Martian Underground Research and Development Outpost (MURADO)

2023 RASC-AL Proposal

BYU Commercial Space Club

Brigham Young University

James Subieta – President
Undergraduate Electrical Engineering

James Bleazard – Vice President
Undergraduate Physics & Astronomy

Anna Olson – Team Lead (Habitation Safety)
Undergraduate Applied Physics

Isaac Parker – Secretary
Undergraduate Mechanical Engineering

Jonny Humpherys – Habitation Safety
Undergraduate Physics

Tyler Nielsen – Team Lead (Logistics)
Undergraduate Computer Engineering

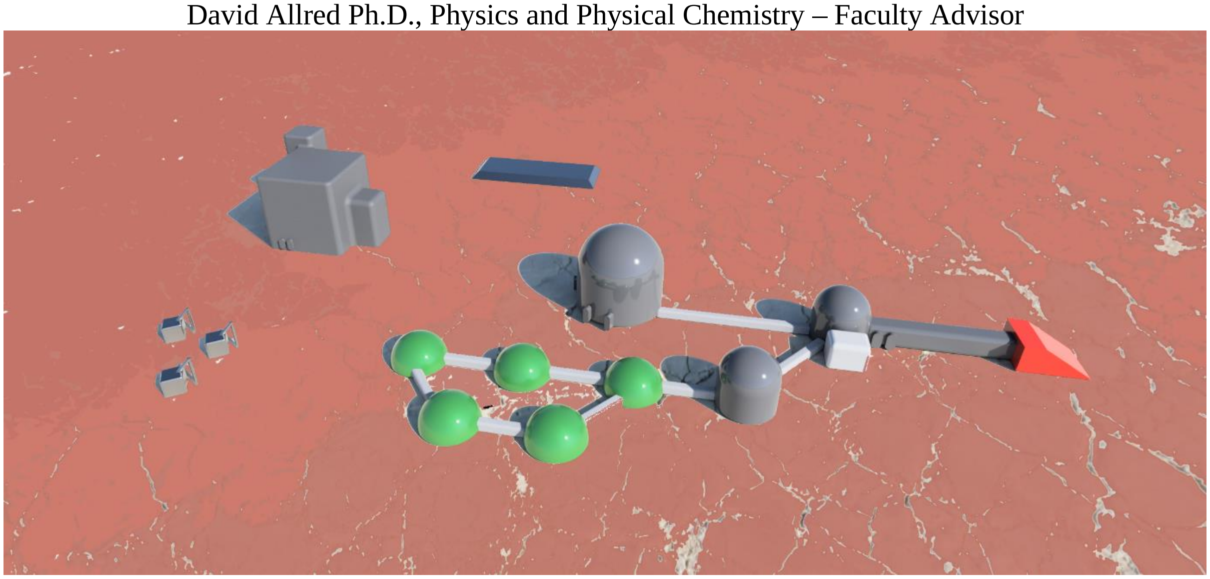
Connor McQuinn – Habitation Safety
Undergraduate Mechanical Engineering

Noah Pulsipher – Team Lead (Human Health)
Undergraduate Applied Physics

Ben Larson – Habitation Safety
Undergraduate Chemical Engineering

Tyler Perkins – Human Health
Undergraduate Electrical Engineering

David Allred Ph.D., Physics and Physical Chemistry – Faculty Advisor



Faculty Advisor Signature:

David D Allred

QUAD CHART

Brigham Young University

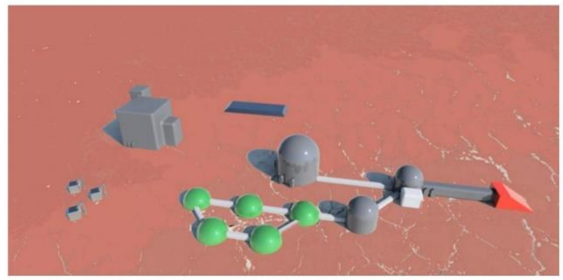
Martian Underground Research and Development Outpost

Theme: Homesteading Mars

Objectives & Technical Approach:

- Protect astronauts going to and on Mars from environmental threats
- Provide opportunities for research on Mars
- Allow for a presence on Mars over years
- Improved Communication with Mars
- Underground habitat and magnetically shielded spacecraft
- Aeroponics and Rodriguez well system

Image:



Key Design Details & Innovations:

- Mass: 568500 kg, not including 5000 kg for resupply
- Power: 333.3 kW_e during the 10 years with 3 nuclear generators
- Data Rate: Up to 48 Mbits/s transmitting to and from Mars, with extra satellites supporting data transfer
- Underground habitat for radiation protection
- Muti-use launches to decrease cost
- Use of Gateway will allow for safer travel
- Rodriguez well allows for onsite water generation
- Interplanetary craft shielded by magnetic field

Schedule:

Time	Action
5 years before launch	Spacecraft begins assembly at Gateway
2 years before launch	Initial supplies and habitat sent to Mars
Launch	Astronauts and final supplies sent to Mars
6 months after launch	Astronauts arrive at Mars and set up habitat
2 years after launch	First resupply mission arrives (of 3-5)
7-10 years after launch	Crew returns home and replacement crew arrives

Cost:

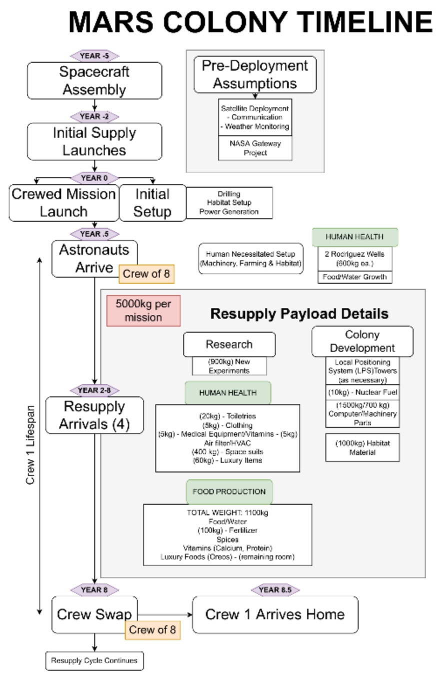
- Total budget is $31 Billion over 15 years

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS LIST

ACS	Atmosphere Control and Supply
CPJ	CO_2 Plasma Jet
CPP-HAB	Cal Poly Pomona Habitat
DPA	Dust Particle Analyzer
EDS	Electrodynamic Dust Shield
EVA	Extra Vehicle Activity
ISRU	In-Situ Resource Utilization
ISS	International Space Station
JPSS	Joint Polar Satellite System
L#	Lagrange Point #
LPS	Local Positioning System
LSS	Life Support System
MOXIE	Moxie Oxygen In-Situ Resource Utilization Experiment
MURADO	Mars Underground Research and Development Outpost
NOAA	National Oceanic and Atmospheric Administration
OCHRE	Operative Center of Human Residence and Exploration
OPEG	Oxygen Plasma Electrolysis Generator
Rodwell	Rodriguez Well
SPE	Solar Particle Events
STEREO	Solar Terrestrial Relations Observatory
STMD	Space Technology Mission Directorate
TDRS	Tracking and Data Relay Satellite
ARED	Advanced Resistive Exercise Device
COLBERT	Combined Operational Load-Bearing External Resistance Treadmill
SMD	Science Mission Directorate

INTRODUCTION



Establishing a human presence on Mars will begin with an initial homesteading mission consisting of eight astronauts being sent to Mars for seven to ten years. Starting by sending up initial, automated habitation preparation and communication infrastructure in an unmanned mission, the astronauts will arrive on Mars with equipment and begin semi-permanent habitation processes such as growing food and extracting water. Every two years the mission will be resupplied with resources they cannot produce on Mars. At the conclusion of the mission, these initial pioneers will be replaced, leaving behind established infrastructure able to reliably support the next generation of astronauts.

PHASE 0: PRE-MISSION

0.1 MAJOR ASSUMPTIONS

Many milestones will need to be reached before homesteading Mars can be attempted. One of our main assumptions is that NASA's current plans for the Gateway mission will allow for a presence on the Moon which can be used as a waystation for Martian missions. Another is that NASA maintains and improves current Deep Space Network infrastructure allowing for effective and reliable communication and signal reception. We also assume that, prior to the mission, weather satellites will have been deployed and used to create accurate models to forecast Martian weather events, particularly major dust storms.

0.2 MISSION LOCATION

The Lomonosov Crater in the Northern Hemisphere of Mars is our choice for placement of MURADO. This location is advantageous because of its high likelihood of subterrestrial ice, which is to supply the outpost with water, as well as the sheerness of the crater topography that allows the astronauts to burrow into its center mountain in order to add effective radiation shielding to the main crew habitat[1].

0.3 CREW ROLES/TRAINING

Astronauts chosen will be people with purposely different backgrounds and occupations in an effort to represent as much scientific knowledge as possible. A few specialists that are necessary include a biologist/medical professional, mechanical and electrical engineers, and pilots. All crew members would be put through mental health, compatibility, and qualification screening to ensure they work well together and all tasks can be performed effectively under high stress. These requirements will increase the likelihood that our astronauts are able to survive and thrive on the Martian surface.

PHASE 1: PRE-DEPLOYMENT

This phase consists of the movement of uncrewed supplies to Mars and the initial automated setup of the habitat, largely occurring in the Earth-to-Mars window prior to crewed launch. Any failures or malfunctions with this step will occur prior to astronaut deployment on the mission, giving plenty of time for technology to be replaced. Although such an event may push astronaut deployment back potentially to the next Earth-to-Mars launch window, it is necessary to minimize potential risk to astronaut well-being. Alongside these logistical components, this first Earth-to-Mars launch will include cargo space for non-delicate crew supplies to be stored until astronaut arrival.

1.1 COMMUNICATION SYSTEMS

To facilitate constant and quality communications with Mission Control throughout the mission, two communications satellites, like the TDRS system[2], will be deployed at Earth Lagrange points L4 and L5 prior to any launch. These satellites will utilize a similar deployment strategy to the STEREO to launch both satellites on a single rocket and then achieve stable orbits at their designated points[3]. These communication satellites will allow the MURADO Mission to have constant uninterrupted communication with Earth, circumventing the typical dead period caused by Mars passing behind the Sun and strengthening signals in both directions.

1.2 EARTH TO MARS PRE-SUPPLY LAUNCH

The main body of phase one will consist of satellites and autonomous equipment being launched directly from Earth to Mars in order to prepare several systems the astronauts will need during their stay.

1.2.1 WEATHER SATELLITES

As a part of this launch, two weather satellites will be deployed in Martian orbit. An addition to the assumed existing system, the two satellites will be solely tasked with predicting weather that may affect MURADO. Based on NOAA's JPSS system[4], they will be deployed in synchronous polar orbit, capturing live weather data which can be relayed to the astronauts on the surface as well as Mission Control.

1.2.2 LOCAL POSITIONING SYSTEM

The first deployment on Mars, an LPS, based the Locata LPS[5], will cover the area around the MURADO to aid the automated systems being deployed and later the astronauts with precise location data. Avoiding the cost and maintenance of a GPS system, this network will be deployed from orbit, using technology like Space X's self-landing boosters[6] to land at specified locations, where they will anchor into the Martian rock, becoming the towers that make up the LPS. To account for damage and potential loss of one or more tower, the system will consist of seven independent towers, allowing the system to continue to function during maintenance or damage to up to three towers.

1.2.3 UNDERGROUND EXCAVATION

While on Mars, the astronauts will require a safe shelter to protect from radiation. To achieve the most adequate radiation protection, an automated micro-tunneling drill will be sent, equipped with a method of thermal drilling,[7] enabling the automated systems to burrow into the crater's central uplift. This drill will land using reverse thrusters like the LPS and the boosters on the Falcon Heavy. This drill is powered by the nuclear power being sent alongside it and will drill approximately 30 meters into the rock face and 4 meters in diameter to allow the CPP-HAB to fit inside the tunnel.

PHASE 2: CREW DEPLOYMENT

This phase consists of the crewed launch from Earth to Mars and the life support solutions necessary to keep them healthy on the nine-month voyage. In addition, it will outline the crew landing on Mars and the completion of the habitat and other essential systems.

2.1 INTERPLANETARY VEHICLE

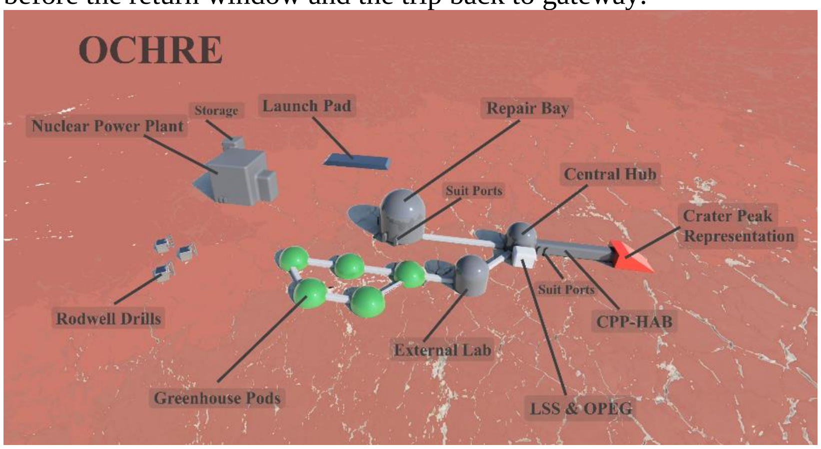
Much of the interplanetary vehicle will be based on established space stations with regards to life support and crew quarters. Like the ISS, it will be constructed in space, but in lunar orbit, using Gateway[8] station infrastructure for assembly and testing. In-space construction will allow the vehicle to forgo any aerodynamic design and allow for modifications necessary for astronaut health throughout their interplanetary voyage. The overall design of the spacecraft will consist of a ring for crew quarters connected to a central pillar carrying cargo, fuel, and the main thruster array.

2.1.1 INNOVATIVE LIFE SUPPORT SOLUTIONS

To avoid the negative effects of zero gravity on the human body, the main crew quarters of the interplanetary vehicle will be comprised of a large, solid-ring centrifuge to produce artificial gravity[9] alongside traditional crew conditioning. This will allow for astronauts to arrive on Mars with maintained bone and muscle density. To avoid the damaging exposure to radiation, the spacecraft will be equipped with an electromagnet[10] oriented in such a way as to generate an artificial magnetic field around the crew quarters ring. This magnetic field will protect from the bulk of normal space radiation. In the event of acute radiation spikes such as a SPE, the spacecraft will also be equipped with a water padded fallback zone where the astronauts will be more protected. Additionally, if the electromagnet fails, the spacecraft will have a 30 cm thick layer of polyethene[11] for some radiation protection.

2.2 CREWED LANDING

After arriving in Martian orbit, the spacecraft will be placed in Mars' L2 point for the duration of the astronaut's stay. This allows the transport to stay in the shade for better temperature control. The fuel will be kept below -423°F to remain usable throughout the mission[12]. The rest of the spacecraft will be kept around 40°F to ensure all electronics work for the astronaut's return. A lander[13] will then take the astronauts to the surface where they will assess the condition of their habitat. The lander serves as a living space for a two-week setup period for the astronauts before they either decide to return home due to habitat failure or stay on Mars. If the habitat is determined to be defective, the astronauts can return to their spacecraft, where extra food and water will maintain the astronauts for the three to four months[14] before the return window and the trip back to gateway.



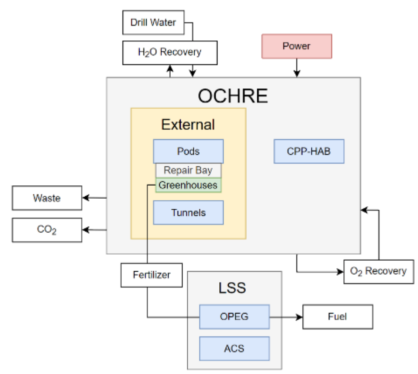


FIGURE 1 (LEFT) – MOCKUP OF OUR HABITAT DESIGN. LOCATED IN THE BOTTOM OF THE LOMONOSOV CRATER, THE TUBE TO THE FAR RIGHT REPRESENTS THE CPP-HAB AND WILL BE UNDERGROUND, INHABITING THE TUNNEL. THIS RENDITION SHOWS IT FARTHER OUT OF THE TUNNEL THAN IT WILL BE FOR VISUAL CLARITY.

FIGURE 3 (RIGHT) – HABITAT SUBSTRUCTURE

2.3 OCHRE FRAMEWORK

OCHRE consists of the interconnected network of tunnels and pods on the crater floor, along with the main astronaut habitat, called the CPP-HAB[15], that is located within the excavated crater peak.

2.3.1 CPP-HAB

Our primary Martian living space will be based on the CPP-HAB, which unfurls from a condensed state into a 4 x 30.4 x 4.5 m tunnel. The structure is lightweight, durable, and constructed from flexible materials, reinforced by rigid trusses. The CPP-HAB can withstand partial gravity, moderate radiation, and common Martian weather conditions[16]. Once set up, this will function as the astronaut's working and living quarters for the entirety of the mission.

2.3.2 PRIMARY FEATURES

One significant advantage of the CPP-HAB is its ability to remain compact during travel, deploy to its full length, and then be rolled inside the crater's excavated tunnel by one of the rovers. All necessary rooms for a crew of eight, including living quarters, laboratories, conference rooms, a kitchen, a gym, and life support will be stored in a landing pod and set up inside the tunnel by the humans upon arrival. Inflatable 10-cm-thick walls made of PVC-coated vinyl can be affixed at different locations inside the tunnel, allowing the team to customize the inside layout according to their needs. The far end (inside the tunnel) of the CPP-HAB will be sealed, while the near end (protruding from the tunnel) will be secured to an external central hub with an airlock in between; this ensures that the CPP-HAB is immune from any depressurization that may occur in the external habitat.

2.4 EXTERNAL HABITAT

Outside OCHRE, several inflatable pods will house a repair bay, secondary research laboratory, storage, and hydrogen fuel cells. Rounded cylindrical pods with half-dome ceilings will be connected by inflatable tunnels. A polyethylene-coated air bladder serves as a lightweight inner material for these structures to prevent the escape of the inside atmosphere. An outer layer, woven from sturdy materials like Vectran, mylar and/or Kevlar, protects the air bladder and restricts the inflation. Outer structural supports, such as a lightweight geodesic dome lattice and cross-beams further strengthen the designs[17].

2.4.2 LSS POD

Martian atmospheric pressure is ideal for plasma ignition within the OPEG system. A separate, unpressurized pod will house the LSS and OPEG systems. Special care must be taken to protect the system’s delicate membranes from damaging Martian dust.

2.4.3 REPAIR BAY

Located near the central hub, the repair bay is a location for construction and repairing equipment brought from outside by rovers. Four of the spacesuit ports are in the repair bay for easy access during outdoor construction and exploration. Besides the power plant, the bay is the only structure equipped with external airlocks, convenient for both human and rover use.

2.4.4 INFLATION PRECAUTIONS

Luna Lab sensors monitor stress caused by creep and micrometers to ensure that damage in the inflatable pods is noticed and addressed quickly, preventing long-duration oxygen leaks and collapse of any part of the habitat structure[18]. Internal airlocks located between the greenhouse domes and between the central hub and the CPP-HAB prevent widespread collapse in the event of a serious leak. In addition, inflatable pods will be anchored to the Martian rock to prevent movement in any extreme situations.

2.5 HABITAT SUBSYSTEMS

OCHRE relies on several subsystems to provide life support, power and temperature regulation, oxygen generation, and additional safeguards in the event of emergency. See fig. 3 to visualize the mechanisms that allow OCHRE to operate smoothly.

2.5.1 AIRLOCK

Half of the spacesuits for outside exploration will be accessible from the protruding end of the CPP-HAB near the central hub and in the repair bay. In order to prevent the entry of hazardous Martian dust into the habitat, astronauts will enter the suits through openings in the walls called suit ports. This ensures that there is no possibility of even moderate amounts of Martian dust entering the habitat airflow. However, if the astronauts need to enter or exit the habitat in another way, the repair bay will house two airlocks, one for humans and one for rovers. Further, an airlock between the CPP-HAB and the central hub serves as a final layer of security in the event of depressurization. Four of the suit ports are located on the emerging end of the CPP-HAB so astronauts can access them even if the rest of OCHRE is offline.

2.5.2 LIFE SUPPORT

Pressure, ventilation, temperature, humidity, and air quality are maintained by OCHRE’s LSS. The LSS checks the air inside the habitat for contaminants, such as any vaporous chemicals released by experiments[19]. Sensors throughout the habitat detect these contaminants and immediately notify the team of their local area. The OCHRE laboratory includes equipment astronauts use to regularly analyze air and water samples, and investigate alerts from the LSS, ensuring that contaminant levels fall within established safety zones[20]. Pressure is controlled by an improved version of the ACS subsystem currently used aboard the ISS. All portions of the habitat are pressurized to one Earth atmospheric pressure.

2.5.3 Oxygen Generation

The habitat will be fitted with an OPEG system, which uses Yttria Stabilized Zirconia non-thermal plasma reactors to break up CO_2 and other gasses in the Martian atmosphere and isolate useful products like O_2. A 6kg model running on 20 W produces up to 14 g O_2/hr using 80 kJ/g O_2, and a full-scale system would output about one hundred times more O_2 than MOXIE's predicted capacity[21]. OPEG is an ideal choice to supply OCHRE because it is compact, versatile, inexpensive, and reliable. The technology runs on renewable energy, can operate at low pressures and temperatures like those on Mars, and has the ability to stop and start operation instantaneously. Another useful feature is the system's ability to convert nitrogen gas into fertilizers and other helpful compounds such as NH_3, NH_4+, and NO, as well as rocket fuel. The system will begin operation during phase one, and reach sustainable oxygen production levels by the time the astronauts arrive during phase two.

2.5.4 Nuclear Reactor Generators

Brayton Cycle CO_2 Fission Power Generators are used both to supply power to the various electrical machines in MURADO and to provide heating for OCHRE. These reactor models are mass-optimal, and three plants generate one MW_e over a fifteen-year time span[22]. In the event of reactor failure, stored hydrogen and oxygen, intended to make rocket fuel, can be used to run hydrogen fuel cells to work as backup generators.

2.5.5 Temperature Control

Water siphoned from a Rodwell is pumped through copper pipes past the nuclear reactor and then beneath the habitat, redirecting thermal energy into the living spaces and warming OCHRE. This cools the reactor to prevent overheating and raises the temperature throughout the habitat through hydronic baseboard heater devices. Cool air is drawn into the bottom and passes over the hot pipe. Heat then flows from the heat reservoir into OCHRE's atmosphere.

2.6 ISRU OF WATER

Large quantities of water would be needed for any large-scale farming, operation of nuclear reactors, clothes laundering, rocket fuel generation, and general cleaning. Mars has a considerable presence of water located underground; the proposed landing site contains nearby underground ice which would be an ideal location for Rodwell drilling. Rodwells are used extensively in the poles and upper north and have been explored as a method to supply water to humans on Mars. While modification is necessary, the Rodwell method represents one of the best options to supply an abundant amount of water cheaply and effectively[23]. A modified Rodwell deployed on Mars with an initial investment of water for use in breaking down the ice could extract more water than the initial quantity within just a few days. Similar Rodwells in Antarctica have been used to output 2082 to 9274 liters and have operated in excess of 10 years[24].

There are still several considerations required for this implementation; this system will need to be designed fully before launch and some form of piping will be required to integrate the Rodwell's output into the Martian base itself. The specifics of this setup will likely require the astronauts themselves to perform much of the setup. Lastly, a Rodwell requires about 150kW to function, which is not more than most refrigerators. Barring considerable improvements in battery technology, this will come from the reactors themselves (alternatively, this could be supplemented using the waste heat from a reactor to act as a heat exchanger). If the Rodwells are incapable of providing water at any time, this will significantly hamper astronauts' ability to sustain all the vital processes for life on Mars. In this regard, redundancy is a mission-critical component, so several Rodwell systems and spares will be included in the shipments.

PHASE 3: LIFE ON MARS

3.1 THE RADIATIVE ENVIRONMENT

In the Lomonosov Crater, the ground consists of a thin, rocky surface above ice-rich soil. In this scenario the average effective radiation exposure is reduced by 27% compared to dry terrain due to the reduction of albedo neutron production in the ground[25]. This information, combined with MSL/RAD measurements (110-330mSv)[26], leads to an outside radiation exposure of 80mSv to 240mSv per year for solar maximum and minimum respectively. The CPP-HAB will be far enough underground that the effective radiation exposure is negligible when inside—including during SPEs. MURADO's satellites will provide SPE prediction, ensuring sufficient time for astronauts to take cover inside the CPP-HAB. Radiation exposure when outside of the habitat will be mitigated through NASA's latest generation of EVA suits. If we estimate that the astronauts will be spending ten years on Mars with 15% of their time outside, then their total radiation exposure would be between 80 mSv and 250mSv. This is under NASA's career limit of 600 mSv[27].

3.1.1 Radiation Exposure

Despite all the steps taken to reduce the amount of radiation the astronauts are exposed to; the medical team should be diligent in watching for symptoms of long-term radiation exposure. If radiation enters the astronauts' body, it is important to remove the internal contamination. Medicines such as Potassium Iodide, Prussian Blue, and DTPA (Diethylenetriamine Pentaacetate)[28] can be used to treat internal contamination. In the rare case that astronauts are exposed to very high levels of radiation over a short period of time, resulting in Acute Radiation Syndrome, medicines like Neupogen can be used to hasten red blood cell production to help the body heal.

3.2 MARTIAN DUST

Mars is blanketed in dust particles that are electrostatically charged due to grain collisions in the atmosphere and incident UV rays, meaning that the dust will attach to all exposed surfaces. The dust itself is toxic to humans and degrades materials. On Mars, NASA's DPA will provide insight into the charge size and particle diameter. Current predictions indicate particles within 1 to 3 μm in diameter and -0.1 femto-C/μm. Our equipment and habitat are coated with the EDS, a system consisting of a layer of electrodes between two dielectric layers (external thickness = 150 μm, internal = 50 μm). The electrodes independently produce out-of-phase electric fields, which exert a dielectrophoretic force on dust particles, causing them to be carried with the traveling field. Because EDS has already been successfully applied to solar panels, optical instruments, thermal radiators, and flexible materials, it serves as an ideal protectant for all exposed portions of the OCHRE habitat. Larger particles of dust may resist the force of the EDS. The CPJ relies on a simple plasma accelerator and a CO_2[29]. This technology would be extremely useful to clean the outside of the habitat where larger particles accumulate, and to remove dust from non-EDS-treated surfaces. It is also expected that some dust will enter the habitat through the airlock in the repair bay. To deal with this hazard, advanced filters on the LSS will remove the fine dust. In the case that air contaminants reach hazardous levels, the crew would evacuate to the CPP-HAB until filtration reduces dust pollutants to nominal levels.

3.3 EVA SUITS

A critical component of the Mars mission includes having the capability to perform EVAs in both space and the Martian environment. Under the assumption that one of the companies contracted with NASA will have a functioning space suit with an external port, the initial crewed mission will be provided with sixteen space suits. Two additional suits will be sent to accompanying crewed missions that will remain in orbit with the spacecraft for use in incoming and outgoing travel. The external ports will allow for astronauts to do EVAs without external contaminants entering the habitat. This will minimize human contact with toxins in Martian dust. If one suit fails, other suits can be used to perform suit maintenance.

3.4 PHYSICAL HEALTH & EXERCISE

Each candidate for the Mars missions will undergo NASA's routine vetting process for their astronauts that they send to the ISS. Candidates would also have health risks mitigated prior to leaving Earth, including receiving updated shots and appendix removal. Keeping our astronauts healthy and at peak performance necessitates that we have a reserve of general medical equipment to treat basic illnesses, and injuries. A base supply will be sent with the initial crewed mission. Within the initial missions, basic medical scanning, imaging, and blood transfusion equipment will be provided. It is especially important that the astronauts be able to measure radiation exposure.

To combat the loss of bone mass and muscle atrophy during travel to Mars and after landing, we will include equipment to provide cardiovascular and muscle stimulation like what is used currently on the ISS, specifically ARED[30] and COLBERT[31]. If these more permanent structures are unable to function, we will include a set of several small, elastic bands like those used during the Apollo missions. This set will then be used on the Martian surface. Additional crewed missions may call for an additional machine set to support traveling crews that will remain onboard the spacecraft.

3.5 MENTAL HEALTH

Astronauts will undergo the aforementioned pre-screening before being selected. Existing psychiatric disorders will probably disqualify one for the mission. A behavioral health team will monitor the astronauts throughout the duration of the mission, collecting data on heart rates, hours of sleep, performance under stress, and other behaviors[32]. They will make these measurements using medical devices aboard the habitat as well as habitat behavior monitoring systems. Astronauts are required to keep a video dialogue journal where they communicate their thoughts, feelings, emotions, and provide updates on the mission status. These journals will be reviewed by the behavioral health team. Other tasks that astronauts are required to perform include daily mental health exercises (i.e., meditation, meeting a minimum number of hours slept[33]), group therapy discussions with fellow astronauts, activities designed to relieve stress and be fun (i.e., video games, movies, reading, messages to family, virtual reality enrichment time), and science done outside the habitat[34].

3.6 RESUPPLY MISSIONS

In case of emergency, the resupply missions will include up to 400 kg of new EVA suits depending on need and 700 kg of repair materials for hardware and electronic components. The resupply will also include necessary materials for day-to-day life. These will include 5 kg of new clothes, 5 kg of medical supplies, and 20 kg of toiletries, including cleaning supplies. To help supplement on-site food production, the resupply will carry at least 1000 kg of food (with excess mass reserved for additional food), 100 kg of fertilizer, and 1000 kg of habitat supplies to facilitate more farming and experiments. The majority of this food will be products that cannot be produced on Mars. Specialty goods, such as 900 kg of new experimental equipment, 10 kg of nuclear fuel, and 60 kg of luxury goods, will also be sent. Luxury goods include items sent by astronauts' families or specific objects requested by astronauts to help with mental health. Lastly, 1500 kg will be replacement parts to repair damaged LPS towers or habitat modules.

3.7 AEROPONICS FOR FOOD SUPPLY

The production of food is a critical aspect of in-situ development and requires extensive investment and experimentation to make plant growth viable. Besides higher levels of background radiation, Martian regolith holds high perchlorates count and no organic material. This means any farming on the Martian soil would require extensive preparation and treatment. A faster and more expedient method would be a system of aeroponic farms initially to rapidly produce food inside the greenhouse pods[35]. With a crew of eight, an aeroponics farm would need to produce approximately 529 kg of food within a month to sustain the crew for another month. The greenhouse environment will house ten or eleven aeroponic systems and have a supply of minerals and water to maintain growth.

Generous deployment of food and food supplements can help fully round out astronauts' diet. An initial deployment of food reserves occasionally supplemented by future shipments can provide variety as well. Once aeroponics proves viable during testing on Earth and low-gravity lunar environments, it will be well-developed and prepared for use on Mars, greatly reducing the reliance on food shipments from Earth.

While on Mars, astronauts will experiment with another avenue for food production: growing directly out of the Martian regolith. This approach has several challenges, including detoxifying the regolith, fertilizing the ground, breaking up the regolith, and designing irrigation systems; [36] these efforts will likely take up the bulk of early experimentation but would provide additional food redundancy. Initial experiments have shown promise but require large-scale testing. Fertilizer could be supplied from both recycled astronaut waste and side products of OPEG. Should results prove successful enough, it may even allow the aeroponics system to be repurposed for other future experiments.

3.7.1 Plants and Radiation

While it is not known exactly how the radiation exposure on Mars will affect plant life, it is expected to reduce crop yields by approximately 35-45%[37], if nothing is done to mitigate exposure[38]. The greenhouse pods will provide a moderate degree of radiation shielding, and plants will be monitored throughout the growing process and before consumption to measure radiation levels. It is recommended that Duckweed[39] be utilized in the growth habitat due to its fast growth rate, protein density, micronutrient production of zeaxanthin and lutein, and ability grow in low light and high-radiation environments. Five identical domes with a radius of 3 meters will be devoted to the hydroponics and aeroponics systems. These pods are each connected and separately sealed with individual airlocks. If one of the pods becomes compromised due to micrometeorite damage, oxygen leaks, or disease, the other pods will be unaffected as isolated systems.

PHASE 4: CREW SWAP

After eight years, a new crew will arrive to relieve the astronauts. Once the new crew arrives, the previous crew will return to their spacecraft and wait for the return window to arrive. The new crew’s spacecraft will also dock at Mars’s L2 point alongside the first ship, and the original crew will take their original transport with new food and fuel back to Gateway and the Moon before returning to Earth.

TECHNOLOGY READINESS LEVELS

Technology	**TRL**	**Explanation**
Interplanetary Transport	2	Based on SLS and Orion
Micro tunnel Drill	5	Demonstrated on Earth
Lander	3	Lockheed Martin concept
LPS	6	Locata Corporation Product
Weather Satellites	9	Mars weather satellites have been flown before.
3D Printer	3	Concept in Journal of Aerospace Engineering
Artificial Gravity	4	Similar centrifuges have been deployed on Earth
Magnetic Field	3	Deemed Viable by STMD Project
Comm. satellites at L4 and L5	5	STEREO and TDRS
Rodwell	6	Used in South Pole
Inflatable Aeroponic System	4	Shown effective in lab environment
COLBERT and ARED	8	Currently Used on ISS
CPP-HAB	5	NASA built on Earth
Luna Lab Sensors	5	Prototypes built on Earth
Atmospheric Control System	7	Used on ISS
Oxygen Plasma Electrolysis Generator	4	Components shown effective in lab environment
Brayton Cycle Generators	3	Concept in Journal of Nuclear Engineering and Radiation Science
Electrodynamic Dust Shield	2	Research done by SMD

MASS AND COST ESTIMATES

Item/Category	**Mass (kg)**	**Cost ($ millions)**	**Crewed Launch**		4100
Phase 1: Pre-Deployment			Space Suits	2200	192
Communications Launch Vehicle		67	Cargo	250000	250
L4 Satellite	4000	289	**Total**	252200	4542
L5 Satellite	4000	289	**Initial Total (Phase 1 & 2)**	820700	31967
Total	8000	645	**Phase 3: Estimates Per Resupply**		
Pre-Deployment Launch		4100	Nuclear Fuel	50	1
LPS + Landers	2500	100	Food & Water	1000	
Petra Drill	50000	150	Fertilizer/Nutrients	100	
Weather Satellite 1	2500	165	Medical Equipment	100	1
Weather Satellite 2	2500	165	Toiletries/Cleaners	40	
Nuclear Reactor	30000	100	Clothes	10	
On Surface Supplies	72,000	500	Luxury Goods	100	
Total	159500	5280	New Experiments	700	10
Phase 2: Crewed Deployment			Computer Parts/ Repair Parts	1500	10
Interplanetary Vehicle		1500	Space Suits	400	30
Building Supplies	401000	20000	More Habitat	1000	100
Total	401000	21500	**Resupply Total**	**5000**	152

APPENDIX A: WORK CITED

[1] F. Costard et al., “The Lomonosov Crater Impact Event: A Possible Mega-Tsunami Source on Mars,” Journal of Geophysical Research: Planets, no. 7, pp. 1840–1851, Jul. 2019, doi: 10.1029/2019je006008.

2 H. Monaghan, “Tracking and Data Relay Satellite (TDRS) | NASA,” NASA, Jan. 05, 2023. https://www.nasa.gov/directorates/heo/scan/services/networks/tdrs_main (accessed Feb. 08, 2023).

3 “SVS: STEREO Visits the Lagrange Points - L4 and L5,” Home - NASA Scientific Visualization Studio. https://svs.gsfc.nasa.gov/3591 (accessed Feb. 08, 2023).

4 “JPSS Mission and Instruments | NESDIS,” NESDIS. https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying/joint-polar-satellite-system/jpss-mission-and (accessed Feb. 08, 2023).

5 J. Barnes, C. Rizos, J. Wang, D. Small, G. Voigt, and N. Gambale, “LocataNet: Intelligent time-synchronised psuedolite transceivers for cm-level stand-alone positioning,” Locata. http://www.locata.com/wp-content/uploads/2011/09/UNSW-Locata-Paper-Nav-World-Congress-Berlin-Oct-03a%5e.pdf (accessed Feb. 08, 2023).

6 “Falcon User’s Guide,” Spacex, Sep. 2021. https://www.spacex.com/media/falcon-users-guide-2021-09.pdf (accessed Feb. 08, 2023).

7 G. Delman, “Petra Unveils the First Tunneling Technology for Utilities to Bore Through the Hardest Rocks in the World - Mining Stock Education,” Mining Stock Education, Dec. 09, 2021. https://www.miningstockeducation.com/2021/12/petra-unveils-the-first-tunneling-technology-for-utilities-to-bore-through-the-hardest-rocks-in-the-world/ (accessed Feb. 08, 2023).

8 K. Mars, “Gateway | NASA,” NASA, Nov. 17, 2022. https://www.nasa.gov/gateway/overview (accessed Feb. 08, 2023).

9 B. Joosten, “Preliminary Assessment of Artificial Gravity Impacts to Deep-Space Vehicle Design,” Feb. 2007. https://ntrs.nasa.gov/api/citations/20070023306/downloads/20070023306.pdf (accessed Feb. 08, 2023).

10 “Spacecraft Scale Magnetospheric Protection from Galactic Cosmic Radiation,” NASA TechPort - Home. https://techport.nasa.gov/view/95569 (accessed Feb. 08, 2023).

11 L. Narici et al., “Performances of Kevlar and Polyethylene as radiation shielding on-board the International Space Station in high latitude radiation environment,” Scientific Reports, no. 1, May 2017, doi: 10.1038/s41598-017-01707-2.

12 “NASA - Liquid Hydrogen--the Fuel of Choice for Space Exploration,” NASA. https://www.nasa.gov/topics/technology/hydrogen/hydrogen_fuel_of_choice.html (accessed Feb. 22, 2023).

13 T. Cichan, S. Bailey, A. Burch, and N. Kirby, “Concept for a Crewed Lunar Lander Operating from the Lunar Orbiting Platform-Gateway,” lockheedmartin, Oct. 2018. https://www.lockheedmartin.com/content/dam/lockheed-martin/space/documents/ahead/LM-Crewed-Lunar-Lander-from-Gateway-IAC-2018-Rev1.pdf (accessed Feb. 08, 2023).

14 “How long would a trip to Mars take?,” NASA - IMAGE Science Center. https://image.gsfc.nasa.gov/poetry/venus/q2811.html#:~:text=All%20in%20all%2C%20your%20trip,is%20no%20way%20around%20this. (accessed Feb. 22, 2023).

15 “Architecture and Engineering Students Design Mars Habitat | PolyCentric,” PolyCentric | University News Center. https://polycentric.cpp.edu/2018/10/architecture-and-engineering-students-design-mars-habitat/ (accessed Mar. 06, 2023).

16 M. Fox, M. Schulitz, M. Gerschfeld, and M. Cohen, “Full Integration: Closing the Gap on Technology Readiness.” http://papers.cumincad.org/data/works/att/acadia18_98.pdf (accessed Mar. 13, 2023).

17 W. Gythiel, C. Mommeyer, T. Raymaekers, and M. Schevenels, “A Comparative Study of the Structural Performance of Different Types of Reticulated Dome Subjected to Distributed Loads,” Frontiers in Built Environment, May 2020, doi: 10.3389/fbuil.2020.00056.

18 “Innovative Sensors for Inflatable Space Habitats | Luna,” Luna. https://lunainc.com/blog/innovative-sensors-inflatable-space-habitats (accessed Mar. 06, 2023).

19 S. Jackson, “Life Support Systems | NASA,” NASA. https://www.nasa.gov/content/life-support-systems (accessed Mar. 06, 2023).

20 Guides for Short-Term Exposures of the Public to Air Pollutants, 4th ed. The Committee of Toxicology of the National Academies of Sciences, 1973.

21 V. Guerra et al., “Plasmas forin situresource utilization on Mars: Fuels, life support, and agriculture,” Journal of Applied Physics, no. 7, p. 070902, Aug. 2022, doi: 10.1063/5.0098011.

22 K. E. Harris, K. J. Schillo, Y. M. Hew, A. Kumar, and S. D. Howe, “Mass Optimization of a Supercritical CO2 Brayton Cycle Power Conversion System for a Mars Surface Fission Power Reactor,” Journal of Nuclear Engineering and Radiation Science, no. 3, May 2017, doi: 10.1115/1.4035974.

23 S. Hoffman, J. Lever, A. Andrews, and K. Watts, “Mars Rodwell Experiment Final Report,” NASA, 2022. https://ntrs.nasa.gov/api/citations/20205011353/downloads/Rodwell%20Experiment%20Final%20Report%20TP-20205011353.pdf.

24 Haehnel, R.B. and Knuth, M.A., "Potable water supply feasibility study for Summit Station, Greenland," ERDC/CRREL TR-11-4. Hanover, NH: U.S. Army Engineer Research and Development Center, 2011.

25 L. Röstel, J. Guo, S. Banjac, R. F. Wimmer-Schweingruber, and B. Heber, “Subsurface Radiation Environment of Mars and Its Implication for Shielding Protection of Future Habitats,” Journal of Geophysical Research: Planets, no. 3, Mar. 2020, doi: 10.1029/2019je006246.

26 J. Guo et al., “Radiation environment for future human exploration on the surface of Mars: the current understanding based on MSL/RAD dose measurements,” The Astronomy and Astrophysics Review, no. 1, Sep. 2021, doi: 10.1007/s00159-021-00136-5.

27 NASA SPACE FLIGHT HUMAN-SYSTEM STANDARD: VOLUME 1: CREW HEALTH, 1st ed. NASA, 2022.

28 “CDC Radiation Emergencies | Treatments for Radiation Exposure and Contamination,” Centers for Disease Control and Prevention. https://www.cdc.gov/nceh/radiation/emergencies/countermeasures.htm (accessed Mar. 05, 2023).

29 C. I. Calle, “The electrostatic environments of Mars and the Moon,” Journal of Physics: Conference Series, p. 012006, Jun. 2011, doi: 10.1088/1742-6596/301/1/012006.

30 “ARED – RESISTIVE EXERCISE IN SPACE,” Math and Science at Work. https://www.nasa.gov/pdf/553871main_AP_ST_Phys_ARED.pdf (accessed Mar. 06, 2023).

31 J. Ryba, “NASA - COLBERT Ready for Serious Exercise,” NASA, Oct. 23, 2010. https://www.nasa.gov/mission_pages/station/behindscenes/colberttreadmill.html (accessed Mar. 06, 2023).

32 E. Suni and A. Dimitriu, “Mental Health and Sleep | Sleep Foundation,” Sleep Foundation, Sep. 18, 2020. https://www.sleepfoundation.org/mental-health (accessed Mar. 05, 2023).

33 “How Sleep Deprivation Impacts Mental Health | Columbia University Department of Psychiatry,” Columbia University Department of Psychiatry, Mar. 16, 2022. https://www.columbiapsychiatry.org/news/how-sleep-deprivation-affects-your-mental-health.

34 J. Li, B. Zeng, and P. Li, “The Influence of Leisure Activity Types and Involvement Levels on Leisure Benefits in Older Adults,” Frontiers in Public Health, Jul. 2021, doi: 10.3389/fpubh.2021.659263.

35 D. Penca, “NASA - Inflatable Aeroponic System,” NASA, Jan. 27, 2010. https://www.nasa.gov/offices/ipp/centers/kennedy/success_stories/Inflatable_Aeroponic_System_BBlinds.html (accessed Mar. 06, 2023).

36 A. Heiney, “Farming in ‘Martian Gardens’ | NASA,” NASA, Aug. 06, 2017. https://www.nasa.gov/feature/farming-in-martian-gardens (accessed Mar. 06, 2023).

37 N. Tack et al., “Influence of Martian Radiation-like Conditions on the Growth of Secale cereale and Lepidium sativum,” Frontiers in Astronomy and Space Sciences, Aug. 2021, doi: 10.3389/fspas.2021.665649.

38 T. A. Mousseau and A. P. Møller, “Plants in the Light of Ionizing Radiation: What Have We Learned From Chernobyl, Fukushima, and Other ‘Hot’ Places?,” Frontiers in Plant Science, May 2020, doi: 10.3389/fpls.2020.00552.

39 “Duckweed is an incredible, radiation-fighting astronaut food – and by changing how it is grown, we made it better | Colorado Arts and Sciences Magazine | University of Colorado Boulder,” Colorado Arts and Sciences Magazine, Jul. 14, 2020. https://www.colorado.edu/asmagazine/2020/07/14/duckweed-incredible-radiation-fighting-astronaut-food-and-changing-how-it-grown-we-made (accessed Mar. 05, 2023).