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Humanity's Journey to The Red Planet

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MSPO 513: Space Habitation and Life Support Systems

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Abstract

Being the fourth planet in our solar system, Mars is half the size of Earth and constitutes a gravity near 0.38 g. Like its fellow terrestrial planets, it has a central core, rocky mantle, and solid crust. Coupled with a thin atmosphere, its surface features are reminiscent of both the Earth and Moon. Given adequate accessibility, Mars has been a hub for scientific exploration. With past and present robotic missions, they have gradually provided information about the Martian environment to help aid future human exploration. For humanity's first manned mission to the Martian crater, Aram Chaos, a crew of six selected individuals will reside for twelve weeks before journeying back to Earth. Associated with deep space travel, problems include but are not limited to radiation, microgravity, isolation, etc. Supporting this 9-phase mission plan, space habitation and life support systems are assessed together to mitigate these issues as best as possible. Ultimately prioritizing the physiological and psychological well-being of all crewmembers.

Keywords: Mars, manned mission, Aram Chaos, crew, physiological, psychological

Humanity's Journey to The Red Planet

Technologies developed with Mars as the focus, have included landers, rovers, and orbiters. With past systems such as the Mars Phoenix having confirmed the presence of water ice in the Martian subsurface through excavation and extractions (National Aeronautics and Space Administration, 2012), this opportunistic collection could support astronauts, plant growth, and production of rocket fuel via electrolysis. Furthermore, through the Mars Curiosity Rover utilizing its Radiation Assessment Detector (RAD) instrument, an average dose rate of about 0.7 milliSieverts of radiation per day has been recorded on the surface, which assists in providing a basis how much radiation shielding is needed among crews (National Aeronautics and Space Administration, n.d.). Finally, looking at Mars MAVEN orbiter currently in operation, it has created a global wind map of the planet's upper atmosphere (The Planetary Society, 2021). Given that Mars has prevalent dust storms, this map alongside studies of climate and weather can highlight areas for human settlements.

Mission Overview

A designated crew of six individuals will travel to Mars for an exploration mission. There they will reside twelve weeks on the surface before returning to Earth. Upon arrival, EVA suits, rovers, and an exploration facility are made available for the team. Aram Chaos, a 280 km diameter Martian crater, is chosen as the team's destination given its low elevation (-2 to -3 km), natural features for additional shielding from space radiation, and rich areas of extensible resources (hydrated sulfates, hematite, ferric oxides) (Sibille et al., 2015). Totaling 9 phases in this mission plan, elements from existing/conceptual space habitation and life support systems will be examined together.

Space Habitation Literature Review

A manned habitation module traveling back-and-forth from Mars is critical as the foundational build determines how well astronauts can conduct their daily activities. Looking at the International Space Station (ISS), its ability to support 6 people at a time, requires modules that can be mass-produced from Earth (Chen et al., 2021). Taking these same modules, Smitherman (2016) lists the schematic design of a 7.2 m diameter conceptual cylindrical habitat with 3 decks shown in **Figure 1**.

Starting on the lower deck, utility pallets correspond to placements of needed Life Support Systems which will provide temperature control, water, breathable air, etc. To ensure the habitat is well ventilated, vertical circulation vents are placed on each deck. Moving on, the Crew Health Care System (CHECS) present on the ISS, contains basic subsystems (fire extinguisher, defibrillator, and stowed medical equipment) to assist in the event of specific emergencies (Williams, 2006). Finally, the crew shall conduct their daily exercises here through various equipment mentioned later.

Shifting to the main deck, this includes crew quarters where individuals can rest and relax. Located on opposite ends, two storage facilities hold clothes, personal hygiene items, books, etc. In addition to this, astronauts have access to dual workstations which can be used for research or leisure. Lastly, the waste management room is provided for astronauts to use when needed.

On the top deck, two additional storage facilities stockpile a variety of foods that astronauts can choose from. Alongside additional workstations, a Galley & Wardroom Area offers the team a place to eat together and hold meetings.

Radiation Shielding

As the crew conducts their exploratory mission, exposures of space radiation will need to be considered to, on, and from Mars. Without proper protection, the likelihood of cancers, heart disease, and cataracts increases (Mars, 2021). Ensuring the mission is a success, measures must be in place to mitigate potential contamination and sicknesses.

Polyethylene Composite

To start, the implementation of a polyethylene composite proves quite useful against space radiation. Looking at polyethylene (PE) in general, its efficiency in limiting harmful effects is attributed to having the highest hydrogen content among all polymers (Laurenzi et al., 2020). Being certified for use aboard the International Space Station, these authors write this material to be non-toxic, recyclable, chemically stable, cheap, and three times lighter than aluminum. Despite its poor mechanical properties, a test by Laurenzi et al. (2020) was conducted with different fillers to determine an optimal polyethylene-based composite. The results highlighted in **Table 1**, showcase a graphene oxide (GO) polyethylene mix as an optimum choice due to it maintaining the highest presence of hydrogen atoms. Ultimately, from applying this compound, it yields great potential in protecting the crew throughout their deep space travel.

Kevlar Fabric

In company with, the utilization of Kevlar fabric stems as an additional form of protection from space radiation. Through its adaptability and viability, Narici et al. (2017) underlines how Kevlar fabric is prominent for Extra-Vehicular Activity (EVA) suits and provides extra shielding in critical locations of habitats, such as crew sleeping quarters. Confirming its shielding effectiveness, measurements performed on the ISS during the ALTEA-shield project were compared to Polyethylene. All in all, **Figure 2** represents an identical performance between both materials when exposed to High Latitude, a location where the radiation environment best mimics deep space (Narici et al., 2017). Going forward, applications of this material can not only help to fortify the crew's space suits but exploration facilities on Mars.

Microgravity

Residing in space, the increasing effects of microgravity must be accounted for. From the removal of one's own bodyweight, structural changes in bodily systems include demineralization of the skeleton, deconditioning in muscular apparatus, reduced orthostatic tolerance, disrupted coordination of movement, etc. (Kozlovskaya et al., 2015). With a mission to Mars taking over a year, multiple techniques must be situated for the body to properly operate in a reduced gravity environment.

Exercise Equipment

Contributing heavily, exercise has served as a primary countermeasure for many astronauts aboard the ISS. Utilizing various equipment within the habitation module and on Mars allows for a full-body workout. Starting with ARED (Advanced Resistive Exercise Device), its ability to mimic free weight exercise promotes skeletal health, muscular strength, and endurance (Loehr et al., 2011). Accommodating individuals of all sizes, loads range from 5 to 273 kg with its main arm assembly. On top of this, hardware attachments include an exercise bench with a belt, heel-raise platform, cable pull bar, cable-pull handles, and ankle cuffs (Hackney et al., 2015). With its portable load-monitoring devices, accurate readings for exercise loads, resistance exercise performance, and biomechanical analyses can be monitored (Hackney et al., 2015). Engaging numerous muscle groups, ARED's versatility, and applicability make it ideal for deep space. Continuing forward, Hackney and his team describe functionalities for both the Cycle

Ergometer with Vibration Isolation System (CEVIS) and Second-Gen Treadmill (T2). From pedal speeds of 0 to 125 revolutions per minute, CEVIS provides aerobic and cardiovascular conditioning. Coupled with an isolation system, it negates subtle vibrations that result from biking. Like ARED, an integrated monitor measures performance data against heart rate. Granted CEVIS' purpose, its ability to replicate biking on Earth can give astronauts comfort while being away from home. Lastly, T2's improved capabilities include maximum speeds up to 5.5 m/s. Having a redesigned passive vibration isolation system, astronauts strapped down can properly replicate running while remaining in a confined space. Just like the other devices, T2 logs similar data from its sensors and accelerometers. Altogether, the exercise equipment chosen for this Martian mission helps to provide a structural foundation in supporting the crew's overall health.

Bisphosphonates

Use of bisphosphonates can further provide protection for astronauts against the effects of microgravity. As said by LeBlanc et al. (2013), a study of pre- and post-space flight measurements located in **Table 2**, compares the BMD (Bone Mineral Density) of different areas in the bone for two groups. These authors note, the pre-ARED group consisted of 9 American astronauts and 9 Russian cosmonauts who flew on the ISS from 2001 to 2004. Prior to installation of ARED in 2009, this group utilized iRED (Interim Resistive Exercise Device) instead. Switching over, the Bisphosphonate group consisted of six males and one female. Three weeks before flight and continuing throughout their 5.5-month mission, members in this group were instructed to take 70 mg/week of Fosamax (bisphosphonate). Pills came packaged in foil push-out cards and were assigned respectively. Adding to this, the exercise equipment this group had access to include a treadmill, cycle ergometer, and ARED. Experiment results showcased two things for the bisphosphonate group. Firstly, percentage changes yielded more positives which indicated areas of bone-strengthening. Secondly, the negative percent changes were minimal when compared to those in the pre-ARED group. As a result, elements of exercise in conjunction with bisphosphonates prove a vital asset for the human body to withstand long durations in space.

Lower Body Negative Pressure

Aiding astronauts in microgravity, lower body negative pressure (LBNP, or Chibis) offers an additional opportunity. Here, a device encloses the lower abdomen and extremities to sustain a controlled pressure differential below ambient (Clément, 2011). From terrestrial testing, uniformed pressure distributions to the lower extremities in combination with exercise have shown efficiency for counteracting microgravity-induced deconditioning (Dailey et al., 2014). Optimizing this existing LBNP, Dailey and her team discusses the designs of integrating a lightweight compactable exercise machine with a collapsible chair highlighted in **Figure 3**. Exploring further, the exercise machine will offer a constant compressive load on the musculoskeletal system, whereas the chair's flexible assembly aids how an astronaut may sit. With these factors geared towards deep space exploration, **Figure 4** layouts this exercise machine and collapsible chair schematic within the LBNP. Adjustable preloads in the spring yield different levels to account for an astronaut's strength with the maximum being 1.16 BW (232 lbs) and minimal 0.68 BW (136 lbs). Given that a BW (Bodyweight) over 1 is comparable to exercises on Earth (Dailey et al, 2014), this improved design boasts value in protecting astronauts in space and making sure they receive proper fitness.

Life Support Systems Literature Review

Critical for any manned mission, life support systems provide the essential constituents a crew needs to survive and function. With a crew traveling in space and residing on Mars, both environments must be accounted for. That said, ample systems can establish sustainable and dependable habitats to guarantee daily operations are met.

Advanced Closed Loop System (ACLS)

First and foremost, this encompasses the Advanced Closed Loop System (ACLS). Going more in-depth, Bockstahler et al. (2013) discuss the varying capabilities for such a versatile apparatus. Labeled as a regenerative life support system for closed habitats, the ACLS comprises of three subsystems: CO_2 Concentration Subsystem (CCA), CO_2 Reprocessing Subsystem (CRA), and Oxygen Generation Subsystem (OGA). Through main functions that include regulating CO_2 levels, supplying breathable oxygen via electrolysis, and catalyzing conversions of carbon dioxide with hydrogen to produce water and methane, **Table 3** details the numerical values the ACLS collectively generates daily. Meanwhile, **Figure 5** puts into perspective the ACLS' cycle processes. Since the installment of this system aboard the International Space Station, it has already recycled 50% of carbon dioxide levels to save 400 liters of water (European Space Agency, n.d.). As a result, the ACLS' implementation is substantially vital as resources for the crew will be finite throughout their entire Martian mission.

Water Recovery System (WRS)

Next, the Water Recovery Stem (WRS) is underlined. Comprising of the Urine Processor Assembly (UPA) and Water Processor Assembly (WPA), the Water Recovery System (WRS) provides clean water for astronauts by recycling urine as well as cabin humidity condensate from crew sweat, respiration, and hygiene (Garcia, 2021). With assumed recovery efficiencies for the UPA (80%) and WPA (99%), the WRS is situated as an advantageous system on long-duration exploration missions (Jones, 2017). That said, information provided in **Table 4**, numbers the WRS' ability to produce clean water from waste generated by each crewmember. Granted water is the most crucial resource for humans, such recyclable methods need to be in place to extend reserves when traveling in space and on Mars.

Active Thermal Control System (ATCS)

Moving onwards, the Active Thermal Control System (ATCS) is emphasized. Responsible for temperatures around 24 °C on the ISS, the Active Thermal Control System (ATCS) capitalizes on three functions: heat collection, transportation, and rejection (Let's Talk Science, 2019). Beginning this process, Tongue et al. (1997) state, heat is first acquired from the station's electronics and inhabitants, through water to ammonia heat exchangers. Here, one ATCS pipe loop transports the heated water to a second ATCS pipe loop filled with ammonia. Due to the low-temperature ammonia, it acts as a cooling agent and reduces flow to increase system heat rejection. However, if the ammonia warms up, heat can also be transferred to the ISS large radiator wings. Since the crew will utilize a 3-deck module, temperatures should be sufficient with smaller sized radiators. Within the ATCS, there also exists an isolation/relief valve to prevent the backflow of ammonia, mitigate over-pressurization, and isolate mechanical parts from the freezing water. Diving deeper, **Figure 6** lays a blueprint schematic for an Orbital Replacement Unit (ORU), which are modules that make up major components in the ATCS.

Spacesuits

Switching over, each crewmember will have two different types of spacesuits for this Martian mission. The first is the xEMU, which improves on the suits previously worn during Apollo, and those currently in use for spacewalks outside the International Space Station (Loff, 2019). Like the Moon, Mars has a low gravity and dusty surface which is problematic for astronauts. Encompassing this suit, is the Exploration Portable Life-Support Subsystem (xPLSS), Exploration Pressure Garment Subsystem (xPGS), Exploration Informatics (xINFO) Subsystem, and EVA tools (National Aeronautics and Space Administration, 2021). Diving into each unit, NASA explains, the xPLSS provides an astronaut with oxygen, removes carbon dioxide, odors, and humidity that build up inside the suit. In addition to this, body temperature is regulated by a fan circulating oxygen. On the other hand, the xPGS protects the astronaut's body through pressurization, heat insulation, and from debris, all the while offering mobility to conduct physical operations. Following this, the xINFO issues high-definition video, worksite illumination, high-rate suit data recording, and associated antenna transmission + connection via electrical harnesses. Lastly, EVA (Extra- Vehicular Activity) Tools consist of handrails, sample collection bags, scissors, etc. Although still in development, **Figure 7** identifies these part placements on the xEMU suit.

During mission launch or reentry, it is also important astronauts have an additional layer of protection. Accounting for these pivotal periods the Orion suit as displayed in **Figure 8** will instead be worn. Sometimes referred to as a flight or entry suit, improvements in helmet design help reduce noise and make it easier to talk to other crew members, or receive instructions from mission control (Crane, 2019). Going in-depth the author describes supplemental features pertaining to Orion with such including a pressure garment that incorporates a restraint layer to control the shape and ease astronauts' movements. As well as durable touch-screen compatible gloves and fire-resistant boots to help an astronaut move more nimbly. Initially aimed for the Moon, Crane (2019) exclaims the Orion suit also prepares for future missions to Mars. As a manned expedition commences, the crew's safety + well-being remains top-priority indefinitely.

Food/Beverages

Proper nutrition is substantial for crewmembers as physical activities will be conducted daily for a Martian mission. Not only this, but accessibility to multiple options while staying within a desired diet allows for personal preference. Following guidelines, each astronaut's daily calorie intake will range from 2,700 to 3,700 (American Heart Association, 2018). Adapting the same menu as the ISS in **Figures 9, 10, 11, & 12**, each astronaut will have a choice on what items to bring. Ensuring an adequate diet is met, **Figure 13** organizes each food group and their respective daily servings. Finally, when it comes to liquids, astronauts in addition to other beverages they have, should also aim for half a gallon of water at minimum. That said, guidelines must be in place to help avoid symptoms of malnourishment and dehydration amongst any crew altogether.

Space Habitation Analysis & Findings

Adapting this 7.2 m diameter conceptual cylindrical habitat by Smitherman (2016), its primary design is aimed at supporting a 4-person crew, over a 1000-day Mars transit mission. Adding to this, he notes that surrounding systems and stowage volumes help achieve maximum protection when crew quarters are placed in the middle of the main deck. From this habitat's vertical layout, it also boasts more compatibility with artificial gravity vehicle configurations. As well as surface lander designs, where the transit and surface habitats might have similar layouts. With specifications detailed in **Figure 14**, this offers insight into the amount of space a crew has and an estimated need for resources. Furthermore, this numerical baseline can allow for adjustments that will be needed to accommodate a six-person crew to Mars. Considering their psychological state during this trip, improvements to the habitat should include LED lights and ample free-time activities. Requiring little power and having high durability, LEDs can produce specific colors of light, which can help overcome sleep and circadian disruptions during spaceflight (National Aeronautics and Space Administration, 2015). When it comes to breaks, options can range from watching movies, listening to music, reading books, or playing cards

(May, 2021). Overall, giving astronauts the opportunity to bring their personal belongings allows for preferences that contribute towards positive mental reinforcement.

HDPE and Kevlar Fabric Analysis & Findings

Looking deeply at High-Density Polyethylene (HDPE), **Figure 15** showcases the material comparison against aluminum for calculated particle energies on a 500-day Mars mission. With an HDPE like polyethylene graphene oxide, total effective dose can be as low as 0.25 mSv/day when areal density shielding is high (300 g/cm^2) (Barthel & Sarigul-Klijn, 2018). Even for missions longer than 225 days, Singleterry (2013) underlines that polyethylene yields ample shielding which can help to protect crews accordingly. Likewise, with Kevlar Fabric also bolstering uniform results, its hypervelocity protection is a necessity against abrasions, dust, and micrometeoroids (Christiansen & Lear, 2012). Hence, without this durable and flexible material, astronaut suits would likely be susceptible to micro-tears. Overall, leading to overexposures from the radiation environment which can result in headaches, appetite loss, vomiting, etc. (Centers for Disease Control and Prevention, n.d.). All in all, affecting a crew's psychological and physiological well-being to fulfill necessary objectives.

ARED, CEVIS, and T2 Analysis & Findings

Tackling exercises in microgravity, a five-month protocol with ARED was evaluated for functionality, durability, and reliability by a six-person crew (Donald, n.d.). After 159,000 repetitions, the author concluded, no significant changes were noticed in the performance of ARED. On that note, **Table 5** denotes each crewmember's opinion via a rating system for different exercises that were conducted with ARED. Collectively, subjects expressed easiness + ample comfortability, whilst also mentioning the ARED device itself felt smooth and balanced

(Donald, n.d.). Considering these previous astronaut's experiences, the foundation listed for the ARED apparatus proves useful to serve a six-person Martian crew.

Switching over, **Table 6** details NASA's Expeditions 20–25 Protocols for the Cycle Ergometer with Vibration Isolation System (CEVIS). Here, Leohr et al. (2015) denote two modes (Simple Ride & Hill) in which elapsed time was compared against staged time. Measured with respective to maximum oxygen consumptions levels ($VO_{2\ max}$) taken prior for crewmembers, data indicates that everyone was mostly able to outperform their scheduled stage time. With the machine resulting in little to no strains present, it offers enabling support for a crewed Mars mission to carry out physical activities (EVAs, research, team meetings, etc.) competently.

Regarding the Second-Gen Treadmill (T2), **Table 7** and **8** display an average kinematic dataset for two treadmill exercises in both a microgravity and 1G environment. As discussed by Everett et al. (2009), six participants (3 men and 3 women) exercised on a prototype T2 by jogging (JOG) around 3.13 m/s and fast running (RUN) at 5.36 m/s respectively. From 1G being conducted on a ground facility, a microgravity setting fostering 80% bodyweight loading was achieved using parabolic flight on a DC-9 aircraft. Through observations, a more squat-like position during JOG occurred in microgravity, whereas RUN minor changes in angles for parts of the body between both domains. That said, with the authors goals of replicating exercise in microgravity as accurately as possible, they note if RUN were a part of in-flight training, it could improve the efficacy of treadmill exercise as an osteogenic and cardiorespiratory countermeasure. Playing to optimize proper fitness, such an adaptation in preparation for a team to Mars may contribute to promoting physiological and psychological welfare.

Bisphosphonate Analysis & Findings

Within an ISS experiment, crewmembers in the bisphosphonate group had a >98% compliance with the dosing schedule (LeBlanc et al., 2013). With **Figure 16** displaying a similar bisphosphonate distribution card that was assigned to each astronaut, it is important to note this medication be taken on an empty stomach with a glass of water, either 70 mg once weekly, or 10 mg once daily (John Hopkins Arthritis Center, 2012). From giving astronauts the flexibility in choosing how they wish to take the medication orally; this also stems as an additional source of protection alongside the onboard exercise equipment. When addressing deep space travel in its entirety, options must emphasize protecting crews both internally and externally against the effects of microgravity.

Lower Body Negative Pressure Analysis & Findings

Progressing forward, a study available in **Table 9** compares upright exercises-1G with supine exercises-LBNP (Lower Body Negative Pressure). Going more in-depth, Murthy et al. (1994) write, nine male volunteers were assigned one of two positions (upright or supine) randomly and were instrumented with ECG electrodes, a transducer-tipped catheter, and a strain gauge. From monitoring the heart rate quantified intramuscular pressure and pooling of fluids in the leg, post-information indicated exceeding cardiovascular stress in such area due to supine-exercises-LBNP. Taking this into account, a recommended partial reduction of LBNP-induced venous pooling may possibly be achieved using the already mentioned lightweight exercise machine and collapsible chair. While it is important for astronauts in space to replicate Earth-based exercises accurately, factors tying into comfortability and vitality need also remain a priority when it comes to using any physical system for long durations.

Life Support Systems Analysis & Findings

Analyzing the components in the ACLS (Advanced Closed Loop System), **Table 10** archives CCA (CO_2 Concentration Subsystem) data for average CO_2 flow and concentration amongst 5 days aboard the ISS (Witt et al., 2020). During this cycle, consistent measurements are recorded, highlighting system reliability and dependability. That said, applications for a mission to Mars will require similar systems, that can work effectively with little to no human assistance. Alongside this**, Figure 17** graphs the OGA's (Oxygen Generation Subsystem) operation period for a crew's asleep and awake time (Witt et al., 2020). Here, an initial steady increase in O_2 levels eventually reaches constant peaks which can be attributing to the operational time of this device showcasing its ability to gradually adjust respective O_2 levels automatically. This is quite important as other daily activities for a manned mission will require much needed attention. Lastly, **Figure 18** denotes the CRA (CO_2 Reprocessing Subsystem) constituents during a 16-hour work phase (Kappmaier et al., 2016). With products mainly following a fixed output, this capitalizes on the system's ability to multitask, which is a necessity for any deep space travel, as the recycling of current crew resources can easily make or break the viability of a mission.

WRS Analysis & Findings

Looking at the WRS (Water Recovery System), a graphical summary in **Figure 19** compares its UPA's (Urine Processor Assembly) unit water production rate versus up mass (Carter et al., 2012). Upon inspection, the water produced outweighs the up mass (waste) by a factor of 2.8x. Through sufficient water recovery, crewed missions are able to sustain hydrating foods, oxygen production + consumption, and personal hygiene long-term. Being especially imperative for deep space exploration, the extensive transporting of water from Earth else otherwise is likely to be time-consuming and costly.

ATCS Analysis & Findings

With regards to the ATCS (Active Thermal Control System), **Figure 20** plots out heat rejection (exothermic) and power load (endothermic) for a 45-hr nominal mission (Wang & Yuko, 2010). As a result, an analysis reveals near-linear datasets for both points showcasing ample conditions situated by the instrument to yield room temperature. Playing a major role in maintaining homeostasis, the prospect of traversing Mars and the deep space domain will require that individuals are thermally regulated.

Spacesuits Analysis & Findings

Diving deeper, the National Aeronautics and Space Administration (2021) underlines that new xEMU spacesuits will include a maximum 9-hour EVA time, sizing that accommodates most of the population, and rear entry. On that note, sufficient durations for EVA's conducted beyond LEO not only give astronauts flexibility to explore further regions, but assist in lessening any stresses or worries that may arise when venturing into new territories. Coupled with a flexible fit and rear accessibility, this allows for the xEMU spacesuit to be worn more comfortability while reducing the prep time needed to prepare for EVAs beforehand. Operating similarly, Jacobs et al. (2018) emphasize that the Orion Spacesuit will incorporate unassisted suit donning/doffing, full anthropometric range (1^{st} percentile female to the 99^{th} percentile male), and pressurization at 4.3 psia (pounds per square inch absolute) for 144 hours. Although both spacesuits serve different purposes, together they are vital to the health of all crew members throughout each mission phase.

Space Nutrition Analysis & Findings

Finally, Tang et al. (2021) discuss a few prominent notes pertaining to long-term space nutrition. First and foremost, they write any crew must prioritize the following 16 essential nutrients: protein, calcium, iron, vitamin A, vitamin C, thiamine, riboflavin, vitamin b-12, folate, vitaminD, vitamin E, magnesium, potassium, zinc, fiber, and pantothenic acid. From here, a minimum requirement for macronutrient composition would average 15% protein, 30% lipids, and 55% carbohydrates. That said, in order to avoid monotony on space missions, diets are to follow a 4-to-6-day cycle in which the food alternates every day except for the beverages (Tang et al., 2021). Examples of such diets followed by American astronauts and Russian cosmonauts are listed in **Table 11**. All in all, adopting these procedures allows a variety amongst crewmembers whilst keeping their nutrition levels in check. Ultimately, ensuring that peak physiological and psychological responses are prevalent throughout a Mars mission.

Synthesis and Interpretation

Phase 1 – Pre-Launch

Amongst this six-person Martian crew, they comprise of different positions: **One Commander**, **One Flight Surgeon**, **One Aerospace Engineer**, **One Electrical Engineer**, **One Geologist**, and **One Botanist**. Assigned duties and responsibilities for each role are listed below.

- **Crew Commander (CC)** – Pilot spacecrafts, conducts administrative duties, and leads non-emergency situations.
- **Crew Flight Surgeon (CFS)** - Manages medical evaluations for crewmates, diagnoses symptoms, and treats illnesses/pains.
- **Crew Aerospace Engineer (CAE)** - Tests, maintains, and repairs space-related equipment's/systems.

- **Crew Electrical Engineer (CEE) -** Works alongside the CAE and is responsible for monitoring power outputs, radiation levels, and Life Support Systems.
- **Crew Geologist (CG)** – Studies Mars' natural resources, environmental conditions, and optimal grounds for future manned missions.
- **Crew Botanist (CB)** – Collects Martian soil samples and surveys crop growth.

Prior to the start of the mission, all astronauts will have undergone an extensive preparation process. Entailing a series of analog missions (CHAPEA) at the Mars Dune Alpha habitat, to simulate year-long stays, this facility scaling 1,700 square feet contains private crew quarters, a kitchen, and dedicated areas for work, fitness, recreation, etc. (National Aeronautics and Space Administration, n.d.-b). Moreover, NASA details that major crew activities such as simulated spacewalks via virtual reality, exercise, hygiene, etc., will operate with environmental stressors (resource limitations, isolation, equipment failure, and significant workloads) to achieve a realistic Mars-like scenario. On that note, other forms of training for crews involve ARGOS (The Active Response Gravity Offload System), which provides a simulated reduced gravity environment that responds to human-imparted forces, through input/feedback sensors, fast-response motor controllers, and custom-developed software algorithms (National Aeronautics and Space Administration, n.d.-c). As well as the VMS (Vertical Motion Simulator), to help configure cockpits of existing or future aerospace vehicles, using its five interchangeable cabs, motors, and system of hydraulics (Tabor, 2020). In conjunction with these training opportunities, members are also encouraged to spend time with one another through casual activities (eating, exercise, field work, etc.). All in all, establishing a bond outside the presence of work to promote cooperativeness and morale.

Phase 2 – Launch to LEO

After a vehicle inspection check by Ground Control, Mission Control will proceed with a go/no go launch rubric for each subsystem. Once complete, Mission Control contacts and awaits confirmation per crew member. After confirming, the launch director shall give the final call, initiating a countdown for takeoff. With their Orion Spacesuits equipped, the crew is vertically positioned to counteract stresses on the body from high acceleration. Taking approximately 8.5 minutes to reach LEO (Leinbach, n.d.), Mission Control commences a final checkup before the team departs to Mars.

Phase 3 – LEO Launch to Destination Orbit

During this 9-month journey, individuals are required to exercise on the lower deck for approximately 2.5 hours/day, using ARED, CEVIS, T2, and LBNP. Operating on a weekly rotation, everyone is assigned a workout buddy by the Crew Commander to avoid isolation/stagnation. When it comes to dining, the Crew Commander also calls everyone together for breakfast, lunch, and dinner in the Galley & Wardroom Area. Apart from snacks being accessible 24/7, time allocated for each meal is between 1-2 hours, allowing everyone to acquire their food and chat leisurely as they please.

Moving on, 3-5 hours will be scheduled for work tasks, which include maintenance, cleaning, project planning or research via the onboard workstations if needed. After said duties are completed, astronauts are free to relax however they wish, by either watching movies, reading, playing cards, etc. As the day concludes, it is required that everyone gets around 8.5 hours of sleep to ensure ample workflow the next day. By the end of each week, the Crew Flight Surgeon is responsible for administering medical evaluations and performing necessary actions regarding one’s health. Meanwhile, the Crew Commander or someone else stated otherwise sends reports back to Mission Control detailing their travels. With a series of integrated Life Support Systems (ACLS, WRS, & ATCS) already serving as critical assets to humans traveling in deep space, a structured guideline additionally promotes both order and flexibility. Conclusively, preparing the team mentally and physically upon their arrival to Mars' orbit.

Phase 4 – Destination Orbit Down to Surface

Once in Martian orbit, the Crew Commander does a ready checkup and reviews the arrival procedure for everyone. Shuttling down to Aram Chaos with their Orion spacesuits, **Group A (CC, CAE, CEE)** checks out the Martian Surface Habitat, for leaks or damages to systems that would hinder human survival. While this is being done, **Group B (CFS, CG, CB)** carries supplies brought into the shuttle. This can include EVA equipment, clothes, personal belongings, etc. Once thoroughly assessed, the Crew Commander signals **Group B** to rendezvous at the Mars Habitat entrance.

Phase 5 – Surface Stay

As the habitat begins to pressurize, the crew enters their new home and changes into casual clothing. After some time (2-3 days) adjusting to the new environment, the Crew Commander then lays out daily operations for the team's stay. Encompassing 2 EVA sessions 3x a week, with one happening in the morning and the other at afternoon, a maximum of 3 members at a time are to equip their supplied xEMU suit, while the remaining members standby at base to establishing a two-way line of communication. In preparation for these expeditions, the Crew Commander calls upon everyone the night before to discuss respective times and groups. With short EVAs lasting between 1-2 hours and long EVAs 3-4 hours, the purposes of these journeys include assisting the Crew Geologist in analyzing environmental conditions, excavating natural resources, and exploring areas for future manned missions. Furthermore, soil sample are to be collected, in order to aid the Crew Botanist in studying chemical compositions needed for crop growth. Depending on the target destination for each EVA, available rovers stem as an alternative option to help traverse long distances. Adapting the same schedule and systems used during space travel, in combination with EVAs, gives astronauts a variety of tasks to avoid repetition, confinement, and idleness.

Phase 6 – Surface to Orbit

Succeeding their twelve-week stay on Aram Chaos, the crew will then head back to the shuttle wearing their Orion spacesuits, bringing back the items initially brought down. Here, EVA samples are to be studied on the trip back home and on Earth. Expediting this process promptly, a checklist is issue beforehand to ensure nothing is left behind. Prior to launch, the Crew Commander does a ready checkup similar to that when the crew landed. Once cleared, the crew is shuttled back up into Martian orbit.

Phase 7 – Orbit to LEO

Once arriving at the space habitation module, the crew then removes their Orion spacesuits and transports the materials brought to and from Mars. After settling back in, the 9-month voyage back to LEO (Low-Earth Orbit) begins. Like how they arrived, the crew follows the same lifestyle and procedures traveling back to LEO.

Phase 8 – LEO to Earth

Upon approaching LEO (Low-Earth Orbit), the Crew Commander contacts Mission Control. Suiting up in the Orion Spacesuits one last time, the crew begin their reentry into Earth’s atmosphere. Tracking their trajectory, Mission Control finalizes operations to rendezvous with the landed spacecraft. Assisting the crew’s descent period, a capsule system of 11 Orion parachutes assembles in the air, slowing down the spacecraft from 300 mph to 20 mph for splashdown in the ocean (Garcia, 2018). Accounting for the crew's orthostatic intolerance developed during deep space travel, individuals are to remain in their seats while a ground team transports them back to headquarters.

Phase 9 – Post-mission on Earth

Finally reaching headquarters, on-site medical personnel measure crew member's respective post-flight vitals via blood reports, QCT scans, and urine samples to assess changes in the body. Afterwards, the ASCR (The Astronaut Strength, Conditioning and Rehabilitation) group comprised of licensed professionals, provides athletic rehabilitation training for the crew's musculoskeletal systems to assist in 1G readaptation (Lewis, 2021). Initially incorporating stretches, massages, and assisted walking, as the body conditions over time, cardiovascular fitness is then introduced using treadmills, cycles, ergometers, and hydrotherapy (Kale et al., 2013). Although daily sessions are to range from 2-4 hours, doctors + therapists are made available to visit an astronaut's home to offer services that can include counseling, yoga therapy, and medical checkups. Considering the duration of this Mars manned mission, the rehabilitation program is aimed to initially last around 3-4 months. However, depending on a crew member's personal progress, this time may be extended or shortened accordingly.

Mars Mission Summary

All in all, with Mars continuing to be a scientific center for exploration, its Earth-like conditions permit prospective habitability and research. Tying all elements presented for this research mission, findings showcase these listed apparatuses have the potential to accommodate key necessities for manned space travel. With previous assessments already conducted, strengths are underlined to maintain areas of an astronaut's health. Despite Mars having yet to be explored by humans physically, this 9-phase plan offers insight into constructing a foundation tailored for future expeditions that emphasizes crew safety and optimizes daily duties.

Mars Mission Conclusions

On that note, operations should be executed in the mid-2030s as the long-term effects of microgravity are still unknown for a mission at this length. Furthermore, given that current methods only help to mitigate microgravity, additional advancements in technology are needed to fully address this crucial space obstacle. That said, lessons learned from the upcoming 2024 ARTEMIS missions to the Moon may serve as a catalyst in advocating potential human expeditions to other celestial bodies. Ultimately, supporting humanity to becoming an interplanetary species.

Mars Mission Recommendations

Approaching the technicalities for a Martian mission, two recommendations can be introduced to further sustain human health. First and foremost, is model updates to all current exercise equipment onboard (ARED, CEVIS, and T2). Adapting future versions that have been properly tested on Earth, ensures exercising in space is optimized accordingly to promote proper fitness. Serving as a backbone for an astronaut's health, these systems must always operate at peak performance long-term. Alongside this, the implementation of artificial gravity can additionally help to mitigate bone loss in space, as well as provide a controlled environment for individuals to require less time to exercise in space. Being possibly applicable with the introduced space habitation cylindrical design as stated earlier, this advancement can be an overall vital constituent in supporting manned voyages beyond the Moon.

References

American Heart Association. (2018, March 22). *Astronauts need extra exercise and calories in space*. Phys. https://phys.org/news/2018-03-astronauts-extra-calories-space.html

Barthel, J., & Sarigul-Klijn, N. (2018). Radiation production and absorption in human spacecraft shielding systems under high charge and energy Galactic Cosmic Rays: Material medium, shielding depth, and byproduct aspects. *Acta Astronautica*, *144*, 254–262. https://doi.org/10.1016/j.actaastro.2017.12.040

Bockstahler, K., Lucas, J., & Witt, J. (2013). Design Status of the Advanced Closed Loop System ACLS for Accommodation on the ISS. *43rd International Conference on Environmental Systems*. https://doi.org/10.2514/6.2013-3450

Carter, L., Tobias, B., & Orozco, N. (2012). *Status of ISS Water Management and Recovery*. NASA. https://ntrs.nasa.gov/api/citations/20120015013/downloads/20120015013.pdf

Centers for Disease Control and Prevention. (n.d.). *Acute Radiation Syndrome | CDC*. CDC. Retrieved February 9, 2022, from https://www.cdc.gov/nceh/radiation/emergencies/ars.htm#:%7E:text=These%20symptoms%20include%20loss%20of,also%20can%20have%20skin%20damage.

Chen, M., Goyal, R., Majji, M., & Skelton, R. E. (2021). Review of space habitat designs for long term space explorations. *Progress in Aerospace Sciences*, *122*, 100692. https://doi.org/10.1016/j.paerosci.2020.100692

Christiansen, E. L., & Lear, D. M. (2012, February). *Micrometeoroid and Orbital Debris Environment & Hypervelocity Shields*. NASA. https://ntrs.nasa.gov/api/citations/20120002584/downloads/20120002584.pdf

Clément, G. (2011). *Fundamentals of Space Medicine* (2nd ed.). Springer New York.

Crane, A. (2019, October 22). *Orion Suit Equipped to Expect the Unexpected on Artemis Missions*. NASA. https://www.nasa.gov/feature/orion-suit-equipped-to-expect-the-unexpected-on-artemis-missions/

Dailey, C. M., Reinholtz, C., Russomano, T., Schuette, M., Baptista, R., & Cambraia, R. (2014). Resistance exercise machine within lower body negative pressure for counteracting effects of microgravity. *Gravitational and Space Research*, *2*(1), 94+. https://link.gale.com/apps/doc/A426999646/AONE?u=embry&sid=bookmark-AONE&xid=dd0d7b84

Donald, H. R. (n.d.). *Advanced Resistive Exercise Device (ARED) Man-In-The-Loop Test (MILT) (ROI_ARED_MILT)*. NASA. Retrieved February 10, 2022, from https://lsda.jsc.nasa.gov/Experiment/exper/1399

European Space Agency. (n.d.). *Advanced Closed Loop System*. ESA. Retrieved February 5, 2022, from https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Research/Advanced_Closed_Loop_System#:%7E:text=ESA's%20Advanced%20Closed%20Loop%20System,the%20Space%20Station%20into%20oxygen.&text=Steam%20is%20then%20used%20to,methane%20is%20vented%20into%20space.

Everett, M. E., O'Connor, D. P., & DeWitt, J. K. (2009). Lower Limb Position During Treadmill Jogging and Fast Running in Microgravity. *Aviation, Space, and Environmental Medicine*, *80*(10), 882–886. https://doi.org/10.3357/asem.2414.2009

Garcia, M. (2018, June 29). *Orion Parachute Tests Prove Out Complex System for Human Missions*. NASA. https://www.nasa.gov/feature/orion-parachute-tests-prove-out-complex-system-for-human-deep-space-missions/

Garcia, M. (2021, February 26). *New Brine Processor Increases Water Recycling on the Station*. NASA. https://www.nasa.gov/feature/new-brine-processor-increases-water-recycling-on-international-space-station/

Hackney, K. J., Scott, J. M., Hanson, A. M., English, K. L., Downs, M. E., & Ploutz-Snyder, L. L. (2015). The Astronaut-Athlete. *Journal of Strength and Conditioning Research*, *29*(12), 3531–3545. https://doi.org/10.1519/jsc.0000000000001191

Jacobs, S. E., Tufts, D. B., & Gohmert, D. M. (2018). *Space Suit Development for Orion*. Tdl. https://ttu-ir.tdl.org/bitstream/handle/2346/74166/ICES_2018_199.pdf

John Hopkins Arthritis Center. (2012, April 25). *Fosamax Information: Alendronate:* https://www.hopkinsarthritis.org/patient-corner/drug-information/alendronate-fosamax/

Jones, H. W. (2017, July). *Would Current International Space Station (ISS) Recycling Life Support Systems Save Mass on a Mars Transit?* (ICES-2017-85). NASA Ames Research Center. https://ntrs.nasa.gov/citations/20170007268

Kale, S. R., Master, H. S., Verma, C. V., Shetye, J., Surkar, S., & Mehta, A. (2013). Exercise Training for Astronauts. *Indian Journal of Physiotherapy and Occupational Therapy - An International Journal*, *7*(2), 82. https://doi.org/10.5958/j.0973-5674.7.2.017

Kappmaier, F., Matthias, C., & Witt, J. (2016). *Carbon Dioxide Reprocessing Subsystem for Loop Closure as part of the Regenerative Life Support System ACLS*. Tdl. https://ttu-ir.tdl.org/bitstream/handle/2346/67702/ICES_2016_391.pdf?sequence=1

Kozlovskaya, I. B., Yarmanova, E. N., Yegorov, A. D., Stepantsov, V. I., Fomina, E. V., & Tomilovaskaya, E. S. (2015). Russian countermeasure systems for adverse effects of microgravity on long-duration ISS flights. *Aerospace Medicine and Human Performance*, *86*(12), 24–31. https://doi.org/10.3357/amhp.ec04.2015

Laurenzi, S., de Zanet, G., & Santonicola, M. G. (2020). Numerical investigation of radiation shielding properties of polyethylene-based nanocomposite materials in different space environments. *Acta Astronautica*, *170*, 530–538. https://doi.org/10.1016/j.actaastro.2020.02.027

LeBlanc, A., Matsumoto, T., Jones, J., Shapiro, J., Lang, T., Shackelford, L., Smith, S. M., Evans, H., Spector, E., Ploutz-Snyder, R., Sibonga, J., Keyak, J., Nakamura, T., Kohri, K., & Ohshima, H. (2013). Bisphosphonates as a supplement to exercise to protect bone during long-duration spaceflight. *Osteoporosis International*, *24*(7), 2105–2114. https://doi.org/10.1007/s00198-012-2243-z

Leinbach, M. (n.d.). *NASA - Ask The Mission Team - Question and Answer Session*. NASA. Retrieved February 16, 2022, from https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts121/launch/qa-leinbach.html#:%7E:text=It%20takes%20the%20shuttle%20approximately,8%2D1%2F2%20minutes.

Let's Talk Science. (2019, September 23). *Temperature on Earth and on the ISS*. https://letstalkscience.ca/educational-resources/backgrounders/temperature-on-earth-and-on-iss

Lewis, R. (2021, August 12). *Strength, Conditioning and Rehabilitation*. NASA. https://www.nasa.gov/content/astronaut-strength-conditioning-and-rehabilitation/

Loehr, J. A., Guilliams, M. E., Petersen, N., Hirsch, N., Kawashima, S., & Ohshima, H. (2015). Physical Training for Long-Duration Spaceflight. *Aerospace Medicine and Human Performance*, *86*(12), 14–23. https://doi.org/10.3357/amhp.ec03.2015

Loehr, J. A., Lee, S. M. C., English, K. L., Sibonga, J., Smith, S. M., Spiering, B. A., & Hagan, R. D. (2011). Musculoskeletal Adaptations to Training with the Advanced Resistive Exercise Device. *Medicine & Science in Sports & Exercise*, *43*(1), 146–156. https://doi.org/10.1249/mss.0b013e3181e4f161

Loff, S. (2019, October 28). *A New Spacesuit for Artemis Generation Astronauts*. NASA. https://www.nasa.gov/image-feature/a-new-spacesuit-for-artemis-generation-astronauts/

Mars, K. (2021, June 9). What Happens to the Human Body in Space? NASA. https://www.nasa.gov/hrp/bodyinspace/

May, S. (2021, April 28). *Free Time in Space*. NASA. https://www.nasa.gov/audience/foreducators/stem-on-station/ditl_free_time/

Murthy, G., Watenpaugh, D., Ballard, R., & Hargens, A. (1994). Exercise against lower body negative pressure as a countermeasure for cardiovascular and musculoskeletal deconditioning. *Acta Astronautica*, *33*, 89–96. https://doi.org/10.1016/0094-5765(94)90112-0

Narici, L., Casolino, M., di Fino, L., Larosa, M., Picozza, P., Rizzo, A., & Zaconte, V. (2017). Performances of kevlar and polyethylene as radiation shielding on-board the international space station in high latitude radiation environment. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-01707-2

National Aeronautics and Space Administration. (2006). *Advanced Resistive Exercise Device (ARED) Man-In-TheLoop Test (MILT)*. Tika. https://corpora.tika.apache.org/base/docs/govdocs1/892/892484.pdf

National Aeronautics and Space Administration. (2012, August 2). *Phoenix Mars Lander*. NASA. https://www.nasa.gov/redplanet/phoenix.html#:%7E:text=The%20lander%20dug%2C%20scooped%2C%20baked,first%20detected%20remotely%20in%202002.

National Aeronautics and Space Administration. (2015). *LEDs Illuminate Bulbs for Better Sleep, Wake Cycles | NASA Spinoff*. NASA. https://spinoff.nasa.gov/Spinoff2015/cg_6.html

National Aeronautics and Space Administration. (2021, August). *Nasa's Development of Next-Generation Spacesuits* (IG-21-025). NASA. https://oig.nasa.gov/docs/IG-21-025.pdf

National Aeronautics and Space Administration. (n.d.). Radiation Levels on the Surface of Mars. NASA. Retrieved January 26, 2022, from https://spacemath.gsfc.nasa.gov/planets/10Page74.pdf

National Aeronautics and Space Administration. (n.d.-a). *Appendix B: International Space Station Daily Menu Food List*. NASA. Retrieved February 5, 2022, from https://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf

National Aeronautics and Space Administration. (n.d.-b). *A Step Toward Mars*. Retrieved February 16, 2022, from https://www.nasa.gov/chapea/about/

National Aeronautics and Space Administration. (n.d.-c). *Full-Size Reduced Gravity Simulator For Humans, Robots, and Test Objects | T2 Portal*. NASA. Retrieved February 16, 2022, from https://technology.nasa.gov/patent/MSC-TOPS-60

Nimon, J. (2012, February 23). *NASA - Strong Bones and Fewer Renal Stones For Astronauts*. NASA. https://www.nasa.gov/mission_pages/station/research/news/Strong_Bones.html

Sibille, L., Mueller, R., Niles, P. B., Glotch, T., Archer, P. D., & Bell, M. S. (2015). *Aram Chaos: a Long Lived Subsurface Aqueous Environment with Strong Water Resources Potential for Human Missions on Mars* (No. 1048). NASA Kennedy Space Center. https://ntrs.nasa.gov/citations/20150019643

Singleterry, R. (2013). Radiation engineering analysis of shielding materials to assess their ability to protect astronauts in deep space from energetic particle radiation. *Acta Astronautica*, *91*, 49–54. https://doi.org/10.1016/j.actaastro.2013.04.013

Smitherman, D. V. (2016, September). *Habitation Concepts for Human Missions Beyond Low-Earth-Orbit* (No. M16-5504). NASA Marshall Space Flight Center. https://ntrs.nasa.gov/citations/20160012094

Tabor, A. (2020, February 22). *What is the Vertical Motion Simulator? - "Flying" Before You Can Fly*. NASA. https://www.nasa.gov/ames/vms/

Tang, H., Rising, H. H., Majji, M., & Brown, R. D. (2021). Long-Term Space Nutrition: A Scoping Review. *Nutrients*, *14*(1), 194. https://doi.org/10.3390/nu14010194

The Planetary Society. (2021, June 22). *MAVEN, studying how Mars lost its atmosphere*. https://www.planetary.org/space-missions/maven#:%7E:text=MAVEN%20created%20a%20global%20wind,changes%20in%20the%20Martian%20atmosphere.

Tongue, S., Taddey, E., & Dellinger, B. (1997). ISS Active Thermal Control System (ATCS) Heat Exchangers and Cold Plates. *SAE Technical Paper Series*. https://doi.org/10.4271/972347

U.S. Department of Agriculture. (2014, October 30). *Food Guide Pyramid - Print Materials*. USDA. https://www.fns.usda.gov/food-guide-pyramid-print-materials

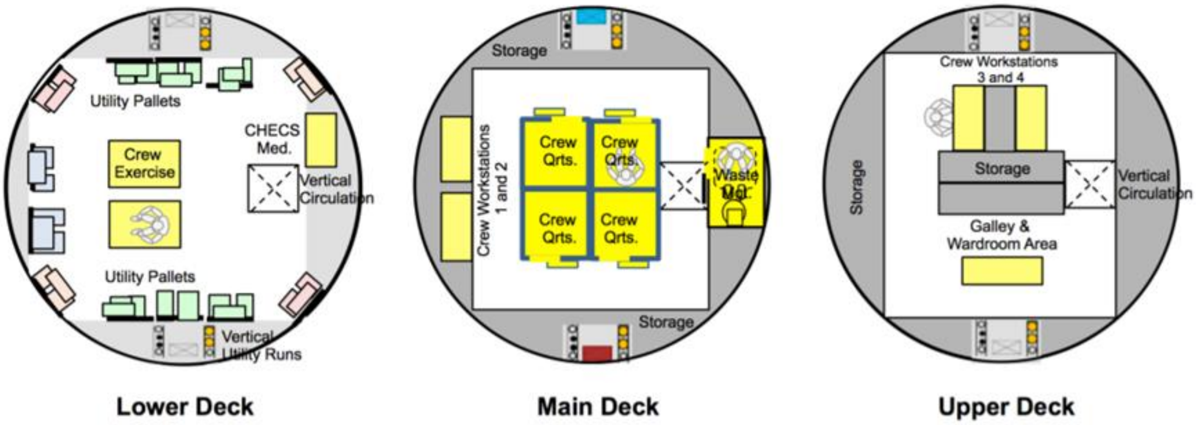
Wang, X. J., & Yuko, J. (2010). *Orion Active Thermal Control System Dynamic Modeling Using Simulink/MATLAB*. NASA. https://ntrs.nasa.gov/api/citations/20100022150/downloads/20100022150.pdf

Williams, D. E. (2006, July). *Lessons Learned from the Crew Health Care System (CHeCS) Rack 1 Environmental Control and Life Support (ECLS) Design* (No. 2006–01–2060). SAE International. https://doi.org/10.4271/2006-01-2060

Witt, J., Hovland, S., Laurini, D., Matthias, C., Boettcher, F., Bevilacqua, T., & Redondo, C. (2020). *On-orbit Testing of the Advanced Closed Loop System ACLS*. Tdl. https://ttu-ir.tdl.org/bitstream/handle/2346/86479/ices-2020-510.pdf?sequence=1

Figure 1

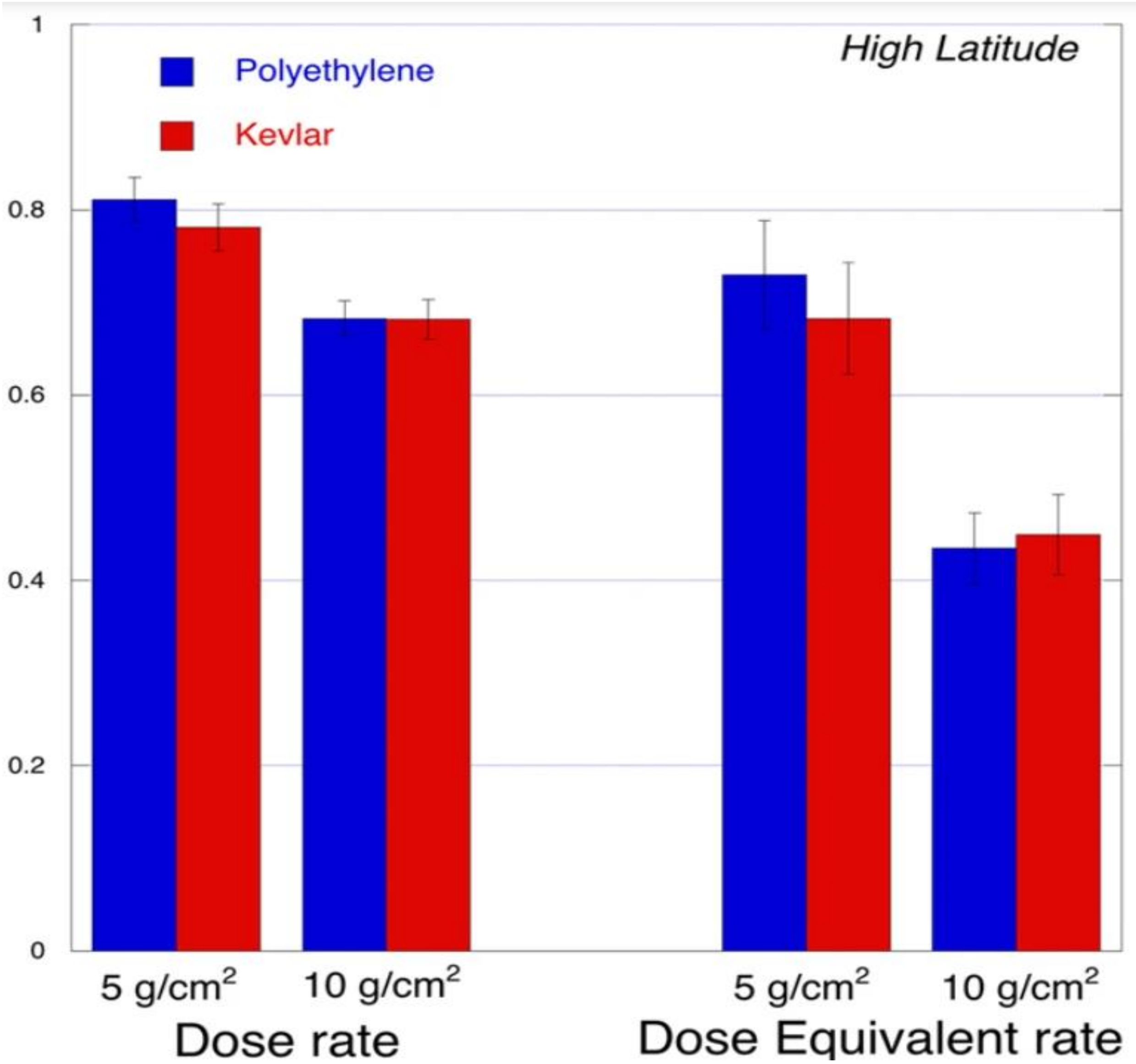
7.2 m Diameter Cylindrical Habitat



Note. A top-down view for each deck and its following components are listed. From *Habitation Concepts for Human Missions Beyond Low-Earth-Orbit*, by Smitherman, 2016, (https://ntrs.nasa.gov/citations/20160012094).

Figure 2

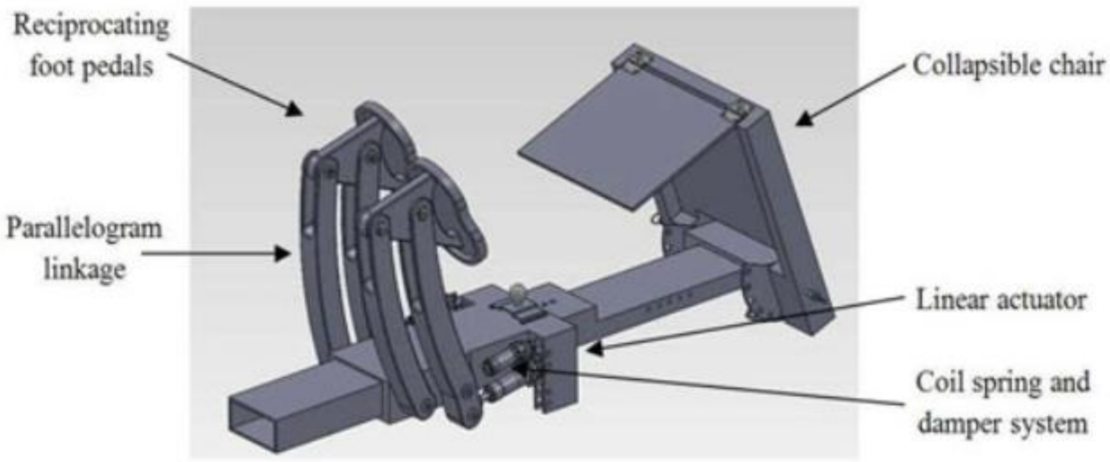
Polyethylene vs Kevlar



Note. Comparison of Polyethylene and Kevlar in the High Latitude environment. Measurements indicate an identical performance. From *Performances of kevlar and polyethylene as radiation shielding on-board the international space station in high latitude radiation environment*, by Narici et al., 2017, (https://doi.org/10.1038/s41598-017-01707-2).

Figure 3

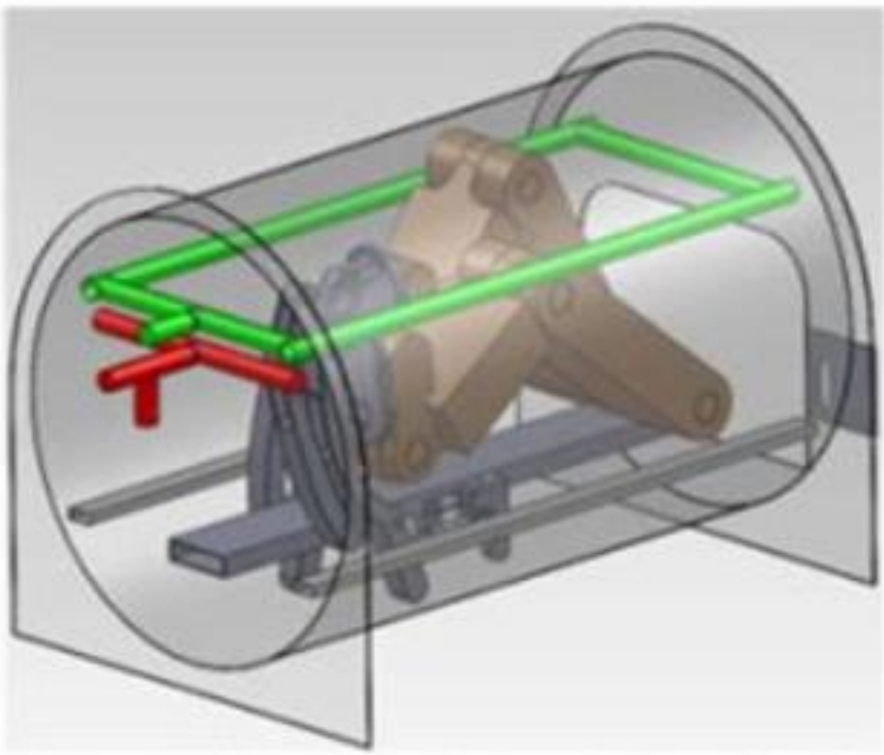
Lightweight Compactable Exercise Machine with Collapsible Chair



Note. Components for the Exercise Machine and Collapsible Chair are represented. From *Resistance exercise machine within lower body negative pressure for counteracting effects of microgravity*, by Dailey et al., 2014, (https://link.gale.com/apps/doc/A426999646/AONE?u=embry&sid=bookmark-AONE&xid=dd0d7b84).

Figure 4

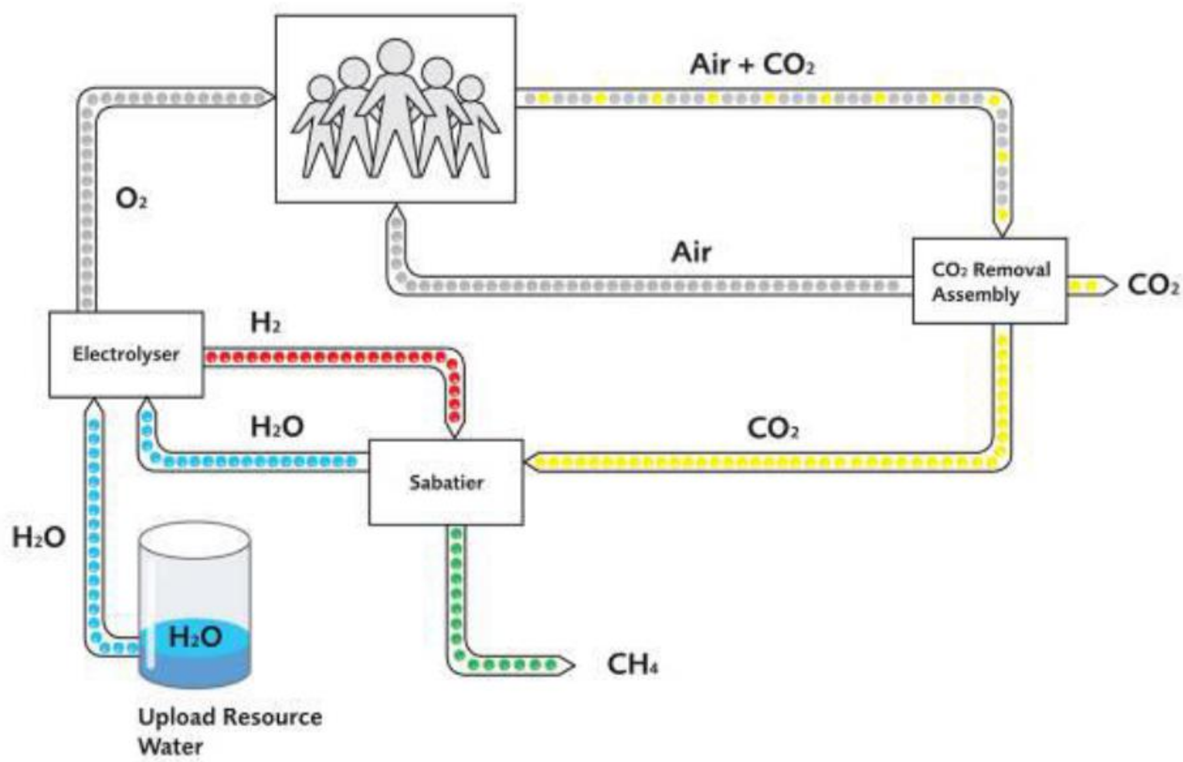
Integrated LBNP Box



Note. Brown-colored areas detail human legs and feet laying on top of the exercise machine within a LBNP Box. The green and red tubes represent cooling ducts. Although not visible, outside this apparatus the rest of the astronaut's body sits on the collapsible chair. From *Resistance exercise machine within lower body negative pressure for counteracting effects of microgravity*, by Dailey et al., 2014, (https://link.gale.com/apps/doc/A426999646/AONE?u=embry&sid=bookmark-AONE&xid=dd0d7b84).

Figure 5

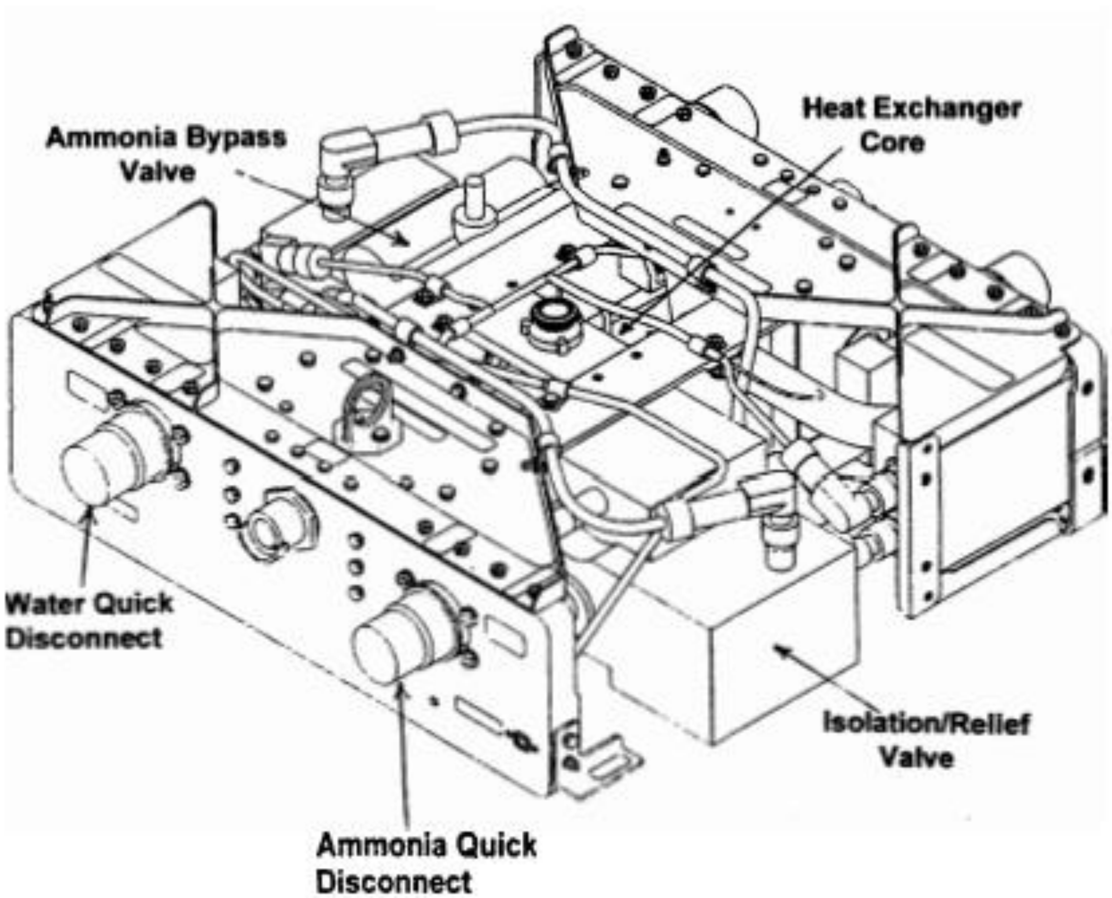
ACLS Closed Loop System



Note. As a result, from this system process, post-products include excess CO_2 (carbon dioxide) and CH_4 (methane). From *Design Status of the Advanced Closed Loop System ACLS for Accommodation on the ISS*, by Bockstahler et al., 2013, (https://doi.org/10.2514/6.2013-3450).

Figure 6

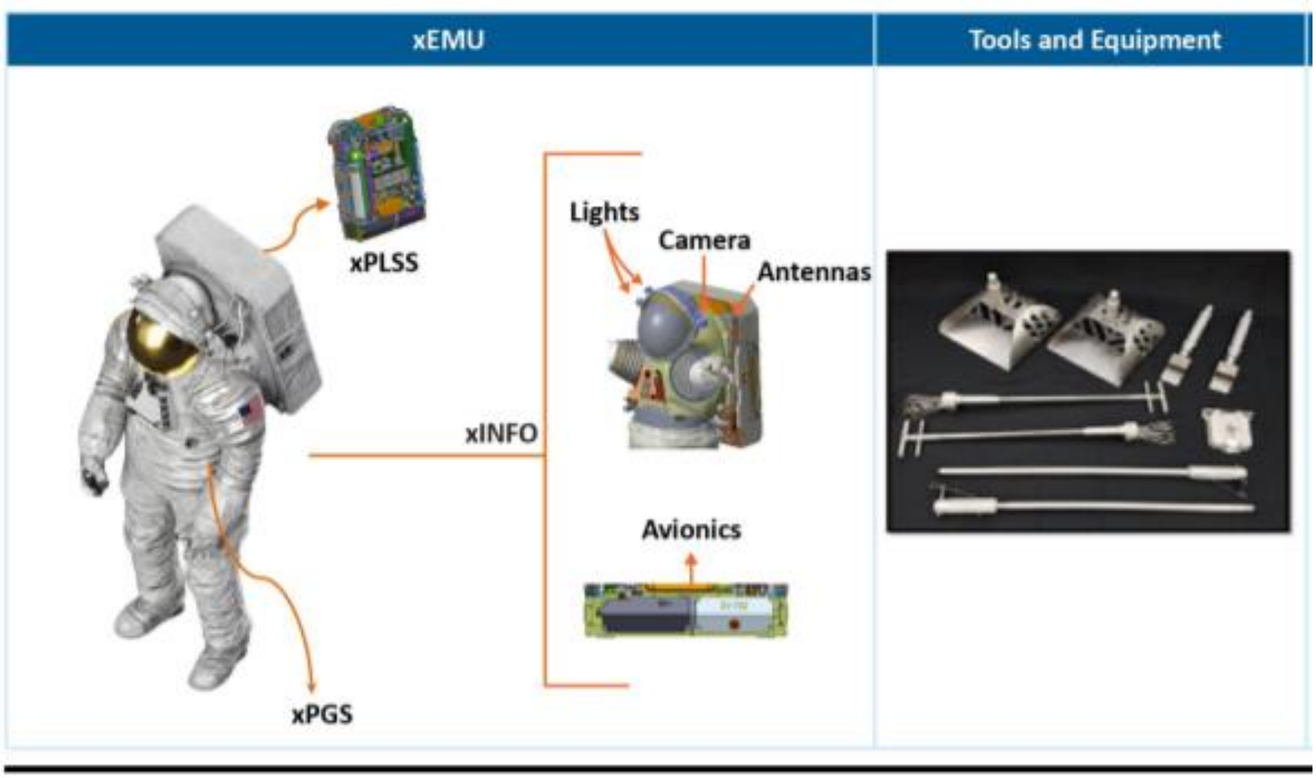
Heat Exchanger ORU



Note. Mechanisms associated with the ORU for a Heat Exchanger are labelled. From *ISS Active Thermal Control System (ATCS) Heat Exchangers and Cold Plates*, Tongue et al., 1997, (https://doi.org/10.4271/972347).

Figure 7

xEMU Suit



Note. Constituents associated with the xEMU Suit are tagged. From *NASA's Development Of Next-Generation Spacesuits*, National Aeronautics and Space Administration, 2021, (https://oig.nasa.gov/docs/IG-21-025.pdf).

Figure 8

Orion Suit

Note. An individual wearing a model of the Orion suit is shown. From *Orion Suit Equipped to Expect the Unexpected on Artemis Missions*, Crane, 2019, (https://www.nasa.gov/feature/orion-suit-equipped-to-expect-the-unexpected-on-artemis-missions/).

Figure 9

ISS Menu Foods (I)

Refrigerated

Dairy

Cheese
Cheese slices
Cream cheese
Sour cream
Yogurt, fruit

Fruits

Apple
Grapefruit
Kiwi
Orange
Plum

Frozen

Meat and Eggs

Beef:

Beef, brisket, BBQ
Beef, enchilada with spanish rice
Beef, fajita
Beef, patty
Beef, sirloin tips with mushrooms
Beef, steak, bourbon
Beef, steak, teriyaki
Beef, stir fried with onion
Beef, stroganoff with noodles
Luncheon meat
Meatloaf with mashed potatoes and gravy

Lamb:

Lamb, broiled

Poultry:

Chicken, baked
Chicken, enchilada with spanish rice
Chicken, fajita
Chicken, grilled
Chicken, oven fried
Chicken, pot pie
Chicken, stir fried with diced red pepper
Chicken, teriyaki with spring vegetables
Duck, roasted
Meatball, porcupine (turkey)

Pork:

Bacon
Bacon, Canadian
Ham, baked with candied yams
Pork, chop, baked with potatoes au gratin
Pork, sausage, patties
Pork, sweet and sour with rice

Seafood:

Fish, baked
Fish, grilled
Fish, saut ed
Lobster, broiled tails
Scallops, baked
Seafood, gumbo with rice
Shrimp, cocktail
Tuna, noodle casserole

Eggs:

Egg, omelet, cheese
Egg, omelet, vegetable
Egg, omelet, ham
Egg, omelet, sausage
Egg, omelet vegetable and ham
Egg, omelet, vegetable and sausage
Eggs, scrambled with bacon, hash browns sausage
Quiche, vegetable
Quiche, lorraine

Pasta mixtures:

Lasagna, vegetable with tomato sauce
Noodles, stir fry
Spaghetti with meat sauce
Spaghetti with tomato sauce
Tortellini with tomato sauce, cheese

Note. Page One denotes available refrigerated and frozen foods. From *Appendix B: International Space Station Daily Menu Food List*, National Aeronautics and Space Administration, n.d.-a, (https://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf).

Figure 10

ISS Menu Foods (II)

Other:

Egg rolls
Enchilada, cheese with Spanish rice
Pizza, cheese
Pizza, meat
Pizza, vegetable
Pizza, supreme

Fruit

Apples, escalloped
Peaches, sliced with bananas, blueberries
Peaches with bananas, grapes, strawberries
Strawberries, sliced

Soups

Beef, stew
Broccoli, cream of
Chicken, cream of
Chicken noodle
Mushroom, cream of
Won ton

Grains

Biscuits
Bread
Cornbread
Dinner roll
Garlic bread
Sandwich bun, wheat/white
Toast, wheat/white
Tortilla

Breakfast items:

Cinnamon roll
French toast
Pancakes, buttermilk
Pancakes, apple cinnamon
Waffles

Pasta:

Fettuccine alfredo
Macaroni and cheese
Spaghetti

Rice:

Fried
Mexican/Spanish
White

Starchy Vegetables

Corn, whole kernel
Potato, baked
Potatoes, escalloped
Potatoes, oven fried
Potatoes, mashed
Yams, candied
Succotash
Squash corn casserole

Vegetables

Asparagus tips
Beans, green
Beans, green with mushrooms
Broccoli au gratin
Broccoli
Carrot coins
Cauliflower au gratin
Chinese vegetables, stir fry
Mushrooms, fried
Okra, fried
Peas
Peas with carrots
Squash, acorn with apple sauce and cinnamon
Zucchini, spears, fried

Desserts

Cakes:

Angel food cake
Brownie, chocolate
Chocolate fudge
Shortcake
Yellow cake with chocolate frosting

Dairy:

Ice cream, chocolate
Ice cream, strawberry
Ice cream, vanilla
Yogurt, frozen

Note. Page Two continues with more available frozen foods. From *Appendix B: International Space Station Daily Menu Food List*, National Aeronautics and Space Administration, n.d.-a, (https://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf).

Figure 11

ISS Menu Foods (III)

Pies and Pastry:

Cheesecake, chocolate
Cheesecake, plain
Cobbler, peach
Pie, apple
Pie, coconut cream
Pie, pecan
Pie, pumpkin

Beverages

Apple juice
Grape juice
Grapefruit juice
Lemonade
Orange juice

Condiments

Margarine
Grated cheese

Cereals

Hot cereal:

Oatmeal
Cream of wheat
Grits

Thermostabilized

Fruit

Applesauce
Fruit cocktail
Peaches
Pears
Pineapple

Salads

Chicken salad
Tuna salad
Turkey salad

Vegetable:

Bean salad, three
Pasta salad
Potato salad, German
Sauerkraut

Soups

Chili
Clam chowder
Egg drop
Miso, Japanese
Vegetable

Desserts

Pudding, butterscotch
Pudding, chocolate
Pudding lemon
Pudding, tapioca
Pudding, vanilla

Condiments

Barbecue sauce
Catsup
Chili con queso
Cocktail sauce
Cranberry sauce
Dill pickle chips
Dips, bean
Dips, onion
Dips, ranch
Honey
Horseradish sauce
Jelly, assorted
Lemon juice
Mayonnaise
Mustard
Mustard, hot Chinese
Orange marmalade
Peanut butter (chunky, creamy, whipped)
Picante sauce
Sweet and sour sauce
Syrup, maple
Taco sauce
Tartar sauce

Beverages

Fruit juices:

Cranberry
Cranberry apple
Cranberry raspberry
Gatorade, assorted
Pineapple
Pineapple grapefruit
Tomato
V-8

Note. Page Three finishes with the rest of the frozen section and lists the Thermostabilized foods. From *Appendix B: International Space Station Daily Menu Food List*, National Aeronautics and Space Administration, n.d.-a, (https://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf).

Figure 12

ISS Menu Foods (IV)

Milk:

Skim
Low fat
Chocolate (low fat or skim)
Whole

Natural Form

Fruit

Apples, dried
Apricots, dried
Peach, dried
Pear, dried
Prunes
Raisin
Trail mix

Grains

Animal crackers
Cereal, cold
Chex mix
Crackers, assorted
Baked chips, tortillas
Baked chips, potato
Pretzels
Goldfish
Tortilla chips
Potato chips
Rye krisp, seasoned

Desserts

Cookies:

Butter
Chocolate chip
Fortune
Rice krispies treat
Shortbread

Snacks

Beef jerky

Nuts:

Almonds
Cashews
Macadamia
Peanuts

Candy:

Candy-coated chocolates
Candy-coated peanuts
Lifesavers
Gum (sugar free)

Eva Food

In-suit fruit bar

Rehydratable

Beverages

Apple cider
Cherry drink
Cocoa
Coffee (assorted)
Grape drink
Grapefruit drink
Instant breakfast, chocolate
Instant breakfast, vanilla
Instant breakfast, strawberry
Orange drink
Orange mango drink
Orange pineapple drink
Tea (assorted)
Tropical punch

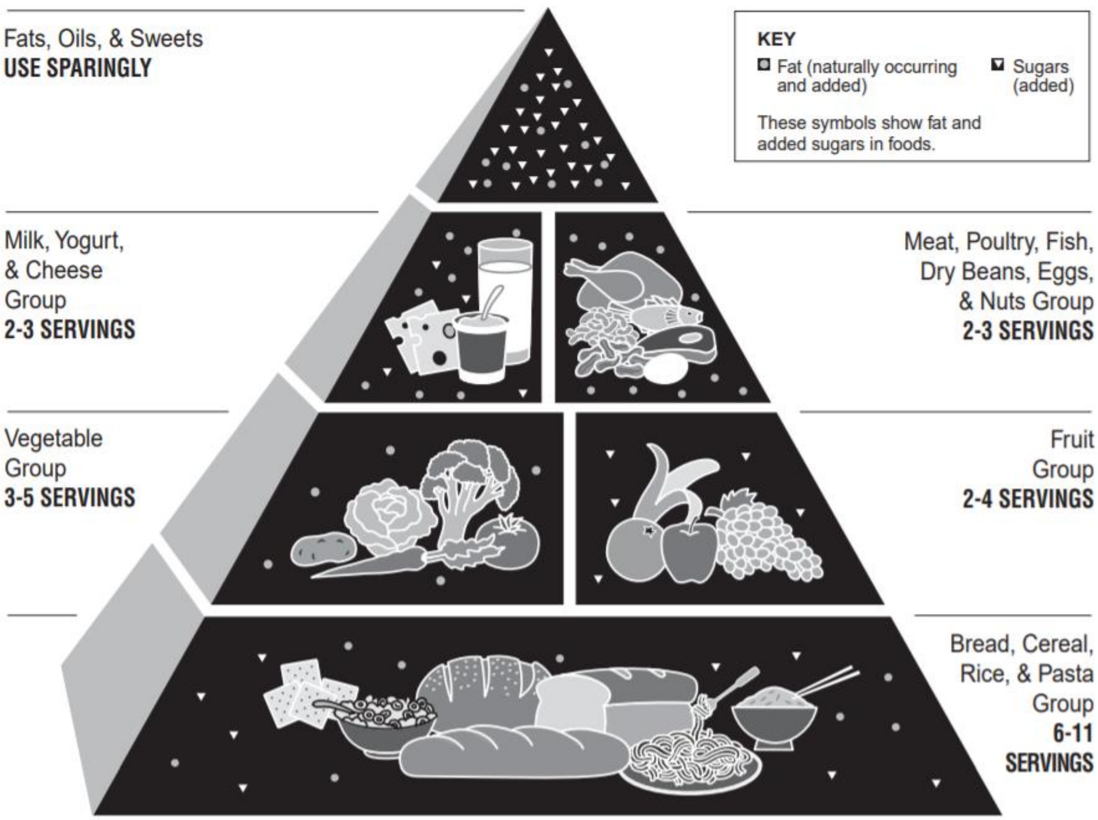
Irradiated Meat

Beef steak
Smoked turkey

Note. Page Four concludes with the thermostabilized options and categorizes the remaining food/beverage choices. *International Space Station Daily Menu Food List*, National Aeronautics and Space Administration, n.d.-a, (https://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf).

Figure 13

USDA Food Guide Pyramid

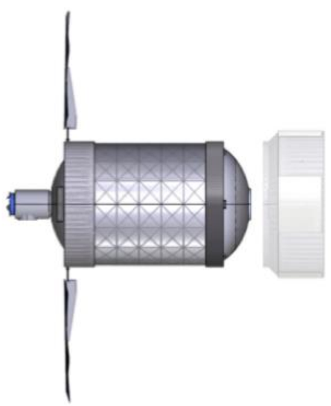


Note. The pyramid denotes a hierarchy of foods that be capitalized daily. From *Food Guide Pyramid - Print Materials*, U.S. Department of Agriculture, 2014, (https://www.fns.usda.gov/food-guide-pyramid-print-materials).

Figure 14

7.2 m Habitat Specifications

3b. 7.2m HAB Summary



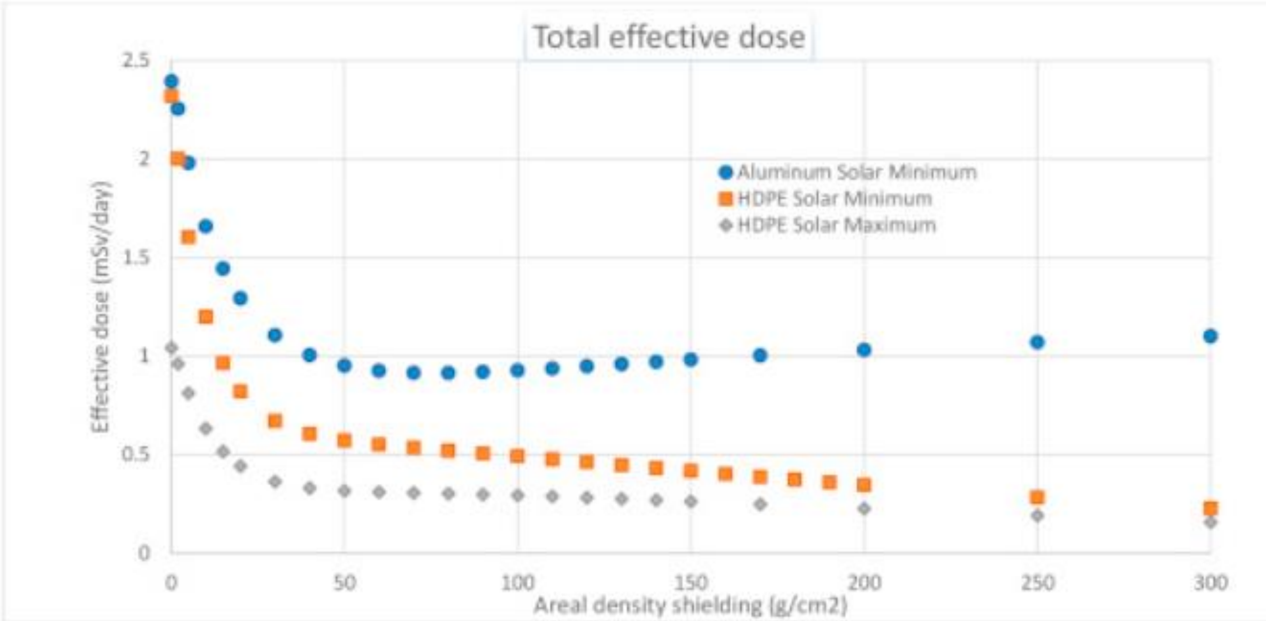
Design Constraints & Parameters	
Crew Capacity	4
LAB Mission Duration (days)	300
Mars HAB Mission Duration (days)	1000
EOL Solar power generation (kW)	30.7
Power load during battery operation (kW)	9.6
Solar Array area (m^2)	298.4
Thermal Radiator area (m^2)	122.4
TRL (Weighted Average)	5.96
ECLSS Closure - Water	Closed
ECLSS Closure - Air	Closed
Habitat Structure	Aluminum
Habitat Length (m)	10.92
Habitat Diameter (m)	7.20
Pressurized Volume (m^3)	392.00
Habitable Volume (m3)	245.00
Stowage Volume (m3)	94.00
Mass Growth Allocation	9.44%
Project Manager's Reserve	10%

Mass Summary	LAB	Mars HAB
MEL	**Mass (kg)**	**Mass (kg)**
Structures	7,204	7,770
Propulsion	0	0
Power	1,659	1,659
Avionics / C&DH, C&T, GN&C	1,166	1,166
Thermal	1,777	1,777
Radiation Protection	1,399	1,399
ECLSS	2,764	2,764
Crew Systems	2,502	2,502
EVA	427	941
Research	6,139	761
Dry Mass	**25,037**	**20,738**
Stowed Provisions	4,999	7,975
Consumables	2,577	8,438
Non-propellant Fluids	0	0
Inert Mass	**7,576**	**16,413**
Total Less Propellant	32,613	37,152
Propellant	0	0
Wet Mass	**32,613**	**37,152**
Payload Adapter	0	0
Project Manager's Reserve	3,261	3,715
Total LAB Mass	**35,874**	
Total Mars HAB Mass		**40,867**

Note. Associated subcomponents for a 7.2 m Habitat are organized. From *Habitation Concepts for Human Missions Beyond Low-Earth-Orbit*, by Smitherman, 2016, (https://ntrs.nasa.gov/citations/20160012094).

Figure 15

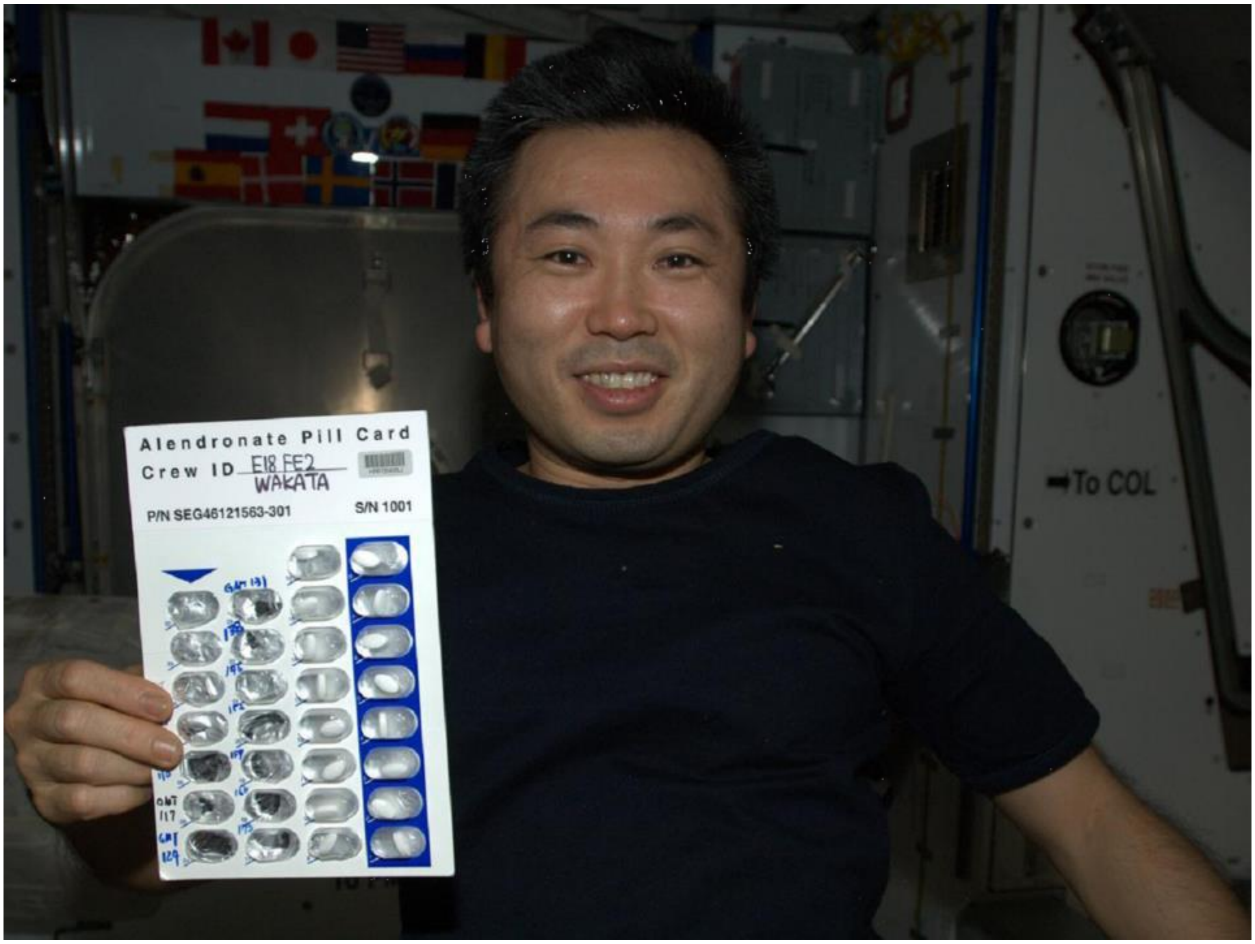
Particle Energies On a 500 Day Mars Mission



Note. Shielding areal density versus GCR effective dose for HDPE and aluminum. From *Radiation production and absorption in human spacecraft shielding systems under high charge and energy Galactic Cosmic Rays: Material medium, shielding depth, and byproduct aspects*, by Barthel and Sarigul-Klign, 2018, (https://doi.org/10.1016/j.actaastro.2017.12.040).

Figure 16

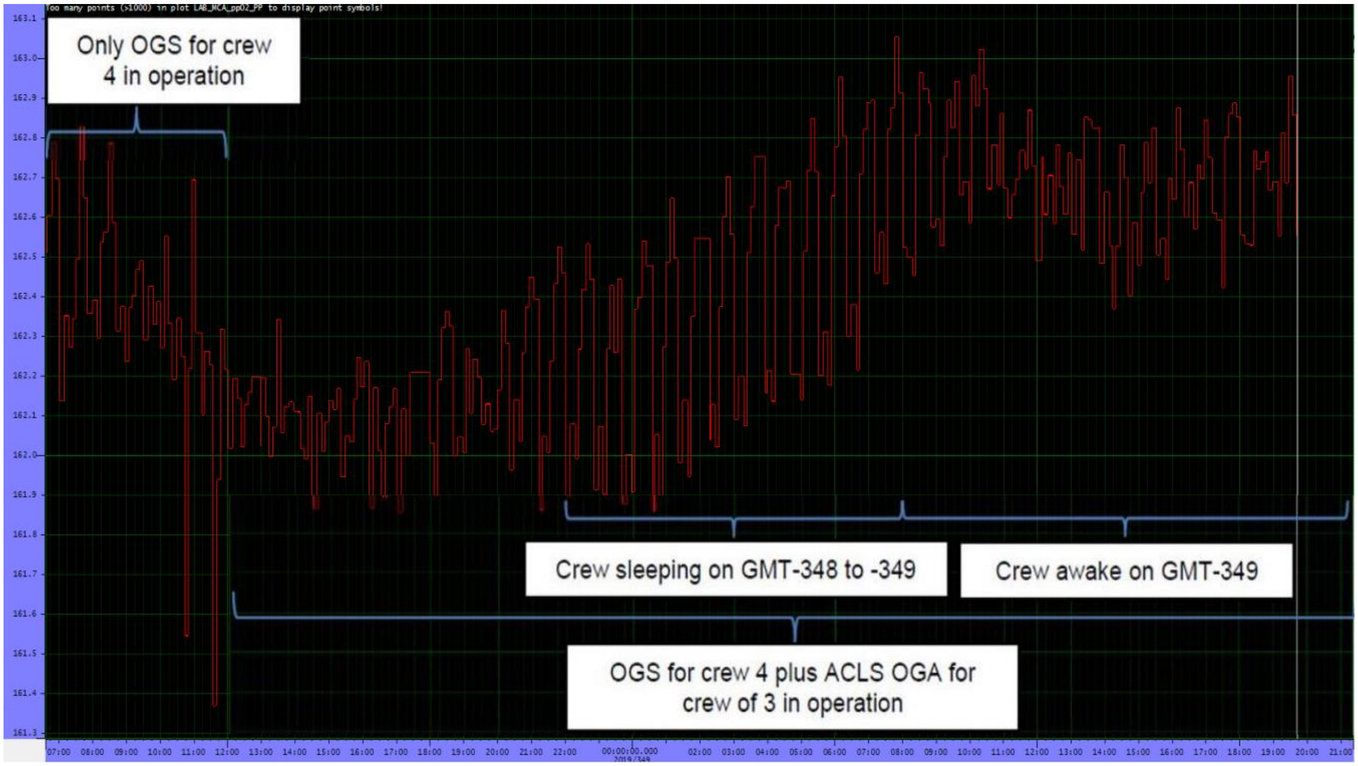
Bisphosphonate Distribution Card



Note. Astronaut Wakata displays his assigned alendronate (type of bisphosphonate) card. From *Strong Bones and Fewer Renal Stones For Astronauts*, by Nimon, 2012, (https://www.nasa.gov/mission_pages/station/research/news/Strong_Bones.html).

Figure 17

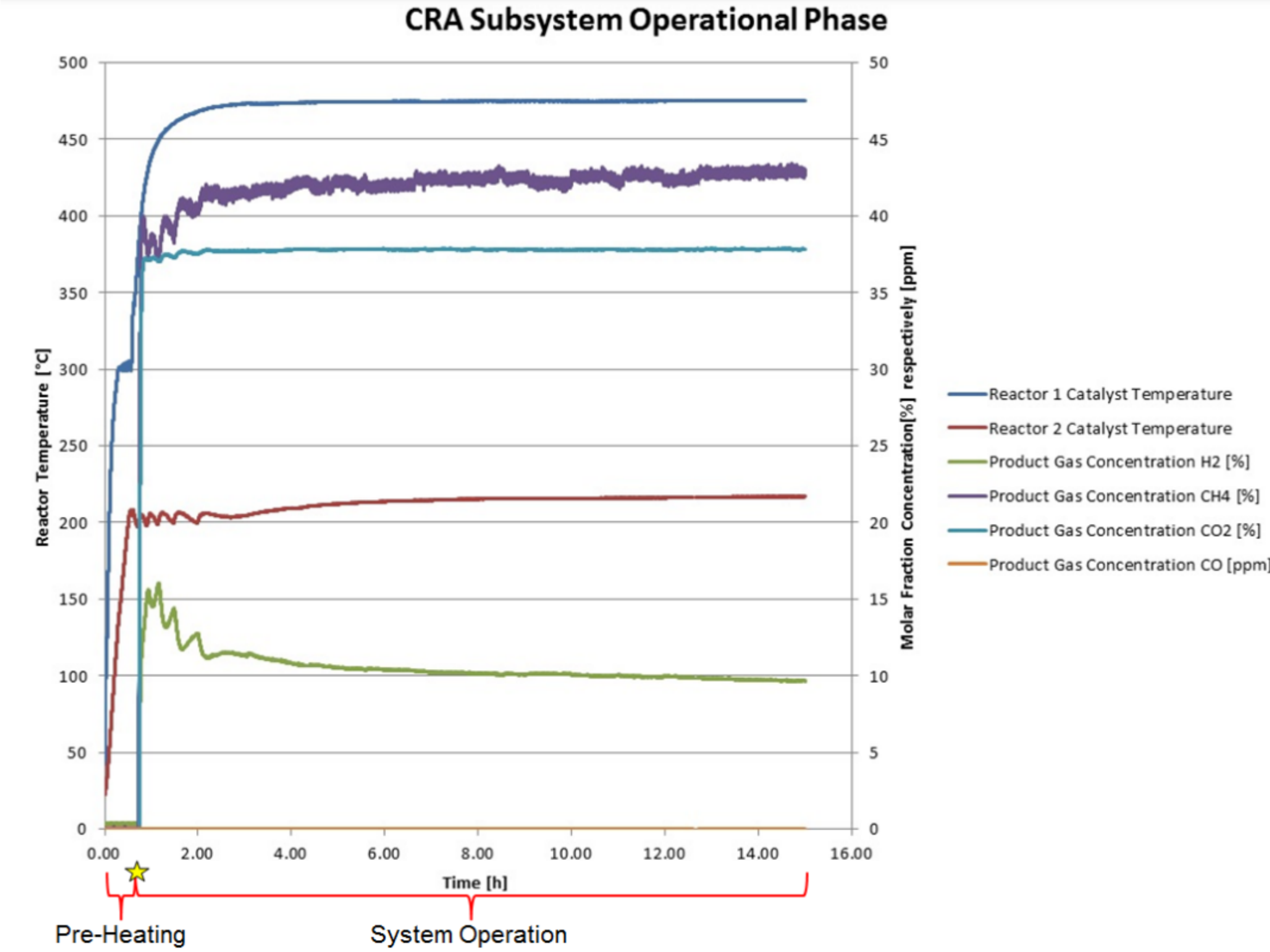
OGA (Oxygen Generation Subsystem) Operational Period



Note. When OGA is in operation, O_2 values begins to arise and are sustained when the crew is awake. From From *On-orbit Testing of the Advanced Closed Loop System ACLS*, by Witt et al., 2020, (https://ttu-ir.tdl.org/bitstream/handle/2346/86479/ices-2020-510.pdf?sequence=1).

Figure 18

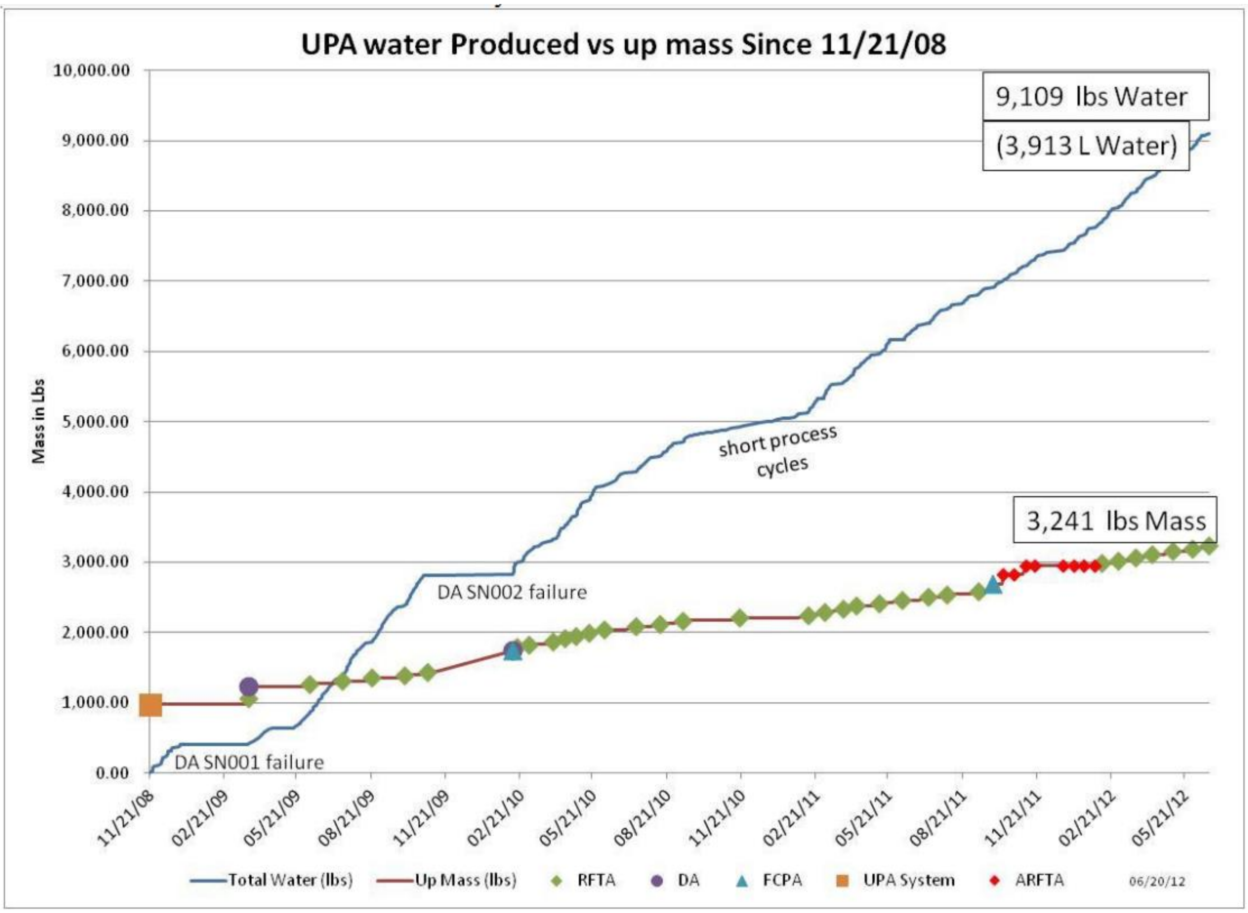
CRA (CO_2 Reprocessing Subsystem) 16 Hour Period



Note. Different constituents and their respective concentrations at designated temperatures are color coded. From *Carbon Dioxide Reprocessing Subsystem for Loop Closure as part of the Regenerative Life Support System ACLS*, Kappmaier et al., 2016, (https://ttu-ir.tdl.org/bitstream/handle/2346/67702/ICES_2016_391.pdf?sequence=1).

Figure 19

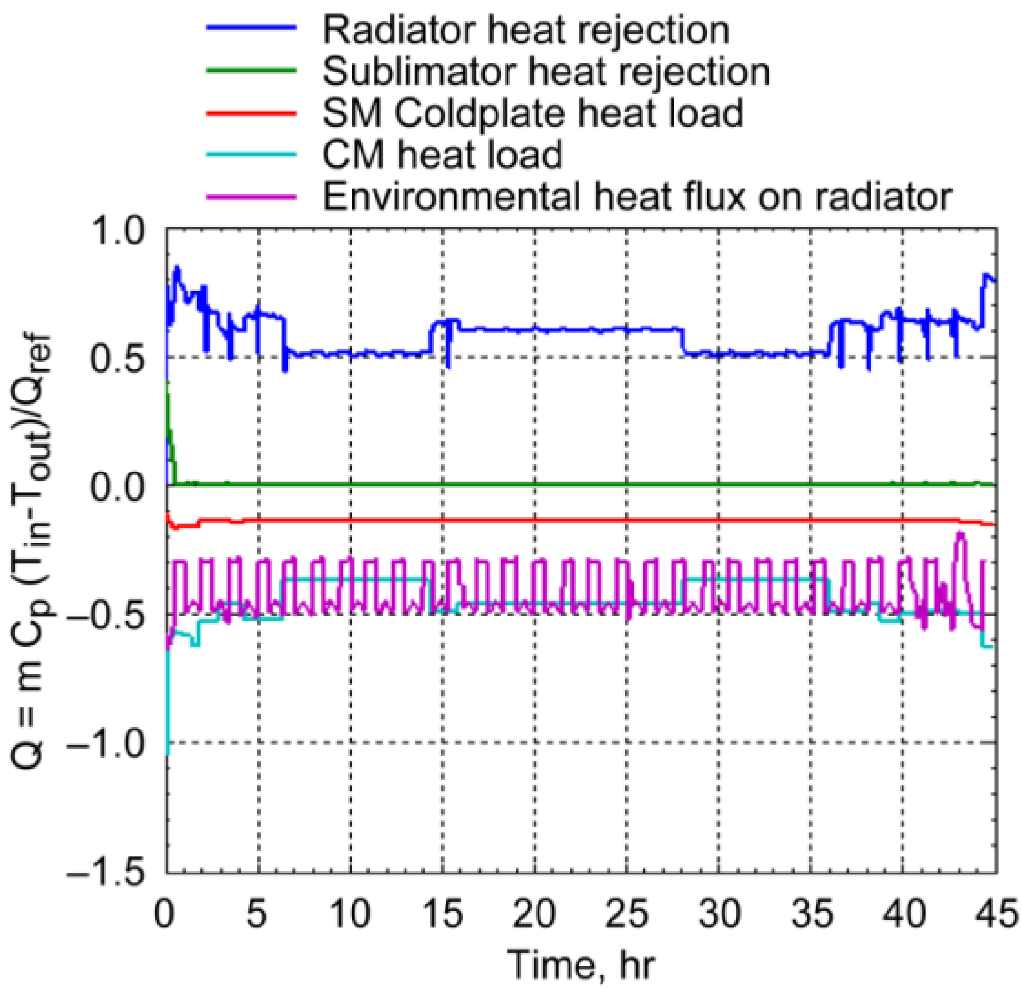
UPA (Urine Processor Assembly) Water Production Vs. Up Mass



Note. From 2008-2012 highlights the performance of the UPA to produce water vs the waste produced on the ISS. From *Status of ISS Water Management and Recovery*, Carter et al., 2012, (https://ntrs.nasa.gov/api/citations/20120015013/downloads/20120015013.pdf).

Figure 20

45-Hour Nominal Mission Timeline for ATCS (Active Thermal Control System)



Note. Q expresses Heat. Positive values represent an exothermic reaction meaning heat is released (rejection), while negative values mean an endothermic reaction where heat is absorbed (load). From *Orion Active Thermal Control System Dynamic Modeling Using Simulink/MATLAB*, Wang & Yuko et al., 2010, (https://ntrs.nasa.gov/api/citations/20100022150/downloads/20100022150.pdf).

Table 1

Polyethylene-Based Composites

MDPE/filler (% by wt)	Density (g cm⁻³)	H	B10	B11	C	N	O
1% CB_4	0.9540	8.514	0.00872	0.0349	4.2570	/	/
2% CB_4	0.9601	8.428	0.0174	0.0698	4.2358	/	/
5% CB_4	0.9787	8.170	0.0436	0.1743	4.1395	/	/
10% CB_4	1.0115	7.740	0.0872	0.3486	3.9789	/	/
15% CB_4	1.0466	7.310	0.1307	0.5113	3.8184	/	/
20% CB_4	1.0838	6.880	0.1743	0.6946	3.6578	/	/
1% GO	0.9530	8.5202	/	/	4.2986	0.00043	0.00564
2% GO	0.9577	8.4404	/	/	4.2973	0.00086	0.01128
5% GO	0.9725	8.201	/	/	4.2932	0.00215	0.02822
10% GO	0.9983	7.8002	/	/	4.2864	0.00430	0.05644
15% GO	1.0255	7.4003	/	/	4.2796	0.00645	0.08466
20% GO	1.0542	7.0004	/	/	4.2727	0.00860	0.11288
1% CNT	0.9506	8.514	/	/	4.3071	/	/
2% CNT	0.9531	8.428	/	/	4.3143	/	/
5% CNT	0.9610	8.170	/	/	4.3358	/	/
10% CNT	0.9744	7.742	/	/	4.3717	/	/
15% CNT	0.9881	7.311	/	/	4.4075	/	/
20% CNT	1.0023	6.880	/	/	4.4433	/	/

Note. Densities and atoms content for different fillers (polyethylene composites) are noted. Here, 1% GO (Graphene Oxide) with polyethylene has the highest hydrogen amount with 8.5202 g/cm^3. From *Numerical investigation of radiation shielding properties of polyethylene-based nanocomposite materials in different space environments*, by Laurenzi et al., 2020, (https://doi.org/10.1016/j.actaastro.2020.02.027).

Table 2

Pre- and post-flight BMD changes for Pre-ARED and Bisphosphonate Groups

QCT	Pre-ARED (*n* = 18)			Bisphosphonate (*n* = 7)		
	Pre	Post	Change (%)	Pre	Post	Change (%)
Trabecular vBMD (g/cm^3)						
Femoral neck**	0.137 ± 0.03	0.117 ± 0.03	−15.0 ± 9.8*	0.102 ± 0.03	0.107 ± 0.03	+6.5 ± 14.8
Trochanter**	0.148 ± 0.03	0.128 ± 0.03	−13.5 ± 6.5*	0.122 ± 0.02	0.120 ± 0.02	−1.9 ± 9.9
Total hip**	0.147 ± 0.03	0.127 ± 0.03	−13.6 ± 6.4*	0.121 ± 0.02	0.119 ± 0.02	−1.1 ± 9.8
Cortical vBMD (g/cm^3)						
Femoral neck	0.546 ± 0.05	0.523 ± 0.05	−4.0 ± 5.5*	0.479 ± 0.03	0.475 ± 0.04	−1.0 ± 4.8
Trochanter	0.558 ± 0.03	0.540 ± 0.03	−3.2 ± 3.3*	0.483 ± 0.04	0.482 ± 0.05	−0.5 ± 5.0
Total hip	0.541 ± 0.04	0.523 ± 0.03	−3.2 ± 3.5*	0.477 ± 0.03	0.474 ± 0.05	−0.6 ± 4.7
Integral vBMD (g/cm^3)						
Femoral neck**	0.363 ± 0.05	0.330 ± 0.05	−9.0 ± 6.2*	0.311 ± 0.04	0.306 ± 0.05	−1.9 ± 7.1
Trochanter**	0.333 ± 0.04	0.299 ± 0.04	−10.1 ± 6.1*	0.279 ± 0.04	0.275 ± 0.05	−1.8 ± 6.9
Total hip**	0.335 ± 0.04	0.303 ± 0.04	−9.8 ± 5.9*	0.285 ± 0.03	0.281 ± 0.04	−1.6 ± 6.4

Note. QCT Scans of different areas of the bones (Trabecular, Cortical, Integral) indicate more bone loss in the Pre-ARED group. From *Bisphosphonates as a supplement to exercise to protect bone during long-duration spaceflight*, by LeBlanc et al., 2013, (https://doi.org/10.1007/s00198-012-2243-z).

Table 3

ACLS Performance

In continuous operation ACLS -> Removes 3 kg/day of CO_2
In continuous operation ACLS -> Generates at least 2.52 kg/day of O_2
In continuous operation ACLS -> Generates at least 1.2 kg/day of liquid water

Note. Daily continuous operations for the ACLS (Advanced Closed Loop System) are listed. From *Design Status of the Advanced Closed Loop System ACLS for Accommodation on the ISS*, by Bockstahler et al., 2013, (https://doi.org/10.2514/6.2013-3450).

Table 4

Water Input & Output

	Mass flow rate, kg/crewmember-day
Water consumption	
Drinking and food preparation water	2.38
Urine flush water	0.50
Wash water	1.29
Total water	4.17
Waste water	
Respiration and perspiration condensate	2.28
Urine and flush water	2.00
Used wash water	1.29
Total waste water	5.57
UPA	
UPA input	2.00
UPA output (80%)	1.60
UPA final output (80% * 99%)	1.58
WPA without UPA	
WPA input without UPA	3.57
WPA output without UPA (99%)	3.53
WRS	
WRS input	5.57
WRS output	5.12

Note. UPA input comes from urine and flush water. WPA input comes from respiration and perspiration condensate + used wash water. From *Would Current International Space Station (ISS) Recycling Life Support Systems Save Mass on a Mars Transit?*, by Jones, 2017, (https://ntrs.nasa.gov/citations/20170007268).

Table 5

ARED Exercise Ratings

Exercise:		Statement: 1	2	3	4	5	6
Bench Press	Session 1	3.8	3.8	3.7	4.2	4.3	3.8
	Session 5	4.1	4.2	4.1	4.4	4.4	4.2
	Session 10	4.2	4.5	4.5	4.5	4.5	4.3
Bent Over Row	Session 1	3.9	4.0	3.8	4.0	4.1	3.5
	Session 5	4.4	4.4	4.2	4.3	4.5	4.2
	Session 10	4.4	4.3	4.3	4.4	4.4	4.3
Deadlift	Session 1	3.7	3.9	3.8	4.3	4.5	3.6
	Session 5	4.3	4.3	4.3	4.5	4.5	4.2
	Session 10	4.4	4.4	4.4	4.5	4.6	4.5
Heel Raise	Session 1	3.7	3.4	3.2	3.9	4.2	3.7
	Session 5	4.2	4.1	4.0	4.2	4.2	4.0
	Session 10	4.1	4.0	4.1	4.2	4.2	3.9
Single Leg Heel Raise	Session 1	4.0	3.4	3.4	4.1	4.3	3.9
	Session 5	4.4	3.8	3.6	4.1	4.3	3.9
	Session 10	4.8	4.6	4.6	4.8	4.8	4.6
Single Leg Squat	Session 1	4.0	3.6	3.6	4.2	4.4	3.8
	Session 5	4.5	4.0	4.1	4.5	4.4	4.1
	Session 10	4.6	4.4	4.4	4.4	4.6	4.3
Shoulder Press	Session 1	3.9	4.0	4.0	4.2	4.3	4.1
	Session 5	4.3	4.2	4.3	4.3	4.4	4.1
	Session 10	4.4	4.3	4.5	4.5	4.4	4.2
Shrugs	Session 1	4.1	4.0	4.0	4.3	4.4	3.9
	Session 5	4.6	4.7	4.7	4.8	4.8	4.7
	Session 10	4.8	4.8	4.5	4.8	4.8	4.8
Squat	Session 1	3.9	4.1	4.0	4.1	4.3	3.8
	Session 5	4.3	4.2	4.2	4.4	4.4	4.2
	Session 10	4.4	4.5	4.5	4.6	4.6	4.5
Straight-leg Deadlift	Session 1	4.2	4.2	4.1	4.4	4.4	4.1
	Session 5	4.4	4.4	4.4	4.5	4.5	4.2
	Session 10	4.7	4.5	4.5	4.7	4.7	4.3
Upright Row	Session 1	3.9	3.8	3.6	4.0	4.2	3.9
	Session 5	4.2	4.2	4.2	4.3	4.3	4.2
	Session 10	4.7	4.3	5.0	5.0	5.0	4.7

Note. 1-6 corresponds to each crewmember, where in each session they rated out of 5 how easy an exercise was with ARED. From *Advanced Resistive Exercise Device (ARED) Man-In-TheLoop Test (MILT)*, by National Aeronautics and Space Administration, 2006, (https://corpora.tika.apache.org/base/docs/govdocs1/892/892484.pdf).

Table 6

CEVIS Protocols for NASA's Expeditions 20-25

SIMPLE RIDE PROTOCOL		
Elapsed Time	Stage Time	% $\dot{V}O_{2max}$
3	3	55
28	25	75
31	3	55

HILL PROTOCOL		
Elapsed Time	Stage Time	% $\dot{V}O_{2max}$
4	4	60
8	4	70
12	4	80
16	4	70
20	4	60
24	4	70
28	4	80
32	4	70
36	4	60

Note. Each row corresponds to measurements taken for an astronaut. From *Physical Training for Long-Duration Spaceflight*, by Loehr et al., 2015, (https://doi.org/10.3357/amhp.ec03.2015).

Table 7

Kinematic Data for JOG in Microgravity Vs. 1 G

				95% CI	
Kinematic Variable	**Microgravity**	**1 G**	**Effect Size**	**Lower**	**Upper**
Thigh (°)	54.1 (4.9)	64.0 (3.1)	−2.25	−3.69	−0.80
Shank (°)	87.3 (4.9)	85.3 (3.1)	0.44	−0.70	1.59
Foot (°)	3.8 (4.0)	7.2 (3.6)	−0.83	−2.00	0.35
Knee (°)	33.2 (8.7)	21.3 (5.2)	1.53	0.25	2.82
Ankle (°)	6.5 (5.6)	11.9 (5.9)	−0.86	−2.04	0.32
Hip-toe vector (°)	123.2 (2.2)	124.0 (1.9)	−0.37	−1.51	0.77
Stride Time (s)	0.6 (0.0)	0.6 (0.0)			

Note. At a 95% Confidence Interval, angles for the thigh, foot, ankle, and hip-toe vector are lower in microgravity vs 1 G. From *Lower Limb Position During Treadmill Jogging and Fast Running in Microgravity*, by Everett et al., 2009, (https://doi.org/10.3357/asem.2414.2009).

Table 8

Kinematic Data for RUN in Microgravity Vs. 1 G

Kinematic Variable	Microgravity	1 G	Effect Size	95% CI	
				Lower	Upper
Thigh (°)	51.3 (3.2)	56.1 (6.1)	−0.88	−2.12	0.36
Shank (°)	89.1 (7.4)	84.8 (3.2)	0.72	−0.51	1.94
Foot (°)	−0.1 (10.8)	6.5 (6.5)	−0.70	−1.92	0.52
Knee (°)	37.9 (9.9)	28.7 (8.3)	0.92	−0.32	2.17
Ankle (°)	0.8 (7.4)	11.7 (8.2)	−1.27	−2.57	0.03
Hip-toe vector (°)	121.7 (5.6)	122.5 (7.1)	−0.11	−1.30	1.08
Stride Time (s)	0.5 (0.1)	0.5 (0.0)			

Note. At a 95% Confidence Interval, angles for the shank and knee are higher in microgravity vs 1 G. From *Lower Limb Position During Treadmill Jogging and Fast Running in Microgravity*, by Everett et al., 2009, (https://doi.org/10.3357/asem.2414.2009).

Table 9

Upright Exercise-1G vs Supine Exercise-LBNP

Parameters	Upright Exercise-1G	Supine Exercise-LBNP
Reaction force (N)		
peak	808 ± 26	981 ± 57*
mean	701 ± 24	743 ± 37
oscillatory	202 ± 25	369 ± 41*
Soleus IMP (mmHg)		
peak	103 ± 13	115 ± 10
mean	47 ± 7	55 ± 8
oscillatory	94 ± 8	103 ± 10
Leg volume increase (%)	0.4 ± 0.4	3.3 ± 0.5*
Heart rate (beats/min)	81 ± 3	99 ± 5*
Mean arterial blood pressure (mmHg)	97 ± 3	99 ± 4

Note. Increased parameters under Supine Exercise-LBMP leads to the cardiovascular system working more. From *Exercise against lower body negative pressure as a countermeasure for cardiovascular and musculoskeletal deconditioning*, by Murthy et al., 1994, (https://doi.org/10.1016/0094-5765(94)90112-0).

Table 10

CCA (CO_2 Concentration Subsystem) Levels

Date	Average CO_2 flow rate [kg/day]	Average CO_2 conc. in Lab [mmHg]*
25.04.2019	2.9	2.6
26.04.2019	3.2	2.8
27.04.2019	3.2	2.6
29.04.2019	2.9	3.0
30.04.2019	3.0	2.8

Note. Flow rate and concentration for CO_2 abord 5 days on the International Space Station are listed. From *On-orbit Testing of the Advanced Closed Loop System ACLS*, by Witt et al., 2020, (https://ttu-ir.tdl.org/bitstream/handle/2346/86479/ices-2020-510.pdf?sequence=1).

Table 11

Meal Types for American Astronauts

Meal Type	Foods/Beverages
A	Peaches, Roast Beef, Scrambled Eggs, Pancakes, Cocoa, Orange Drinks, Vitamin Pills, and Coffee
B	Pork Mix, Turkey Sausage, Bread, Bananas, Almond Crackers, and Apple Drink
C	Shrimp, Steak, Risotto, Broccoli, Cocktail, Pudding, Grape Juice, and Ice Cream

Note. General diet of American astronauts split into A, B, and C meals. From *Long-Term Space Nutrition: A Scoping Review*, Tang et al., 2021, (https://doi.org/10.3390/nu14010194).