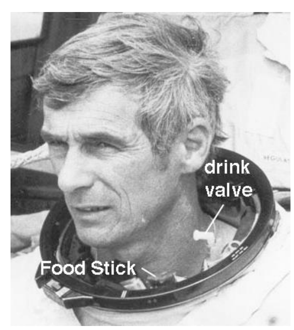

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Photos on title page (left to right): Apollo helmet mounted feed port, Apollo 16 EVA-2 Cuff Checklist, Apollo food stick and drink bag nozzle.
(source: https://www.hq.nasa.gov/alsj/alsj-DrinkFood.html)

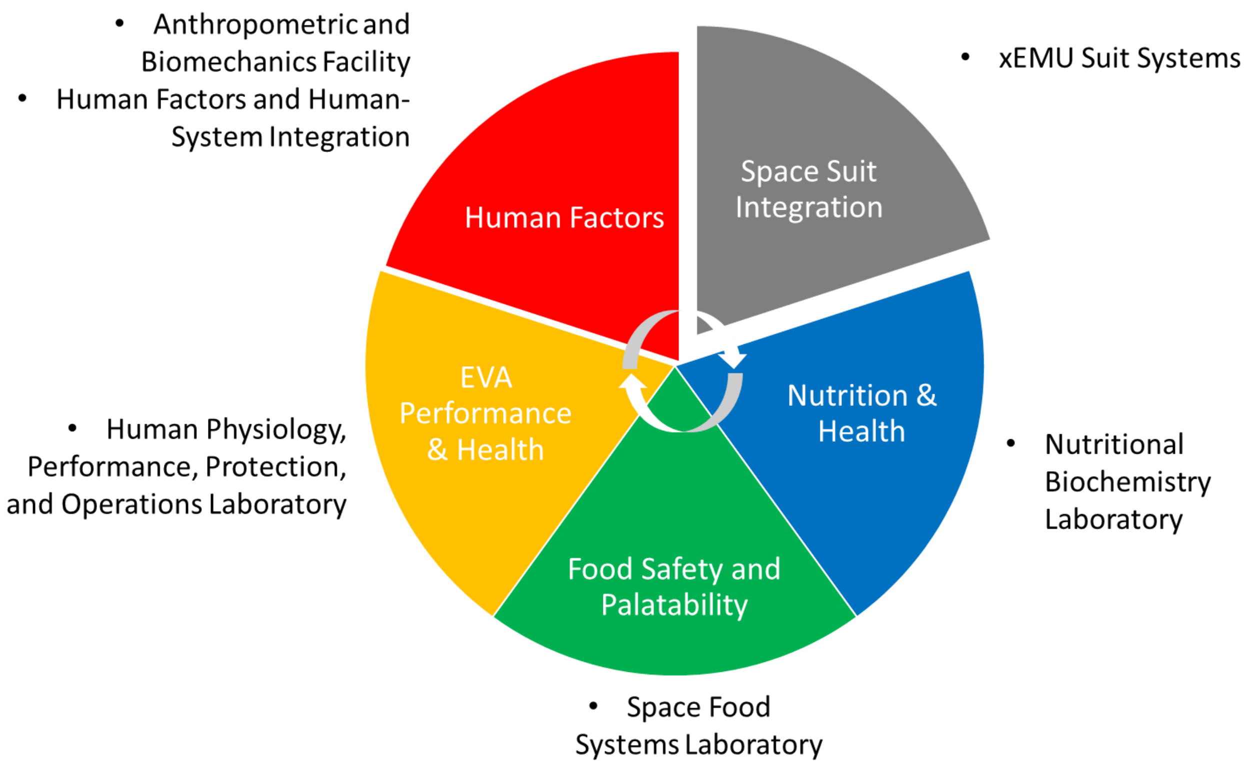
Collaborators & Stakeholders

Collaborators

- Human Physiology, Performance, Protection, and Operations Laboratory (H-3PO)
- Nutritional Biochemistry Laboratory
- Space Food Systems Laboratory (SFSL)
- Anthropometry and Biomechanics Facility (ABF)
- Human Factors and Human-System Integration
- xEMU Suit Systems

StakeHolders

- Human Research Program (HRP)
- EVA and Human Surface Mobility Program (EHP)
- EVA Development Configuration Control Board (CCB)
- EVA and Human Surface Mobility Program Integration Panel (EHP IP)
- Human Systems Risk Board (HSRB)
- Human Health and Performance Directorate (HHPD)



Introduction

The concept of providing hydration and nutrition during extravehicular activity (EVA) is nearly as old as the space program itself. Astronauts currently have access to 32 ounces of water through a disposable in-suit drink bag (DIDB) while they are confined to their space suit. During the Apollo program, methods for providing food/nutrition to crewmembers in space suits were included as contingency solutions (1) but were eventually abandoned. The main reasons that provision of in-suit nutrition beyond water was discontinued after Apollo were the complicated engineering requirements, the additional mass and volume that was required for the applicable food formulations, hardware needed for a suit-specialized food system, and because the perceived need for in-suit nutrition during EVAs was not sufficient during the Space Shuttle and the International Space Station (ISS) eras. A custom-made 165-kcal fruit bar was fitted into the EVA suit during the Space Shuttle program, but crewmembers rarely consumed it during the EVA and rather chose to consume it before or after suited activities (2). Since 2011, between 4 and 13 EVAs have been conducted from the ISS each year, with durations ranging from 1:32 to 8:17 hours (https://www.nasa.gov/mission_pages/station/spacewalks). It has been acceptable for the crewmembers to schedule food intake around these relatively infrequent suited activities. Because upcoming Artemis missions will include nominal 8-hour lunar exploration EVAs that are expected to increase in frequency to several (4 to 5) sorties per week (3), the desire for an in-suit nutrition system has increased. In preparation for these missions, requirements to provide in-suit nutrition has been outlined in the most recent NASA Human Spaceflight Standards documents (4). Establishing general recommendations for in-suit nutrition systems precedes the selection of a lunar EVA pressure suit system. The current document is intended to define the rationale for nutrition to support EVA (whether in-suit or from the pantry in the habitat), document the requirements, constraints, and crewmember preferences, and recommend necessary next steps for developing an in-suit EVA nutrition system.

Assessments presented in this report include a review of commercial off-the-shelf (COTS) food products as potential in-suit formulations, a comparison of conceptual designs for delivering nutrition to a crewmember while confined to a space suit, an evaluation of space suit volume constraints for the placement of in-suit nutrition systems, and feedback from astronauts regarding preferences for nutrition support during EVA. Based on these assessments, recommendations were formulated that can be used to help develop a method to deliver nutrition safely and acceptably to a crewmember while they are confined to a space suit for an EVA duration of up to 8 hours, and a total time in the suit of up to 12 hours.

Background

The design of the extravehicular mobility unit (EMU) suit and EVA operations allow for the consumption of only water from the time the helmet is put on (donned) until it is removed (doffed), which is typically 7 to 10 hours. In the future, Artemis missions will require crewmembers to conduct more frequent and tightly scheduled EVAs on alternating or consecutive days for the duration of time they spend on the lunar surface. High-tempo EVA days are expected to have limited mealtime (e.g., 30 minutes or less for breakfast and 30 to 60 minutes for dinner). It is unknown how much time will occur between conducting EVAs and the scheduled meals, and whether this time separation will be consistent given potentially different mission objectives. If nutrition is provided during EVAs this would allow crewmembers to consume some of their nutritional requirements between the 2 meals, and this could benefit overall crew health, performance, and morale.

Because EVAs increase energy expenditure, a crewmember's energy requirements during EVA increase by an estimated 200 $kcal \cdot h^{-1}$ above nominal energy expenditure (5, 6). Thus, NASA-STD-3001 Volume 2, states that daily food provisions should support an additional 837 $kJ \cdot h^{-1}$ (200 kcal) for surface (e.g. Moon, Mars) EVA (4, 7). Furthermore, the requirements state, "*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.*" Provision of food during the EVAs would reduce the need for the crewmembers to meet their nutritional requirements in only 2 meals, and this will provide additional benefits to physical and cognitive performance during and after EVA operations (8).

A concerted effort from several technical disciplines is required to fully address the following questions regarding the physiological, logistical, and engineering aspects of an EVA food system.

- How much and what type of nutrition support (e.g., kcal, macro- and/or micronutrients) 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? (i.e., determining the physical form of the food (e.g., liquid, solid, limited production of foreign object debris [FOD, i.e., crumbs]), content (e.g., low residue [low fiber]), safety (e.g., microbiologically), and palatability)
- What are the limitations of the suit? (e.g., suit volume, waste management, ports)
- What are the functional capabilities of a suited crewmember? (e.g., will their hands be free to access the nutrition delivery mechanism, will they have restricted movement, what is the injury risk of eating in the suit)
- What are practices and preferences that astronauts commonly follow that should be considered? (e.g., habits regarding eating and drinking before and after EVA or before and after training in the Neutral Buoyancy Laboratory [NBL])

This document summarizes collaborative recommendations from physiologists, food scientists, nutritionists, human factors engineers, and exploration extravehicular mobility unit (xEMU) project engineers and is based on the review of relevant literature addressing planetary EVA and feedback from astronauts.

Rationale for Nutrition during EVA

Total Energy Expenditure (TEE) and Intake (TEI) during Lunar EVA

Nominal nutritional requirements for astronauts have been defined (2, 4, 7, 9); however, data on the potential need for nutritional provisions during surface EVA operations has largely relied on predictive models, data collected during performance in a microgravity environment (10, 11), and limited data collected during the Apollo lunar missions (4-6). Apollo astronauts had substantially (90%) higher metabolic rates during terrestrial training activities before flight than they did during the lunar EVAs: Metabolic rates during ground training at 1 g were 1649 $BTU \cdot h^{-1}$ (the 1649 British thermal units per hour reported equal 416 $kcal \cdot h^{-1}$), and rates were 863 $BTU \cdot h^{-1}$ (218 $kcal \cdot h^{-1}$) when performing the same tasks at 0.17 g during lunar EVA (6). The discordance between ground-based and spaceflight metabolic data complicates establishing accurate in-suit nutritional recommendations for surface EVAs. Existing recommendations for intake of fluid and nutrients during a space mission are based on the 24-hour nutrient needs required to maintain nutritional status and overall health throughout the mission, and these recommendations do not address optimization of task performance.

Establishing the needs for in-suit nutrition during lunar EVA requires some knowledge regarding the expected task loads, duration of the activities, and the frequency of EVAs. Data from the Apollo era provide valuable starting points for such expectations but are nevertheless limited in applicability for establishing Artemis relevant models. Apollo missions were relatively short (up to 3 days on the lunar surface) and no more than 3 EVAs were conducted per mission. In comparison, Artemis missions will be longer with more frequent EVAs, specifically, including EVAs of up to 8 hours, 4-5 times a week (although the total in-suit time is constrained to no more than 24 hours per crewmember per week) (3). Furthermore, Apollo space suits were lighter, yet had less mobility than the suits projected to be available for Artemis EVAs. Thus, even if mission objectives were the same, the physical effort required to perform specific tasks are expected to be different during Apollo and Artemis missions. In addition to data from Apollo lunar missions, other data that can be used to make predictions of metabolic needs during future lunar EVA include athletic, occupational, and military sources and limited EVA simulation studies. Therefore, recommendations outlined in this document will draw from multiple sources and their respective assumptions. Where possible, these assumptions will be aligned with existing or expected NASA standards. For instance, 24-hour recommendations from the International Society of Sports Nutrition (12, 13) and American College of Sports Medicine (14) recommend that total nutrient intake for healthy individuals who exercise follows a standard macronutrient derived energy distribution of about 60% carbohydrate (CHO), 15% protein (PRO), and 25% fat (15). These recommendations specifically target athletes rather than the general population but are still in general agreement with the currently used NASA macronutrient standards for spaceflight (4) and the requirements for future extended duration exploration missions of up to 365 days (45–65 % CHO, 1.2 - 1.8 g $protein \cdot kg^{-1}$ body weight, and 20–35 % fat) (7).

Energy Balance: Doubly Labeled Water (DLW) Experiments during Spaceflight

Doubly labeled water (DLW) experiments are among the most accurate methods for measuring energy expenditure in humans. Total energy demand was assessed by DLW experiments during Space Shuttle missions from 1992 to 1994 (10) and in 1996 (11). Ground-based and flight values for TEE and TEI were compared (**Table 1**).

Table 1. Comparison of calculated total energy expenditure (TEE) and total energy intake (TEI) during pre-flight ground-based operations and in-flight Space Shuttle.

Setting	TEE	TEI	
	kcal·day^{-1}	kcal·day^{-1}	
Ground-Based	3,336 ± 669	2,725 ± 492	(10)
In-flight	2,796 ± 454	2,094 ± 540 *	
Ground-Based	No data	3,025 ± 180	(11)
In-flight	3,320 ± 155	1,943 ± 179 *	

*$p < 0.05$ vs. in-flight TEE

No significant differences were detected between ground-based and in-flight values of TEE (10). Similarly, TEI closely matched TEE during ground-based operations; however, in both studies, TEI was significantly lower than TEE during in-flight operations demonstrating a consistent negative energy balance. Adequate nutrition depends on each astronaut's individual selection of food from a closed, variety-limited food system. Food intake during more recent ISS missions has averaged around 80% of what is recommended (2). Although some ISS astronauts do consume the amounts of food recommended to maintain body mass during a mission, losses between 5 to 10 % of pre-flight body weight are not uncommon. Thus, a risk of undernutrition during spaceflight exists, which may be a function of inadequate overall availability of nutrients, inadequate time to prepare and consume planned provisions, or reduced in-flight *ad libitum* intake due to behavior, preferences, or appetite.

Although the energy balance study provided a foundational understanding of in-flight TEE, the evaluation did not include tasks during EVA when access to exogenous nutrients is restricted for the duration of extended suited operations. Of additional interest from this data set is the imbalance between TEE and TEI during 8 to 16 days of spaceflight. This imbalance during these short duration missions contributed to the loss of body mass of -1.5 ± 1.3 and -2.6 ± 0.4 kg for 8- and 16-day flights, respectively (10, 11). Given the significant decrease in body mass, the imbalance between TEE and TEI demonstrates inadequate overall dietary intake despite unimpeded access to provisions. Although Space Shuttle crewmembers had almost continuous uninterrupted access to provisions (10, 11), they still did not consume enough. It is unclear if adding regular, daily extended lunar EVAs to an operation would reduce intake even more than previously reported (10, 11). If the stress of limited time to access food is added (such as conducting frequent EVAs without nutritional support), this may exacerbate inadequate TEI (i.e., from diminished *ad libitum* intake and decreased overall time to access). From this perspective, in-suit nutrition could be considered imperative to improve overall mission access to food, which will (1) minimize chronic nutrient energy imbalance and (2) provide exogenous energy and nutrients for muscle performance during the EVA.

The DLW data collected during spaceflight provides a gold standard estimate of TEE that represents a foundation for future research that may include lunar surface nutrient needs (10, 11). Although not inclusive of lunar EVA, the above noted values of TEE do include details regarding physical activity such as treadmill and ergometer training periods that vary considerably between the astronaut subjects; however, the energy demands of these tasks cannot be partitioned out of the calculated TEE or compared to expected lunar EVA tasks or demands. Estimates of TEI for mission days that include an 8-hour lunar EVA range from about 4,100 to 4,396 $kcal \cdot day^{-1}$ (2,500 kcal [NASA-STD-3001 base estimate] or 2,796 kcal (10), + 1600 kcal [200 $kcal \cdot h^{-1}$ for 8 hours of EVA]).

Additional rationale and data are necessary to define how much of the nutritional support should be available to the crew while they are wearing the space suit and how much can be leveraged before and after EVA operations. It is therefore important to consider how delivery and access to nutrition can be adjusted in response to a nominal 8-hour lunar EVA in reference to how and when the additional ~1600 kcal (200 $kcal \cdot h^{-1}$ x 8 hours) may be provided across pre, during, and post EVA phases. If provisions are unavailable during a lunar EVA, this leaves about two 30-minute meal periods for nutrient intake (considering an 8-hour EVA, pre- and post-EVA activities, reporting, vehicle maintenance activities, personal hygiene, and 8 hours for sleeping). The reported imbalance between TEE and TEI during spaceflight (10, 11) would likely be exacerbated during lunar operations with multiple EVAs per week.

The estimated range of metabolic rates during several Apollo lunar surface EVAs has been previously reported (898 ± 414 $BTU \cdot h^{-1}$, 226 ± 104 $kcal \cdot h^{-1}$) (16). This range of metabolic rates included the basal energy demands of a typical hour (when *not* on a lunar EVA). Basal metabolic rates have never been directly determined during spaceflight but were determined to be near 70 $kcal \cdot h^{-1}$ after 57 days of head down bed rest as an analog for spaceflight induced unloading (17). The addition of 200 $kcal \cdot h^{-1}$ over background energy demands of ~70 $kcal \cdot h^{-1}$ therefore accounts for TEE and the commensurate total 24-hour nutrient needs during EVA. However, when considering the inclusion of potential emergency-oriented situations and extended walk-back scenarios (estimated at 330-540 $kcal \cdot h^{-1}$) the expected energy expenditure (EE) may be higher, and the food system as a whole must be able to support the worst-case scenario.

Of additional concern is the timing of nutrient delivery to support the expected TEE. While the general macronutrient distribution should be considered, it is imperative to consider that periodically during lunar missions, approximately a third of each day will include suited operations that require adjustments to scheduling of nutrient intake across the day. Logistical factors limit the provision of substantial food and fluids during suited operations and loading intake before and after EVA operations may increase the potential for nutrient imbalance as previously noted (10). In addition, the risk of impaired comfort (such as gastrointestinal [GI] issues, fullness, sluggishness, bowel urgency, etc.) could be aggravated by regularly expecting the crew to consume excessive amounts of food prior to embarking on an EVA. In-suit nutrition could bridge many concerns, although, it is still necessary to consider the macronutrient distribution of potential suited provisions, design considerations (e.g., location and delivery system of provisions in the suit), and the composition of provisions (liquid vs. solid sources).

Rationale for Providing Nutrition during EVA (in-suit) vs. before and after EVA (habitat)

As mentioned above, limited data are available to provide clear requirements for the development of in-suit nutritional formulations. Until additional data are available, some approximations can be made using a combination of flight data, military/occupational practices, and performance-oriented nutrition research. The provisionary recommendations below are based on sources available from NASA (2, 5, 6, 9), armed forces (18-21), sport nutrition (12-14, 22, 23), and extreme occupations such as wildland firefighting (24-26). However, each of these approaches must be validated in terms of metabolic demands in comparison to the metabolic demands of suited operations during spaceflight.

Wildland firefighters (WLFF) perform highly demanding tasks that require careful consideration to meet energy demand while on the job, including consuming approximately 30% of daily energy needs in the field (26). Although the direct effects of consuming meals during performance are unclear (and would be very difficult to study), detailed dietary intake studies of WLFF crews indicate that as much as 40% of total daily caloric intake (3684 ± 1493 kcal) occurs during the shift. For work shifts lasting 14 ± 1 hours, WLFF consumed 878 ± 352 kcal (23%) at breakfast (before their shift), 1494 ± 592 kcal (41%) during the shift, and 1312 ± 550 kcal (36%) at dinner (after their shift) (26). This study alone indicates it would not be possible to rely on consuming food only before and after a shift to maintain energy balance and this strongly supports the argument for in-suit nutrition during planetary surface operations. Essentially, the crew has only a third of the day in which they can consume nutrients in the absence of in-suit nutrition systems (i.e., 8 hours after accounting for 8 hours of sleep and 8 hours of EVA). Furthermore, even when access to nutrition is not an issue, astronauts may still find it challenging to consume enough to maintain energy balance (10, 11). During the Apollo missions, crewmembers reportedly did not eat all the food available due to decreased hunger, feelings of fullness in the abdomen, nausea, and preoccupation with the critical mission tasks. Apollo mission astronauts had limited access to nutrition during suited operations, and they consumed most of their nutrition while in the lunar module. The critical impact of including in-suit nutrition (e.g. liquids during the Apollo 14 mission, followed by liquids plus solids during the Apollo 15 mission) during lunar missions may have been captured in the following 2 passages from the "Biomedical Results from Apollo" (27):

1. *"The Apollo 14 flight marked the first time space crewmen returned to Earth without a significant change in body weight. The Commander and the Lunar Module Pilot had consumed essentially all of their programmed food supply. The Apollo 14 food system included an in-suit drinking device. This allowed the astronauts to better maintain fluid balance during extensive lunar surface operations."*
2. *"Apollo 15 crewmen consumed solid food while working on the lunar surface. High nutrient density food bars were installed inside the full pressure suit… …The in-suit drink device was designed to provide, water or fruit flavored beverages. This crew was the first to consume all of the mission food provided. Negligible weight losses, after equilibration for fluid losses, reaffirmed that the diet provided adequately for the crew's energy requirements."*

Regardless of the many improvements in the food system since the Apollo program, it is still not practical to assume that future surface EVAs will adequately stimulate appetite enough to ensure post-EVA pantry "catch up". Assuming the current average spaceflight requirements of 2500 kcal·day^{-1} (2, 4, 7, 9), an additional 1600 kcal·day^{-1} (to support 8 hours of EVA) would amount to about 40% of the 4100 kcal·day^{-1} provided across the day. Presently, limited data exists to adequately set a minimum threshold for the dietary energy that is needed in a pressure suit. Requiring the provision of 1600 kcal (40% of daily energy needs) during an EVA is logistically challenging but could serve as a theoretical upper threshold for in-suit nutrition systems. Identifying the lowest threshold for in-suit nutrition that benefits the crew above having nothing at all is more challenging and requires an understanding of when and how nutrition affects acute performance.

Energy demands can be met through various macronutrient compositions. As mentioned above, the in-suit nutrition system must be designed with the entire spaceflight food system in mind. The appropriate balance of macronutrients (from which energy will be derived) for in-suit provisions should not disrupt micronutrient balances of the food system as a whole. While allowing for flexibility in the in-suit formulations to optimize EVA performance, the food system as a whole (i.e., in-suit + pantry) must remain balanced to provide approximately 50-55% carbohydrates, <35% protein, and 25-35% fat (4).

Carbohydrates (CHO)

General agreement exists that the provision of energy derived largely or entirely from carbohydrates can aid physical and cognitive performance during extended (>3 hours) activities. Supporting data include laboratory data, ultra-marathon runners in races of up to 50 km, and soldiers engaged in sustained and intense mission-oriented activities (13, 14, 18, 21, 23, 28). Superimposing these recommendations without adjusting for the expected task-specific energy expenditures would grossly inflate the true needs for EVA activities (16). Regardless, these data may still contribute to our understanding of the physiological limits in scenarios where intensities of surface operations exceeded nominal.

Current recommendations for performance nutrition suggest providing 30–50 g $CHO\cdot h^{-1}$ (13) or 30–60 g $CHO\cdot h^{-1}$ (14) for endurance exercise, including "stop and start" sports lasting 1.0–2.5 hours. The recommendations include increases up to 90 g $CHO\cdot h^{-1}$ for endurance and ultra-endurance exercise lasting 2.5–3.0 hours (14). A curvilinear dose response of CHO ingestion has been reported during higher intensity cycling, reaching plateau at about 80 g $CHO\cdot h^{-1}$ (29). The recommendations of 30–60 g or as high as 90 g $CHO\cdot h^{-1}$ are intended to support much higher sustained metabolic demands than are anticipated during lunar surface EVA operations. These hourly CHO dose ranges would provide 120–360 $kcal\cdot h^{-1}$ (4 $kcal\cdot g^{-1}$ x 30 to 90 g). If CHO was the sole macronutrient provided, the provision of 50 $g\cdot h^{-1}$ range (13) is in accordance with the suggested provision of up to 200 additional $kcal\cdot h^{-1}$ x 8 hours (4) and could provide as much as 1600 kcal per EVA.

These recommendations are also reflected in nutrition plans for various military mission scenarios, as outlined in the Special Operations Forces Nutrition Guide (30). Some examples of in-field provision of calories range between 210 $kcal\cdot h^{-1}$ during 14 hours of 'unusual warfare', 163 $kcal\cdot h^{-1}$ during 10 hours of 'special reconnaissance', and 135 $kcal\cdot h^{-1}$ during 14 hours of 'nighttime air missions'. Although fewer calories are provided for the less active hours of the day, these meal plans provide a daily TEI of 3640, 3608, and 3145 kcal, respectively. It is presumed that lunar EVA activities would more likely approach the metabolic needs of the 2 latter scenarios: the addition of 1600 $kcal\cdot day^{-1}$ for EVA support in addition to current average requirements of 2500 $kcal\cdot day^{-1}$ would approximate a total of 4100 $kcal\cdot day^{-1}$ (2, 4, 7, 9). Using the 'nighttime air missions' recommendation of 135 $kcal\cdot h^{-1}$ during mission operations as a target upper bound and keeping the lower bound of 120 $kcal \cdot h^{-1}$ would provide a target in-suit range between 960-1080 kcal for 8-hour EVA scenarios.

Eventual in-suit energy provisions are not intended or expected to fully match EE in real time but are intended to allow for optimal performance during activity and rely on the remainder of the energy deficit to be met before or after EVA. During a controlled 10-hour laboratory exercise trial where peak oxygen consumption (VO_2 peak) was determined, men and women completed multiple hourly modes of exercise including upper body ergometry (9 min, self-selected intensity), cycle ergometry (19 min, 43 ± 6% VO_2 peak) and treadmill walking (20 min, 44 ± 5% VO_2 peak) (23). Based on periodic metabolic gas collections during the cycle portion of the trials, the estimated energy expenditure was about 7 $kcal \cdot min^{-1}$ for women and 9 $kcal \cdot min^{-1}$ for men. Considering that subjects were active for 48 minutes each hour, hourly estimates of exercise EE were about 336 $kcal \cdot h^{-1}$ for women and 432 $kcal \cdot h^{-1}$ for men (not inclusive of the EE during the 12 minutes of seated recovery). Throughout the trial, subjects were provided with either a placebo or 0.6 g CHO per kg of fat free mass, resulting in about 32 $g \cdot h^{-1}$ (128 $kcal \cdot h^{-1}$) for women and 41 $g \cdot h^{-1}$ (164 $kcal \cdot h^{-1}$) for men. At these metabolic rates and feeding schedules, calculated rates of total CHO oxidation were maintained through 9 hours of exercise indicating that the skeletal muscle was receiving adequate energy. In contrast, when exogenous CHO was not provided, total CHO oxidation decreased significantly over time during exercise.

Although lunar EVA will likely increase the crewmembers' overall metabolic needs, the expected energy demands of a lunar EVA are still considerably lower than the above noted hourly EE during the 10-hour exercise trial (23). If the hourly rate of CHO intake ($kcal \cdot h^{-1}$) was proportional to the estimated hourly EE ($kcal \cdot h^{-1}$) then CHO intake/expenditure ratios for women and men were approximately 0.38 (128/336 for women and 163/432 for males) in the above noted study (23). When this ratio is applied to the hourly EE during Apollo lunar EVAs (226 $kcal \cdot h^{-1}$) it corresponds to an intake of 21 g CHO per hour (= $[0.38 \times 226\ kcal \cdot h^{-1}] / 4\ kcal \cdot g^{-1}$)..

It should be noted that the ratio calculated from the above 10-hour laboratory data (23) is based on a relatively high respiratory exchange ratio (RER between 0.90–0.92) indicative of the exercise intensity. Therefore, the expected RER and subsequent rate of total CHO oxidation may be lower during lunar EVA operations if the metabolic rate is lower (16).

This simplified approach of estimating exogenous CHO needs suggests a starting point for which to refine future data collection. This approach estimates that about 15–20 g $CHO \cdot h^{-1}$ should be provided over an 8-hour period (480-640 kcal) during in-suit operations, and also assumes that 100% of the in-suit nutrition is in the form of CHO rather than a mixed macronutrient source. If the estimated kcal needs were met using a mixed macronutrient approach, such as COTS food bar formulations (e.g., 200 Calories from 36 g CHO, 7 g protein, and 2.5 g fat), 2.5 to 3 total bars would be required. This provides context to determine how handsfree, suited nutrient provision might be designed. These logistical challenges and perspective designs are discussed later in this review. A summary of example macronutrient ranges for in-suit nutrition is presented in **Table 2** to provide additional context. Rationales for the inclusion and composition of protein and fat follows in the sections below. Again, it should be noted that these values are based on physically demanding operations in 1 g conditions, and the requirements for EVA activity on the lunar surface may be lower. The example range of

480–640 kcal equates to about 2.4–3.2 hours of in-suit nutrition according to the 200 $kcal \cdot h^{-1}$ EVA requirement (4).

Table 2. Summary example of in-suit provision for macronutrients.

		Total per hour					Total for 8 hours				
		Energy (kcal/h)	CHO (g/h)	PRO* (g/h)	Fat** (g/h)	Mass (g/h)	Energy (kcal)	CHO (g)	PRO* (g)	Fat** (g)	Mass (g)
CHO-only			100%	-	-			100%	-	-	
	Lower	60	15	-	-	15	480	120	-	-	120
	Upper	80	20	-	-	20	640	160	-	-	160
Balanced			55%	25%	20%			55%	25%	20%	
	Lower	60	8	4	1	13	480	66	30	11	107
	Upper	80	11	5	2	18	640	88	40	14	142

* The bottom of the recommended range of about 5–10 $g \cdot h^{-1}$ protein (PRO) is presented here. Increasing PRO content assumes that carbohydrate (CHO) or fat content will be adjusted to keep these recommendations isocaloric. Including a minimum of 30 g of quality protein (containing ≥ 10 g essential amino acid) may provide an additional anabolic stimulus during the day to protect skeletal muscle.
** No specific recommendations for acute fat intake exist other than provision of calories, palatability, and maintaining daily recommendations. The balanced profile presented in this table assumes that about 20% of in-suit calories are provided as fat.

Protein and Amino Acids

Most studies have focused on consumption of protein, essential amino acid (EEA), or leucine supplementation during the pre- and post-exercise periods. Nevertheless, the inclusion of protein *during* activity may help maintain satiety and promote improvements in the overall rate of protein synthesis during activity and for extended periods of time after activity (upwards of 24 hours) (22). Collectively, the data in the literature also demonstrate a distinct dose and time response to stimulate muscle protein synthesis. However, the literature lacks the external validity to clearly suggest best practices during extended lunar operations that require repeated daily EVAs. The logistical preparations prior to and immediately after EVA may limit including the best practices in protein or EAA intake that are used on Earth. Data from Lane et al. (10) provide a warning with regards to the adequacy of TEI during spaceflight. As noted above, these data were collected during Space Shuttle missions when astronauts had no disruption in access to provisions due to EVA. These data in combination to the small number of studies that have considered the effect of protein intake during activity strongly advocate for the ingestion of either optimized intact protein sources (perhaps as part of the solid food bar formulation) or as EAA added to the food system. Thus, the inclusion of protein during activity may aid in maintaining satiety and preventing the onset of CHO-induced fatigue (22, 31). It is common practice to provide 5–10 g of protein per hour of activity to sustain acute performance during sports and military operations (13, 30). However, higher quantities of protein (especially boluses containing at least 20–30 g high quality protein) consumed during and/or after exercise may be even more beneficial for promoting muscle protein synthesis and aiding recovery after activity (12). Quality protein sources are readily digestible and should provide at least 10 g of EAA (and ~2 g of leucine) per 20–30 g serving (32, 33) Providing 25–50 g CHO + 5–10 g PRO per hour of activity would have the same caloric density as 30–60 g of CHO-only formulations and may improve the overall quality of in-suit nutrition.

Fat

The inclusion of fat increases caloric density but may slow digestion and intestinal absorption, contributing to GI distress. Dietary fats may also deliver longer term benefits on metabolic regulation of fuels, although evidence is insufficient to make specific recommendations for requirements, especially regarding inclusion of fat in EVA provisions (2, 6). Thus, no specific recommendations exist for acute fat intake to support performance other than provision of calories, increasing palatability, and maintaining daily recommendations. Although provision of CHO may be sufficient to power acute performance (28), inclusion of 25–35% of kcal as fat may be warranted to support daily TEI recommendations (4, 13) if it does not impair palatability and ingestion. Inadequate data exists to suggest that fat should replace additional CHO and protein or EEA sources when space constraints and the logistics of delivery mandate maximal efficiency of design. Maximizing the form and function of design that provides in-suit nutrition is imperative. Even if CHO is sufficient to power acute performance (28), including 25–35% of kcal as fat may be considered to support standard daily recommendations (4, 13).

Other Nutrients

For prolonged exercise of more than 1 hour, recommendations suggest replacing sodium by including 0.5–0.7g/L in fluid (34). However, this concept has almost no relevance to suited EVAs because a liquid cooling garment assists in the overall thermoregulation. The anticipated losses of sodium through sweat during EVA are likely much less than during exercise on the ISS or during ground-based training. Except for sodium, no strong evidence exists supporting the acute need for augmentation of specific micronutrients and vitamins during physical activities. Moreover, the reported average daily sodium intake during spaceflight is high, suggesting no need to specifically include additional sources of sodium in the fluid reservoir drinking system.

Space Food Systems

A food product needs to be identified or developed that meets minimum nutritional requirements, is compatible with the suit (i.e., low in FOD, potential for hands-free access), and remains safe to consume throughout the EVA (i.e., low microbial growth). The most efficient solution would be a COTS food bar, beverage powder, or nutritional gel, if any can be identified that meet all requirements. Each solution introduces different challenges for delivery to suited crewmembers. Crewmembers cannot use their hands to aid with food consumption while in the suit, making solid food delivery, such as a bar, a challenge. Gels may also be challenging to access hands-free. During the Space Shuttle program, a solid, FOD-free food, similar to a fruit rollup in texture, was developed for hands-free access in the helmet during EVAs. Many crewmembers opted to consume this item prior to donning the suit because this was an easier option, so inclusion of food was discontinued (source: personal communication between G. Douglas and former ISS Food System Manager, V. Kloeris). Unless an easy delivery solution is developed, COTS bars are likely to be consumed similarly to the discontinued fruit rollup item and will not provide a viable option for nutrition throughout an 8-hour EVA. Food bars are also the most likely to produce FOD.

Powdered beverages could be rehydrated prior to the EVA, but microbiological safety may be an issue for all high-moisture nutritional products held at room temperature for over a 2-hour timeline. Additionally, no space currently exists in the suit for an extra beverage in addition to the water already provided. Commercial liquids would need to be processed to a powder before any additional evaluations would be feasible, and they would include the same microbiological challenges as COTS powders.

Practical Aspects and Engineering Considerations

Space suits could, at least in concept, be designed with the capability to provide 200 kcal$\cdot$h^{-1} during 8 hours of EVA, based on the additional requirements expected for expenditures during nominal EVAs. From an engineering perspective, the new exploration EMU suits are designed to accommodate a total of ~9600 BTU per EVA. For example, this capacity supports average metabolic profiles of 1200 BTU$\cdot$h^{-1} (303 kcal$\cdot$h^{-1}) for up to 8 hours of EVA. A max output of 303 kcal$\cdot$h^{-1} for 8 hours equals 2424 kcal, which is close to the expected daily requirement for most crew. Additionally, individual needs and preferences will vary during in-suit operations, as will task intensities and metabolic rates. The recommendations outlined above do not account for variations between individuals or specific mission objectives. The proposed recommendations for in-suit nutrition are not intended to match any of these upper limits, but instead, they should address the added energy requirements needed for EVA and provide sufficient nourishment during these activities to optimize crew performance.

Summary

The assessments and recommendations provided here are a starting point for the development of relevant in-suit formulations and nutrition delivery systems for lunar EVAs. These recommendations aim to provide a reasonable and effective amount of nutrition to maintain satiety while contributing to the muscle fuel demands and cognitive requirements of the EVA. In-suit provisions are not intended to deliver the entire additional energy demands during suited conditions but may provide an opportunity to improve intake compliance and limit the likelihood of persistent negative balance for energy and protein. For example, in-suit provision of approximately 480–640 (**Table 2**) of the 1600 kcal allocated to replenish added energy expenditures (200 kcal$\cdot$h^{-1} during 8 hours of EVA) assumes that the remaining energy (1120–960 kcal) will need to be accounted for during un-suited time periods (i.e., meals from the pantry consumed before and after EVA). Although nominal EVAs are expected to last 8 hours or less, crew may spend considerably longer periods in the suit, albeit at lower metabolic rates. Although procedures for future exploration EVAs are expected to be more time efficient, at present it is not unusual for crew to spend 2 hours confined to the suit before and/or after ISS EVA operations and isolated from the standard sources of nutrition. Striving to provide between 400–600 kcal of energy in the suit is a realistic target. Whereas 400 kcal would provide a minimum for in-suit nutrition, including up to 600 kcal would directly replenish the energy expenditure required for approximately 3 hours of EVA (note that per NASA-STD-3001, the requirement for in-suit nutrition becomes effective after 4 hours of EVA (4)). However, providing more than ~600 kcal is not expected to further add to astronaut performance and could potentially contribute to increased waste if the provisions are not consumed during the EVA.

As indicated above, limiting the TEI to unsuited periods in the lunar capsule may impair the likelihood of matching TEE and maximizing the muscle protein synthesis and balance. The need exists for a unique in-suit nutrition strategy that supports the added metabolic cost of the EVA and contributes to the goal of near energy and protein balance. Feedback from Apollo astronauts and transcripts indicate that both the fruit type food bar and the fluid delivery system were satisfying and effective countermeasures for thirst and fatigue during extended EVAs (source: personal communication on 2022-04-08 between B. Ruby and Apollo 16 lunar module pilot, C. Duke, and accounts available online in the Apollo Lunar Surface Journal (https://www.hq.nasa.gov/alsj/main.html)). However, the fruit type food bar was discontinued after crewmembers provided feedback during the Space Shuttle Program. Feedback from past and current crewmembers will also be considered and discussed as solutions are developed for future missions.

Assessments

Assessment of Bars, Powders, Beverages, and Gels for EVA Nutrition

COTS foods were reviewed in March 2021 and rated by likelihood for success as potential in-suit formulations. The preliminary evaluation assessed nutritional potential for supporting lunar EVA missions. High calorie snacks, nutritional shakes, and meal replacement therapies were identified. Because it will be challenging to meet requirements of up to 1000 calories during an EVA using COTS items, a minimum caloric content of 400 kcal per serving was targeted that contained carbohydrate content between 35 g and 50 g per serving; sodium content between 200 mg and 500 mg per serving; and potassium content greater than 100 mg per serving. Higher calorie options could be developed in house. The full list of commercial products that were identified are attached in **Appendix A**.

Results: Nutritional Assessment

Several COTS bars and beverage powders were identified that met minimum nutritional requirements, but only if multiple servings are used (**Table 3**). Increasing the serving size may inhibit the product's ability to fit within the space that will be allotted for food within the suit, which is extremely limited (**Figure 1**). Additionally, some COTS items are fortified to high levels. Increasing the serving size may put levels of some nutrients above maximum recommendations, especially when considered within the complete nutrition of the whole food system and this may introduce a toxicity risk.

From the COTS items considered, no gels were identified that met the minimum nutritional requirements. Beverages (ready to consume, no hydration required) were omitted from this list. However, both gels and liquids may be considered with further product formulation and development, such as spray drying or freeze-drying options or development of a compatible delivery system for the suit.

Results: Microbiological Assessment

In addition, the Space Food Systems Laboratory conducted microbiological assessments of the products listed in **Table 3** and the 2 COTS gels, to determine if these items would be compatible with EVA timelines. The bars, beverage powders, and gels were also tested for water activity, as necessary, to determine potential for use as in-suit nutrition. To meet multi-year room temperature storage requirements, products must be commercially sterile in the original intact packaging in which they were processed, or they should have a water activity below 0.60 and meet space food microbiological requirements outlined in NASA-STD-3001 (4) before and after they are packaged. Water activity up to 0.80 may be acceptable after additional hurdle technology methods such as modified atmosphere packaging or certain preservatives. To meet the 12-hour in-suit use requirements without generating a microbiological hazard, products must meet space food microbiological requirements outlined in NASA-STD-3001 throughout the entire timeline. All products evaluated met baseline (dry, unopened) microbiological requirements, but no products met both the timeline microbiological requirement and the FOD requirement (**Appendix B**).

Table 3 Products considered for further assessment and for potential/suit spacing, FOD, acceptability, and microbiological safety over 8 hours. Full list of products and information is available in Appendix A.

Bars	**Notes**
Level 1 Bar (Birthday Cake)	Sodium content is above the specified range.
RxBar	Various flavors meet nutritional requirements, but potassium content would need to be assessed for the timeline and within the whole diet.
Wonder Slim Meal Bar (Dark Chocolate S'more)	These are fortified and total nutrition would need to be assessed within whole diet.
Powdered Beverages*	**Notes**
Naturade Weight Gain—Instant Nutrition Drink Mix	Sodium content is slightly above the specified range; whole milk powder can be added to increase caloric content. Potassium content would need to be assessed within whole diet.
Healthy Height Shake Mix	May require additional sodium.
Hormel Vital Cuisine Shake Mix (with 1 cup of Judee's whole milk)	These are fortified and total nutrition would need to be assessed within whole diet.

*Beverage rehydration procedures may vary according to product. Rehydration must be completed before donning the suit.

No products assessed met nutritional, microbiological, and FOD requirements, so further COTS analysis or product development would be needed. Products would have to be further assessed to ensure nutrients would not be above maximum requirements within the whole diet, and evaluated for spatial configuration, FOD compliance, and delivery potential within the suit. Sensory evaluation (42) would also be required to verify that selected products remain acceptable for the duration of the EVA mission. Food types that did not meet microbiological requirements would need further development to determine if microbiological requirements can be met. These assessments could include co-design with nutritional delivery mechanisms to determine if this would help meet the requirements.

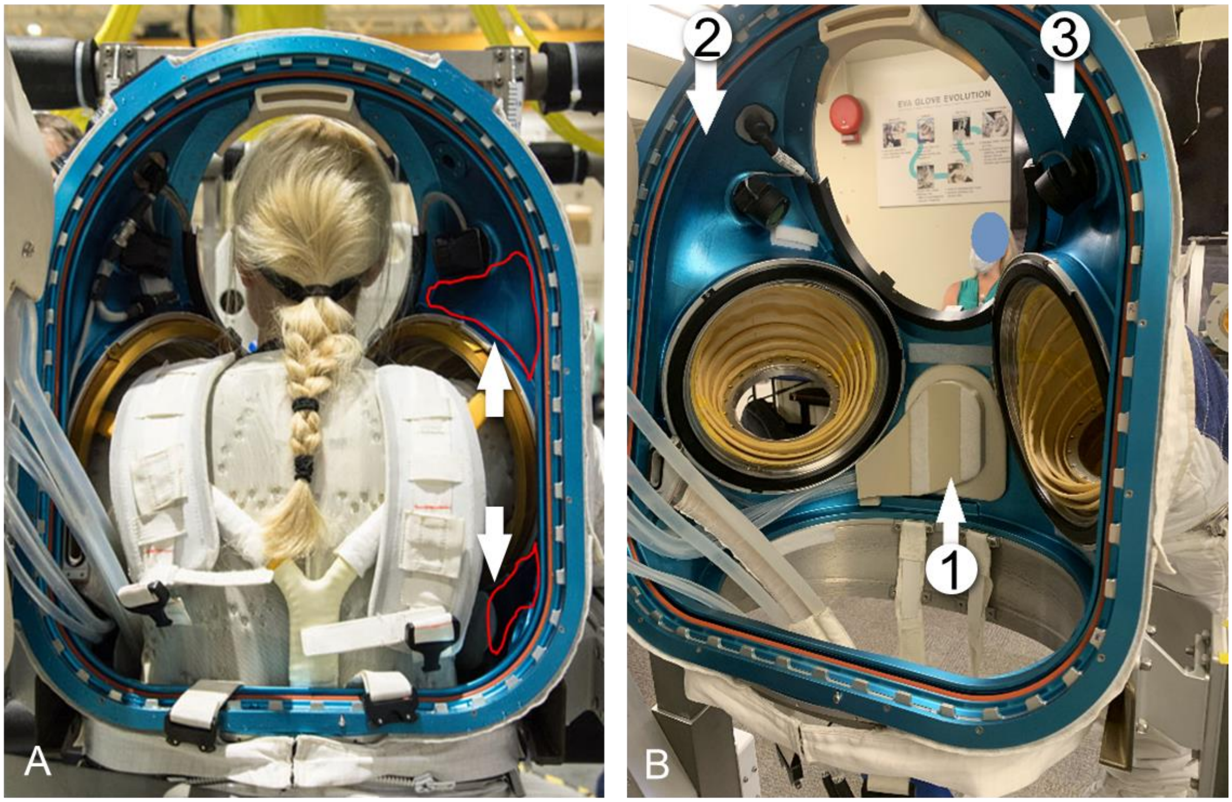


*Figure 1 Examples of potential location for food within the xEMU hard upper torso (HUT). **A.** Top right side, which is 2" x 5" x 0.5" depth area can be allocated for an in-suit nutrition system. Left shoulder (scye opening) is also a potential area where a straw can be held in place with Velcro for a tube food option. Lower right area is under consideration for a 64 oz disposable in-suit drink bag (DIDB). **B.** Numbered white arrows indicate potential locations of an in-suit nutrition system.*

Assessment of Concept Design References for In-Suit Nutrition Delivery Systems

Based on historical content, input from subject matter experts, and potential COTS foods or product development options, 4 generalizable concepts for delivering in-suit nutrition were chosen for further discussion. Advantages and disadvantages of the 4 high level concept designs will be discussed in the results section.

The historical content that was consulted included the SP-368 Biomedical Results of Apollo (43); Apollo Food Technology (27); the Apollo Experience Report—Food Systems (1); the Man-Systems Integration Standard (NASA-STD-3000, which was superseded by NASA-STD-3001 (4) but is still available for reference at https://msis.jsc.nasa.gov/sections/section07.htm#7.2.2.2); and the Apollo Technical Debriefings available online through the Apollo Lunar Surface Journal (https://www.hq.nasa.gov/alsj/main.html). The 4 concept designs include preparations that provide nutrition in the form of liquid or solid foods to the astronaut in the suit (**Table 4**). Two of these concepts support handsfree delivery of liquid nutrition inside the suit, one concept supports handsfree delivery of solid nutrition within the suit, and one concept supports the delivery of (semi)liquid nutrition through an external helmet port. Each concept comes with inherent advantages and disadvantages that are addressed below.

At present, capabilities are already in place that provide fluids to astronauts while they are confined to a space suit. DIDBs are currently used to provide hydration (water) to crewmembers during EVA. A maximum absorbency garment (MAG) is worn by the crewmembers, which allows them to dispel waste while confined to the suit. The DIDB holds approximately 1L of fluid (32 oz) and larger versions (64 oz) are being considered for development to expand in-suit hydration capabilities. In-suit drink bags have been used in the past to provide crewmembers with potassium fortified orange flavored drinks during EVA (44) and during ground-based testing of nutritional formulations (45). The consumption of anything besides water while in a pressure suit was discontinued after the Apollo missions, presumably due to the limited trade-off between added nutritional value and the added inconveniences, such as those related to in-suit spills and cleanup. Theoretically, using a DIDB to provide liquid nutrition remains a possibility. The current configuration would require filling the DIDB with a liquid formulation before the EVA. This approach introduces food safety limitations that must be considered, including a predefined time windows (i.e., 2 hours) during which the food should be consumed to prevent foodborne illness and to ensure crew health. Another disadvantage of providing liquid nutrition is that due to the volume of the current DIDB, installing 2 bags to provide hydration plus nutrition separately may be a limiting factor in current space suit design. Although water will always be provided in the suit, adjustments in the volume of drinking water could be considered. For instance, the addition of liquid nutrition may reduce the desire for water, whereas including solid food may stimulate thirst and the desire for more water. Extended capabilities in future pressure suit designs can be envisioned that address the concerns mentioned. However, because the capabilities do not yet exist, it is unknown if they will require development of custom foods, packaging, and suit systems.

Results: Nutrition Delivery System Design Concepts

The in-suit nutrition system design concepts were assessed for known or expected advantages and limitations by experts in nutrition, food science, and suit engineering (see discussion above and a summary in Table 4).

Concept 1: Drink Bag (Liquid)

Sterilized drink bags that are filled and sealed before flight are among the possible and likely implementable solutions for providing extended shelf-life foods in liquid form for consumption during suited operation. Such bags could be positioned alongside DIDB to provide water and nutrition separately (**Figure 2, Figure 3**). The advantage of a prefilled drink bag is that it is a sterile, ready-to-consume approach comparable to the “thermostabilized wet packs” first introduced during the Apollo program (1, 44). Numerous COTS foods are available on the market today that provide examples of this concept (**Appendix A**) but no specific products have been identified that meet all flight requirements. Although liquids are discussed here, semi-liquid (i.e., gel) formulations could also be considered. Ready-to-consume formulations conceptually require minimum preparation during flight, although rigorous development and testing of foods and packaging will be necessary. Historically, the use of foods with high water content has been somewhat limited for several reasons, including food stability, but also to reduce overall mass and launch costs. Furthermore, food packaging alone can contribute to as much as 17% of the up-mass for foods (46). The advantages of flying dehydrated foods were first realized during the Mercury Program (1). The need to launch water for consumption was lessened during the Mercury through the Space Shuttle programs because water was an available byproduct of the fuel cells used, and flying dehydrated foods saved mass. Because current ISS and future Artemis missions do impose a need to launch water for hydration, less incentive exists to dehydrate foods for reasons besides food stability and safety. Additionally, launch costs are at a historic low and continue to decline, which supports providing fully hydrated food to maximize nutritional quality and acceptability (47).

Although the use of sterile, ready-to-consume liquid formulations appears to be a simple approach to adopt, there are a several limitations that must be considered depending on the intended in-suit application. The first approach to consider is a scenario where the food product is opened and installed just prior to donning the space suit. From a food safety perspective, breaking the package seal essentially marks the beginning of a 2-hour time window within which the food is no longer sterile and must be consumed. Beyond this time window, microbiological growth and the risk for foodborne illness increases. In this scenario, provisions would be available during the initial stage of confinement to the pressure suit even though the requirements for in-suit nutrition do not take effect until at least 4 hours into the EVA (4). This is an undesirable scenario and would likely not be implemented or could unintentionally result in crewmembers choosing to consume the food prior to donning the suit, beyond the shelf life of the opened product, or not at all. Eating the food prior to donning the suit would negate the intent of providing the capability of in-suit nutrition and consuming the food past its shelf-life presents a health risk to the crew. Any food not consumed contributes to waste, which is especially costly in spaceflight environments where supplies and calories are limited. Hypothetical

Figure 2. Rough concept of a liquid filled bag on top of an empty disposable in-suit drink bag.

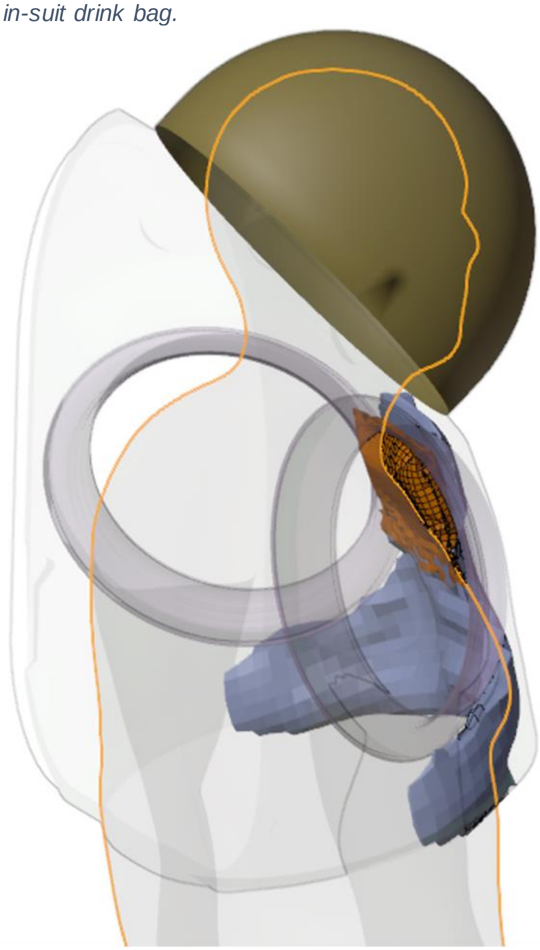


Figure 3 Preliminary volumetric representation of a drink bag integrated in the xEMU.

work-around engineering solutions include developing in-suit refrigeration systems or other means to extend the shelf-life of opened products well into the latter parts of the EVA when nutritional support is needed most. This capability does not currently exist and has not yet been explored. The second approach to consider involves determining the feasibility of developing custom packaging capabilities that would allow the sterile food product to remain sealed while installed in the suit. In this scenario, the astronaut would need to have the capability to puncture the sealed package (such as a bite valve) at any time during the EVA and initiate consumption of the contents at that time. However, the seal would have to be strong enough that it would not be accidentally punctured prior to crew intended initiation. This is a desirable approach from a food safety perspective and may help reduce the incentive for the crewmembers to consume the food prior to the EVA. Customized products and capabilities, including packaging, would need to be developed and produced for this application. It remains unknown whether this development would occur internal to NASA or in cooperation with future commercial industry partners, or whether it would even be successful.

Concept 2: Drink Bag (Hydratable Powder)

As an alternative to providing ready-to-drink liquids (**Figure 4A**), drink bags could be provided as freeze-dried powdered packages that require rehydration prior to consumption (**Figure 4B**). This approach was first used and tested for food products during the Apollo program. Several scenarios could be envisioned with this general approach. The most straightforward approach is that the food product would be reconstituted with water just prior to EVA. In this case, consumption would be limited to the first hours of the EVA (similar to opened ready-to-drink liquid bags). Just like opening prefilled drink bags prior to donning the pressure suit, this would be of limited value to the crew without additional in-suit capabilities such as refrigeration or other solutions that extend the shelf life of opened consumables. Another approach would require developing an in-suit food hydration system. The capability to hydrate powdered nutrition handsfree from within the suit during later phases of an EVA would allow for consumption at demand. This capability does not currently exist and is not in development.

Drink Bag Limitations. As for all of the liquid-based nutrition solutions (i.e., ready-to-consume or rehydrated), the window of consumption will be approximately 2 hours after breaking the packaging seal without measures that are specifically designed to extend product shelf-life

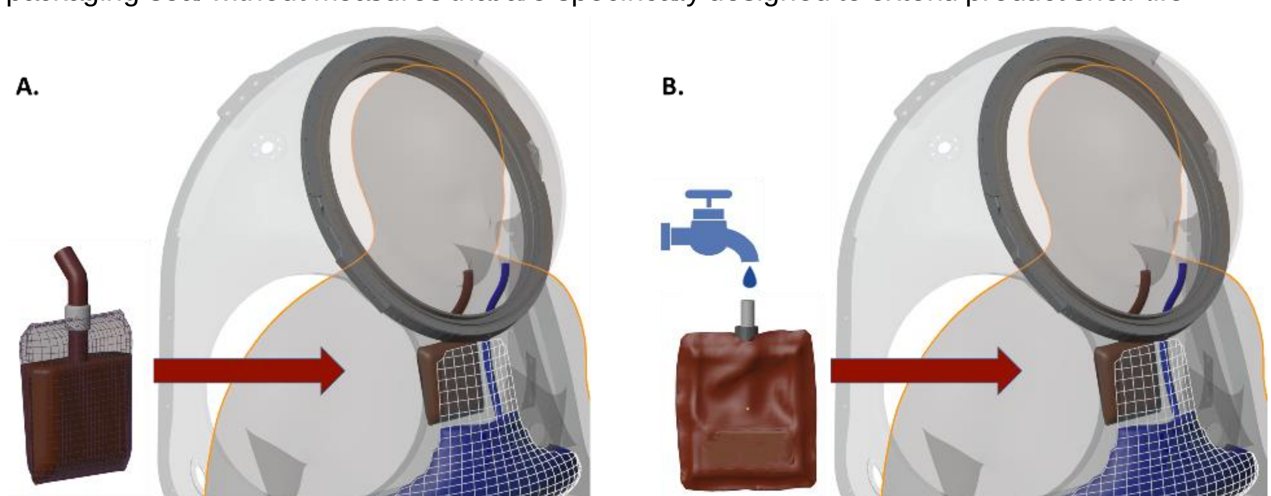


Figure 4. Representation of a conceptual in-suit nutrition system as either ***A.*** *prefilled drink bag or* ***B.*** *hydratable drink bag.*

beyond this time frame. This severely limits the application of several approaches because the nutrition would have to be consumed soon after donning the pressure suit. Engineering solutions that allow for adding/transferring water to hydrate the nutrition beverages within the pressure suit, or major advances in food science to prolong shelf life, would be needed to make hydratable drink bags a more viable solution. These capabilities do not currently exist. The use of sterile prefilled bags would likely be more operationally feasible than adding water within the suit, as long as the crewmember can break the packaging seal handsfree while confined to the pressure suit. This capability, which has also yet to de demonstrated but likely will be required for mission success, would give the astronaut the freedom to initiate consumption when the need for nutrition arises and initiates a 2-hour consumption window starting at that time.

Concept 3: Food Stick (Solid)

Solid foods have been successfully used during EVAs since the Apollo program, albeit with mixed acceptance by the crewmembers and subsequent abandonment. Solid food bars were developed in several flavors and coated in edible paper to prevent sticking. Each weighed about 53–62 g and provided approximately 188 kcal each (> 3 kcal per gram) (44). The bars were secured within the suit helmet space for handsfree consumption (**Figure 5, Figure 6)** (1). The placement allowed the crew to reach, bite, and pull the bar up by mouth while suited. The Apollo 15 crew reported relying on these food bars to provide highly desirable ‘energy boosts’ during lunar surface operations, especially when the drink bags did not function properly (Apollo 15 Technical Crew Debriefing, https://www.hq.nasa.gov/alsj/alsj-tecdbrf.html). However, not all crewmembers agreed they needed a solid food option and sometimes preferred the drink bags for nourishment because they found the food bars ‘messy once they became soggy’ (Apollo 16 Technical Crew Debriefing, https://www.hq.nasa.gov/alsj/alsj-tecdbrf.html). Inclusion of solid “fruit bars” in space suit operations were subsequently abandoned during the Space Shuttle program because crewmembers generally did not perceive the need for in-suit nutrition as great enough to overcome the burdens associated with installing the food bar and consuming it during EVA. This may in part highlight operational or perceived differences between conducting surface vs.

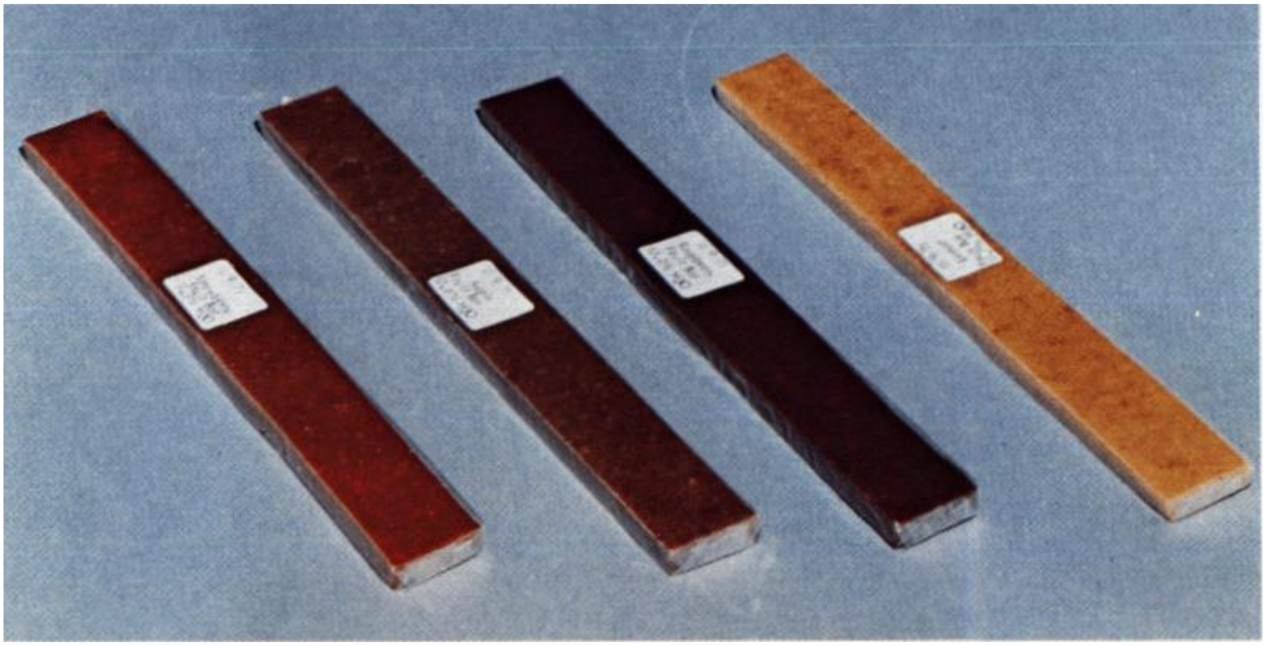


Figure 5. High density food bars developed during Apollo.

microgravity EVA. The solid food concept remains a highly viable consideration for exploration missions where EVA duration and frequency will increase and the crewmember's desire for in-suit nutrition is expected to be higher than during previous space programs. Assessments of the crewmember's head/jaw motions and occupancy position/volume within the helmet can also help to optimize the design of the delivery system so it does not interfere with the critical EVA activities, such as communication or securing the field of view.

A. B.

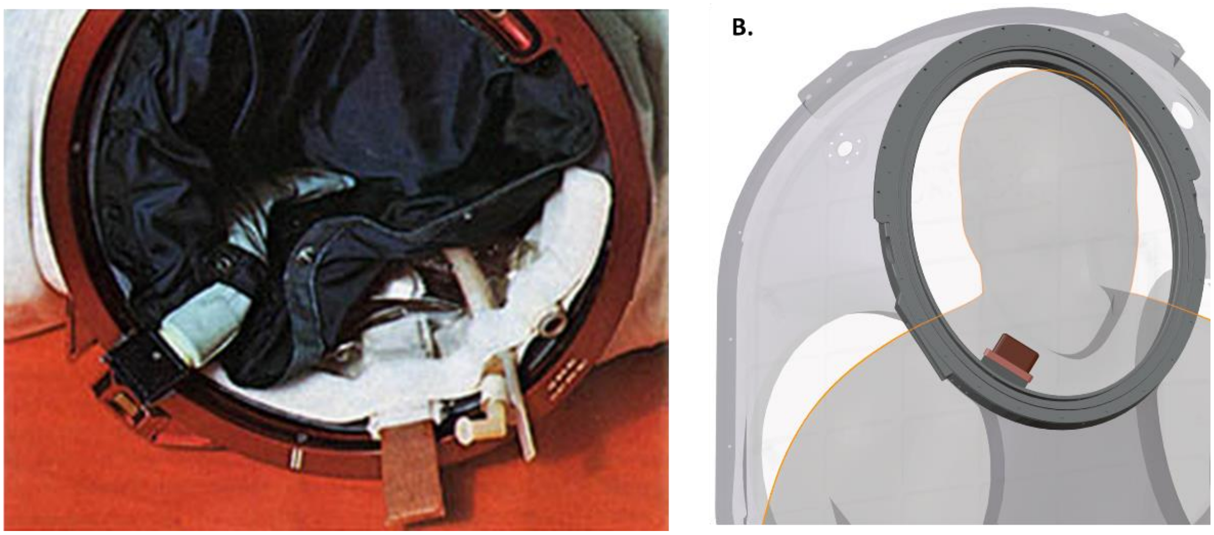


Figure 6 ***A.*** *Food and fluid dispenser attached to helmet neck ring of Apollo pressure suit.* ***B.*** *Concept illustration of solid food stick placement in xEMU suit*

Concept 4: Feed Port (Liquid)

The use of a helmet feed port was first introduced as a solution to provide nutrition to suited crewmembers in contingency situations during Apollo missions (**Figure 7**) (1). Several redesigns were implemented before a final successful system was included for use in contingency operations during Apollo 10 through 14. Because it was established as a contingency measure for crewmembers who were confined to pressurized suits for unforeseen extended durations (up to 115 hours), crew never had an actual need to use these feed ports during the missions. The final system included a mounted helmet port on the crew left side. The port provided entry for a 6-inch extended one-way valve adapter tube (referred to as pontube) that could be connected to beverage packages. Because the port was in an awkward position it was anticipated that using this system might require assistance from fellow crewmembers. Zippered nylon food-restrainer pouches that were developed to hold a beverage package were intended to allow for rehydration of the fruit-flavored beverage powder and prevent rupture of the package during pressure equalization with the space suit (3.5 psia). After mating the system with the helmet port and opening the valve, the application of positive external pressure on the pouch and suction by the crewmember from the pontube was intended to allow for consumption of the beverage. It did not work as intended in recent testing; external pressure by the crewmember was not great enough to overcome the pressure differential from the suit. Therefore, a new design for such an in-suit nutritional delivery system (involving a helmet feed port) was recently developed with significantly improved usability for specific contingency scenarios, but it requires crew to use pressurized gloved hands, and it would still require them to consume the product within 2 hours of rehydration to prevent foodborne illness (48).

Developing a helmet port system requires significant engineering efforts as well as the development of additional procedures. Including a helmet port may impose additional risks to suit integrity and function that need to be mitigated because the port will have to withstand the pressure differential between the internal and external environments when not in use but stay open when connected to the nutrition system. The interface between the helmet port and the nutrition system must also be manageable for the astronaut to use. Furthermore, physiochemical (dust) mitigation must be considered because particles may physically interfere with the helmet port mechanisms and could enter and contaminate the food system, posing possible health concerns. Finally, future surface EVAs may involve entry through a back hatch of space suits that are positioned to face external to the vehicle. This is very different from current ISS operations where suited astronauts exit the vehicle through airlocks and can carry tools and supplies out with them. This is an important logistical difference because rear entry suit operations would require that the foods be prepared and then staged outside the vehicle before the EVA.

A. B.

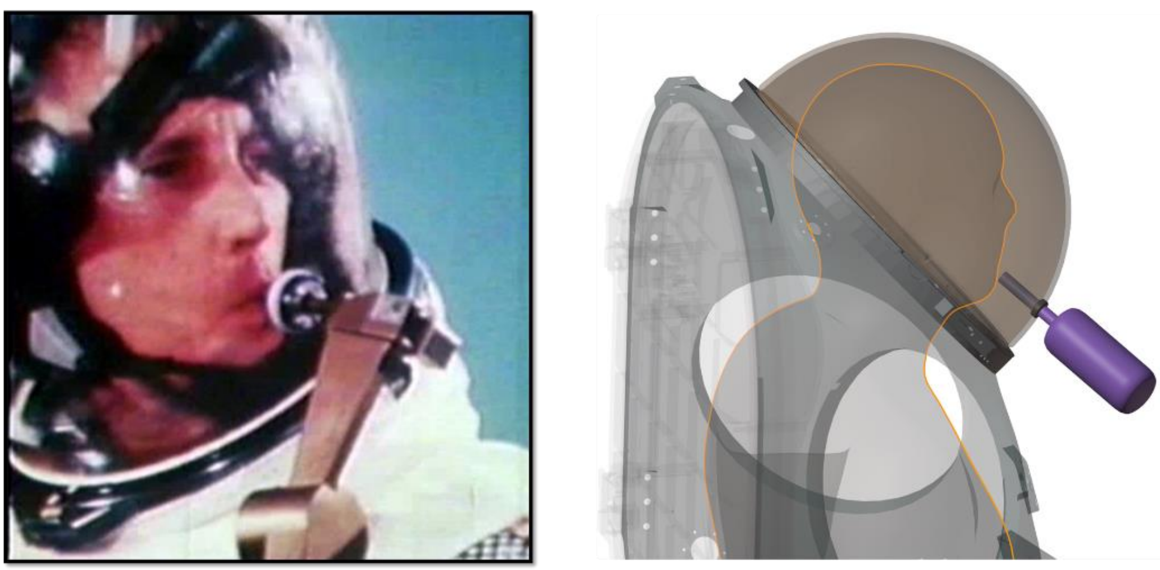


Figure 7 ***A.*** *Demonstration of the Apollo contingency helmet feed port.* ***B.*** *Concept illustration of an external nutrition system with xEMU helmet feed port.*

Table 4. Design concept characteristics

Delivery Concept		In-flight Prep	Special Capabilities Needed or Desirable	Advantages	Limitations
Drink Bag Prepackaged (Semi)Liquid	**Thermostabilized**	Open BEFORE EVA	- Handsfree Access - Desirable: advances in engineering to extend food shelf life	- Ease of install/use/removal - Variety of implementation (potential COTS available)	- Higher launch mass (water) - Must be consumed during early phase of EVA (within 2 hours of breaking seal)
Drink Bag Prepackaged (Semi)Liquid	**Thermostabilized**	Open DURING EVA	- Handsfree Access - Handsfree opening/breaking seal within suit - Desirable: advances in engineering to extend food shelf life	- Ease of install/use/removal - Consume at time when nutrition is desired during EVA - Variety of implementation (potential COTS available)	- Higher launch mass (water) - Delivery hardware has not been developed and feasibility is unknown
Drink Bag Powder	**Rehydratable**	Rehydrate BEFORE EVA	- Handsfree Access - Desirable: advances in engineering to extend food shelf life	- Low launch mass - Ease of use/removal - Variety of implementation (potential COTS available)	- Requires rehydration prior to donning pressure suit - Must be consumed during early phase of EVA (within 2 hours of breaking seal/adding water)
Drink Bag Powder	**Rehydratable**	Rehydrate DURING EVA	- Handsfree Access - Requires advances in engineering to provide in-suit Hydration Mechanism	- Low launch mass - Ease of use/removal - Extended window for consumption during EVA - Variety of implementation (potential COTS available)	- In-suit hydration technology not currently available
Food Bar Solid	**Low Moisture**	Open BEFORE EVA	- Handsfree Access - Crumb prevention	- Low launch mass - Ease of install/use/removal	- Production of suitable food products (nonstick, crumb prevention, consistency, integrity, etc.)
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

Assessment of In-Suit Nutrition System Placement

Although nutritional value and nutrient stability are important factors when identifying the best nutritional product, another important consideration is the volumetric limitations within the pressure suit. Because the suit is designed to maintain life while maximizing occupant functional capabilities, little volume is available within the suit to include additional hardware or nutrition. This limitation presents a challenge to the design of a nutrition delivery system because the form factor of the system will depend on the physical characteristics of the nutritional product (solid vs. liquid). Preliminary assessments have identified candidate locations where the suit may accommodate a delivery system, including the area above the occupant's shoulders and the front inner surface of the xEMU hard upper torso (HUT) (**Figure 1**). Because the nutritional solution has not yet been identified, it is unknown if these locations will be ideal. Additionally, potential design constraints that may be imposed by xEMU system hardware requirements must be identified. The pressure suit is a closed loop life support system that continuously filters out contaminants and CO_2. Within the ventilation loop, a filter is used to capture FOD. In-suit nutrition systems that release FOD may decrease the service life of the life support system and increase the need for additional maintenance and surface mass. As a result, FOD free nutrition systems are preferred. Similarly, for a liquid-based nutrition solution, an analysis may be necessary to determine if the composition of that liquid would negatively affect the function and performance of the pressure suit system if the liquid spills and intrudes into the suit. High level design references for potential nutrition delivery systems were developed and explored to address this. Volumetric modeling of usable suit space was conducted to assess maximum allowable volumes and to visualize specific areas within the suit that can accommodate in-suit nutrition systems based on the design references.

Systems Integration and usability of the drink bag was assessed assuming placement in the central chest position of the xEMU. Design requirements were that the delivery systems must fit within the volumetric spaces available without causing interference or crew contact during nominal operations of the suit. Additionally, the delivery system must be accessible and usable while wearing the pressure suit. The fit was iteratively assessed using a 3D CAD model of xEMU and statistically generated 3D body shape manikins. For each configuration, the potential volume and area of the contact and interference between the wearer's body and the delivery system were calculated for average female and male users. Then the position and volume available for the drink bag was estimated within the HUT for each person's body size and shape. The assessment was repeated using a large number of 3D body scans (n > 2000) representing a crew-like population as defined by NASA's current EVA requirements documents (4). The EVA Nutrition outcome was then statistically analyzed and the configuration variables were parametrically adjusted to optimize the form factor and location of the delivery system within the suit.

Results: Suit Volumetric Modeling

The impact of the design reference concepts on suit constraints were modeled to assess in-suit placement and potential suit sizing implications. Preliminary modeling illustrated volume limitations when positioning of a drink bag on top of the DIDB at the mid-chest area within current xEMU HUT designs (**Figure 8**). Using population averages for female and male models within the xEMU HUT and the 32oz DIDB filled to capacity (1070 mL), the maximum volume available for an additional liquid bag was 260 mL for a median size female crewmember and

190 mL for a median size male crewmember. These volume limitations would set constraints on the amount of nutrition that could be included in the suit. The working assumption for liquid nutrition is to assume 1 mL per kcal provided, suggesting that 400 mL is the minimum volume required to provide 400 kcal. Furthermore, the discrepancy between available space and nutritional needs would be aggravated with larger crewmembers who may require more nutritional content but have less available suit space. Some crewmembers also prefer to be indexed to a maximum forward position within the HUT, which would also restrict the space available for a nutrition bag placed in the front chest area, as shown in **Figure 8**. Thus, in the current xEMU configuration, additional suit spaces available for nutrition would need to be explored and tested. Dedicated volumes for nutritional systems within future pressure space suits should be considered during the design phase.

Results: In-Suit Refrigeration

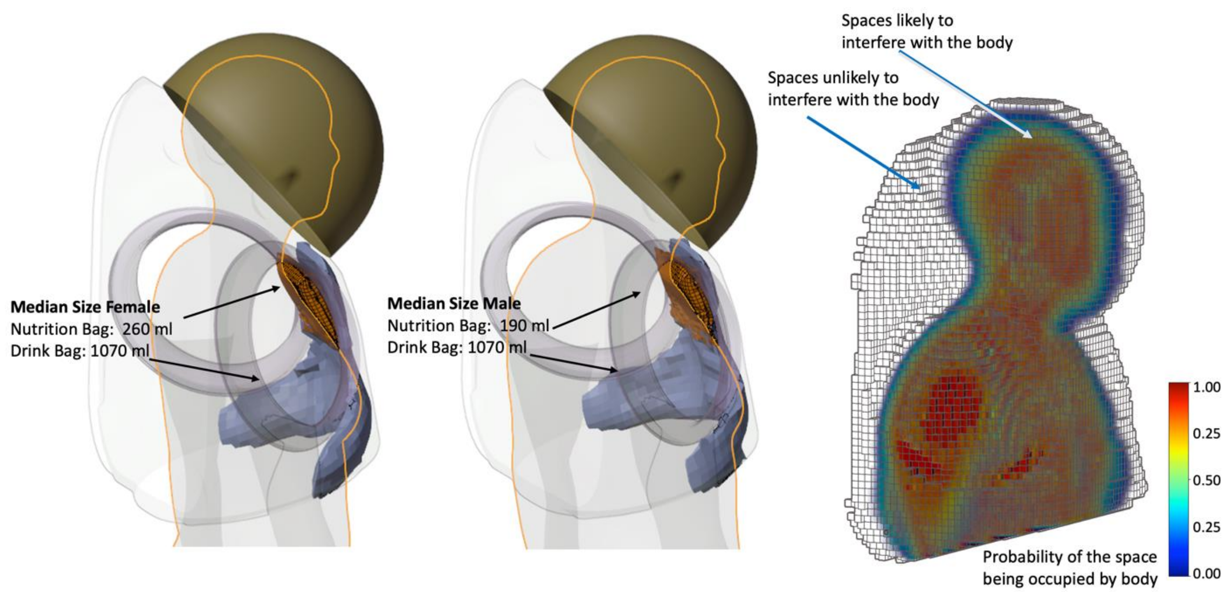


Figure 8. Preliminary volumetric modeling of xEMU HUT with 32oz DIDB and liquid nutrition bag (left and middle pane). Simulation of space availability within the HUT using crew-like female population data (right pane)

From a food safety perspective, a means of keeping food outside of the 'danger zone' (4–60 °C) for microbiological growth while in the suit would be a huge advantage and allow for extended access to open food packages. This would require an extensive expansion to the cooling capabilities generally provided by the suit system. The liquid cooling and ventilation garments (LCVG) that astronauts wear to support life and personal comfort (25–30 °C) while wearing the pressurized suit are insufficient to prevent microbiological growth from thriving in exposed food items within the suit (**Figure 9**). Without refrigeration, beverages are limited to a 2-hour shelf life for consumption once the package seal is broken. There are currently no plans for in-suit refrigeration and the feasibility for such designs and their implementation are unknown.

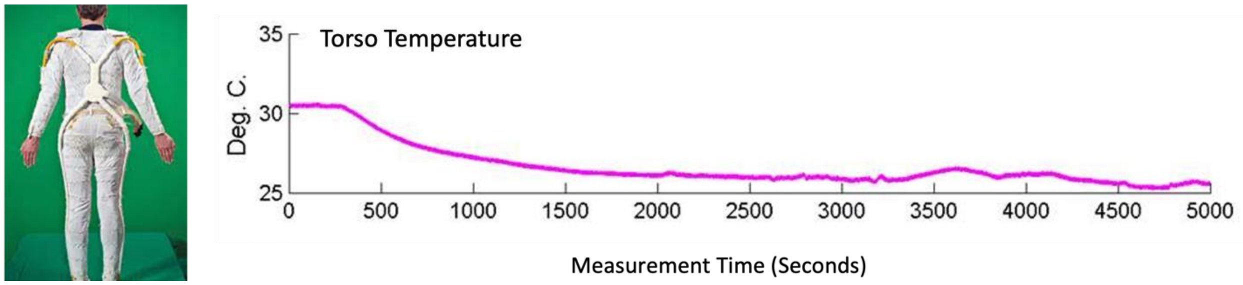


Figure 9. Pressurizede suit temperature readings during a Neutral Buoyancy Laboratory run. (Courtesy of the Anthropometry and Biomechanics Facility 'EVA Glove Sensor Feasibility" project, 2016.)

Potential Test Recommendations

Developing an in-suit nutritional systems will require additional testing before use during 8-hour lunar EVAs. The in-suit nutrition system must be certified for up to 12 hours continuous use. Quantity control during production is important to consider as well. Usability testing must be performed to demonstrate that the crew can access the food product while they are in the suit. It is unclear how the packaged food will be secured in the suit: Velcro attach points within the suit are among the likely applications. Placement of the product will affect this application because it must be secure enough to stay in place during handsfree manipulation such as biting off solid foods or using a bite valve and drinking through a straw. The placement must not negatively impact airflow.

It must be demonstrated that the in-suit nutrition system does not interfere with the range of motion of the head and jaw during donning, doffing, and nominal operations in the suit, and that it does not induce discomfort for the crewmember while they are suited. This should be demonstrated during all nominal postures including standing, seated, microgravity, and dynamic whole-body movement. Because the nutrition system will be provided in addition to drinking water, installation, access, and removal must be demonstrated.

Furthermore, the nutrition system must not negatively affect the helmet structure, valsalva pad, and Fresnel lens. Loads assessments should be performed to secure the safety clearance and assess risks during off-nominal impact events such as trips/falls and rover operations. Solid foods may become dislodged, break, or produce crumbs. These could get in the crewmember's eyes, nose, or ears, the suit filtration system, folds of the pressure bladder, or other locations with the potential for choking or abrasion damage. Liquid foods, although potentially less risky to the crew or the integrity of the suit than FOD from solid foods, could spill and cleanup operations should be developed.

<u>Assessment of Crew Preferences for In-Suit Nutrition</u>

Crew input is important to develop and improve suited capabilities. A general questionnaire was developed to obtain anonymous feedback from astronauts regarding the status of in-suit hydration, nutrition, and waste management, and how accurate simulated EVAs compare to flight EVAs. This questionnaire allowed crewmembers the opportunity to provide valuable feedback that will be used during xEMU development such as the work proposed below. This information was intended to supplement engineering requirements for hydration, nutrition, and waste management during suited operations. The questionnaire did not collect identifiable information and was classified as ‘not human subject research’ by the NASA Institutional Review Board (IRB) in December 2020. The project was proposed to the crew office in April 2021 and the questionnaire was administered as a web-based survey (Qualtrics.com). The questions and results are presented in **Appendix C**.

In a second survey, astronaut feedback was solicited to obtain preferences and opinions regarding the major design reference concepts and the expectations of required nutrition during surface (lunar) EVAs. The IRB also determined this as ‘not human subject research’ in June 2022. The project was proposed to the crew office in July 2022 and the questionnaire was administered as a web-based survey (Qualtrics.com). The questions posed to the crewmembers followed by a report of the responses are presented in **Appendix D.** A summary of the results from both surveys are discussed below.

Results: Crew Feedback on General Preferences for Hydration, Nutrition, and Waste Management in Space Suits

At least 20 responses were collected within one week of rollout and the final results included 25 unique crew responses. The rate of responsiveness alone confirmed that crewmembers have thoughts and opinions about this topic. The quality of responses was also high and indicated high expectations from the astronaut population.

The development of in-suit nutrition is coupled to the continued ability to provide adequate hydration and waste management solutions. Currently in the EMU, astronauts use a 32 oz. disposable in-suit drink bag (DIDB) for water and a maximum absorbency garment (MAG) for waste collection. These systems are all closely linked, and it is important to characterize suited nutrition, hydration and waste management capabilities together. This questionnaire was prepared to solicit astronaut feedback regarding current (microgravity) capabilities on suited hydration and waste management (**Appendix C**). Responders were divided into two groups: those with spaceflight EVA experience and those with NBL experience only.

Hydration. In preparation for suited activity, astronauts indicated they tend to consume more liquid than usual to avoid any potential thirst or dehydration. This included both an increase in water and coffee/tea; there were no respondents who indicated that they avoided caffeinated beverages. During suited activities, astronauts almost universally always consumed all the liquid in the DIDB (Appendix C, S1). Prior to EVA activities on the ISS, many of the crew stated that they would partially underfill the DIDB for a more optimal suit fit. During training runs, the DIDB is prefilled by suit engineers. Regardless of fill level, most respondents indicated a preference for more water (Appendix C, S2). For several of the questions, responders marked “Other” to further elaborate on their drinking habits and desire for more water. Most of the responses fell under the “Always” option. Interest in beverages in addition to water was also high among the respondents, although some felt strongly that anything other than water was unnecessary; this sentiment was higher among those with spaceflight experience.

Nutrition. There is no in-suit nutrition system for the EMU that is currently used on the ISS. Questions in this section were aimed at characterizing astronaut preferences before and after suited operations on-board the ISS and during training operations at the NBL.

For current training and spaceflight operations, astronauts indicated they have a larger breakfast and usually a last-minute snack, e.g., protein or granola bar, prior to entering the suit. For training at the NBL this usually occurs in the locker room or during morning debriefs; on the ISS this occurs prior to crew entering the hard upper torso (HUT). After suited activity, many of the responses indicated that there were no prevailing preferences or routines, but most respondents indicated they wanted a large and filling meal after training or EVA operations. No specific types of food were mentioned and, in essence, was best summarized by one of the responses: “eat lots of food.” While this trend and feedback was received from both groups, responses from those with spaceflight EVA experience noted that they preferred “Russian food” due to the higher fat and salt content; a particular favorite was the Russian mashed potatoes. In addition to the “lots of food,” most noted that they are usually thirsty when exiting the suit. During training at the NBL, astronauts are provided a bottle of water when exiting the suit.

The primary takeaway at the time of this questionnaire was that astronauts preferred additional liquid nutrition, such as a protein shake or electrolyte liquid but that water was still a must and that any form of nutrition should be supplemental.

Waste Management. The MAG is the primary waste management system in the EMU for suited operations and is primarily designed to handle liquid waste. With a potential increase in the amount of water provided or supplemental liquid nutrition, there is a need to characterize the current acceptability and usage of the waste management system. Questions in this section were centered around usage and comfort of the MAG.

The consensus amongst the respondents was that there were no major comfort issues with the MAG, both before and after use and the majority of users did not notice the MAG during EVA.

When considering the usage and (potential) leakage of the MAG, there were differences in experiences. Most astronauts used the MAG if it was needed. However, leaks, while not uncommon, were not much of an issue and there was no specific strategy for urination during suited operations. It is worth noting that many of the respondents who did use the MAG, used it when they needed to. This can be summarized by one of the responses: “I go when I need to go.” In the cases where the MAG was not used, it often came to the respondent being occupied with the tasks being performed. In other words, they were too busy and did not notice the urge to urinate.

The final set of suited waste management questions were based on the issue of leakage. For most, leaks were experienced, but it was a non-issue. Several of the astronauts mentioned that it could often be difficult to discern the difference between sweat and urine, particularly in training where the workload is higher. The liquid cooling and ventilation garment (LCVG) worn underneath the pressure suit would often become saturated, thus making it difficult to feel if the MAG was leaking. A report of the responses is presented in **Appendix C**.

Results: Crew Feedback on Concept Design References for In-Suit Nutrition Systems

A total of 17 unique responses from the astronaut population were collected within 3 weeks of rollout. Of these, 9 astronauts reported they had spaceflight EVA experience whereas 8 reported they did not. A summary of the results from the questionnaire is presented below and the anonymous responses to the open questions are presented in **Appendix D**.

Prefilled drink bag. When presented with the concept design for the ready-to-consume drink bag, all respondents indicated a positive acceptability rating (1 to 4 on a 1 to 10 scale) for the anticipated impact on preparation time, installation time, effort before EVA, ease of use of this system during EVA, cleanup time, disposal time, and effort after EVA (Appendix D, L2).

The most pressing concerns regarding the prefilled drink bag were related to the limited window for consumption once the seal is broken and the potential for spills in the suit.

Hydratable powder drink bag. The responses to the hydratable drink bag option were generally positive but a few concerns were raised regarding preparation before and usability during EVA (Appendix D, P2).

The 2-hour time window for consumption after mixing the bag contents were the primary driver for the lower rating compared to the prefilled drink bag rating. Mass efficiency (i.e., launching water separately and not bound to a prefilled bag) was mentioned as a possible positive aspect than the ready-to-consume option.

Solid food stick. The concept of including solid food in the suit received a more variable response than the liquid option (Appendix D, S2). Although most responses were still positive, some concerns were noted, mostly around ease of use during EVA, messiness in the suit, and disposal after EVA.

The most often cited concern was that of FOD, such as food crumbs, could cause messes. Additional concerns included the placement of and interference from instruments in the helmet, the increased difficulty of reaching and consuming solids compared to liquids, and risk of choking. Lack of experience with solid foods in the suit was also mentioned. The positive responses appeared to be more subjective and pointed towards personal preferences for desiring solid food over liquids. The potential for needing additional water to wash down solid food was also mentioned.

Helmet feed port. The helmet feed port concept received the most concerns although it still skewed towards the positive scale of acceptability (Appendix D, H2). The concerns were largely driven by skepticism regarding the added complexity of the engineering involved and concerns that the risks of adding additional 'holes' in the space suit did not outweigh the potential benefits.

Most responders indicated that including a helmet port added possible points of failure to the space suit. The concept of having food available outside of the suit instead of, or in addition to, having a nutrition system occupy internal suit volume was regarded as a positive, and some crewmembers indicated they would welcome this capability. At least one crewmember referenced the feed tube system that is implemented during high altitude and long-range WB-57 flight operations (https://airbornescience.nasa.gov/aircraft/WB-57_-_JSC). Among the known factors that would prevent these existing tube foods from being rapidly adapted to EVA operations is that the typical food consistencies combined with the metallic packaging materials could not be used when substantial pressure differentials exist between the external and internal suit environment. Finally, a few responses mentioned factors such as temperature, pressure, and contamination that would require special considerations during the design and implementation of a helmet feed port.

Concept Comparisons. Individual preferences were provided when asked to directly compare the 4 concepts (Appendix D, R0). On average, the crewmembers preferred liquid drink over solid food. The helmet food port ranked the lowest overall.

Although most responders preferred the liquid bags (especially prefilled bags), this preference was not unanimous and each concept was at least chosen once as an individual's favorite. This variation in preferences was also reflected in the responses indicating the primary drivers for ranking of the concept designs.

Additional questions were posed to obtain further insight into how the concepts compared regarding the overall likelihood of development and implementation (Appendix D, R1), functionality as designed and intended (Appendix D, R2), likelihood that the crewmembers would use the system as intended (Appendix D, R3), ease of use (Appendix D, R4), and safety concerns (Appendix D, R5). Overall, the drink bags (prefilled and hydratable) scored higher than the solid food bars and the helmet food port concept, although individual preferences continued to exist. A few additional comments were also provided.

As a close out to the comparisons between the concepts, the crewmembers were provided an opportunity to further elaborate on any of the previous questions and offer unsolicited input regarding nutrition, hydration, or waste management in space suits (Appendix D, G1). Among the key responses, especially when considering the individual variation in preferences that was observed, was the recognition that multiple concepts could be considered for implementation rather than selecting just one.

Because the requirement for inclusion of in-suit nutrition is specific to surface exploration EVAs (4), and current crew conduct or train for microgravity EVAs that require no in-suit nutrition, the responders were reminded about this distinction and asked to indicate whether their opinions would be different between surface vs microgravity EVA (Appendix D, G2). The main differences noted were that FOD associated with solid bars and risk of losing the external drink bag associated with the helmet port were a bigger concern for microgravity EVA compared to surface operations. Next, the responders were asked to indicate whether the expectation of conducting multiple/consecutive EVAs (i.e., 4 EVAs over 5 days) would play a factor in their indicated preferences for in-suit nutrition systems (Appendix D, G3). Most responses confirmed that the expectation of multiple/consecutive EVAs would increase the need for access to nutrition during EVA, especially high density (i.e., solid) foods and foods that are easy to prepare (i.e., not powders). Finally, because the 4 general design references presented were a limited representation of all conceivable concepts, responders were given the opportunity to share their own ideas and concepts (Appendix D, Q123). A few suggestions for consideration were offered, including looking into bite size solid options, further research into macronutrient ratios and inclusion of electrolytes, and including crew in testing and training during the development of the nutrition system. A report of the responses in presented in **Appendix D**.

Summary. The responses provided several converging opinions and expectations as well as diverging individual variations in preferences for the implementation of in-suit nutrition. Many considerations echoed the options and inputs of the subject matter experts involved in this project. However, the results from the questionnaire underscored several important aspects to consider during the selection and development of in-suit nutrition systems.

1. Ready to consume drink bags received the most consistent (but not unanimous) ranking among the 4 concept design references presented.
2. Limited shelf-life reduced enthusiasm for the hydratable drink bag option.
3. Lack of experience with solid food in the suit and concern of messiness may have contributed to lower enthusiasm for this option. Having solid food as a high-density food option was desired by some.
4. Skepticism of the helmet feed port was largely driven by uncertainties in the feasibility of implementing this concept. Demonstration of a reliable system could result in more enthusiasm because the idea of keeping food outside of the suit was regarded as a positive attribute.
5. One size may not fit all. Parallel development of multiple systems should be considered as opposed to selecting a single solution.
6. Crewmember involvement during the early design stages is paramount. The rationale by subject matter experts for not including specific options (constraints) may not be known to the astronauts.

In addition to providing useful feedback for developing recommendations for in-suit nutrition systems, the general and anonymous surveys provided important pilot data for more targeted projects in the future—such as integration of metabolic rate, hydration status, and crew perception data during suited activities.

Recommendations

The recommendations summarized below are professional opinions from subject matter experts involved in the project and are based on review of literature, internal data, and discussions with experts within and outside of the project team. Preliminary summaries were presented in abstracts for the 2022 and 2023 Human Research Program Investigators' Workshops (HRP IWS) (**Appendix E**).

Because the mission objectives of Artemis missions are not yet known and the next generation of pressure suits are not yet developed, the following boundaries are assumed to align with NASA-STD-3001 and with the rationale and recommendations for partial gravity aerobic and muscle fitness standards currently under development and captured in a report to HRP.

1. Nominal EVAs will last no longer than 8 hours.
2. Nominal confinement to the space suit will last no longer than 12 hours.
3. The food system (in-suit plus pantry) shall provide an extra 200 kcal per hour of EVA to the crewmember's nominal daily diet.
4. Nominal average sustainable effort of working while in the suit does not exceed 40% of the maximum capacity (VO_{2peak}) of the crew.
5. The xEMU portable life support system (PLSS) can sustain up to 9600 BTU (2421 kcal) over 8 hours of operation.

Nutritional Recommendations

The following recommendations are based on the available data outlined above (assuming expenditure of 200 kcal per hour x 8 hours of EVA = 1600 kcal and assuming up to 12 hours of confinement to the pressure suit).

1. Future pressure suit designs should strive to accommodate provision of at least 400 kcal to the individual confined to the suit. (Providing more than ~600 kcal in the suit is not expected to add benefit to performance and may contribute to increased food waste).
2. The food system will provide the remaining energy (= 1600 kcal for 8 hours of EVA) during regular meals before or after suited operations.
3. In-suit nutrition may consist of COTS foods or custom formulations (including high carbohydrate or high protein content), as long as the daily nutritional provisions adhere to current macronutrients and micronutrients standards for extended duration exploration missions (7).

Food System Recommendations

These recommendations assume that the in-suit nutrition system will provide at minimum 400 kcal of energy.

1. **Volume.** Needs for the following minimum volumes are anticipated based on selection of the COTS foods that are currently available (note: no current COTS food meets all nutritional, microbiological and FOD requirements, this is only a volume assessment). These are volumes (and/or masses) estimated for 400 kcal of nutrition alone, not including packaging and system components.

Liquids	Beverages (approximately 1 kcal per mL):	> 400 mL
Semi-liquid	Gels (approximately 2-3 kcal per gram) (49):	> 200 mL (~200 g)

Solids Food bar (approximately 3-4 kcal per gram) (44): > 100 mL (~100 g)

2. **Microbiological Safety.** Due to the limited 2-hour window for consumption for liquid nutrition after the packaging seal is broken (i.e., the first instance of opening the package for hydration or consumption) it is recommended that the system either
    a. allows for installation of prefilled (sealed sterile) liquid nutrition in the suit and provides a mechanism to break the seal at the time that consumption is desired.
    b. demonstrates that the unsealed food product shelf life (solid or liquid) intended for use with the pressure suit allows for safe consumption after at least 12 hours of EVA.

Suit Integration Recommendations

Because the design of the Artemis EVA suits is still unknown and the volumetric analyses were performed using the xEMU HUT, the findings and recommendations below may not be applicable and should be addressed in future suit designs.

1. Primary location for placing nutrition in the xEMU (front of chest near the DIDB) is currently limited to approximately 200–250 mL when a DIDB is already filled with water. This volume is insufficient to provide the recommended minimum of 400 kcal as liquid (which requires at least 400 mL).
    a. Future pressurized suit designs should include a dedicated volume for nutrition systems based on the food system recommendations mentioned above.
    b. Larger individuals may require larger volumes dedicated to nutrition to meet their metabolic demands.
2. Dedicated volumes in the suit must be within reach for handsfree access.
3. Options to break the seal of prefilled food grade quality packaging to access a sterile, shelf-stable beverage should be included so the astronauts can consume liquid nutrition while confined to the suit. Sterile beverages with a mechanism to break the seal at time of consumption would need to show that the seal cannot be accidentally broken, and crew need to be trained to consume within 2 hours after they break the seal. Alternatively, in-suit refrigeration for the beverage could enable it to be safely opened and consumed over the full EVA length.
4. Foods must demonstrate to be FOD compatible with the suit.
5. Helmet feed ports require additional considerations such as staging of the foods prior to the EVA, overcoming pressure differentials during consumption of food that is external to the pressure suit, physiochemical (dust) mitigation, and maintaining food safety.
6. The nutrient delivery system should not interfere with the crewmembers' jaw, head, or neck motions.

Future Directions

The variability between ground-based and spaceflight operational data demonstrates the difficulty of establishing in-suit nutritional requirements for space exploration. Carefully planned investigations must be executed to address gaps in our understanding of the metabolic and performance needs under surface EVA conditions and to define the requirements for providing nutritional support during EVA. Expanded COTS testing and/or development of foods that meet all space flight requirements, such as nutritional content, water activity, microbiology, FOD, and acceptability will be necessary. Multiple solutions, including liquid as well as solid formulations, should be developed through continued parallel efforts at NASA and xEVAS contractors.

Future research during actual spaceflight operations could consider additional DLW experiments to better understand the TEE inclusive of multiple lunar EVA operations. However, such studies are complex and lengthy, making them difficult to implement during flight. Ground-based testing of prototype in-suit nutrition systems could be performed using 3D printed mockup suit components in addition to pressurized suits to iteratively evaluate the human factors, ergonomics, and human-system integration of the EVA food system prototype, and to inform refinements as needed. The ongoing Physical and Cognitive Exploration Simulations (PACES) project could be used as a platform to test potential food products under shirt-sleeve conditions and EVA training runs in the NBL and/or Active Response Gravity Offload System (ARGOS) can be used to incorporate the expected EVA food system within environments that closely simulate realistic EVA scenarios. Without these data, only the historic spaceflight DLW data (10, 11) coupled with estimates from Apollo EVAs (16) can be loosely combined to provide expected estimates of 24-hour nutrient needs.

Conclusions

Future space suits will be designed to offer the capability for nutritional support during lunar surface EVAs lasting longer than 4 hours or any suited activities greater than 12 hours in duration. Recommendations are needed 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. 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. In addition, four concept design references that included liquid and solid food formulations were conceptualized and assessed for strengths and limitations as potential in-suit nutrition systems for surface EVA. Recommendations were formulated based on these assessments and represent contemporary approaches that could be expanded and investigated further. Development of space suit engineering solutions alternative to the ones presented may also be conceivable and are highly encouraged. The ability to meet the increased need for nutrition during surface EVAs through provision of nutrients in the suited configuration will benefit overall crew health, performance, and morale, and thereby increase the likelihood of mission success.

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Appendices

Appendix A. List of Commercial Off-The-Shelf (COTS) Food Products

Appendix B. Summary Report of Water Activity and Microbiological Stability of Commercial Off-The-Shelf (COTS) Bars, Gels, and Beverage Powders to Determine Potential for Use in EVA In-Suit Nutrition

Appendix C. Questionnaire to Obtain Crew Feedback on Concept Design References

Appendix D. Crew Feedback

Appendix E. HRP Investigators' Workshop Abstracts

Appendix A. List of Commercial-Off-The-Shelf (COTS) Food Products

LIQUID

Item	Type	Serving Size	Total Kcal (400+)	Carbohydrate (g) 35–50 g	Fat (g)	Protein (g)	Sodium (mg) 200–500 mg	Potassium (mg) 100mg	Notes	Product Link
Kate Farms - Peptide 1.5 Protein Shake	Liquid	325 mL	500	45	25	24	350	800	Meets all nutritional requirements. Potassium content may present a challenge. These are fortified so total nutrition would need to be assessed within whole diet.	https://shop.katefarms.com/products/peptide-plain-1-5-formula?gclid=Cj0KCQiAt
Boost - Very high calorie complete nutritional drink (Very Vanilla)	Liquid	237 mL	530	52	26	22	280	315	Carbohydrate content is slightly above the specified range	https://www.carewell.com/boost-very-high-calorie-oral-
Reason Nutrition Beverage	Liquid	11 fl oz (325.3 mL)	450	55	18	18	270	280	Carbohydrate content is slightly above the specified range	https://reasonhealth.com/product/nutrition-
Hormel Vital Cuisine 500 Shakes (Chocolate or Vanilla)	Liquid	8.45 fl oz (250 mL)	520	60	21	22	380	380	Carbohydrate content is slightly above the specified range	https://www.cwimedical.com/nutritional-shakes/hormel

Premier Protein Shake (Chocolate)	Liquid	11 fl oz (325.3 mL)	160 (480 based on 3 servings)	5 (15)	3 (9)	30 (90)	180 (540)	420 (1260)	Carbohydrate content is below the specified range; sodium content is slightly above the specified range. Potassium content may present a challenge.	https://www.walmart.com/ip/Premier-Protein-Shake-Chocolate-30g-Protein-11-Fl-Oz-4-Ct/451523917wmlspartner=wlpa&selectedSellerId=0&wl13=4446&&adid=2222222534473095568wl0=&wl1=g&wl2=c&wl

Key

Items highlighted in green can meet the specified requirements if the serving size is increased beyond the specified serving size. Several of these items require further assessment of maximum micronutrient quantities within the whole food system.

Only items in green provide additional information on fortification.

Items highlighted in yellow meet all but one of the specified nutritional requirements. Several of these items would also require further assessment of maximum micronutrient quantities within the whole food system.

Items highlighted in orange meet all but 2 of the specified nutritional requirements. Several of these items would also require further assessment of maximum micronutrient quantities within the whole food system.

The serving size of several items was increased to meet the minimum caloric requirements. Values in parenthesis represent the nutritional content based on the expanded serving size.

Products containing >800mg potassium may present a challenge if menu consumption is unbalanced.

Red text is used to indicate which nutrient(s) do/does not fall within the specified range.

POWDER (Standardized to 400kcal)

Item	Type	Serving Size	Total Kcal (400+)	Carbohydrate (g) 35–50 g	Fat (g)	Protein (g)	Sodium (mg) 200–500 mg	Potassium (mg) 100 mg	Notes	Product Link
Hormel Vital Cuisine Shake Mix - Chocolate	Powder	1/4 cup (40 g)	370 (400 based on 1.08 serving, with 1 cup whole milk)	42.12	10.8	16.2	226.8	766.8	Meets all nutritional criteria; these are fortified so total nutrition would need to be assessed within whole diet.	https://www.hormelhealthlabs.com/product/hormel-vital-cuisine-shake-mix/
Puritan's Pride - Daily Nutrition Shake (Chocolate)	Powder	2 scoops (33 g)	110 (400 based on 3.63 servings)	39.93	10.89	54.45	399.3	1089	Potassium content may present a challenge. These are fortified so total nutrition would need to be assessed within whole diet. This blend also includes probiotics, which may not be approved microbiologically.	https://www.puritan.com/puritans-pride-fitness-brand-1243/ppmeal-replacemnt-choc1-lbp-058218?scid=45182&utm_source=pla&utm_

Shakeology (Vanilla)	Powder	1 scoop (37 g)	140 (400 based on 2.86 servings)	42.9	5.72	48.62	429	286	Meets all nutritional criteria; these are fortified so total nutrition would need to be assessed within whole diet. This blend also includes probiotics, which may not be approved microbiologically.	https://img1.beachbodyimages.com/teambeachbody/raw/upload/Teambeachbody/shared_assets/Shop/Shakeology/Shakeology%20Vanilla/Benefits/Ingre
Prime Trim MEAL Whole Food Meal Replacement Shake	Powder	1 packet (46 g)	220 (400 - based on 1.82 servings)	21.84	18.2	36.4	200.2	200.2	Carbohydrate content is below the specified range	https://completenutrition.com/products/prime-trim-
Healthy Height Shake Mix	Powder	2 scoops (43 g)	231 (400 based on 1.73 servings with whole milk)	48.44	10.38	27.68	181.65	411.74	Sodium content is slightly below the specified range	https://www.healthy-height.com/products/growth-boosting-shake-
Level 1- Meal Replacement Protein Powder (Caramel Latte)	Powder	1 scoop (37 g)	150 (400 based on 2.67 servings)	18.69	24.03	61.41	373.8	480.6	Carbohydrate content is below the specified range	https://1stphorm.com/products/level-1?variant=31157418295382&a_aid=f707

Level 1 - Meal Replacement Protein Powder (Cinnamon Cookie Batter)	Powder	1 scoop (37 g)	150 (400 based on 2.67 servings)	13.35	8.01	64.08	427.2	427.2	Carbohydrate content is below the specified range	https://1stphorm.com/products/level-1?variant=31157418295382&a_aid=f7076c74
Level 1 - Meal Replacement Protein Powder (Ice Cream Sandwich)	Powder	1 scoop (37 g)	140 (400 based on 2.86 servings)	20.02	7.15	68.64	457.6	371.8	Carbohydrate content is below the specified range	https://1stphorm.com/products/level-1?variant=31157418295382&a_aid=f707
Wellness Code - Advanced Whey Protein Isolate (Vanilla)	Powder	1 scoop (23 g)	60 (400 based on 6.67 servings)	6.67	Not Listed	93.38	266.8	600.3	Carbohydrate content is below the specified range	https://www.lifeextension.com/vitamins-supplements/item02246/wellness-code-
Nutrica - Scandishake High Calorie Weight Gain Shake Mix	Powder	1 envelope (85 g)	580 (400 based on 0.7 servings)	39.2	14.7	2.8	73.5	<3500	Sodium content is below the specified range	https://www.allegromedical.com/dietary-supplements-

Naturade Weight Gain - Instant Nutrition Drink Mix	Powder	2 scoops (48 g)	220 (400 based on 1.81 servings)	41.63	16.29	18.10	543.00	760.20	Sodium content is slightly above the specified range; whole milk powder can be added to increase caloric content. Potassium content may present a challenge.	https://www.pureformulas.com/weight-gain-powder-sugar-free-vanilla-40-oz-by-naturade.html?accountid=53000
Muscle Milk Pro Series NSF Certified - Knockout Chocolate	Powder	2 scoops (82 g)	310 (400 based on 1.29 servings)	21.93	6.45	64.5	232.2	909.45	Carbohydrate content is below the specified range. Potassium content may present a challenge	https://www.vitaminshoppe.com/p/muscle-milk-pro-series-protein-powder-
MET-Rx Vanilla Performance Powder	Powder	4 scoops (167 g)	602 (400 based on 0.66 servings)	53.46	5.28	35.64	330	1181.4	Carbohydrate content is slightly above the specified range. Potassium content may present a challenge.	https://shop.metrx.com/Xtreme-Size-Up-Vanilla/p/MTRX-158237&c=METRx@P

Dr. Kellyann - Collagen Shake (Chocolate Almond)	Powder	1 packet (26 g)	100 (400 based on 4 servings)	24	8	60	160	160	Carbohydrate content is below the specified range. Sodium content is below the specified range.	https://drkellyann.com/products/collagen-shake-chocolate-almond-
Garden of Life - Raw Organic Meal & Shake Replacement w/ 20g of Protein (Chocolate)	Powder	1 scoop (35 g)	120 (400 based on 3.33 servings with whole milk)	26.64	6.66	66.6	33.3	599.4	Carbohydrate content is below the specified range. Sodium content is below the specified range.	https://www.vitaminshoppe.com/p/garden-of-life-raw-meal-mini-chocolate-cacao-1-34-lb-powder/gu-
Sprout Living Pumpkin Protein	Powder	2 scoops (30 g)	102 (400 based on 3.92 servings)	15.68	11.76	78.4	7.84	1646.4	Carbohydrate content is below the specified range. Sodium content is below the specified range. Potassium content may present a challenge.	https://www.sproutliving.com/shop/pumpkin-seed-protein-powder/?attribute_select-size=16+oz+(15+servings)&g

GNC Pro Performance Weight Gainer	Powder	4 scoops (182 g)	700 (400 based on 0.57 serving)	66.12	1.995	28.5	148.2	285	Carbohydrate content is above the specified range. Sodium content is below the specified range.	https://www.gnc.com/best-sellers-shop-all/369936.html?mrkgadid=&mrkgcl=109
Level 1 - Meal Replacement Protein Powder (Blueberry Muffin)	Powder	1 scoop (37 g)	140 (400 based on 2.86 servings)	20.02	5.72	68.64	543.4	520.52	Carbohydrate content is slightly below the specified range. Sodium content is slightly above the specified range.	htt+I23:L23ps://1stphorm.com/products/level-1?variant=31157418
Level 1 - Meal Replacement Protein Powder (German Chocolate Cake)	Powder	1 scoop (37 g)	150 (400 based on 2.67 servings)	18.69	6.675	61.41	507.3	600.75	Carbohydrate content is below the specified range. Sodium content is slightly above the specified range.	https://1stphorm.com/products/level-1?variant=311574182 95382&a_aid=f7076c74

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SOLID

Item	Type	Serving size	Total Kcal (400+)	Carbohydrate (g) 35–50g	Fat (g)	Protein (g)	Sodium (mg) 200–500mg	Potassium (mg) 100 mg	Notes	Product Link
RxBar (Blueberry)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	24 (48)	7 (14)	12 (24)	140 (280)	460 (920)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/
RxBar (Coconut Chocolate)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	23 (46)	9 (18)	12 (24)	170 (340)	480 (960)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/
RxBar (Banana Chocolate Walnut)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	25 (50)	9 (18)	12 (24)	130 (260)	430 (860)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/
RxBar (Mixed Berry)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	24 (48)	7 (14)	12 (24)	140 (280)	480 (960)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/
RxBar (Vanilla Almond)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	24 (48)	8 (16)	12 (24)	210 (420)	411 (822)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/
RxBar (Chocolate Raspberry)	Bar	1 bar (52 g)	210 (420 based on 2 servings)	23 (46)	8 (16)	12 (24)	170 (340)	439 (878)	Meets all nutritional criteria. Potassium content may present a challenge.	https://www.rxbar.com/

Level -1 Bar (Birthday Cake)	Bar	1 bar (63 g)	260 (520 based on 2 servings)	19 (38)	13 (26)	20 (40)	190 (380)	79 (158)	Meets all nutritional criteria	https://1stp horm.com/p
WonderSlim Meal Bar, Dark Chocolate Smore	Bar	1 bar (45 g)	160 (400 based on 2.5 bars)	18 (45)	5 (12.5)	15 (37.5)	170 (425)	190 (475)	Meets all nutritional criteria; these are fortified so total nutrition would need to be assessed within whole diet	https://www.dietd rect.com/wondershorm
RxBar (Chocolate Sea Salt)	Bar	1 bar (52g)	210 (420 based on 2 servings)	23 (46)	9 (18)	12 (24)	260 (520)	480 (960)	Sodium content is slightly above the specified range. Potassium content may present a challenge.	https://www.rxbar .com/shop/rxbar-
Level - 1 Bar (Chocolate Crunch, Pumpkin Spice Crunch, Peppermint Bark, Chocolate Mint Cookie, Chocolate PB Pretzel, Salted Caramel, PB Lover)	Bar	1 bar (63g)	260 (520 based on 2 servings)	19 (38)	13 (26)	20 (40)	370 (740)	70 (140)	Sodium content is above the specified range	https://1stphorm.com/products/level-1- bar?a_aid=f7076c74&utm_source=Go

Verb Energy 90-cal energy bars with caffeine	Bar	1 bar (22 g)	90 (405 based on 4.5 servings)	13 (58.5)	3.5 (15.75)	2 (9)	0	Not Posted	Carbohydrate content is slightly above the specified range. Potassium content is below the specified range.	https://www.verbenergy.co/bundle

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Appendix B. Summary Report of Water Activity and Microbiological Stability of Commercial Off-The-Shelf (COTS) Bars, Gels, and Beverage Powders to Determine Potential for Use in EVA In-Suit Nutrition

Grace L. Douglas, Takiyah Sirmons, Sarah Foster, Todd Elliott
(HRP Report 2022-01-26)

Introduction

EVA in-suit requirements include crewmember access to nutrition with their mouth only (handsfree) for a time-period of up to 12 hours. Current delivery methods require the food to be open when the crewmember dons the suit, which would begin the timeline for microbiological growth. Products that do not meet microbiological requirements over this time (12 hours) will increase risk of foodborne illness and mission failure.

In this evaluation, COTS bars, beverage powders, and gels were evaluated for microbiological status and water activity, as necessary, to determine potential for consumption in the space suit. To meet the requirements for multi-year storage at room temperature, products need to be commercially sterile in the original intact packaging in which they were processed, or they should have a water activity below 0.60 and meet space food microbiological requirements outlined in NASA-STD-3001 before and after they are packaged. Water activity up to 0.80 may be acceptable with additional hurdle technology methods such as modified atmosphere packaging or certain preservatives. To meet the 12-hour in-suit use requirements without generating a microbiological hazard, products should have a water activity under 0.60, and meet space food microbiological requirements outlined in NASA-STD-3001.

Methods

Microbiological Evaluation: Three COTS bars and 3 COTS beverage powders that had the potential to meet some EVA nutritional requirements were assessed for initial microbiological quality per the raw material testing protocol used by the NASA Microbiological Laboratory. Two gels that did not meet nutritional requirements were also assessed to provide some initial data on the potential of a gel to meet microbiological requirements.

Water Activity: All products were assessed in triplicate for water activity using the AquaLab 4TE (Decagon Devices, Pullman, WA).

Microbiological Time-Course: The 3 beverage powders were hydrated and assessed for growth over a 24-hour time-course.

Results

All 8 products met requirements for initial raw material microbiology (Table 1, attached). Gels had high water activity, above 0.9. One of the 3 food bars met water activity requirements (below 0.60). The other 2 bars had water activities between 0.60 and 0.70 (Table 1, attached). Dry beverage powders all met water activity requirements (Table 1, attached). However, all hydrated beverages failed the time-course microbiological assessment and could present a risk of foodborne illness within 5 hours of rehydration (Figure 1).

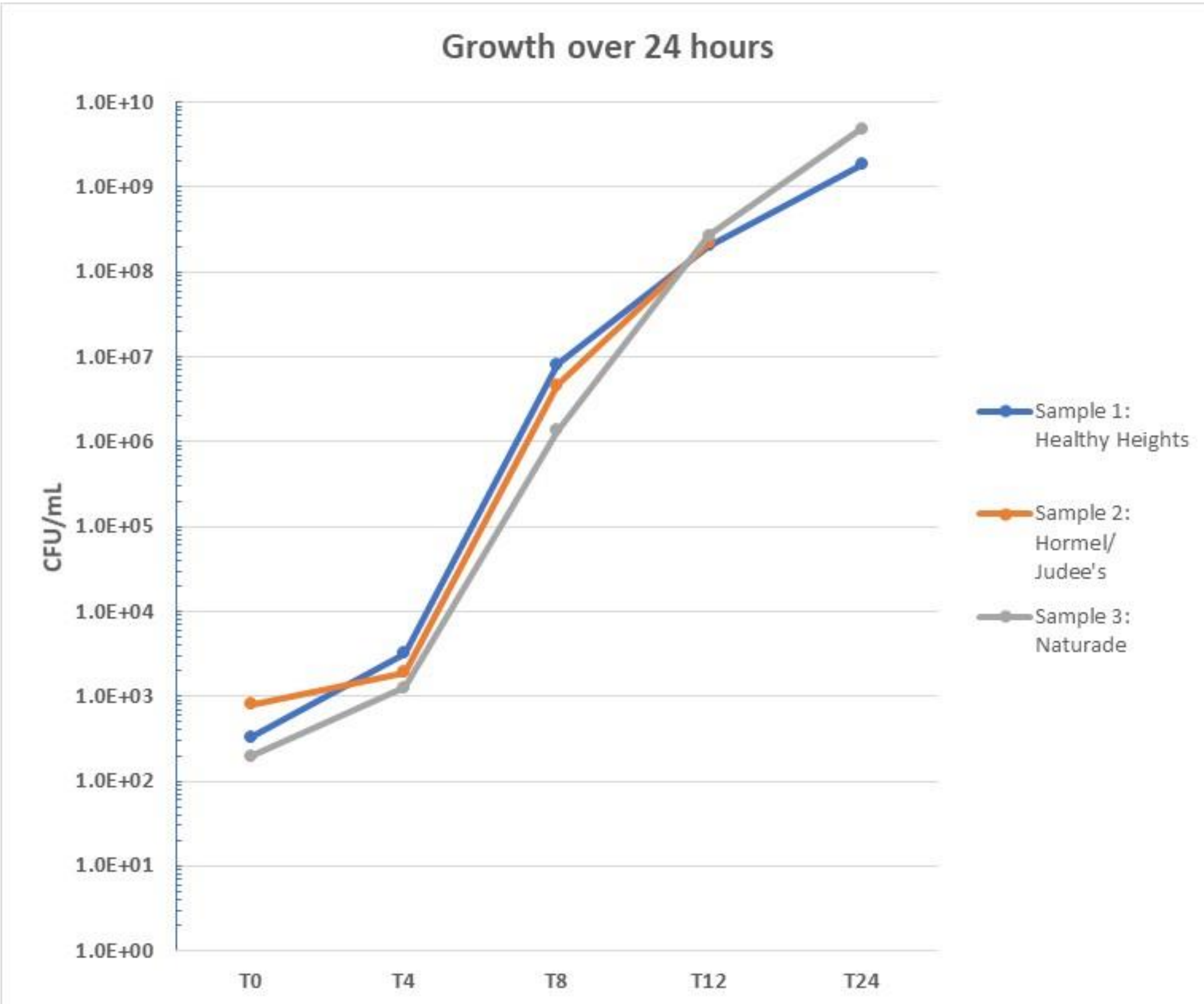

Figure 1. Time-course microbiological assessment (aerobic plate counts) of 3 potential beverage powders. Current delivery methods would require these powders to be rehydrated before the crewmember dons the suit, which would begin the timeline for microbiological growth. Microbial growth would be in logarithmic phase and would fail microbiological requirements within 5 hours of rehydration.

Discussion

Water activity should be below 0.60 to ensure no microbiological growth (bacterial, yeast, or mold) and to meet shelf stability requirements at room temperature. Products with water activities between 0.60 and 0.80 would require additional hurdles such as modified atmosphere in packaging or preservatives, unless processed to commercial sterility. The water activity limitations provide a safety margin for the levels of water activity where pathogens begin to grow.

The food bars in this assessment were all low enough in water activity that, with additional hurdles during storage, they could meet microbiological requirements throughout the 12-hour time-course. However, bars are the most likely to produce foreign object debris (FOD), and in addition to 12-hour microbiological assessments, additional assessments would be needed to evaluate crumbs and the potential for handsfree delivery in a suit.

The water activity of the gels was higher than the water activity requirement for microbiological safety, and they would likely become a microbiological concern within hours after opening. It is recommended that testing of gels should not continue.

Although beverage powders all met recommended water activity during dry storage, they would be expected to be above 0.9 after rehydration (water activity not tested), which would not meet water activity requirement for microbiological safety. Due to the crewmembers' interest in having a beverage in the suit, time-course microbiological testing was done to assess the microbiological state of the hydrated products over a realistic in-suit timeframe of 12 hours. An additional assessment at 24 hours was included to demonstrate worst case (Figure 1). These products would be expected to become a foodborne illness concern within 5 hours of hydration. Before beverages can be consumed during EVA, delivery methods must be developed to prevent foodborne illness. A possibility would be to investigate the feasibility of developing commercially sterile beverages with a packaging delivery system that can withstand processing and can be opened hands-free during the EVA, at the time of consumption. No packaging or delivery method currently exists or is currently in development to support this.

Appendix C. General Hydration, Nutrition, and Waste Management Questionnaire

Appendix C. Qualtrics Questions

https://nasajsc.qualtrics.com/jfe/form/SV_3gzmn8PfCSeNwNg

Overview

To inform engineering requirements for hydration, nutrition, and waste management during suited operations, this questionnaire aims to gather anonymous feedback from crewmembers on lessons learned during suited EMU operations both during training at the NBL and during flight on the ISS.

Rationale

Your feedback will help inform the Exploration Extravehicular Activity (xEVA) Human Health and Performance (HHP) open actions for the development of solutions for providing adequate in-suit hydration, nutrition, and waste management. This project will give crew the opportunity to provide valuable feedback that can be used during xEMU development.

Who Will Access the Data

The Human Physiology, Performance, Protection & Operations (H-3PO) Laboratory will administer the questionnaire and tabulate the results.

Results

The data will not be linked to personally identifiable information and is not intended to be used for publication nor crew selection purposes. The questionnaire is completely anonymous.

H-3PO Background

H-3PO is an integrated laboratory within the Biomedical Research and Environmental Sciences (BRES) Division and Human Health and Performance Directorate (SA) organized into three technical areas: Exercise Physiology and Performance, Spacesuits and Exploration Operations, and Applied Injury Biomechanics.

→

Background

Do you have spaceflight EVA Experience?

Yes

No

←

→

The following questions are about any final concerns or comments you may have regarding in-suit nutrition, hydration, and waste management.

Do you have any tips for newbies that you wish you had been told before your first NBL run or EVA?

Is there anything else that you think would be helpful for us to know about hydration, nutrition, or waste management in the suit? (i.e. suggestions to improve hydration, nutrition, and/or waste management in the suit; Desired delivery method for solid foods; etc)?

Would any of your answers change if you were expected to conduct multiple consecutive EVAs (i.e. 4 over 5 days) opposed to single EVA?

- No
- Yes, some (please briefly explain)
- Yes, many (please briefly explain)

← →

For questions or additional feedback, please contact one of the following H-3PO team members: Lichar Dillon (edgar.l.dillon@nasa.gov), Grant Harman (grant.w.harman@nasa.gov), or Jason Norcross (jason.norcross-1@nasa.gov)

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Appendix C. Crew Feedback on General Preferences for Hydration, Nutrition, and Waste Management in Space Suits

Hydration Questions

(How) do you change your water intake habits before suited activity?		
	Spaceflight Experience	**NBL Only**
Drink much less	0	0
Drink somewhat less	1	0
Do not change	**7**	3
Drink somewhat more	**10**	3
Drink much more	0	1
Do you have a specific water/liquid intake routine before an EVA/NBL run (e.g. avoid diuretics/caffeine, consume an energy drink)?		
No	6	3
Yes	12	4

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *I just make sure to finish my full 32oz of water in my thermos...whereas most days I'd do that by about mid-morning, on NBL days I do it before donning*
- *My goal is to be hydrated but with an empty bladder. I drink a few extra glasses of water the night before the run. Morning of, I drink 1-2 glasses of water as soon as I wake up, and then a small cup of coffee on the way to the NBL. Approx 1.5 hours prior to start of run I am essentially done with fluid intake.*
- *I have my normal coffee in the morning and then try to drink as much water as possible before the run in order to avoid thirst and/or dehydration during the run.*
- *I drink at least 48 oz of water the day of an NBL run prior to suit-up.*
- Drink two coffee
- hydrate well the morning of
- I usually have a double coffee on the day of an EVA
- Small reduction in coffee and replace with breakfast drink
- continue caffeine to prevent any caffeine withdrawal symptoms. But drink lots of water before the run. Should stay hydrated, which means you'll need to urinate in your MAG.
- my breakfast is usually high in protein: Meat an eggs. I tend to keep the fluid/caffiene intake pretty constant
- drink lots of water and coffee, make sure you have your diaper with extra adsorber pads
- I do not avoid caffeine, I consume no energy drink, I just make sure I'm well hydrated.
- Wake up early to have coffee, so that I can go #2 before suiting up.
- Drink about a liter of water over the 30 minutes before donning the helmet
- start hydrating the day before. have coffee as usual day of but earlier to take care of all business as soon as possible.
- Train like you fly. Use the same protocols you have gotten your body used to during all your NBL training

Do you usually finish your drink bag during suited activity?		
	Spaceflight Experience	**NBL Only**
Never	2	2
Sometimes	2	1
Often	0	1
Always	**6**	3
Other	**8**	0
When during a typical EVA/NBL run do you usually finish your water?		
0 – 2 Hours	1	0
2 – 4 Hours	0	0
4 – 6 Hours	7	3
6+ Hours	1	2
Finish water at the end	5	N/A
Finish with reserve water	2	2
Do you have a strategy to conserve water during an EVA (e.g. to help during repressurization) or do you drink until you run out?		
Drink until I run out	2	1
Conserve water for as long as possible	0	0
Other (please explain)	6	0
Balanced approach / Drink as needed	9	4
Complete run with reserve water	1	2

Responses:

- I try to drink small sips during the EVA to wet my throat, and keep a little at the end for repress. The feeling of 4.2 psi in the suit leaves you with a very dry throat and not wanting to cough drives me to take small sips. I was always worried about running out.
- I drink water whenever I have the opportunity.
- The questions are referring to EVA, but I assume this is in reference to NBL. For NBL, I always drink when the divers are swimming us over to other structures. On actual EVA, it was not as physically tough as the NBL and there were no swim-over breaks, so I drank when repressing - not to help with anything, but just because it was the first time I stopped working.
- instead of drinking a lot at once, I drink in sips to make sure i don't run out of water but continually stay hydrated.

Do you have a reason(s) for not finishing the drink bag (select all that apply)?		
	Spaceflight Experience	NBL Only
Too busy with tasks	1	1
Want to avoid using MAG	0	1
Forgot/Not thinking about	2	2
Difficulties with DIDB	0	0
Not thirsty	1	1
Want to finish with excess	0	1
Other (explain)	0	2

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience*:

- *Pre-load hydration such that I require minimal water intake during the run.*
- *I do try to moderate my intake so that I don't run out early in the run. If I had more water, I'd definitely drink it.*

If you had access to more water, would you drink it?		
	Spaceflight Experience	NBL Only
No	5	4
Yes	6	3
Other (explain)	7	0
Would you prefer to drink anything besides water? If so, please describe.		
I prefer water	6	2
Something else	12	5

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience*:

- *Would be nice to have some flavored drink like crystal light, gatorade, something with flavor so it's not so bland*
- *Endurox R4 or similar sports drink would be amazing. I would prefer this to water if we can only have one or the other.*
- *I was involved in the study where our drink bags were filled with a flavored supplemental drink. I much prefer that over water. There was no quantitative increase in performance but physiologically my energy levels felt higher.*
- *something with electrolytes and protein for protein like isopure mix.*
- *If we had a liquid that provided calories, I would definitely prefer that. In an ideal world, I'd want water and a separate way to get calories, liquid or solid.*
- When I finish an EVA, my energy level is very low. Something with calories would be good.
- I very much appreciate having water, but am also open to other options that still feel refreshing/hydrating but also instill some calories and/or protein (as has been tested in the NBL).
- I would not mind having a second drink bag with a carb/protein drink. But I would want one that just has water as well.
- Water is ok, but a no sugar energy drink, maybe with caffeine, would be a way to boost energy.
- We tried a clear whey protein drink in our in-suit drink bag as part of a study in the NBL. I felt it made a big difference in reducing overall fatigue level.

- flavor
- I would like a gatoraid/erg tyupe drink
- That said, I think if there was an independent means/source of liquid electrolyte in addition to pure water, I would definitely enjoy that.
- I think I prefer water, but I also think we could sustain energy longer if we had some protein gel or something similar to eat. Like a chunk of a protein gummy loaded somewhere we could bite off or ingest somehow (like distance runners and bikers do).
- energy drink/electrolytes
- something with electrolytes/energy/calories. would prefer to have both available in the suit
- No way! Water only. Anybody who tells you differently hasn't done long EVAs in an EMU.

Nutrition Questions

How are the following meals changed before and after an EVA?											
	Eat less		Do not change		Eat more		Skip meal		Not applicable		Total
Dinner (night before)	0%	0	76.5%	13	23.5%	4	0%	0	0%	0	17
Breakfast (day of)	5.6%	1	**33.3%**	**6**	**61.1%**	**11**	0%	0	0%	0	18
Pre-suit donning	5.6%	1	11.1%	2	**44.4%**	**8**	5.6%	1	**33.3%**	**6**	18
Post-suit doffing	0%	0	47.1%	8	35.3%	6	0%	0	17.7%	3	17
Dinner (after suited run)	0%	0	**41.2%**	**7**	**58.8%**	**10**	0%	0	0%	0	17
How are the following meals changed before and after an NBL run?											
Dinner (night before)	0%	0	71.4%	5	28.6%	2	0%	0	0%	0	7
Breakfast (day of)	14.29%	1	**42.9%**	**3**	**42.9%**	**3**	0%	0	0%	0	7
Pre-suit donning	0%	0	0%	0	**42.9%**	**3**	0%	0	**57.1%**	**4**	7
Post-suit doffing	0%	0	**14.3%**	**1**	**57.1%**	**4**	0%	0	28.6%	2	7
Dinner (after suited run)	0%	0	**57.1%**	**4**	**42.9%**	**3**	0%	0	0%	0	7

Additional Snacks Before Suited Activity:

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *I typically eat a pack of Clif Shot Bloks immediately prior to suit donning.*
- *I snack on whatever, the fattier the better.*
- Sometimes I will eat a power bar before getting into the suit if available.
- Eat a 500 calorie snack just prior to donning.
- my normal breakfast would be about 400cal, on EVA day I tried to pack 1800-2000cal. Steak and eggs early in the morning, 2 protein bars before donning.
- I do eat more complex carbs as part of breakfast, and some filling fats as well. But not too much, as that may impair activity early in the EVA.
- For the NBL I like to have coffee and an apple around 0600 to move things along.
- note; for dinner the night before and for breakfast, I focus on high energy food thjat I know does not give me gas or bulky stools; don't want to poop in a suit
- How much I eat is not as much a factor as what I eat. I will increase my healthy fat intake prior to a run (i.e. at breakfast) with foods like avocado and unsalted nuts. I also increase protein.
- Almost all crewmembers eat a protein bar in the airlock right before entering the HUT. We crouch below the HUT to do so so the cameras don't see us.
- I eat a "second breakfast" (banana, cheese stick, and protein bar) in the locker room while changing into my LCVG.
- before i ate the russian tyorg. it is thick, protein dense cottage cheese with nuts and sugar. Lots of energy in a compact amount. Limited (maybe psycologically) feeling of having to go number 2. dense food that will just sit in your belly.
- Just a detail on the pre-suit donning line above - continued to munch on additional 'energy' bar until helmet donning

Additional Snacks After Suited Activity:

- I find that I also am much hungrier and consume more calories on the day following an EVA or NBL run.
- Normal dinner
- I feel the need for hot liquids, soups, etc. after an EVA. And likely eat more, just because I'm hungry, after the EVA.
- I will consume a digestible protein shake post run (either whey or aminos) to replenish my muscles, followed by fiber (berries, celery, plant based foods w/high water content).
- On orbit, orange juice was a favorite thing to be handed right when we got back inside (we also did this for the cosmonauts). Actually we do this for crews arriving to ISS also. Its a refreshing, cold drink with sugar and calories that is great immediately post-EVA. On the ground, I have a protein recovery shake right after an NBL run (same kind I use after heavy lift workouts).
- I eat what I would have had for lunch (sandwich, apple) during debrief.
- Super hungry at the end of the day, so typically eat a bunch. No special plan - just eat whatever.
- just hungry afterwards, as normal.

How often are you hungry before, during, and after an EVA?									
	Never		Sometimes		Often		Always		Total
Before	**61.1%**	**11**	22.2%	4	11.1%	2	5.6%	1	18
During	22.2%	4	**55.5%**	**10**	**16.6%**	**3**	5.6%	1	18
After	0%	0	11.1%	2	5.6%	1	**83.3%**	**15**	18
How often are you hungry before, during, and after an NBL run?									
Before	**85.7%**	**6**	14.3%	1	0.00%	0	0.00%	0	7
During	14.3%	1	28.6%	2	42.9%	3	14.29%	1	7
After	0.00%	0	0.00%	0	**28.6%**	**2**	**71.4%**	**5**	7

If you do get hungry, how distracting is hunger during EVAs?		
	Spaceflight Experience	NBL Only
Not distracting	**12**	**1**
Slightly distracting	**4**	**4**
Moderately distracting	**0**	1
Very distracting	**0**	**0**
I am not normally hungry	**2**	1
Do you have a specific food routine after an NBL run?		
No	7	3
Yes (what/where/when do you typically like to eat/drink to recover?)	11	4

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience*:

- *I often eat a steak afterwards.*
- *Burger*
- *I immediately drink water and eat carbs.*
- *I eat a late but otherwise standard lunch during the debrief.*
- I eat a massive meal with lots of carbs
- I eat more carbs and protein after an EVA.
- Russian food, as much fat and salt as possible. I always wanted some hot food, meat and vegetables. Am definitely hungry and thirsty when I get out of the suit.
- Not a routine, but it's nice to have some 'favourites' available.
- I eat and drink my lunch late - and am usually very hungry and thirsty.
- eat lots of food
- Mentioned previously - protein shake (either whey or amino acids) and high-water content fiber(berries, celery, peppers). I also will have something sweet if no berries.
- Just a protein or juice drink right after. On the ground I usually eat whatever. On orbit, we normally save the crew's favorite foods for right afterward - but that is more of a treat than any particular food. I preferred the Russian food before/after an EVA because it is higher calorie/salt/fat.
- See above. After returning home, I eat a normal dinner.
- eat a lot of whatever i really like at that time. Russian mashed potatoes were awesome so i loved those afterwards. Something to fill you up.

Would you like In-Suit Nutrition?		
	Spaceflight Experience	NBL Only
Yes	7	4
Sometimes	5	1
No	6	2
Do you have any preferences for in-suit nutrition? (select all that apply)		
Liquid nutrition (e.g. meal replacement shake)	12	4
Solid nutrition (e.g. protein bar)	4	2
Gel/paste (e.g. energy gel)	8	4
No preference	2	2

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *Would be happy with flavored drink*
- *Clif Shot bloks. Margarita and salted watermelon flavors have 2-3x sodium, great for avoiding muscle cramps. Consistency seems well-suited for in-suit delivery without a mess. Much tastier than Gu or other energy gels.*
- *Look into the paste that high altitude U2 Air Force Pilots get to east. https://www.af.mil/News/Article-Display/Article/109733/fueling-the-high-flyers-u-2-tube-food-calms-cravings-in-the-cockpit/*
- Solid would probably be the best, because it would make you feel fuller, but it's possible liquid would be easier to consume and spread out throughout the run.
- I am concerned it may be messy inside the suit.
- Solid nutrition may not be practical in the suit (as has been deemed in the past), but I would I be open to evaluating i
- it may be difficult to manage spills. An enclosed system like the DIDB would be good to manage/enclose the nutrition source
- Choking, eye contamination, vision obstruction,and making a mess on visor are definite concerns
- coming apart in the helmet, getting sticky residue on my face. Too much distraction. The helmet is already full of equipment.
- crumbs, choking, etc..
- need to get it done right, don't want food contamination/bactertia contamination to mess up suit interior of get crewmember sick
- What goes in must come out and I prefer not to have it in the suit with me (other than my diluted urine in a diaper).
- I would be concerned with anything solid that could be a choking hazard. I would strongly recommend against solid, and stick with a gel or liquid.
- Crumbs are bad news in microgravity.
- I think the benefits are not worth the risk for either solid or liquid nutrition. I vote to keep it just water.

- yes - mess and making me want to drink more water. I think 6 hours is fine without nutrition.
- We need to make sure our xEMU can accommodate any of the types of nutrition we are planning. I do not think the legacy concerns about liquid nutrition getting in the crew members eyes is any longer a valid safety concern as there have been so many EVAs and no drink bag escapes that were a problem.
- It is not a great idea

Do you have any concerns about in-suit nutrition?		
	Spaceflight Experience	NBL Only
Concerns about liquid nutrition	2	0
Concerns about solid nutrition	10	1
Other concerns (please explain)	14	1
No concerns	2	4

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *My only concern is that we don't have it! I think it has a huge impact on our performance.*
- *[For solid nutrition] Just extra FOD and debris in the suit that could interfere with sealing*
- i wouldn't want some solid liberating inside the suit.
- crumbs in helmet
- Food on orbit can float around your mouth differently than on Earth. So if you had a piece of granola bar stuck in your tooth and you started breathing hard, it could dislodge and float down your throat. It isnt the type of choke hazard that would lead to actual blocked throat, but more of the "that just went down the wrong pipe" choking that leads to a lot of coughing.

Given the limitations of being in a spacesuit, do you have any ideas or suggestions for in-suit nutrition delivery methods?

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *No.*
- *U-2 and other high altitude flight platforms have tubes that can be attached exterior and then run into the mouth so there's never stuff (that could generate debris or FOD) stored inside the suit*
- *Shot bloks seem an attractive option. Could easily extract individual bloks from plastic tube/casing with mouth. Could imagine designing a simple device to squeeze bottom of package such that bloks move toward mouth of (but not out of) plastic tube, held in position where is is accessible to crew member's mouth.*
- *No. Just anything that is calorically dense will be better than nothing. I'm not worried about food/liquids interfering with the suit. I mean the suit takes urine just fine, how can nutrient-dense liquid be any worse?*
- *I do not see a need for in-suit nutrition. I would likely ask not to be provided with in-suit nutrition, since it is just additional stuff that can cause problems.*
- Liquid seems like the easiest option.
- Keep it liquid to maximize simplicity
- I was encouraged by the protein beverage that was fairly recently tested in the NBL. I found I still felt satisfied in terms of thirst/hydration, but perhaps did get an extra boost from the calories.
- A second DIDB with a liquid carb/protein/electrolyte might be the best option. A gel pouch could also work, I use those a lot on marathons/triathlons. Recommend using a commercial product for long duration athletes, rather than NASA inventing our own.
- Liquid nutrition with a bite valve seems like a great option. Look at products like Ucan.
- Given the limited real estate, a hi-calorie drink may provide the most nutrition while not using up more space or creating any in-helmet hazards.
- We had previously discussed two straws, one for water one for nutrition and that seems reasonable. The geometry within the helmet will be interesting to optimize.

- I would have a smallish workshop where a handful of crew/engineers get together and brain storm
- Hard to imagine w/out seeing the spacesuit. In the EMU, there is hardly enough room as it is, I would hate to mix my sweat, snot, and tears with my food.
- Maybe a small packet next to the drink bag with gel in it, that has its own bite valve and can be consumed similar to the regular drink bag. My only other thought is some type of rupturable packet inside of the drink bag that you could puncture to release its contents halfway through the EVA (like by biting something or squeezing it).
- A straw for sucking gel would work well.
- Yeah - don't try it.
- drink bag maybe gel blocks you can easily rip off with your teeth inside helmet.
- Continue to look at the simple route of a larger sized drink bag divided into two sides, one with water, one with liquid in-suit nutrition.
- Yes- don't need solid nutrition until maybe the moon. Maybe.

Waste Management Questions

How often do you change your bowel habits before an EVA?		
	Spaceflight Experience	**NBL Only**
Never	11	**7**
Sometimes	2	0
Often	0	0
Always	5	0
Do you ever experience bowel urgencies in the suit?		
Never	18	6
Sometimes	0	1
Often	0	0
Always	0	0
Have you ever experienced a bowel movement in the suit?		
No	18	7
Yes	0	0
Are you apprehensive that you may experience a bowl urgency during an EVA?		
Never	11	4
Sometimes	5	3
Often	2	0
Always	0	0
How often do you use the MAG for urination?		
Never	3	1
Sometimes	2	3
Often	4	1
Always	9	2

How comfortable is the MAG in the following situations:											
	Very uncomfortable		Somewhat uncomfortable		Do not notice		Somewhat comfortable		Very comfortable		Total
Before Urination	0.00%	0	0.00%	0	**70.59%**	**12**	11.76%	2	17.65%	3	17
After Urination	0.00%	0	13.33%	2	**53.33%**	**8**	13.33%	2	20.00%	3	15
Before (NBL Only)	**0.00%**	**0**	**28.57%**	**2**	**57.14%**	**4**	**14.29%**	**1**	**0.00%**	**0**	**7**
After (NBL Only)	0.00%	0	**50.00%**	**3**	**33.33%**	**2**	16.67%	1	0.00%	0	6

Do you try to avoid or wait to use the MAG during suited activity?		
	Spaceflight Experience	NBL Only
No strategy	6	4
Avoid using the MAG	3	2
Wait until late in the EVA	1	0
Other (please explain)	8	1

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *I try to use the MAG as early as possible or during a weigh out it I don't have the urge to urinate when I'm busy with a task.*

- I use it if I need to. I know it feels hot, then cold, then it dries up and feels normal again. Never felt any major discomfort.
- I try to stay sufficiently hydrated that I use the MAG to urinate. It's a good sign I'm staying hydrated.
- I use mag when on test stand NBL and in airlock depress during EVA. I find there is a psychological barrier to first use and if bladder is bursting full it may be difficult to get the pee flowing. Peeing right away breaks this barrier and makes subsequent use easy.
- Use anytime I pause (waiting for the ground, waiting on my buddy) on EVA. In the NBL, use when I am getting swam by the divers to another structure.
- I pee in it anytime I feel the need. I don't worry about over filling it.
- use when needed. most likely pee during prebreath depending on length of eva, will urinate at least once during it usually.
- Would have used if I ever had a need, but never did
- I go when I need to go.

What is the primary reason for avoiding/waiting to use the MAG?

Reponses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *Avoid sitting in wetted mag particularly in 1G / inverted ops.*
- *I haven't had a need to use the MAG. I typically sweat in sufficient quantities to reduce the need for using the MAG.*
- Potential discomfort
- fear of leak
- My habits so far have allowed me not to use the MAG but, I really don't have a problem should I need to.
- I do not avoid using it.
- I only avoid #2, as i would not want to contaminate the suit. Luckily I have never had the urge to.
- none in my mind - possibly leakage, but in the real suit, the mag actually dries out a bit. may want to meter the flow of urine to make sure there isn't a leak.
- Never had a need

Are MAG leaks a concern?

	Spaceflight Experience	NBL Only
No	5	0
Somewhat	3	3
Yes	1	1
Other (please explain)	9	3

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *I don't know that they actually are a concern as I've never had one but it is something I worry about.*
- *Forces you to meter flow and you're wasting time concentrating on that vs the task at hand...doing normal urination pressure/flow overwhelms the MAG and you wind up with leaks and it's uncomfortable because it gets cold and also smells*
- *Typically do not use the MAG, therefore unsure.*
- They may happen, but other than soiling the LCVG it hasn't been a problem.

- I have always worn but never needed the MAG throughout my career in NBL or EVA so have no experience with a wetted one
- I have to meter the urine flow, which I understand is difficult/impossible for some, and occasionally get a slight leak. But it dries and it doesn't bother me.
- I have tested it (not in the NBL) and not had a problem.
- have to regulate flow; dry MAG takes up urine slower than used; best to have frequent smalll pee'ing than letting go with a big one. Also, can add extra pads
- So far, in training or spaceflight, have never had an issue with leaks.
- Hard to tell what is sweat and what is urine in the suit after doffing...probably both to be honest.
- All of my EVAs have had an over saturated MAG. Urine soaking the LCVG from my knees to my armpits.
- meter flow and this is generally solved.

How often does the MAG leak?		
	Spaceflight Experience	**NBL Only**
Never	8	3
Sometimes	7	2
Often	1	1
Always	1	0
How severe are MAG leaks?		
Not severe	3	0
Minor	5	1
Moderate	0	2
High	1	0
How distracting are MAG leaks?		
Not	4	0
Slightly	5	3
Moderately	0	0
Very	0	0

With transition to planetary EVA ops, do you have questions/concerns about MAG fit or comfort in partial gravity NBL runs?

Responses Note: *Italicized responses are from crewmembers with 'NBL Only' experience***:**

- *We're still in 1G in the pool / not expecting any changes to MAG performance.*
- *The lower legs aren't used in microgravity so if you soil your mag, there really isn't any friction. if you soil your mag on the moon though, all that walking may be unpleasant with a soiled mag. Think rashes.*
- No/none (x8)
- not right now, but would need to try out the run to see
- Just a suggestion that 'pull ups' are more comfortable and easier.
- It may be easier and closer to the NBL with partial gravity
- no One big surprise during EVA; after seemingly filling the MAG to capacity during the EVA, when I de-suited, the MAG was nearly dry. The water in urine had nearly evaporated in the

low suit humidity and was thus now in the suit internal water loops. This might be a good approach to design into a long duration surface suit, plan air flow into the MAG intentionally to recover the water.

- Not so much with the MAG but with the suit around the crotch area. If there is a gap between the suit and the body, the MAG will sag after it has been used. If there is sufficient contact between subject and suit, this will not be noticeable.
- You guys need to think about female time of the month also. Blood is a contaminant that the EVA community talks about a lot, like when we have an abrasion on our hand. But no one seems to talk about MAG leaks and periods. If a woman is on her cycle, she has a choice of a tampon or just using the MAG. Tampons are not recommended to be used over 8 hours due to infection. Mags can leak, and if they leak they could leak blood. I had terrible timing on orbit and started my period unexpectedly during O2 pre-breath (before suit donning). I decided to go put a tampon in. But I thought about what would have happened if it had started 30min later - I would have had the MAG, but if I had urinated enough, blood could have contaminated the suit.
- MAG will function in full or partial gravity as it does in the NBL. Not problems if you throttle your flow rate a little bit. Leaks occur when you let loose all at once.
- If you have to wear the LCVG many times, it could get extremely stinky from all of the urine saturation. I don't think this is a MAG fit issue. Some people, I'm one of them, pee more in 10 hours then the capacity of any MAG.
- needs to be a better system..
- possibly. Need to make sure it doesn't have leaks around the legs at all. in space, this isn't really a factor.

General Questions

How close is the NBL as a model for the following when compared with ISS On-Orbit EVAs:									
	Very Different		Somewhat Different		Slightly Different		Identical		Total
In-suit hydration	**11.1%**	**2**	**27.8%**	**5**	**27.8%**	**5**	**33.3%**	**6**	18
In-suit waste management	0%	0	16.7%	3	22.2%	4	**61.1%**	**11**	18

Responses:

- As mentioned previously, I require more hydration and am more often hungry in NBL runs, because they are significantly more metabolically taxing (mostly because the suit is far too big for me, making it much more difficult to manage in the NBL due to 1g effects).
- NBL runs are much shorter for total duration in the suit with ISLE than EVAs so more hydration is needed. It is also too long to go without nutrition.
- For hydration, there have been instances were droplets of water liberate from the bite valve. I have not seen that in orbit. For nutrition (if solid) my concern would be that the food drops to the helmet and soils the visor.
- the dry oxygen perhaps dehydrates me faster. my throat feels drier after an EVA.
- Temperature impacts all of this and I found it easier to regulate my temperature on orbit than in NBL
- NBL and EVA has no suit nutrition
- On orbit, I control the quantity of water in my DIDB.
- Covered in previous answers
- Hydration: Had to gauge how many ounces in the drink bag using spacecraft fill mechanism. Nutrition: No basis to judge.
- A real EVA is 4 hours longer becasue of the pre-breath time. This exta time is significant
- i usually eat a bagel before NBL run. I know it will be over at 3pm regardless so I don't eat that dense russian cottage cheese. I know I can eat whatever afterwards, which is usually a hamburger.
- hydration and nutrition are different because in the NBL runs we are typically suited for ~6:30 yet on orbit EVAs we are typically in the suits (helmets on) for ~11 hrs with ISLE
- In-suit nutrition really not needed and not applicable

Is there anything that surprised you about on orbit EVAs compared to NBL runs (from a nutrition/hydration/waste perspective)?

Responses:

- As above, was relieved to feel how much less taxing it was to maneuver in the suit on-orbit (of course other things are more difficult on-orbit, but for me simply translating in the NBL can be extremely metabolically taxing due to poor suit fit and the potential for poor weigh outs). This is readily apparent in my metabolic data from NBL vs. on-orbit. This difference is exacerbated for smaller sized crewmembers that have less ideal suit fits.
- How dry my mouth was in 4.2 psi. I need more water during a real EVA and the suited duration is longer. Nutrition would
- No
- No.

- just as exhausting
- I had to figure out a way to achieve my desired nutrition (pre and post) using food available to me on orbit whereas in the NBL, I have more flexibility and options at home.
- Just wasn't as thirsty - EVA is physically easier but mentally tougher, so I found I did not really think about drinking or urinating much. You also don't have the built in breaks like the NBL, so there isn't a good time to do either.
- Easy to underfill drink bag in orbit and end up with too little water.
- How much longer a read EVA feels because of the prebreath time.
- not really.
- didn't drink as much water
- Yes- super dry environment in EVA suit. More water needed.

Do you have any tips for newbies that you wish you had been told before your first NBL run or EVA?

Responses:

- Make sure you try to use the MAG for urination early on so you get comfortable with it.
- Pee early and often.
- You have to modulate urination to ensure absorption in the MAG without leakage.
- nothing to report.
- There are great tips for before first real EVA, compiled by Butch Wilmore. I printed out the email and taped it into the EVA contingency procedure book onboard
- Hydrate as much as you can. If you're trying to avoid using the MAG, train yourself to use it and stay hydrated. (urine only). Defecating in the MAG would be a nightmare.
- Glove and suit fit is the most important factor in maximizing your performance.
- Know your body and create the necessary habits before you start. If there is an exception don't get too stressed about it.
- plan your poops so you don't do that in the suit
- #1 If you're thinking about food while you're in the suit you need to change your eating habits before suit-up. #2 If you're avoiding hydration because you're concerned about a MAG leak, you'll have bigger issues being dehydrated and one of only two people together in the vacuum of space.
- Not really. We had a veteran with us the whole time for the first NBL run, so they could answer questions. When I did EVA on board, we had only rookies there, but specific to food/waste/hydration, it was pretty much just like the NBL.
- Throttle flow of urine when using MAG. Make sure your drink bag is full; err on the side of overfilling.
- Nope. It's hard and I was told it would be hard.
- I actually filled my DIDB up more on orbit (we do it ourselves) than they do at the NBL. I have space in my suit fit and I want to make sure I have enough water to drink thru the insuit prebreathe protcol as well as outside during the EVA, with a little reserve in case the eva goes long.
- Train like you plan to fly. As much as possible use the eating/drinking/toilet habits for NBL runs you plan on using for EVAs. That way there is less chance for surprises and your body is used to the amount of energy you have in your body and the water that you will be able to consume during
- Drink your water

Is there anything else that you think would be helpful for us to know about hydration, nutrition, or waste management in the suit? (i.e. suggestions to improve hydration, nutrition, and/or waste management in the suit; Desired delivery method for solid foods; etc)?

Responses:

- In suit sports drinks or nutrition would be amazing!
- I really think liquid nutrition to be a safer option, based on my own experience racing endurance events.
- No.
- Nothing specific, any movement towards in-suit nutrition will be a huge win.
- If you eat a hardy breakfast and are properly hydrated, I don't see the need for in-suit nutrition or additional hydration.
- Covered it all I think!
- I'm not a fan of in-suit nutrition.
- people should practice as close as they can on the ground to how they will do all this in orbit. No big changes should take place.
- looking forward to seeing the mechanics of the solid food options when you have them
- Can't people wait to eat. 8 hrs is OK. No need to pollute your suit with food.

Would any of your answers change if you were expected to conduct multiple consecutive EVAs (i.e. 4 over 5 days) opposed to single EVA?

	Spaceflight Experience	NBL Only
No	12	4
Yes, some	6	3
Yes, many	0	0

Responses:

- Since I am usually hungrier the day after an NBL run, I think I likely would be hungrier in the suit if I had to do multiple EVAs over consecutive days.
- I'd probably alter my diet to low residue so I'm more confident I wouldn't have to poop in the suit
- hydration and nutrition become even more important with consecutive EVAs. Otherwise our bodies will eat thier own muscle. EVA is a high performance, intense and long duration sport. We should fuel like marathon runners, or triathletes (Olympic distance and above)
- Eat much, especially after each in prep for next
- I would just eat a lot more during dinner and breakfast.
- I think it makes in-suit nutrition WAAAAAY more important than if you have plenty of time to recover between runs.
- Given this was a standard practice on shuttle missions, I don't see my answers changing. I do think better quality proteins and fats need to be manifested.
- Have several LCVGs available.
- I would just be concerned about absence of recovery time for the body and being able to pack in enough energy after the previous EVA and before the next. I would say it makes the in-suit nutrition a mandatory item,

Appendix D. Questionnaire for Feedback on Concept Design References.

Appendix D1. Qualtrics Questions

https://nasajsc.qualtrics.com/jfe/form/SV_88rUTaZHrE98qKa

Feedback on Concept Design References for In-Suit Nutrition Systems

You are asked to provide feedback on some high level concept designs as references for possible suited nutrition systems in future space suit designs. These high level concepts include:

1. Liquid: Drink bag prefilled with liquid nutrition. Placed within the suit and ready to consume.
2. Powder: Drink Bag prefilled with hydratable powder. Placed within the suit after rehydration and mixing.
3. Solid: Food bar. Placed within the helmet ring and ready to consume.
4. Helmet Feed Port: Provides the ability to consume liquid nutrition placed outside the suit.

Please note that the following designs are considered concepts only and are not necessarily in any state of development at this time.

Each of these food systems are intended as additions to the water that is already provided in the suit.

Also note that all pictures shown for each design concept are hypothetical and are provided for illustration purposes only.

Cooper-Harper Rating and Acceptability Scale

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies anticipated		Minor improvements in concept desired and/or Minor deficiencies anticipated		Improvements in concept warranted and/or Moderate deficiencies anticipated		Improvements required and/or Unacceptable deficiencies anticipated		Major improvements required and/or Totally unacceptable deficiencies anticipated	
1	2	3	4	5	6	7	8	9	10

Instructions for Rating the Questionnaires

Please provide your ratings and associated comments regarding how acceptable you believe the different nutrition systems would be during Lunar missions.

Reflect the extent to which the design is considered acceptable (effective, efficient and reliable) and the extent to which improvements, if any, are desired (3-4), warranted (5-6), or required (7-10). The Acceptability Scale is used to provide each rating.

→

Background

What is your primary field of expertise relevant to this project? If multiple fields apply, please choose this based on your primary contribution to this project. If none of these fields apply, please provide your field of expertise.

- Astronaut
- Anthropometry and Biomechanics
- Food Science
- Human Physiology & Performance
- Nutrition
- Suit Engineering
- Other

Are you a member of the In-Suit Nutrition Project team?

Yes

No

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The following questions are about ready-to-consume drink bags.

In this configuration, nutrition will be provided in prefilled drink bags that are ready to install in the suit for consumption during EVA

The prefilled drink bag provides liquid nutrition to the crew member while confined to the suit. The bag is mounted inside of the suit prior to donning and the contents are consumed through a straw during the EVA. This concept assumes engineering solutions are developed for ease of installation in the suit (i.e. attachments or sleeves) and handsfree opening of the drink bag while mounted within the suit (i.e. bite valves).

PRE-EVA

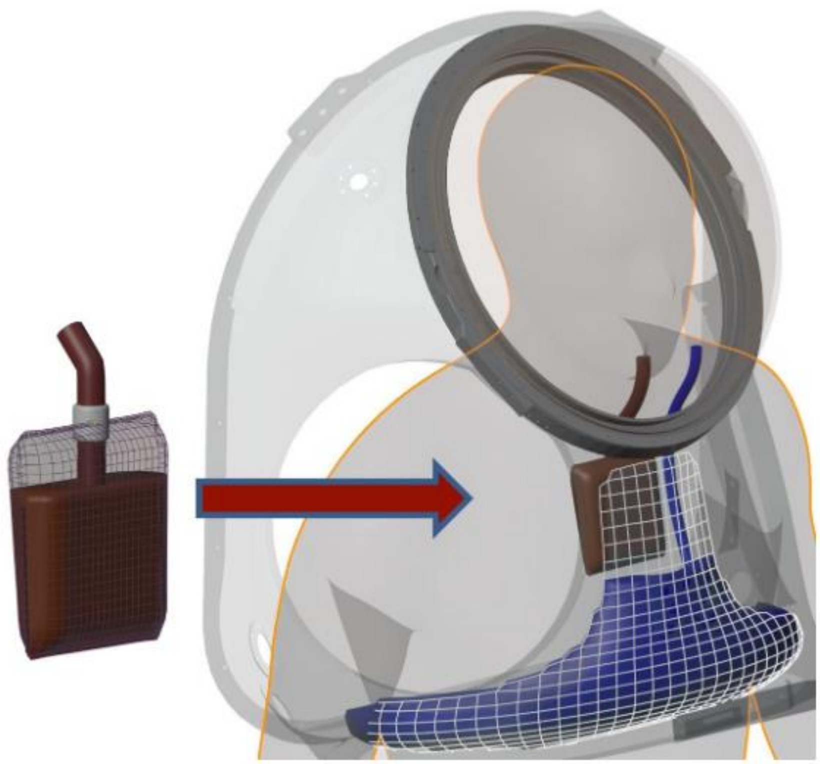
1. Unstow bag
2. Install bag in suit

EVA

3. Break seal
4. Consume beverage (within 2 hrs of breaking seal)

POST-EVA

5. Uninstall empty bag from suit
6. Dispose of empty bag



Please rate the acceptability of this concept design based on **your** anticipated impact on the elements below:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies anticipated		Minor improvements in concept desired and/or Minor deficiencies anticipated		Improvements in concept warranted and/or Moderate deficiencies anticipated		Improvements required and/or Unacceptable deficiencies anticipated		Major improvements required and/or Totally unacceptable deficiencies anticipated	
1	2	3	4	5	6	7	8	9	10

	1	2	3	4	5	6	7	8	9	10
Preparation/installation time and effort before EVA	○	○	○	○	○	○	○	○	○	○
Ease of use of this system during EVA	○	○	○	○	○	○	○	○	○	○
Cleanup/disposal time and effort after EVA	○	○	○	○	○	○	○	○	○	○

Do you have any thoughts about this concept and/or suggestions that you would like to share?

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The following questions are about hydratable drink bags.

In this configuration, drink bags contain powdered nutrition that can be rehydrated and mixed before installing in the suit and consumption during an EVA.

The drink bag contains powdered beverages that are hydrated prior to installation in the suit (similar to the prefilled drink bag concept). Once rehydrated, the bag is mounted inside of the suit prior to donning and the contents are consumed through a straw during the EVA. This concept assumes engineering solutions are developed for ease of installation in the suit (i.e. attachments or sleeves) and handsfree consumption of the drink bag while mounted within the suit.

PRE-EVA

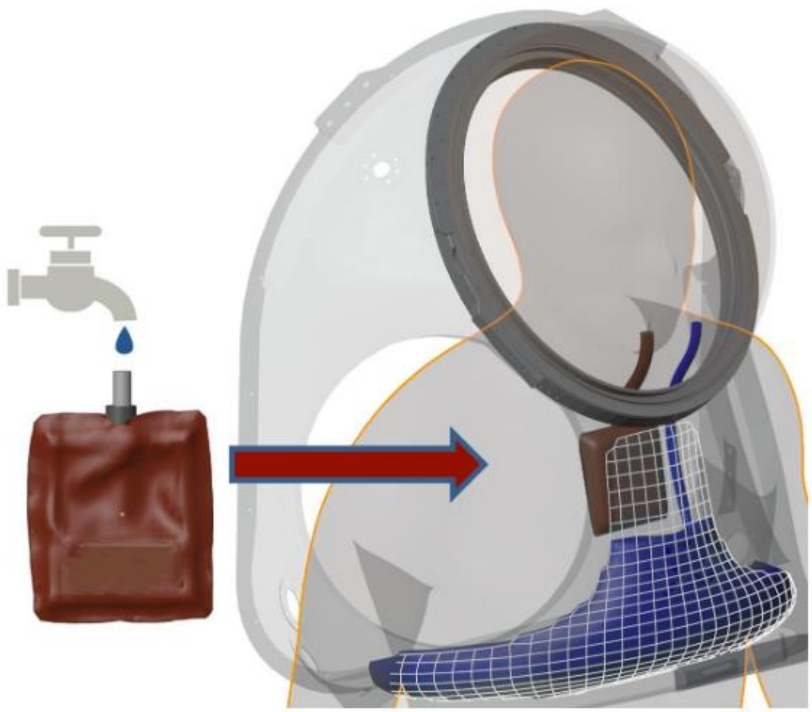
1. Unstow bag
2. Open bag
3. Hydrate & mix bag
4. Install bag in suit

EVA

5. Consume beverage (within 2 hrs of mixing)

POST EVA

6. Uninstall empty bag from suit
7. Dispose of empty bag



Please rate the acceptability of this concept design based on **your** anticipated impact on the elements below:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies anticipated		Minor improvements in concept desired and/or Minor deficiencies anticipated		Improvements in concept warranted and/or Moderate deficiencies anticipated		Improvements required and/or Unacceptable deficiencies anticipated		Major improvements required and/or Totally unacceptable deficiencies anticipated	
1	2	3	4	5	6	7	8	9	10

	1	2	3	4	5	6	7	8	9	10
Preparation/installation time and effort before EVA	○	○	○	○	○	○	○	○	○	○
Ease of use of this system during EVA	○	○	○	○	○	○	○	○	○	○
Cleanup/disposal time and effort after EVA	○	○	○	○	○	○	○	○	○	○

Do you have any thoughts about this concept and/or suggestions that you would like to share?

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The following questions are about solid food bars.

In this configuration, ready to eat solid food bars are installed within the helmet ring that can be reached by mouth for consumption during EVA.

The food bar provides solid food to the crew member while confined to the suit. The food bar is mounted inside the suit/helmet prior to EVA and is reachable by mouth to pull up and bite off pieces as desired. Additional variations of this concept to consider include bite size pieces as alternative to a single bar (engineering solutions TBD).

PRE EVA

1. Unstow bar
2. Install bar in suit

EVA

3. Pull up bar with mouth and bite to consume

POST EVA

4. Uninstall remaining food from suit
5. Dispose of remaining food

Please rate the acceptability of this concept design based on **your** anticipated impact on the elements below:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies anticipated		Minor improvements in concept desired and/or Minor deficiencies anticipated		Improvements in concept warranted and/or Moderate deficiencies anticipated		Improvements required and/or Unacceptable deficiencies anticipated		Major improvements required and/or Totally unacceptable deficiencies anticipated	
1	2	3	4	5	6	7	8	9	10

	1	2	3	4	5	6	7	8	9	10
Preparation/installation time and effort before EVA	○	○	○	○	○	○	○	○	○	○
Ease of use of this system during EVA	○	○	○	○	○	○	○	○	○	○
Cleanup/disposal time and effort after EVA	○	○	○	○	○	○	○	○	○	○

Do you have any thoughts about this concept and/or suggestions that you would like to share?

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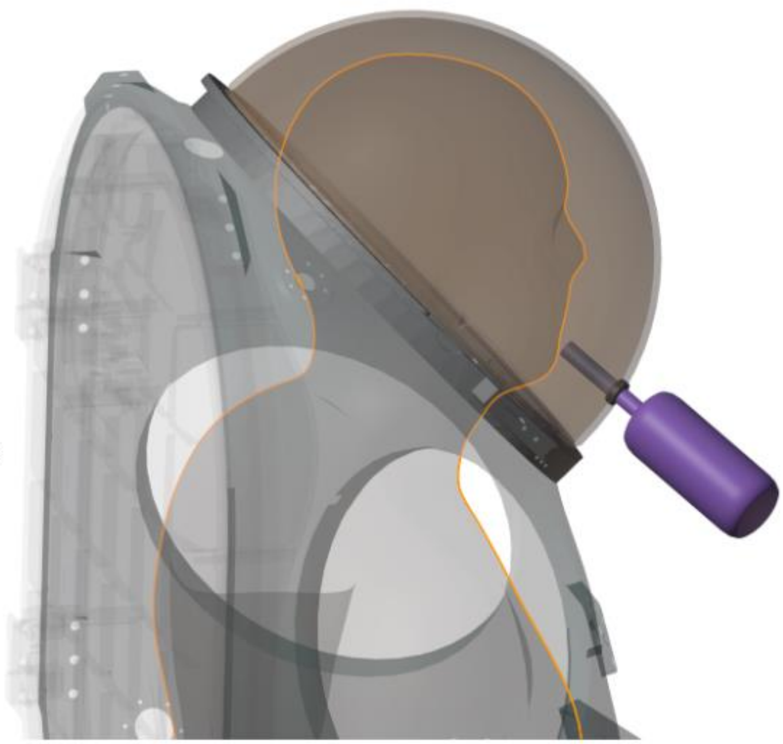
The following questions are about the use of a helmet port.

In this configuration, the suit helmet includes a food port that is accessible by mouth for consumption of liquid nutrition outside of the suit.

The helmet feed port system provides access to either liquid or hydratable nutrition to the crew member while confined to the suit. The suit port is integrated into the helmet and allows insertion of a feed tube connected to the drink bag. This concept assumes engineering solutions are in place to stage food and relevant tools external to the pressurized vehicle prior to the EVA.

PRE EVA

1. Unstow drink bag system
2. Stage and configure drink bag system for access during EVA.



EVA

3. Insert tube through helmet port
4. Consume beverage through tube
5. Disconnect tube from helmet port
6. Configure drink bag system for remainder of EVA.

POST EVA

7. Dispose of drink bag system

Please rate the acceptability of this concept design based on **your** anticipated impact on the elements below:

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies anticipated		Minor improvements in concept desired and/or Minor deficiencies anticipated		Improvements in concept warranted and/or Moderate deficiencies anticipated		Improvements required and/or Unacceptable deficiencies anticipated		Major improvements required and/or Totally unacceptable deficiencies anticipated	
1	2	3	4	5	6	7	8	9	10

	1	2	3	4	5	6	7	8	9	10
Preparation/installation time and effort before EVA	○	○	○	○	○	○	○	○	○	○
Ease of use of this system during EVA	○	○	○	○	○	○	○	○	○	○
Cleanup/disposal time and effort after EVA	○	○	○	○	○	○	○	○	○	○

Do you have any thoughts about this concept and/or suggestions that you would like to share?

← →

Please order the design references below in **your order of preference** (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please elaborate on your rankings in the previous question.

Please rank the systems on your anticipated likelihood that the system **will reach development/implementation** (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please rank the systems on your anticipated likelihood that the system **will function as designed/intended** (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please rank the systems on your anticipated likelihood that the **crew will use the system as intended** (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please rank the systems on your anticipated **ease of use** (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please rank the systems on your anticipated **safety concerns and/or risks** to the crew or mission (drag favorite to top).

Ready to consume drink bags

Hydratable (Powder) drink bags

Solid Food Bars

Helmet Port

Please provide any additional comments on the ratings and your rationale:

←

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The following questions ask you about any final thoughts you may have on nutrition, hydration, and waste management.

Is there anything we forgot to ask or would you like to elaborate on any of the previous topics or anything else related to nutrition, hydration, or waste management in the suit?

We asked these question with Lunar gravity operations in mind. How would your answer be different if you considered this for use in microgravity instead of a surface gravity (i.e. Lunar) environment?

How would any of your answers be different if you were expected to conduct multiple/consecutive EVAs (i.e. 4 over 5 days) opposed to single EVA?

Do you have any recommendations for a different concept system or solution that was not presented?

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Thank you for your feedback. This project will help inform the Exploration Extravehicular Activity (xEVA) Human Health and Performance (HHP) open actions for the development of solutions for providing adequate in-suit hydration, nutrition, and waste management.

And thank you for your time! We welcome additional feedback or cooperation during this project. For questions or additional feedback, please contact someone from our team:

Lichar Dillon (edgar.l.dillon@nasa.gov)
Grant Harman (grant.w.harman@nasa.gov)
Jason Norcross (jason.norcross-1@nasa.gov)

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Appendix D2. Crew Feedback Results

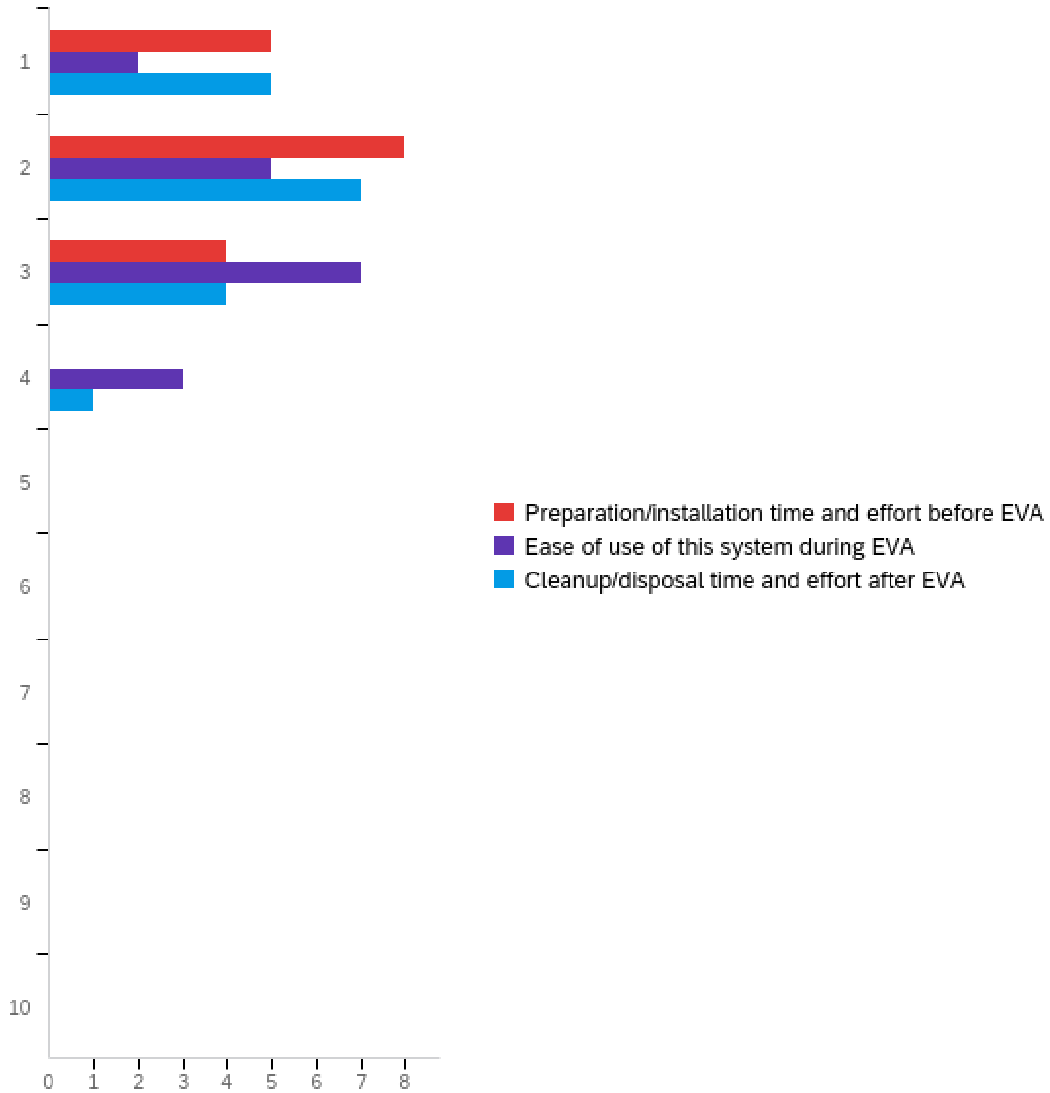
I2 - What is your primary field of expertise relevant to this project? If multiple fields apply, please choose this based on your primary contribution to this project. If none of these fields apply, please provide your field of expertise.

#	Answer	%	Count
1	Astronaut	100.00%	17
	Total	100%	17

I3 - Do you have spaceflight EVA Experience?

#	Answer	%	Count
1	Yes	52.94%	9
2	No	47.06%	8
	Total	100%	17

L2 (Ready-to-Consume Drink Bag) - Please rate the acceptability of this concept design based on your anticipated impact on the elements below:

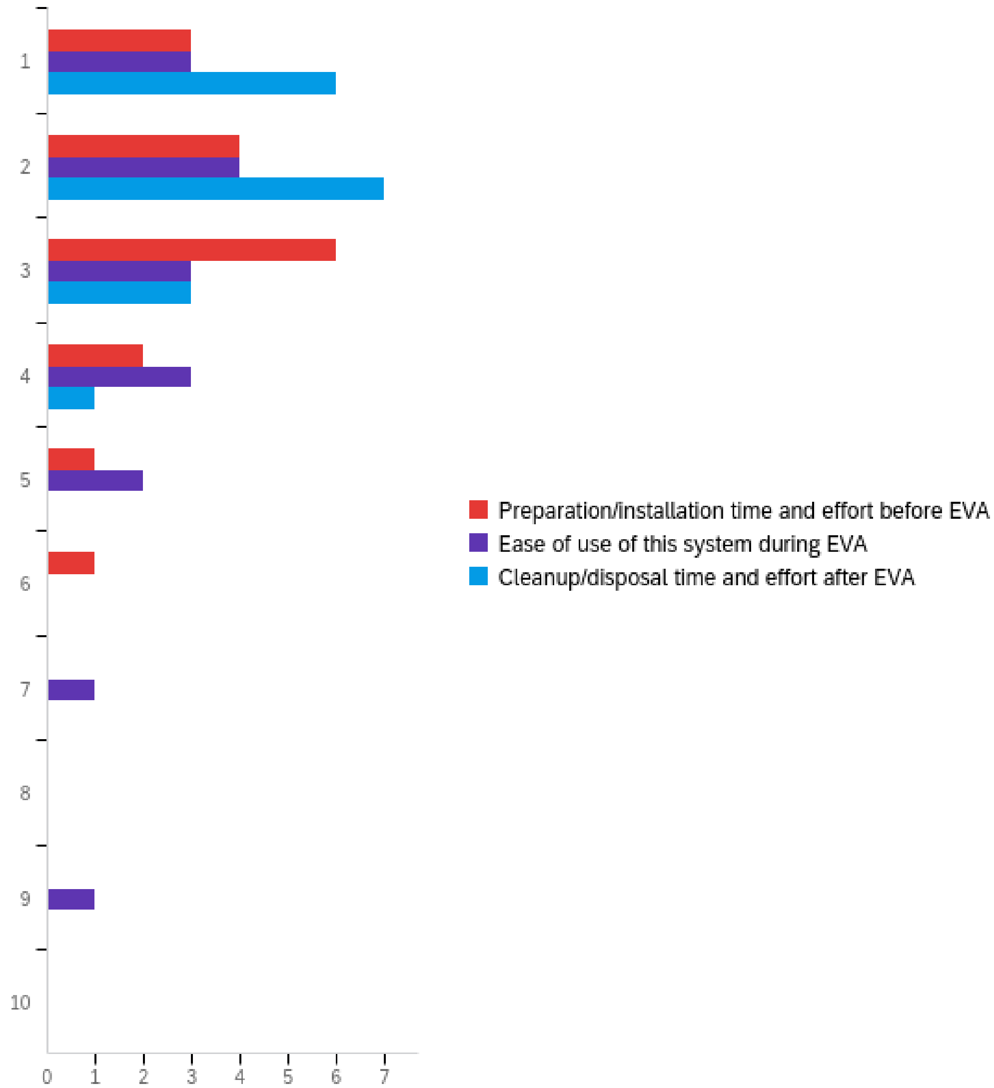


#	Question	1		2		3		4		5		6		7		8		9		10		Total
1	Preparation/installation time and effort before EVA	29.41%	5	47.06%	8	23.53%	4	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	17
2	Ease of use of this system during EVA	11.76%	2	29.41%	5	41.18%	7	17.65%	3	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	17
3	Cleanup/disposal time and effort after EVA	29.41%	5	41.18%	7	23.53%	4	5.88%	1	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	17

L3 (Ready-to-Consume Drink Bag) - Do you have any thoughts about this concept and/or suggestions that you would like to share?

Do you have any thoughts about this concept and/or suggestions that you would like to share?
just normal concerns of food materials getting into the eva systems.
Would prefer something that wasn't limited to 2-hours from the time the seal was broken, but would largely serve the purpose.
This seems very straightforward (assuming it is not replacing the DIDB) and easy to implement, and would be a great snack to help push through the last 2 hours of an EVA.
This seems like a good concept. Even better if the liquid were more of a gel so that droplets wouldn't easily separate to go floating around in the helmet.
The concept sounds easy. I would want to know more about the probability of a spill in the suit, especially with tumbling, and the macronutrients you can put in the bag. Also, it's potentially a waste of water if all of it is not consumed but needs to be after 2 hours. whereas a food bar can be eaten later.
It would be better if the contents lasted full EVA duration once seal is broken 6-7 hours. This gives crewmembers flexibility as to when and how much nutrition they consume (like in Triathlon, small sips of nutrition more frequently may be better for glucose absorption during high exertion).
Flexibility with respect to what goes in the bag will be important.
BIte valves can be tricky to access Bite valves can leak
Assume the seal is easily broken with mouth only (since break seal is during EVA)? Is it possible to extend the drink time beyond 2 hours (more stable items, etc?), since EVAs will be significantly longer than that, in order to better distribute nutrition through out the EVA? Cleanup time could be significantly increased if there is any leakage of the product into the suit. My answer assumes no leaks.

P2 (Hydratable Drink Bag) - Please rate the acceptability of this concept design based on your anticipated impact on the elements below:

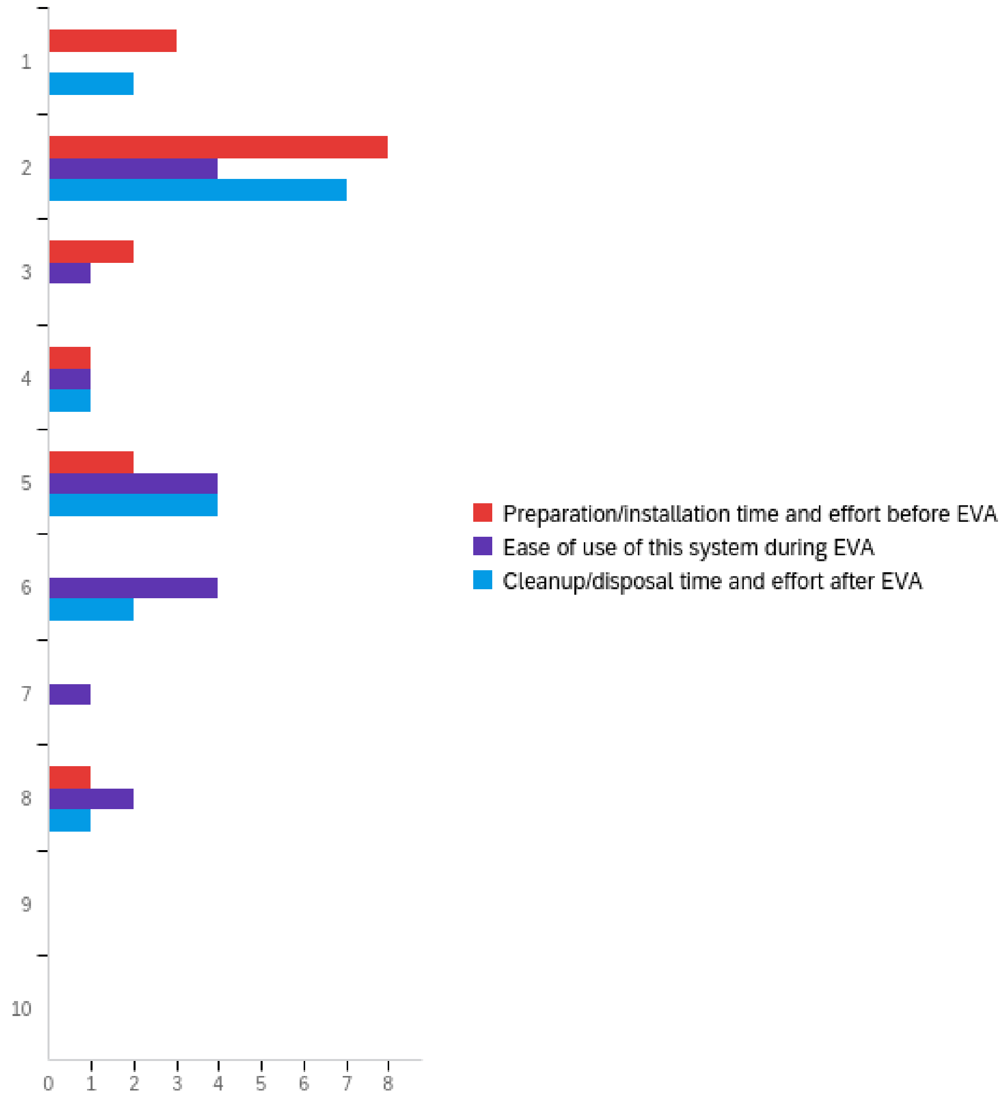


#	Question	1		2		3		4		5		6		7		8		9		10		Total
1	Preparation/installation time and effort before EVA	17.65%	3	23.53%	4	35.29%	6	11.76%	2	5.88%	1	5.88%	1	0.00%	0	0.00%	0	0.00%	0	0.00%	0	17
2	Ease of use of this system during EVA	17.65%	3	23.53%	4	17.65%	3	17.65%	3	11.76%	2	0.00%	0	5.88%	1	0.00%	0	5.88%	1	0.00%	0	17
3	Cleanup/disposal time and effort after EVA	35.29%	6	41.18%	7	17.65%	3	5.88%	1	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	17

P3 (Hydratable Drink Bag) - Do you have any thoughts about this concept and/or suggestions that you would like to share?

Do you have any thoughts about this concept and/or suggestions that you would like to share?
seems to be a more mass-efficient version of idea #1 (in-bag liquid). Same concerns of macronutrients getting stuck in the eva systems.
same as before, need to have the nutrition available during the whole EVA.
Unworkable. The clock starts when I mix the bag--and we rarely if ever get out the hatch within 2 hours of closing the helmet. Now I have no nutrition during the EVA, and in fact I have a bag of toxic waste that I mustn't use or release in the suit.
This may be more efficient that the prefilled back because of lower qualification hurdle, economy of water use, etc.
The 2-hr mixing to consumption constraint seems non-ideal (you would need to consume the nutrition early in the EVA, which may not be when you would most want it)
Same comments as previous, possible to extend consumption time beyond 2 hours? This means that nutrition is only available during the first 2 hours of the EVA. In-suit nutrition would be more desired mid-way or later during the EVA, since the crew will have recently eaten up to the start of the EVA. 2 hours seems pretty conservative for food stability? As previous, this rating assumes no leakage of nutrition product in suit.
Same comments as before, just adds a step on EVA day.
Same as for previous Added risk of leakage from rehydration port
It seems that if the beverage must be consumed within 2-hours of mixing, it might not even make it to the actual EVA dependent on operations, pre-breathe, etc.
I have never had a powder mixed with water that is as good as a premade mixture.

S2 (Solid Food Bar) - Please rate the acceptability of this concept design based on your anticipated impact on the elements below:



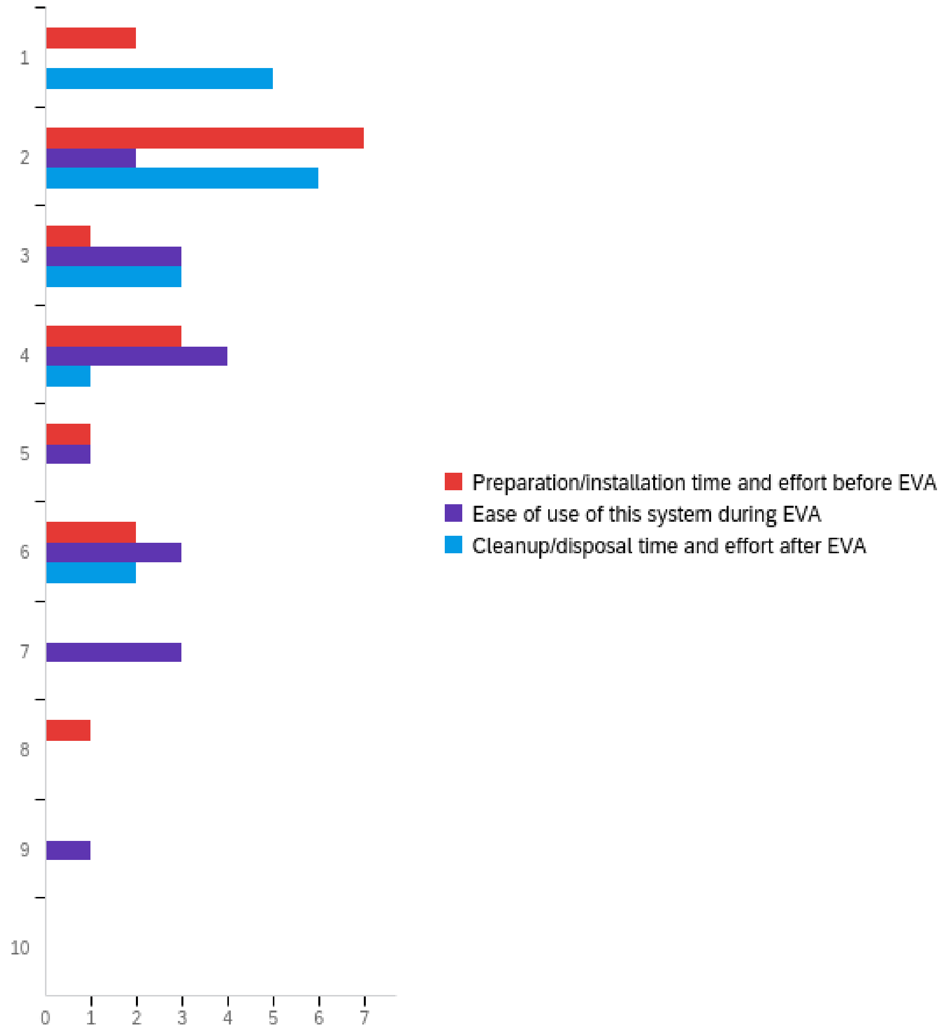
#	Question	1		2		3		4		5		6		7		8		9		10		Total
1	Preparation/installation time and effort before EVA	17.65%	3	47.06%	8	11.76%	2	5.88%	1	11.76%	2	0.00%	0	0.00%	0	5.88%	1	0.00%	0	0.00%	0	17
2	Ease of use of this system during EVA	0.00%	0	23.53%	4	5.88%	1	5.88%	1	23.53%	4	23.53%	4	5.88%	1	11.76%	2	0.00%	0	0.00%	0	17
3	Cleanup/disposal time and effort after EVA	11.76%	2	41.18%	7	0.00%	0	5.88%	1	23.53%	4	11.76%	2	0.00%	0	5.88%	1	0.00%	0	0.00%	0	17

S3 (Solid Food Bar) - Do you have any thoughts about this concept and/or suggestions that you would like to share?

Do you have any thoughts about this concept and/or suggestions that you would like to share?
I would be nervous about food getting liberated and dropping into different parts of the helmet and potentially into the rest of the suit. It would really depend how this was implemented but the idea of the food/crumbs getting liberated makes me nervous. It may also be hard to clean up if there are small pieces of food that could have traveled to different parts of the suit.
Install could be tricky as the bar will need to be installed very specifically to not interfere with crewmember face or micro phones. Ease of use during EVA is a challenge. There is not the flexibility of the straw here to move around and the actual food substance is much closer to the crewmember face to be able to bite, so could cause significant interference. The crewmember may need to crane their neck quite a bit to be able to grab and bite off. Some size crewmembers may not be able to do this, or perhaps risk neck strain. Other issues are the crewmember could choke on the larger pieces of solid food, and the bar could likely be more easily detached and become free in the suit.
This seems like it might be more difficult for the crew to do, and possibly mess up. But a bar is also more satisfying than a drink.
Have never tried a food bar in a suit before. Seems as though this would be a bit of a difficult thing and could lead to inability to use during EVA.
I'm concerned about the amount of force required to bite and tear away a bite-sized piece of bar without ripping the bar free from its installation location. At the opposite end of this spectrum, if the bar is too easy to bite off, I would be concerned about crumbs.
Seems less likely for food materials to get into the systems, unless the solid was very crumby. Would have to be positioned in a way to not be in your face when you don't want to eat it.
I worry about the space the bar might take up near the person's chin, and the potential for the bar getting bumped/hit/in the way, as well as the potential for crumbs/dropped bits.
Prefer this option over liquid food - food like Clif Shot Bloks does not melt and could be arranged into a tube/sleeve/wrapper with a mechanism to push the bloks forward in the tube and a stopper (overridden by bite) that provides slight force to hold the next blok near the tube exit ready to deploy.
crumbs in suit, loose food in suit; this has happened during early shuttle program and made a big mess in the suit; also, dry solid food will require water during consumption so drink bag may need to be made larger (equal to the water necessary to rehydrate/eat the food bar)
Difficult one to rate as I have no experience trying solid food in the EMU, however I do know that previous efforts were not highly regarded due to messiness, etc. Cleanup time could be significant. Assuming the same nutritional intake can be provided in liquid form, this would be preferred.
Complicated. Increased risk (FOD in the suit). Unnecessary.
With news for liquid hydration and a valsalva device and microphones already in the same area on the suit, to me this would not represent enough benefit to warrant the drawbacks. If microphones aren't in a position to snag on this (as they do on current valsalva and bite valve) then this concern would be less. For example if mics are mounted elsewhere On helmet and not on com cap coming down at the corners

of the mouth. I think the type of bar would also have to be carefully selected to not cause any crumbs or liberated pieces nor cause a mess with stickiness in heated and sweaty/moisture conditions. Also in order to evaluate the benefit of this system, would be good to understand total EVA length and strenuous level compared to a typical ISS spacewalk. I didn’t see that specifies in the survey intro.
Higher caloric density than liquids Risk of food bart getting dislodged and becoming FOD
I think this has the potential to make a mess in the suit and be challenging to execute.
Possibly workable. But if crumbs get loose they pose a risk to the crewmember's eyes and lungs and to the air circulation fan. If there are other options then this one should probably not be used.
questions would be the ease of eating it, extending enough bar within reach, but if solved, it seems like a low risk, high yield solution.

H2 (Helmet Port) – Please rate the acceptability of this concept design based on your anticipated impact on the elements below:



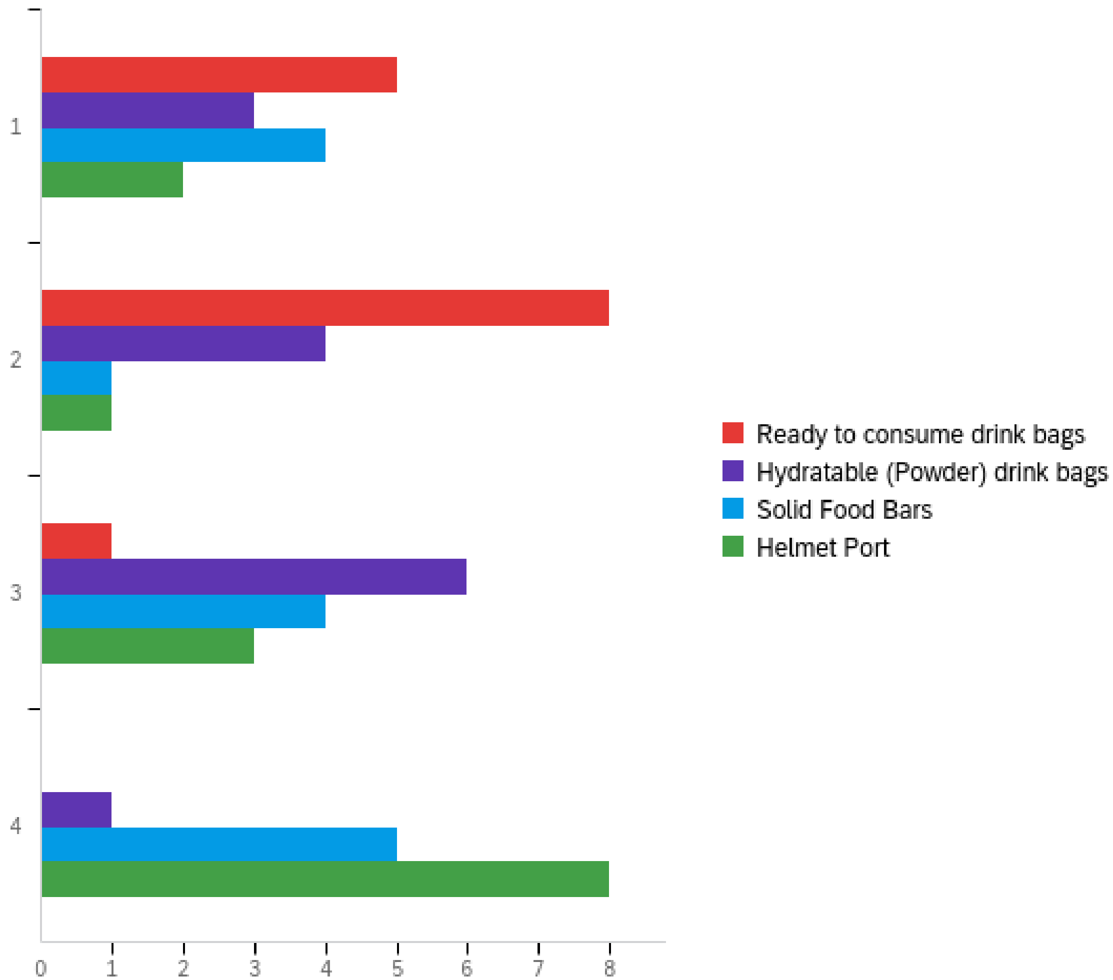
#	Question	1		2		3		4		5		6		7		8		9		10		Total
1	Preparation/installation time and effort before EVA	11.76 %	2	41.18 %	7	5.88 %	1	17.65 %	3	5.88 %	1	11.76 %	2	0.00 %	0	5.88 %	1	0.00 %	0	0.00 %	0	17
2	Ease of use of this system during EVA	0.00 %	0	11.76 %	2	17.65 %	3	23.53 %	4	5.88 %	1	17.65 %	3	17.65 %	3	0.00 %	0	5.88 %	1	0.00 %	0	17
3	Cleanup/disposal time and effort after EVA	29.41 %	5	35.29 %	6	17.65 %	3	5.88 %	1	0.00 %	0	11.76 %	2	0.00 %	0	0.00 %	0	0.00 %	0	0.00 %	0	17

H3 (Helmet Port) - Do you have any thoughts about this concept and/or suggestions that you would like to share?

Do you have any thoughts about this concept and/or suggestions that you would like to share?
Seems similar to the WB-57 method of eating/drinking and I think would likely work well. Don't think this would need to be limited to beverages since it could be similar to the food tubes used for the WB-57. My only concern would be making sure the helmet port sealed again properly once the tube was removed.
I think this concept is a no-go. Introducing a hole in the spacesuit pressure system in a sensitive place like the helmet is not a good idea. Much structural analysis and engineering work would be needed. It will have a sealing system, but adds a lot of risk if that system fails. Other acceptable methods exist that keep the suit and pressure systems intact. Having the nutrition outside the suit poses huge challenges, it will be at vacuum and subject to wild thermal swings. There is risk of contamination of the lunar surface. Having a giant thing outside your helmet in your field of view will be difficult operationally and poses more safety risk. Much better to have the nutrition inside the suit at reasonable pressure and temperature. Safety risk and operational difficulty on this is too high.
This seems like it add unwarranted complexity by adding another interface to the suit / additional failure modes.
I would never intentionally add a hole to my suit.
Concerned about suit seal over time, but strongly like the ability to have food primarily outside the suit not taking up space inside the suit.
This is probably the most convenient way to consume but have concerns about introducing another failure point in the design pressure seal and also where would we stow the food? in a backpack, pocket or on a cart? More stuff = more junk to carry around and lose.
I think many of the trade-offs of this concept would depend on the design of the helmet port, and how easy it is to use (i.e. would it be quick to insert the tube and consume the beverage whenever the crewmember wants, or would it likely require stopping much of the EVA activity), as well as any other trade-offs for including that in the design. I also wonder whether there would be any issues with temperature regulation of the bag system if it is kept externally.
good idea; could use for liquid food as well as additional water or medications; need to see the engineering/ops details to really evaluate; some concern for helmet/suit leaks if food port gets clogged and won't seal after injector is withdrawn; port must be compatible with some lunar dirt contamination (say you trip and fall face down in the dirt and get dirt into the food port; how clean for subsequent use?
Perhaps this system could be used in conjunction with an in-suit drink bag? Since space within the suit is limited, these external tubes could provide additional nutrition for the EVA. This combination would allow for the immediate ease of drinking nutrition in the suit (without having to hook up external tube), but then would provide additional nutrition for a larger total capacity.
Complicated and unnecessary. Likely to drive suit design complications that are unwarranted.
One way this would be better option than the others if if suit port doesn't have any protrusion into the inner helmet when the food tube isn't inserted. Of course this one's benefit is very much engineering solution-dependent.
Convenient, but a priori an added suit leak risk.

This seems like a bad idea.
This concept is risky because it demands a new, dedicated hole in the suit. If the hole won't open you get no nutrition. If the hole won't close you have a suit leak that will cause EVA termination or abort, and possibly kill the crewmember. Accessible tool storage outside the suit is oversubscribed already. Now we would have to add stowage for the nutrition bag in addition to EVA tools. We also need a way to safely stow used containers outside the suit. The nutrition container would have to be vacuum rated. The tube on that container would have to hold the nutrition inside when under hard vacuum, but somehow open up when the tube is inserted so the crewmember can drink from it. The crewmember is unlikely to be able to suck harder than cosmic vacuum. The only advantage of this system is that you could have multiple nutrition packs and use them serially during a long EVA. But I fear the drawbacks outweigh that advantage.
My main concern is the added complexity for certification and potential for another failure point to outside environment that isn't necessarily needed when other solutions exist.

R0 - Please order the design references below in your order of preference (drag favorite to top).



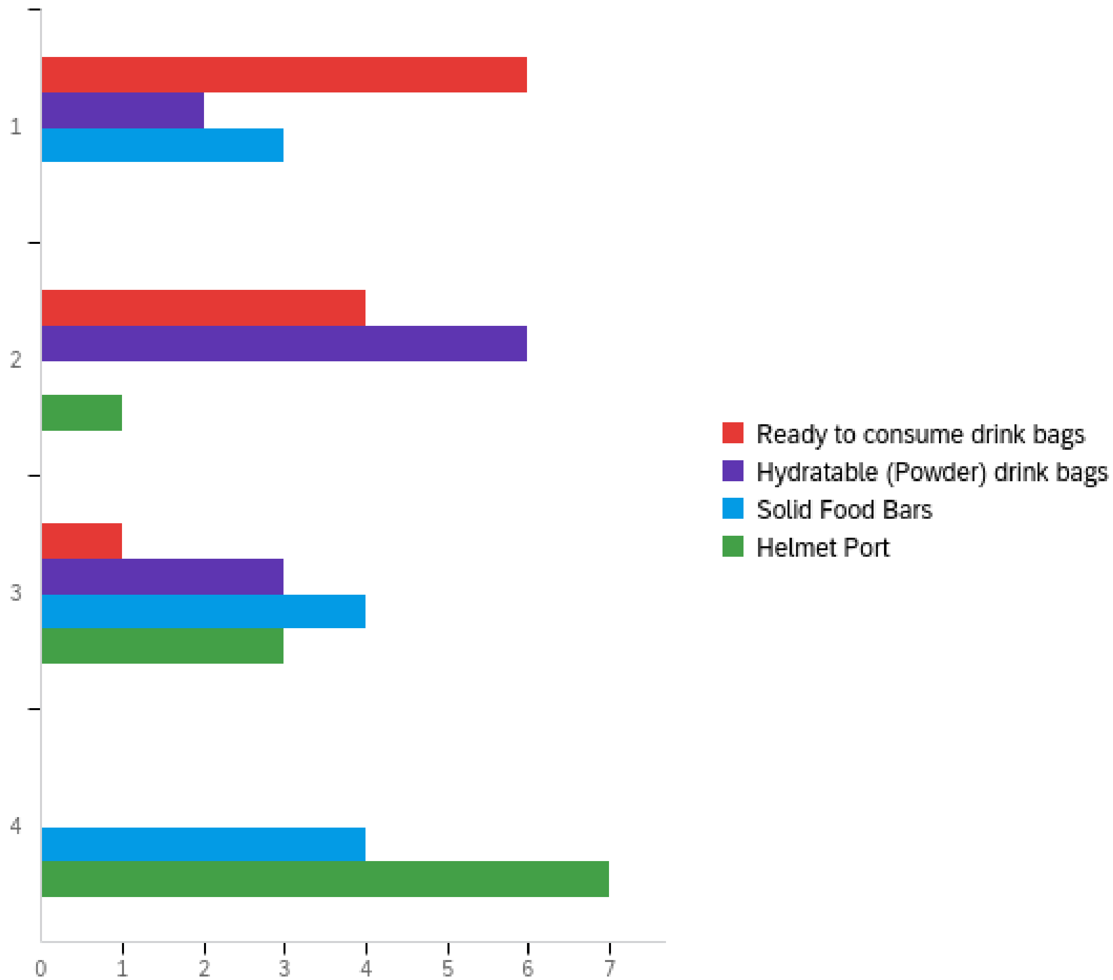
#	Question	1		2		3		4		Total
1	Ready to consume drink bags	35.71%	5	57.14%	8	7.14%	1	0.00%	0	14
2	Hydratable (Powder) drink bags	21.43%	3	28.57%	4	42.86%	6	7.14%	1	14
3	Solid Food Bars	28.57%	4	7.14%	1	28.57%	4	35.71%	5	14
4	Helmet Port	14.29%	2	7.14%	1	21.43%	3	57.14%	8	14

R0 F - Please elaborate on your rankings in the previous question.

Please elaborate on your rankings in the previous question.
pre-hydrated food vs dried food does not save any mission mass due to needing to carry the same amount of water for either case; pre-hydrated food will save crew prep time. Also, this suit will be used on ISS and Gateway, microgravity environments where injecting water in dried food bags could be problematic by introducing bubbles; bubbles can expand during suit ops and force the food into the helmet and make a mess; this happens with drink bag water but it is only water and does not make a mess in the suit (it quickly evaporates)
bars perceived to be better for nutrition and ease of use, drink bags next with dydratable saving more water, and helmet port overly complicated.
While less appealing than a solid food bar, the ease of consuming a drink bag makes me rank it first. As far as ready to consume vs. hydratable, my experience with rehydrating powders is that they don't always fully rehydrate, so I left them in the order presented.
The helmet port seems like a viable option for both food and drinks. I didn't like the ready to consume drink bag limitation of being consumed within 2 hours of breaking the seal, but at least you can break the seal and consume it during the EVA. The solid food bar would be very dependent on implementation and precautions for food not being liberated into the helmet/suit. The hydratable drink bags don't seem like a good option because they need to be consumed within 2 hours of mixing, which happens prior to the EVA and may not even last until the start of the EVA, dependent on operations.
See comments on previous pages.
Ready to consume and hydratable nutrition drink bags are both good options. Choices may depend on type of substance that the nutrition is made of. Is it easier to store hydrated or not? Does either method compromise the food safety or nutrition (dehydrated may be more stable and safer?) Does either method levy requirements on storage during prep, vehicle loading, and pre-EVA flight (temperature requirements? mass and volume requirements?) Does each method allow for a wide range of nutrition substances? Or will there be limits on types of carbohydrates and proteins that cannot be desiccated easily to a powered, or well hydrated? Is either method more prone to clumping, stickiness or straw clogging. Recommend pursuing both and evaluating the above and other factors. Also consider a gel like substance in a drink bag with a straw (like an Accel Gel or Gu). Things that work well for high performance endurance athletes/triathletes/runners will have good functionality for the types of exertion during EVA and operations (small, portable, easily consumed on the go) There a lot of issues with the solid food bar, this is a likely one to drop. Definitely recommend dropping the suit nutrition port. Many safety issues and operationally challenging.
Ready to consume and Hydratable seem mostly equivalent. Hydratable may have longer shelf life
I like the outside-suit food storage best, but concerned about additional challenges of storing and hauling the food in another vessel. As a close second, my choice would be the ready to consume drink bags inside the suit. Hydratable drink bags would make sense for food items that can be more complex if stored in a dehydratable form (protein, fat). Lowest on my list by a LOT is the solid food bar. While my preference is to eat solid foods, I anticipate these food bars to have terrible texture and be so sticky as to require excessive force to eat

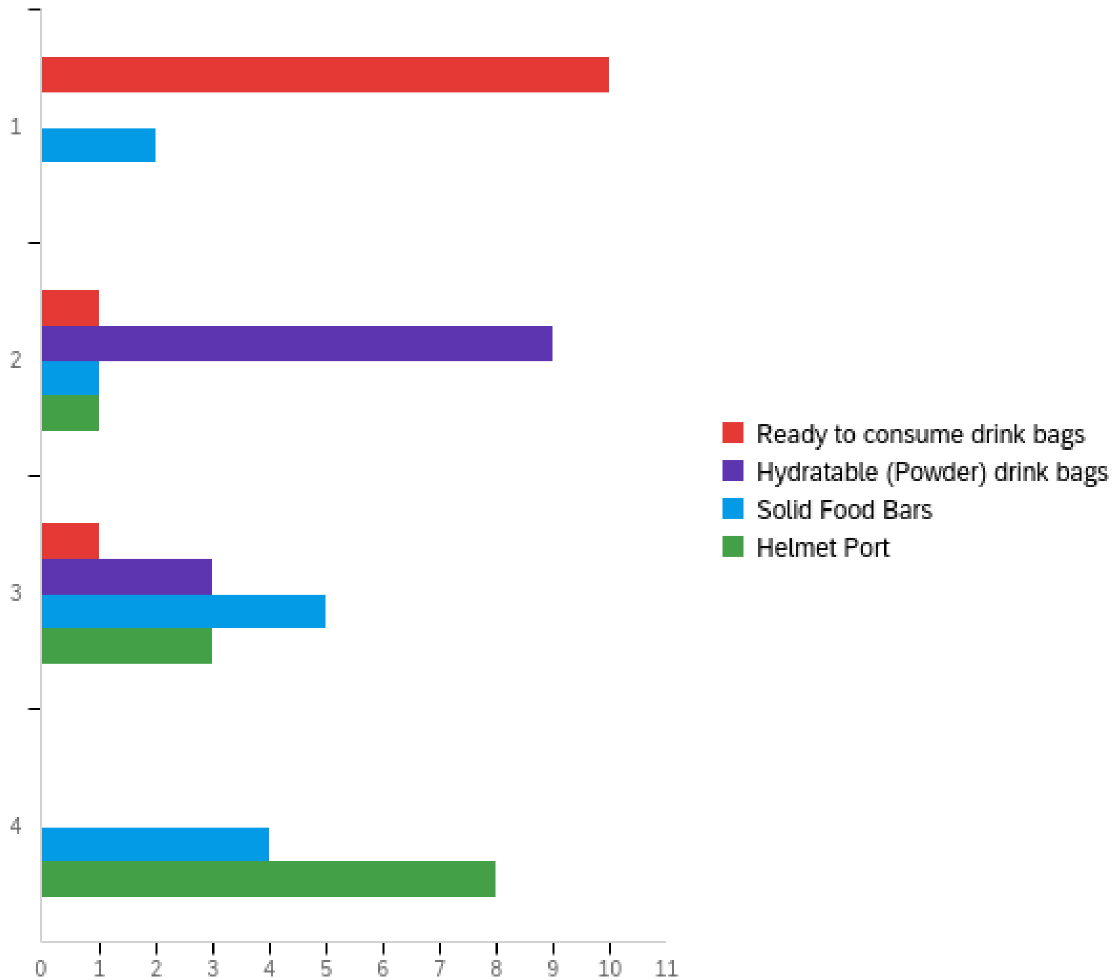
and/or get stuck on our teeth in the process of chewing. (I'm imaging old-school Power Bars.) While we can't get as much caloric density with liquid food, we do get additional hydration.
I have tested in-suit nutrition drink bags in the NBL and have experience with drink bags in space. Although I have never tried solid food in the EMU, I anticipate nutrition in liquid form is easier/less messy. Also, when consuming conventional bar type solid food, I find myself needing to consume more water than usual, which may be limiting in the suit (water consumed during eating and then perhaps not available when thirsty). I rated ready to consume drink bag higher than hydratable only because breaking the seal during the EVA allows for more flexibility in time available to consume, but do hope a solution to allowing consumption for > 2 hours is found. That is limiting. I would be open to trying solid food bars in ground tests in order to provide more of an informed opinion.
I have limited suit experience, but my sense is that the bag-based systems will most easily be accessed by the EVA crewmember, which I think is a high priority (so that the crewmember can access it without needing to interrupt other tasks), and has minimal potential safety issues. I think the main advantage of the ready-to-consume bags is that their 2-hr window does not start until the seal is broken, potentially allowing consumption later in the EVA.
Driven by reliability of access and minimal FOD risk
As long as there is a mechanism to retract/extend the food bars so that it's not in your face, I think this is a pretty good way to get nutrition without compromising food materials getting into the system. Hopefully would not be crumby. Drink bags is a good idea too and not too different than what we already do with water bag systems. I think this idea is equivalent to the food bars. Powder drink bags would also work, but just more work to mix the stuff. Would be more mass efficient I guess. I also worry that it wouldn't mix well, imagine trying to suck chunks of whey protein clumps through a straw. Not saying that is what will happen, just a thought. Helmet port is the most sexy design but introduces additional point of failure in the pressure vessel.
1 and 2 are equal to me for astronaut and more depend on operational variables such as upmass and overall EVA prep time.

R1 - Please rank the systems on your anticipated likelihood that the system will reach development/implementation (drag favorite to top).



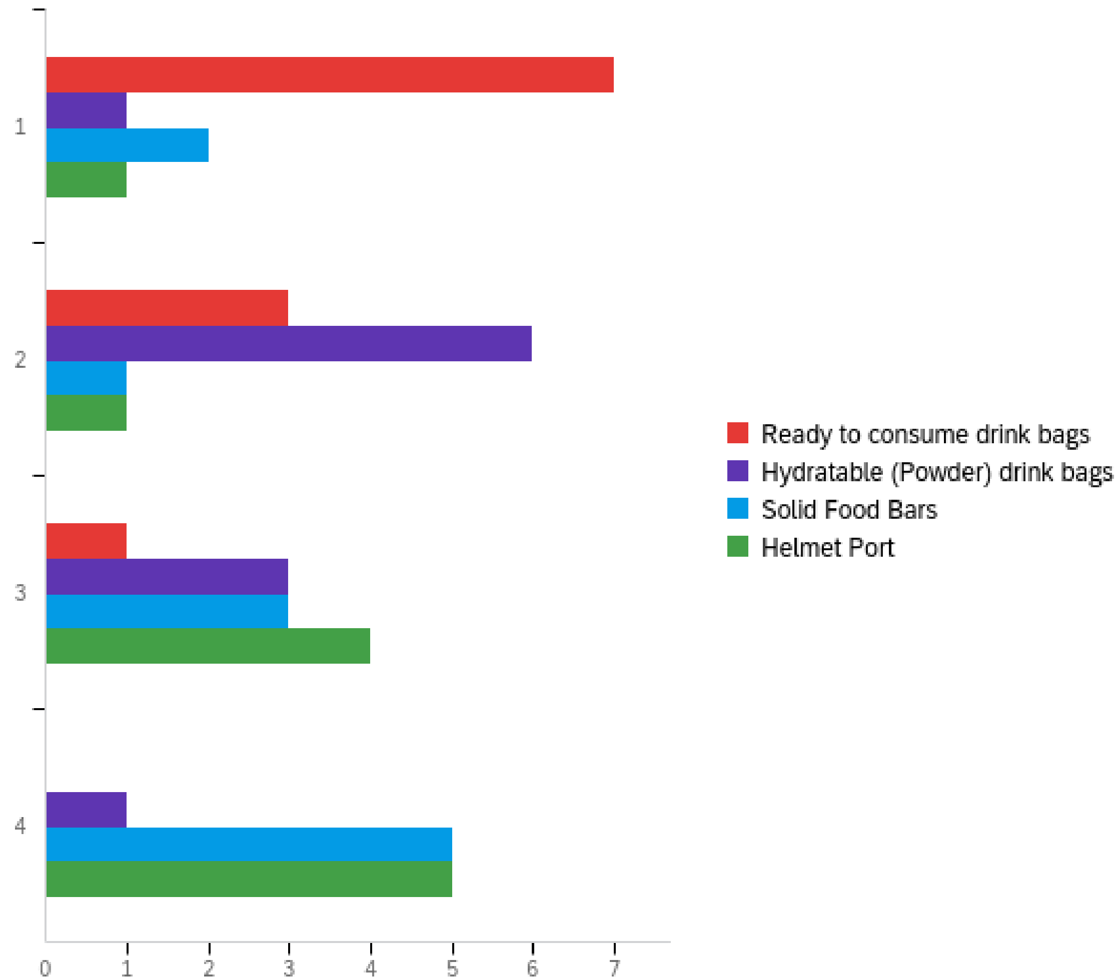
#	Question	1		2		3		4		Total
1	Ready to consume drink bags	54.55%	6	36.36%	4	9.09%	1	0.00%	0	11
2	Hydratable (Powder) drink bags	18.18%	2	54.55%	6	27.27%	3	0.00%	0	11
3	Solid Food Bars	27.27%	3	0.00%	0	36.36%	4	36.36%	4	11
4	Helmet Port	0.00%	0	9.09%	1	27.27%	3	63.64%	7	11

R2 - Please rank the systems on your anticipated likelihood that the system will function as designed/intended (drag favorite to top).



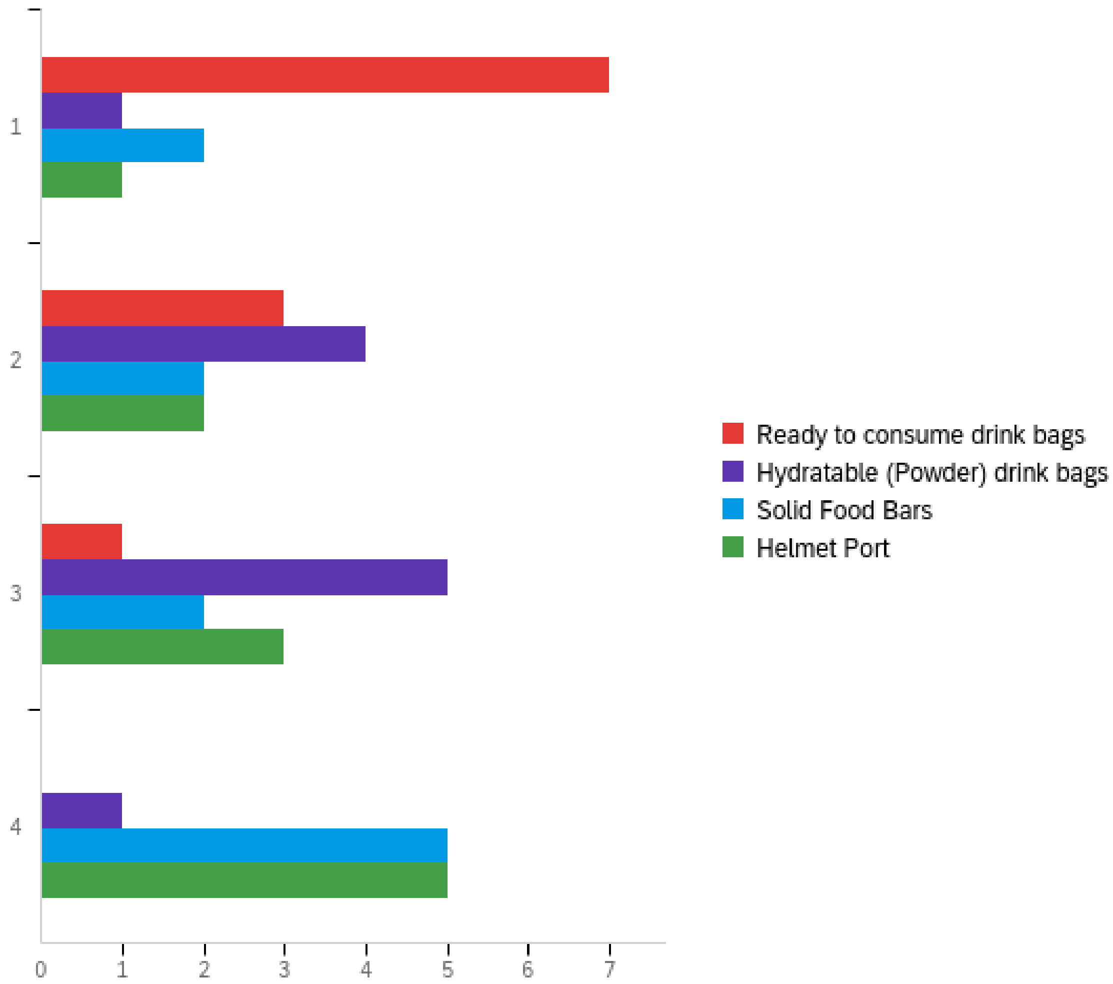
#	Question	1		2		3		4		Total
1	Ready to consume drink bags	83.33%	10	8.33%	1	8.33%	1	0.00%	0	12
2	Hydratable (Powder) drink bags	0.00%	0	75.00%	9	25.00%	3	0.00%	0	12
3	Solid Food Bars	16.67%	2	8.33%	1	41.67%	5	33.33%	4	12
4	Helmet Port	0.00%	0	8.33%	1	25.00%	3	66.67%	8	12

R3 - Please rank the systems on your anticipated likelihood that the crew will use the system as intended (drag favorite to top).



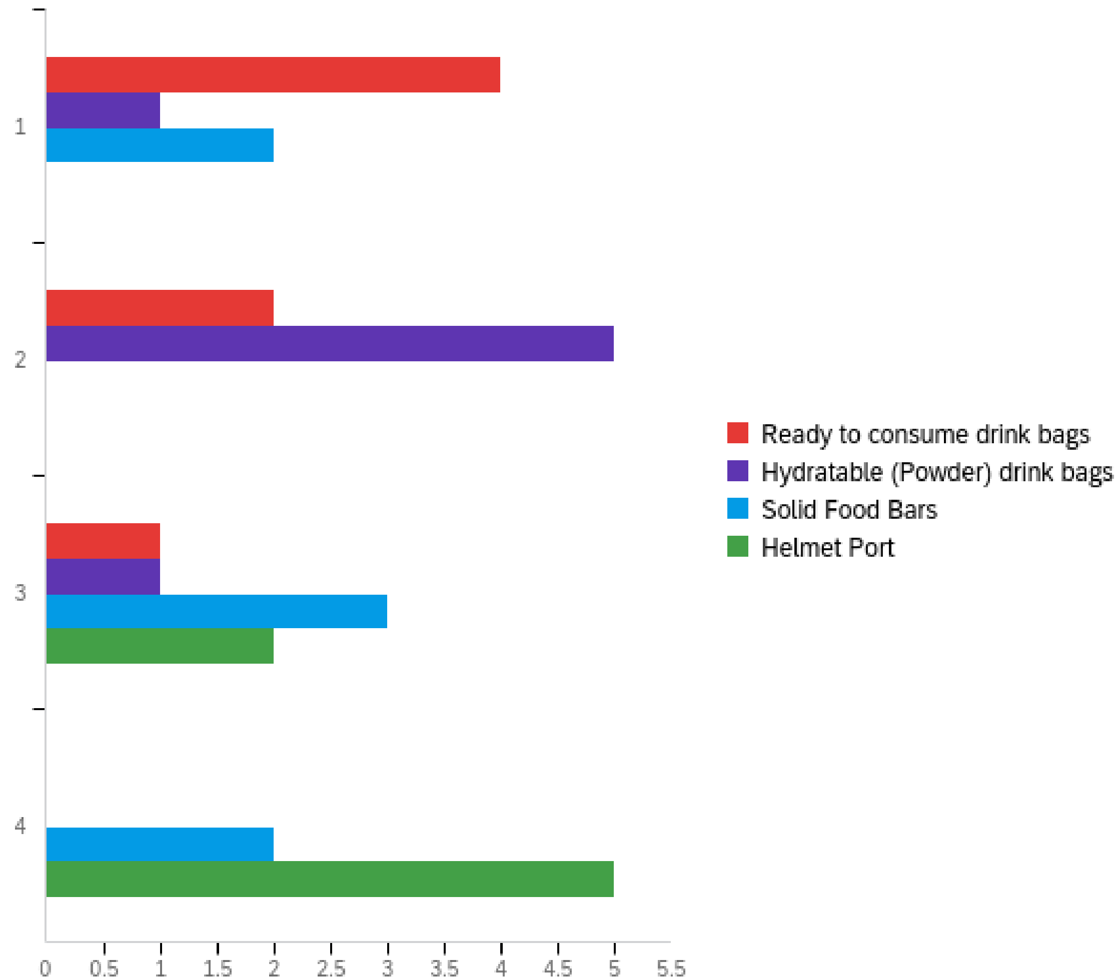
#	Question	1		2		3		4		Total
1	Ready to consume drink bags	63.64%	7	27.27%	3	9.09%	1	0.00%	0	11
2	Hydratable (Powder) drink bags	9.09%	1	54.55%	6	27.27%	3	9.09%	1	11
3	Solid Food Bars	18.18%	2	9.09%	1	27.27%	3	45.45%	5	11
4	Helmet Port	9.09%	1	9.09%	1	36.36%	4	45.45%	5	11

R4 - Please rank the systems on your anticipated ease of use (drag favorite to top).



#	Question	1		2		3		4		Total
1	Ready to consume drink bags	63.64%	7	27.27%	3	9.09%	1	0.00%	0	11
2	Hydratable (Powder) drink bags	9.09%	1	36.36%	4	45.45%	5	9.09%	1	11
3	Solid Food Bars	18.18%	2	18.18%	2	18.18%	2	45.45%	5	11
4	Helmet Port	9.09%	1	18.18%	2	27.27%	3	45.45%	5	11

R5 - Please rank the systems on your anticipated safety concerns and/or risks to the crew or mission (drag favorite to top).



#	Question	1		2		3		4		Total
1	Ready to consume drink bags	57.14%	4	28.57%	2	14.29%	1	0.00%	0	7
2	Hydratable (Powder) drink bags	14.29%	1	71.43%	5	14.29%	1	0.00%	0	7
3	Solid Food Bars	28.57%	2	0.00%	0	42.86%	3	28.57%	2	7
4	Helmet Port	0.00%	0	0.00%	0	28.57%	2	71.43%	5	7

The following questions ask you about any final thoughts you may have on nutrition, hydration, and waste management.

R6 General - Please provide any additional comments on the ratings and your rationale:

Please provide any additional comments on the ratings and your rationale:
Helmet port option seems to have the most risk of potential failure/causing additional problems with suit, since you are opening up a port to the external environment. Though these systems are used with other pressure suits (high altitude flight), there is still more of an opportunity for problems.
just to be clear, rank on safety concerns was most safe to least safe.

G1 - Is there anything we forgot to ask or would you like to elaborate on any of the previous topics or anything else related to nutrition, hydration, or waste management in the suit?

Is there anything we forgot to ask or would you like to elaborate on any of the previous topics or anything else related to nutrition, hydration, or waste management in the suit?
We should ensure we provide plain water in addition to nutrition. Nutrition (even if high water content) is not a substitute for water, and both must be available. Two drink bags one water, one nutrition, each with straws would work very well.
No
I think solid nutrition would be awesome in terms of helping the crew member feel fuller/satiating hunger, but there are some potential issues with the delivery mechanism and consumption compared to liquid nutrition.
As previous, are combinations of these options being considered? Having in suit nutrition in the suit, with the option for additional supplements through a helmet port could be a good contender.
There is also some risk with varied nutrition offered that it would have negative GI affect. To me, being a little hungry is preferred over uncertainty of consuming things during a long strenuous activity. This is true of EVA durations similar to a typical ISS EVA and could change for longer EVAs.
Hydration remains the most important aspect, in my opinion
See previous comments.
Was a gel or goo considered the big question is how much calories each can provide as well

G2 - We asked these question with Lunar gravity operations in mind. How would your answer be different if you considered this for use in microgravity instead of a surface gravity (i.e. Lunar) environment?

We asked these question with Lunar gravity operations in mind. How would your answer be different if you considered this for use in microgravity instead of a surface gravity (i.e. Lunar) environment?
The solid food option seems even less viable and more concerning in microgravity because any liberated food could now travel throughout the helmet into the crew members eyes or other areas.
very similar in microgravity and lunar
Oops - I missed the Lunar gravity part. My answers were for microgravity. The only think I would change though is my preference for solid vs liquid food, assuming Lunar EVAs are longer in duration than microgravity EVAs. Would prefer solid food for longer EVAs.
I dont think answers would change.
No.
Unsure
if this was microgravity I think the exterior bottle idea is not a good one b/c that is one additional item you have to tether to and lose in space.
no change.
yes, see prior answers
No change
Yes, previous detractor mentioned about crumb on food bar would be much less of an issue in lunar gravity because it wouldn't continuously float in helmet volume
Food bar less attractive in zero-G re. FOD risk
I think my answers will be the same.
Yes. Crumbs from solid food in the suit are less of a problem in Lunar gravity. You'd still have to clean the inside of the suit, but wouldn't have to worry about the crumbs getting in your eyes, lungs, or fan mechanisms.
i would be more concerned about the external drink bag

G3 - How would any of your answers be different if you were expected to conduct multiple/consecutive EVAs (i.e. 4 over 5 days) opposed to single EVA?

How would any of your answers be different if you were expected to conduct multiple/consecutive EVAs (i.e. 4 over 5 days) opposed to single EVA?
It would be even more important to have options for food (solid or otherwise). I like the idea of a helmet port because both food and drink could be consumed through this option.
same answers but with multiple/consecutive EVAs nutrition is ABSOLUTELY critical.
No change, except my desire for nutrition would increase. I think ease of use for the astronaut during an EVA is important.
Would not.
I think consecutive EVAs would increase my desire to have solid food. A liquid diet during physical exertion multiple days in a row would compound the desire for solid food.
I would prefer options for multiple EVAs, and may choose to start with or end with higher density food options (e.g. bar) as fatigue increases.
I would not want to mix powder each time if I was doing multiple evas.
No change
No change
No change
No changes.
No different.
bars would be a "nice to have" over liquid nutrition but not a requirement

Q123 - Do you have any recommendations for a different concept system or solution that was not presented?

Do you have any recommendations for a different concept system or solution that was not presented?
I think this is great. I feel that nutrition on the lunar surface is an absolute requirement and will continue to advocate for that with programs. Carb to protein ratio is important. We cannot provide an all protein or all carb drink. 4:1 or whatever is currently best supported by endurance research is needed. Electrolytes will be key, as will taste and texture. Recommend 1) extensive taste testing with the astronaut office (shirt sleeve desktop), and during gym sessions for taste/texture acceptability and- 2) incorporation into NBL testing, field testing like JETT#3, Argos runs. This will collect a lot of valuable data. Production needs to account for the fact that we will need to provide this in all training runs once we have suit designs and are training Artemis III and beyond crews, so we train like we fly, crews are familiar with the system and any bugs can be worked out. Thanks for the work you are doing!!!
Solid food scored or dispensed in bite sized chunks, like how chocolate bars are scored or how "Cliff Bloks" come as discrete bites of nutrition. I'm trying to avoid suggesting a Pez-like dispenser here because a simple solution is needed.
I like the air force food in a tube system for U2 pilots. The food is good and it has decades of use that validate it's pretty robust system. It's simple and straightforward. It's basically the exterior bottle idea but instead of liquid it is solid food. And they taste good.
check out Clif Shot Bloks as an excellent solid food option. Just needs some engineering work on dispensing - but it's doable.
Can't think of anything!
No.
One up side of the bags is that you can mix water and "food" into one item and simplify design.

Appendix E. HRP Investigators' Workshop Abstracts

HRP IWS 2022

ESTABLISHING RECOMMENDATIONS FOR THE DEVELOPMENT OF SPACE SUIT INTEGRATED FOOD SYSTEMS AND THE DELIVERY OF NUTRITION BEFORE, DURING, AND AFTER LUNAR EVA

E.L. Dillon[1], B. Ruby[2], J. Norcross[3], S.M. Smith[4], S. Zwart[1], H. Dlouhy[3], G. Douglas[4], T. Sirmons[5], R.Z. Amick[3], T. Kukla[3], H. Kim[5], Y. Hernandez[3], A. Abercromby[4]

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INTRODUCTION
Extravehicular activity (EVA) operations are complex and challenging, and Artemis missions will include a higher tempo and frequency of EVAs than any previous space program. For this reason, surface EVAs greater than 4 h require additional nutrition support. The ability to provide this additional nutritional support is limited on Artemis missions given crew schedules and the current inability to provide nutrition to astronauts while suited. This project seeks to help define means for provision of nutritional support to Artemis astronauts during lunar EVAs.

METHODS
This project will further detail and document the rationale for in-suit EVA nutrition, the driving recommendations, requirements, constraints, crew preferences, and provisional delivery strategies to chart the path forward for developing an EVA nutrient delivery system. Additionally, conceptual designs will be evaluated with respect to the ability to meet EVA nutrition/hydration requirements, spacesuit constraints, and crew preferences.

RESULTS
Outcomes from this project will provide an evidence-based foundation towards the development of a comprehensive in-suit EVA nutrient delivery system while also considering the implications for nutrition support opportunities immediately pre and post helmet-on operations.

CONCLUSION
The ability to meet for the increased need for nutrition through provision of nutrients in the suited configuration will benefit overall crew health, performance, and morale, and thus increase the likelihood of mission success.

HRP IWS 2023

RECOMMENDATIONS FOR DEVELOPING SPACE SUIT INTEGRATED FOOD SYSTEMS AND DELIVERING NUTRITION BEFORE, DURING, AND AFTER LUNAR EVA

E.L. Dillon[1], B. Ruby[2], J. Norcross[3], S.M. Smith[4], S.R. Zwart[1], H. Dlouhy[3], G.R. Douglas[4], T. Sirmons[5], R.Z. Amick[3], T. Kukla[3], H. Kim[5], Y. Hernandez[3], G.W. Harman[3], A. F. Abercromby[4]

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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 $kcal \cdot hr^{-1}$ 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.