Polar Life and Research Investigation Station Proposal

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Scope Summary

- **Need**: Continue manned extraterrestrial exploration and the search for foreign life while fulfilling the worldwide goal of a permanent Mars settlement.
- **Goal**: Establish a Phase-III, life-seeking outpost on Mars.
- **Objective**: Develop scientific and human-support systems of a Martian base at Planum Australe that aid in discovering signs of life.
- **Mission**: Send 30 astronauts to Planum Australe to establish a permanent Martian outpost and analyze the surrounding region for indicators of past or present lifeforms.
- **Operational Concept**: Launch 30-member crew, approach Mars, then perform a landing. Execute mining-rover tasks to gather in-situ resources, sinter regolith into building materials, and expand on preexisting frameworks of outpost structures, including living quarters. Create geochemical, biophysical, medical, and psychological facilities complete with scientific equipment. Carry out data collection and analysis through studying dry-ice and Martian-regolith samples for signs of life. Crew will exit Martian orbit using ascent vehicle, rendezvous with return spacecraft, and be brought back to Earth.
- **Assumptions**: The Spring Mars Analytical Reconnaissance Tool (SMART) mission set an Earth Return Vehicle (ERV) into orbit around Mars, determined that Planum Australe is safe for humans, and established Phase-II frameworks of structures; All technologies and funding are available.
- **Constraints**: Mission must be launched prior to 2046; Payload must not exceed rocket's weight limit; Outpost must be a 30-person, Phase-III base; Structures and equipment must resist Martian radiation and sustain landing impact; Crew must return to Earth by 2055.

Mission Statement

The Polar Life and Research Investigation Station (POLARIS) mission aims to establish a populated, permanent base on the surface of the Red Planet, with its main scientific goal being to uncover signs of Martian life through deep analysis of the body's southern polar ice cap. This aligns with the Goal I of the Mars Exploration Program Analysis Group (MEPAG): to determine if Mars ever supported life.

Mission Name

As constructing and maintaining a base on the Martian surface has many nuanced and complex aspects, it is key that the base's name provides a broad overview of its setting and goal. Through referencing the research site of Planum Australe, the goal of establishing a scientific base, and the studied topic of extraterrestrial life, the POLARIS title effectively communicates the essence of this mission concept. By alluding to the star Polaris, the name also acknowledges the long-standing goal of developing an advanced, late-phase base on Mars—an idea that has influenced many present-day missions, similar to the North Star's guiding nature (Dyches, 2021).

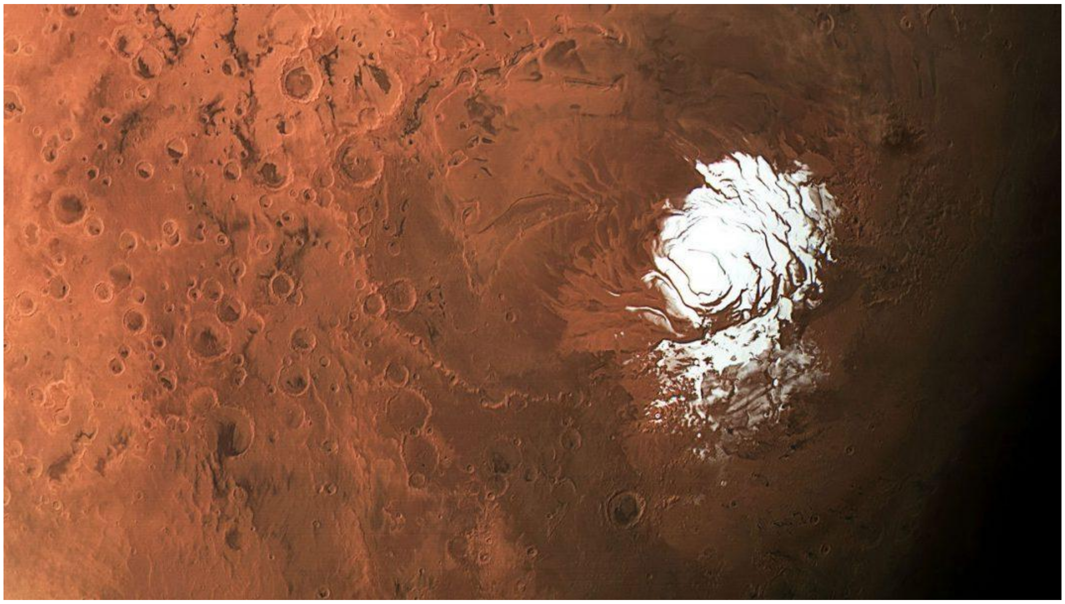
Outpost Location

As the POLARIS mission seeks to analyze and discover potential signs of life on Mars while establishing and upkeeping a Phase III outpost, the planet's southern ice cap is the most apt region to establish the scientific research facility and living quarters. Specifically, the outskirts of Planum Australe at the Martian coordinates 78.9°S 160.0°E will contain a mixture of regolith and ice, eventually allowing the crew to collect and analyze a variety of unique samples (Clery, 2018; Mateescu, 2018). This decision considers the material-rich regolith of the plane, along with its unique property of preserving ancient phenomena that could prove imperative to Martian life studies (Mateescu, 2018). The aforementioned materials include dry- and water-ice, which are available in abundance above and beneath surface-level regolith. Water is a basic requirement for life, placing further importance on this location; if organisms have existed on Mars, Planum Australe is a likely area for them to have dwelled due to this quality. Moreover, any lifeforms once present in the icy plane have great potential to be preserved in the region's cold and undisturbed conditions (Mateescu, 2018).

The water ice provided by Planum Australe will also be liquidized and purified in order to serve as suitable drinking water for the on-site crew. Upon considering the possibility of a subsurface lake beneath the plane's surface, further benefits can be seen in choosing this region for landing; pre-liquidized water will be easier to purify than its frozen counterpart. This crucial step in Martian-base independence will give way for further advancements in POLARIS's upkeep and data-collection potential, with resupply missions becoming less necessary. Furthermore, the even nature of the region's land will simplify rover-based transportation and the launch of aerial vehicles, namely the return module (Mateescu, 2018).

Figure 1

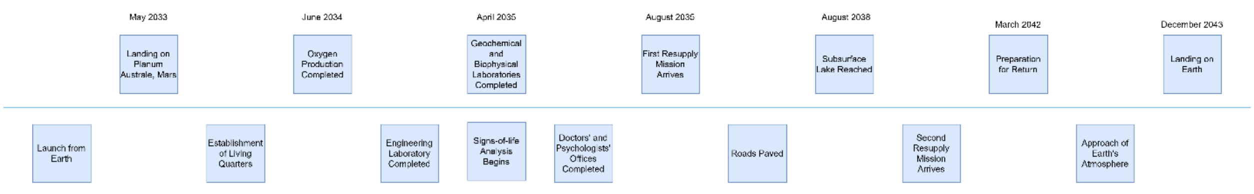
Planum Australe (Mateescu, 2018)



Mission Timeline

Figure 2

POLARIS Timeline



Launch & Landing

POLARIS plans to begin operations in August of 2032, giving all participating space organizations adequate time to prepare the necessary technologies and conduct mission-specific training prior to this launch date. After 9 months of space travel, the crew will land at Planum Australe in May of 2033, marking the start of on-site maintenance and data collection (Dobrijevic, 2022).

Base Establishment and Maintenance

Astronauts will then begin to build on the frameworks instated by the SMART precursor mission using in-situ resources (Martian regolith) and sintering technologies, with the crew-wide living quarters being fully established in March of 2034 (Drake, 2009; Warren et al., 2022). Furthermore, on-site oxygen production will begin at this time using a larger-scaled version of NASA's Mars In-Situ Resource Utilization Experiment (MOXIE) device, with the setup becoming fully operational in June of 2034 (Drake, 2009).

While building towards this advancement, other members of the crew will work to develop three major laboratories: the geochemical, biophysical, and engineering facilities. Due to the importance of structural integrity and accurate technological design within POLARIS, the engineering laboratory will be prioritized and completed earliest, in September of 2034. The geochemical and biophysical facilities will subsequently be finalized in April of 2035, allowing researchers to begin collecting samples and performing analysis. Similarly, the medical center and psychologists' offices will be created near the living quarters, with construction being finished in June of 2035.

As previously mentioned, engineers will conduct thorough, daily maintenance checks for these establishments, ensuring that all systems and structures are behaving as intended in the conditions of the Martian surface. Preexisting resource-gathering equipment, namely the Dry-Ice Gatherer (DIG) rover, along with the aforementioned sintering machines, will allow these engineers to lay the groundwork for paved roads between facilities; the process will be completed in October of 2036 (Warren et al., 2022).

The following 8 years will be dedicated to performing analysis and studying the possibility of life on Mars, most notably through piercing into a suspected subsurface lake in Planum Australe; this latter goal will be achieved in August of 2038 (Mateescu, 2018).

Resupply Missions

During this period, two additional unmanned missions will be conducted, supplying the crew with food and additional medical technologies. The first will take place in August of 2035, shortly after the doctors' quarters have been completed, while the second will arrive in November of 2040, ensuring that the crew is provided with all basic necessities before their return to Earth.

Ascent and Return

In the months following the second resupply mission, the crew will prepare for the ascent and return phase, which will begin in March of 2042. At this time, astronauts will enter the Mars Ascent Vehicle (MAV) and be launched into orbit, where the MAV will connect with the ERV placed into orbit during the SMART precursor mission (Carney, 2024). The system will then begin its journey to Earth, approaching the planet's atmosphere in December of 2043 (Dobrijevic, 2022).

Upon nearing Earth, a deorbit burn will be conducted to significantly reduce the speed of the ERV and ensure the safety of all crew members. The trajectory established earlier in the vehicle's journey will lead to the crew landing on Earth in January of 2044.

Constraints

Prior to implementing POLARIS's procedure, it is imperative to consider and abide by the constraints set by both external forces and the mission's methodology. Most notably, the launch date, number of crewmates, base phase, and time of return must be taken into account. Through understanding these constraints and carefully applying their respective solutions, all conditions for the POLARIS mission's success can be met.

Launch Date

Due to the rapid advancement of aerospace and aeronautics, interrelated missions are often required to follow one another in quick succession. A proposal cannot be postponed indefinitely, nor can it take place long after a precursing mission. As such, POLARIS is planned to launch in the year 2032, following the success of the Spring Mars Analytical Reconnaissance Tool (SMART) mission; this is long before the official constraint of 2046. By launching early, the data collected by SMART is more likely to remain applicable, ensuring that the chosen landing site is safe for human exploration and settlement. However, preparations for the POLARIS mission must also be completed earlier due to this shifted pacing. Further constraints, such as the base's phase, must be thoroughly delineated and considered prior to mission launch.

Return Date

Similar to the launch-date constriction, it is required that the crew members reach Earth prior to 2052. Failure to comply with this constraint could result in numerous health issues for the participating astronauts. As such, POLARIS's return phase will begin in 2042, with the crew reaching Earth in the following year. Through avoiding this deadline by a large margin, flexibility in the astronauts' return time may also be possible, allowing for delayed spaceflight if deemed necessary by the crew and Mission Control Center (MCC). Due to the lengthy timeframe of the POLARIS mission, crewmates will have adequate time to establish all necessary technical and scientific structures within the Martian outpost, as well as conduct experimental analysis.

Base Phase

In building upon the Phase-II base established by SMART, a Phase-III outpost will naturally be constructed during the POLARIS mission. This is in line with externally placed constraints and ensures a linear progression from one phase of Martian outpost to another. Thus, the systems developed for POLARIS will mostly consist of improvements to the previous base's structural framework; technological and scientific advances, including enhanced medical equipment and new research facilities, will be added onto the existing systems. The size of the Martian colony is another key constraint of this mission in regard to early planning.

Number of Crewmates

To keep in line with the Phase-III crew-size boundaries, which allow for 10–40 members, the POLARIS mission will consist of 30 astronauts in total. This balance ensures that earlier requirements, such as the weight limits established by the chosen rocket, are not in danger of being violated. Moreover, this number greatly affects the demographics of the colony, as well as the general division of tasks completed by the crew during POLARIS.

Crew Responsibilities

In order to reach the POLARIS mission's scientific objectives, the 30 astronauts present will be divided into four groups: engineers, geochemists, biophysicists, and healthcare professionals. This focus on STEM and medical expertise is key to the establishment of the Phase-III base, data collection and evaluation, and overall crew morale.

Engineers

Acting as the foundation of the Martian outpost, electrical, civil, and aerospace engineers will be tasked with developing and maintaining all power supplies, buildings, and rotary or aerial vehicles, respectively. Prior to mission launch, these astronauts will work closely with the engineers designing prebuilt POLARIS systems, ensuring that any on-site emergencies at the Planum Australe outpost can be solved without concern.

Furthermore, engineers will conduct routine maintenance checks daily, reporting their findings to the MCC if any issues arise. Upon discovering a contingency, these astronauts will also report the issue between one another; this is especially important when an engineer's specialty does not directly align with the problem at hand. In total, there will be 9 engineers, with three in each of the aforementioned engineering-based disciplines.

Geochemists

Day-to-day tasks for the POLARIS mission's geochemical experts include examining Martian regolith and ice samples, comparing modern data to that of previous exploration missions, and uncovering the chemical makeup of various parts of Planum Australe. If any interesting results are found within and among the wide variety of possible samples, geochemists will consult each other for accuracy in new discoveries, as well as the experimental process taken.

Specifically, data sets from the Perseverance rover will be shared with these astronauts prior to launch, allowing them to familiarize themselves with the already-known patterns in Martian surface samples (Enya et al., 2022). In doing so, anomalies within the chemical composition of certain samples will become clearer upon inspection; any meaningful discoveries found through this method will also be shared with the biophysicists. Six geochemists will be present in the crew.

Biophysicists

While the goal of POLARIS biophysicists is similar to that of the mission's geochemists, the methods by which biophysical experts search for signs of life differ from their geochemical counterparts. Most notably, biophysicists—who also make up six of the 30 crew members—will utilize the results of geochemical experiments, determining whether lifeforms could be present in the surrounding environment of Planum Australe.

For example, if a geochemist discovers a surprising chemical composition within a Martian regolith sample, biophysicists will work to ascertain the biological implications of these anomalies. Through combining their knowledge of the natural sciences, these experts will perform deep analysis on the microscopic level, eventually concluding on whether extraterrestrial life could exist and thrive in Martian conditions (Enya et al., 2022). As the Red Planet's environment is not suitable for humans, however, human-support personnel must be present to prevent both physical and psychological concerns.

Healthcare Professionals

Spending nearly a decade on a foreign planet's surface could lead to countless undesired health effects, meaning that medical and cognitive specialists are imperative to the astronauts' general safety (Barbour et al., 2024). Through providing both physical and psychological therapy to the rest of the crew, the nine healthcare professionals will ensure the welfare of the POLARIS mission's participants.

Medical Doctors

General practitioners, who comprise five of the nine specialists, will be tasked with performing routine, weekly checkups on every crewmate. Specialized equipment, present in the POLARIS's living quarters, will be utilized in determining astronauts' bone density and muscle mass to minimize the possibility of adverse low-gravity health effects (Barbour et al., 2024).

Furthermore, targeted exercises will be recommended on a patient-by-patient basis, enhancing individual wellbeing through the increased personalization of these suggestions. If an emergency occurs regarding an astronaut's psychical health, the crew's medical doctors will immediately step in to solve the issue and provide proper nursing.

Psychologists

Conversely, the crew's four psychologists will respond to any neurological or emotional needs that arise due to long-duration spaceflight and settlement on Mars. Psychologists' offices will be located in the crew-wide living quarters alongside those of the aforementioned medical personnel. These areas will be constantly available for the crew to visit and seek aid, with routine checkups being conducted fortnightly.

Similar to the general practitioners' personalized recommendations, these psychological experts will provide the crew with detailed methods of mitigating high-stress situations. Moreover, they will be responsible for suggesting alternative sleep cycles or diets according to the patient's mental-health symptoms. Through making use of both psychological and medical healthcare, the POLARIS mission's participants will be at far lower risk of neural and physical illness (Barbour et al., 2024).

Mission & System Requirements

To achieve all critical advancements during POLARIS, a key set of mission and system requirements must be carefully met. Whereas mission requirements delineate the general needs to ensure a mission's feasibility, system requirements include specific details pertaining to the technical needs of the mission, including the operational systems being implemented. Nearly every phase of the POLARIS mission necessitates these two types of requirements.

Launch

When planning to launch from Earth at the beginning of the POLARIS mission, the primary concern is the weight of the payload, given that a variety of technologies will be carried alongside human passengers. Fuel requirements must also be considered, given the extreme distance between Earth and Mars.

Mission Requirements

The crew and supplies shall safely launch and exit Earth's orbit. Moreover, they shall make a safe journey to Mars without concern for fuel or excess weight. In doing so, the POLARIS mission will remain on pace for the following phases.

System Requirements

In order to meet the above mission requirements, the rocket used shall have a weight limit above 15,000 kilograms. The rocket used shall also be capable of transporting over 10,000 kilograms to Mars within 9 months using standard RP-1 fuel and liquid oxygen (LOX) oxidizer (Dobrijevic, 2022). These technical functions are paramount to finding success in eventually landing the craft on the Martian surface.

Landing on Mars

Due to the high stakes of manned spaceflight missions, mitigating risks during the landing phase is critical to POLARIS as a whole. Failed landings can be detrimental to the crew and equipment being carried aboard the spacecraft.

Mission Requirements

The POLARIS landing module shall land softly, without damage to the astronauts or technology present onboard the craft. Furthermore, the module shall land precisely and accurately on the outskirts of Planum Australe while maintaining contact with the MCC.

System Requirements

To do this, retro rockets shall be located beneath the POLARIS landing module and activate 25 kilometers above the Martian surface (NASA Science Editorial Team, 2024). Airbags shall be located on the bottom-side corners of the landing module and be activated at this time, further cushioning the payload (NASA Science Editorial Team, 2024). Ka-band antenna, capable of communicating over 225 million kilometers, shall be utilized during landing, with two-way communication being performed between the MCC and crew (Caldwell, 2025; Dobrijevic, 2022). Through adequately following these requirements, the mission can successfully move on to its longest-duration phase: the Martian base's setup and maintenance.

Base Establishment

Upon reaching the surface of Mars, several hazardous conditions will threaten the safety of the crew and equipment within POLARIS. Anti-radiation measures, transportation, breathable air, and relative independence must all be taken into account during this mission, especially considering the permanent nature of the Martian base (Frazier, 2015; Garcia, 2016).

Mission Requirements

The crew shall be shielded from Martian radiation when out of suit and indoors. Similarly, all equipment and samples located indoors at the POLARIS shall be shielded from radiation. Mining rovers shall be capable of performing remote-controlled quarrying functions. Long-range transportation rovers shall support at least 2 astronauts whilst moving at 20 kilometers per hour (NASA, n.d.). Moreover, oxygen shall be produced without requiring external resources from Earth. In doing so, the crew will be protected in both research and regular living settings.

System Requirements

As Martian regolith is highly radiation-resistant, in-situ materials will prove to be an effective strategy for combatting the Red Planet's harsh conditions. Microwave sintering machines shall operate at 1200° Celsius to facilitate the creation of Martian-regolith bricks (Warren et al., 2022). In order to acquire these resources, Martian-Regolith Gatherer (MRG) rovers shall be equipped with 100-Watt Rotary Percussive Coring Drills (ROPEC) and 1-cubic-meter storage compartments (Chu et al., 2014; NASA, n.d.). MRG rovers shall also utilize 2 Ka-band antennas with basic control programs for remote communication and usage. Transportation rovers shall use a solar- and battery-based charging system, as well as inbuilt computer-adaptive pathfinding and communications (Caldwell, 2025). MOXIE shall be made stationary and scaled upward by a factor of 4 for constant use (NASA, 2023). All POLARIS systems shall be powered using a solar grid covering 50 square meters of land area (NASA, 2023).

Data Collection & Analysis

After forming radiation-resistant structures, astronauts can begin experimentation and analysis of Planum Australe, searching for signs of past or present Martian life. Due to the interdisciplinary nature of the crew, a variety of facilities and equipment is required.

Mission Requirements

Geochemical facilities shall contain mass spectrometers to study Martian regolith and dry-ice samples for chemical signs of life (Arevalo et al., 2023). Similarly, the biophysics laboratory shall contain fluorescence microscopes for biological signs of life (Enya et al., 2022). Storage for all studied samples shall be safeguarded from exposure to external conditions, namely radiation.

System Requirements

Laser Desorption Mass Spectrometers (LDMSs) located in the geochemical laboratory shall utilize 266-nanometer Orbitrap analyzers to maximize precision and accuracy during evaluation (Arevalo et al., 2023). In biophysical facilities, fluorescence microscopes shall be adapted to the Perseverance rover's dataset prior to analyzing new samples in order to make comparisons between previous and modern findings, allowing scientists to draw nuanced and more complete conclusions (Enya et al., 2022). By the time these conclusions are reached, it is estimated that the early preparations for the crew's return to Earth will begin.

Ascent and Return

The ascent and return of the POLARIS astronauts will be similar to the initial launch phase; however, due to the relative lack of resources available on Mars, different methods of deorbit and damage prevention will be required.

Mission Requirements

The crew and supplies shall safely launch and exit Mars's orbit using the MAV and ERV in tandem (Carney, 2024). Akin to the primary launch phase, they shall make a safe journey back to Earth without concern for fuel or excess weight.

System Requirements

The MAV shall make use of a thruster vector control system accessed by the crew and MCC, once again using Ka-band antenna, allowing for collaborative effort in the case of an emergency during the return period (Caldwell, 2025; Carney, 2024). The ERV shall be upscaled by a factor of 8 in comparison to the Earth Return Orbiter (ERO) developed by the European Space Agency (ESA), providing astronauts with the necessary space to make a comfortable journey back to Earth (ESA, 2024). Due to this increase in size, the ERV shall also utilize a methane/LOX propulsion combination, alongside both lightweight carbon-fiber reinforced polymer (CFRP) flooring and a 4-times upscaled fuel capacity (ESA, 2024; Polymer Process, 2024). After 9 months of spaceflight in the ERV, the crew will prepare for the final phase of the POLARIS mission (Dobrijevic, 2022).

Reentry and Landing on Earth

Just as landing on Planum Australe required multiple methods of damage control, safely touching onto Earth's surface will necessitate advanced techniques and technologies; the ultimate success of the POLARIS mission relies on this phase's requirements (NASA Science Editorial Team, 2024).

Mission Requirements

When nearing the Earth's atmosphere, the crew shall be protected from all heat-related damage. Upon landing, astronauts shall be safe from all potential damage from the impact.

System Requirements

To provide thermal resistance upon reentry, Avcoat-based heat shielding shall be implemented using a new, high-permeability model to prevent potential char loss (Peters, 2024). Similarly, the ERV's parachute shall be deployed 6 kilometers above sea level to reduce the craft's velocity (NASA Science Editorial Team, 2024). Following this, retro rockets housing a solid propellant of aluminum powder and ammonium perchlorate shall be activated 2 kilometers above sea level, further reducing the spacecraft's speed (Calibre, 2023).

Risk Assessment

Due to the inherent dangers associated with long-duration spaceflight and the colonization of foreign planets, identifying and discussing the risks of POLARIS is crucial to the mission's implementation. In order to complete all necessary tasks, astronauts must first be protected from a wide range of hazards. By understanding the issues of crew selection, breathable air, and Martian radiation, a fitting set of solutions can be enacted to minimize potential threats (Frazier, 2015; Garcia, 2016).

Crew Selection

As the POLARIS mission will consist of 30 members, it is key that the selection of these astronauts is geared not only towards professional abilities, but also the potential social interactions held between crewmates. Studies conducted in the *Wilderness & Environmental Magazine* in 2024 highlight the mental struggle undergone by astronauts during missions of this nature, indicating that conflicts occurring between crewmates could stunt scientific development and seriously impair the psychological environment of the crew (Barbour et al., 2024). Furthermore, conditions such as anxiety and depression are found to be more common when further from the Earth's surface (Barbour et al., 2024). When living on the Martian surface for almost one decade, POLARIS astronauts will be at great risk of contracting similar mental-health issues; mitigating flawed crew-selection will be necessary to sustain this long-term mission.

By implementing holistic reviews of applicants' skill sets, the leading agencies of the POLARIS mission can prevent social incompatibilities between the participating astronauts while remaining firm in their need for STEM expertise (Landon et al., 2017). Moreover, the usage of team-building activities can foster strong connections among the crew (Landon et al., 2017). Prior to mission launch, the social behavior of individual astronauts can be assessed in regard to the synergy they hold with their colleagues. Subsequently, any issues related to improper crew-selection methods can be eliminated at the source, with potential threats to the crew's morale being greatly reduced.

Breathable Air

In contrast to the psychological effects of improper crew selection, the Martian atmosphere poses a grave physical threat: air on the Red Planet is unbreathable (Frazier, 2015). Due to the celestial body's extremely low concentration of oxygen, any human attempting to survive without adaptive gear would last an average of only four minutes, excluding external conditions (Sanchez, 2024). Considering the prompt and rapid harm caused by a lack of breathable air, the POLARIS mission's implementation of oxygen-generation systems is critical to reducing the chances of disaster.

Specifically, utilizing in-situ resources to generate oxygen-rich environments is the only solution to prevent near-immediate asphyxiation; out-of-suit astronauts inside the Martian outpost will require these systems to survive (NASA, 2023). To ensure that breathable air does not get released or contaminated with external substances, airlocks must also be constructed for each standalone facility. When wearing a space suit, crew members must be supplied with additional oxygen to mitigate any potential harm caused by Mars's atmospheric composition. Through implementing these systems, POLARIS astronauts will be safeguarded from a majority of the issues associated with the Martian environment; however, the high levels of radiation on the planet's surface must also be taken into account.

Radiation

As Mars lacks a magnetosphere, the planet cannot effectively prevent solar winds from bringing harmful radiation to the surface (Frazier, 2015). This lack of protection poses a significant threat to astronauts of the POLARIS mission, who will be working both in and out of space suits during their stay at Planum Australe. Cancer, acute radiation syndrome, and general genetic damage threaten those who are exposed to these harsh conditions without adequate prevention measures in place (Frazier, 2015). To mitigate these issues, specific design parameters will be adhered to during the establishment of the Martian outpost.

Namely, the structures developed during the creation of the Phase-III base will be plated in sintered Martian regolith, which is effective in reducing radiation permeability (Frazier, 2015). By doing this, astronauts located indoors will be safe to remove their space suits if desired, providing additional comfort and flexibility for the POLARIS crew. Furthermore, equipment designed for outside usage will be comprised mainly of hydrogenated boron nitride nanotubes (BNNTs), a material currently being developed to combat radiation damage (Frazier, 2015).

References

Arevalo, R., Jr, Willhite, L., Bardyn, A., Ni, Z., Ray, S., Southard, A., Danell, R., Grubisic, A., Gundersen, C., Minasola, N., Yu, A., Fahey, M., Hernandez, E., Briois, C., Thirkell, L., Colin, F., & Makarov, A. (2023). Laser desorption mass spectrometry with an Orbitrap analyser for in situ astrobiology. *Nature Astronomy*, *7*(3), 359–365. https://doi.org/10.1038/s41550-022-01866-x

Barbour, B. N., Twardowska, K., Favero, N., Ghoddousi, P., & Hodkinson, P. (2024). Biopsychosocial health considerations for astronauts in long-duration spaceflight: A narrative review. *Wilderness & Environmental Medicine*. https://doi.org/10.1177/10806032241289106

Caldwell, S. (2025). *9.0 Communications*. NASA. https://www.nasa.gov/smallsat-institute/sst-soa/soa-communications/

Calibre, T. (2023, September 1). *Unveiling ammonium perchlorate in rocket fuel*. Calibre Chemicals. https://calibrechem.com/blog/ammonium-perchlorate-a-key-ingredient-in-solid-rocket-fuel/

Carney, S. (2024, April 16). Mars ascent vehicle. *NASA Science*. https://science.nasa.gov/mission/mars-sample-return/mars-ascent-vehicle/

Chu, P., Spring, J., & Zacny, K. (2014). *ROPEC – ROtary PErcussive Coring Drill for Mars Sample Return*. NASA. https://ntrs.nasa.gov/api/citations/20150004061

Dobrijevic, D. (2022, February 4). Distance to Mars: How far away is the Red Planet? *Space*. https://www.space.com/16875-how-far-away-is-mars.html

Drake, B. (2009). *Human Exploration of Mars: Design Reference Architecture 5.0*. NASA. https://www.nasa.gov/wp-content/uploads/2015/09/373665main_nasa-sp-2009-566.pdf

Dyches, P. (2021, July 28). What is the North Star and How Do You Find It? *NASA Science*. https://science.nasa.gov/solar-system/what-is-the-north-star-and-how-do-you-find-it/

Enya, K., Yoshimura, Y., Kobayashi, K., & Yamagishi, A. (2022). Extraterrestrial life signature detection microscopy: Search and analysis of cells and organics on Mars and other solar system bodies. *Space Science Reviews*, *218*(6), 1–38. https://doi.org/10.1007/s11214-022-00920-4

ESA. (2024). *Europe's Earth Return Orbiter reaches design maturity*. Europe's Earth Return Orbiter Reaches Design Maturity. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Europe_s_Earth_Return_Orbiter_reaches_design_maturity

Frazier, S. (2015, September 30). *Real Martians: How to protect astronauts from space radiation on Mars*. NASA. https://www.nasa.gov/science-research/heliophysics/real-martians-how-to-protect-astronauts-from-space-radiation-on-mars/

Garcia, M. (2016, February 25). *Crew explores breathing risks of long-term space mission*. NASA. https://www.nasa.gov/blogs/spacestation/2016/02/25/crew-explores-breathing-risks-of-long-term-space-mission/

Landon, L. B., Rokholt, C., Slack, K. J., & Pecena, Y. (2017). Selecting astronauts for long-duration exploration missions: Considerations for team performance and functioning. *REACH*, *5*, 33–56. https://doi.org/10.1016/j.reach.2017.03.002

Mateescu, R. (2018, July 26). Liquid water was discovered on Mars – evidence of A pond of water found, says European Space Agency. *Great Lakes Ledger*. https://greatlakesledger.com/2018/07/26/liquid-water-was-discovered-on-mars-evidence-of-a-pond-of-water-found-says-european-space-agency/

NASA. (n.d.). *Space exploration vehicle concept*. Retrieved March 30, 2025, from https://www.nasa.gov/wp-content/uploads/2015/08/464826main_sev_factsheet_508.pdf?emrc=0855ca

NASA. (2023, June 19). *Mars oxygen in-situ resource utilization experiment (MOXIE)*. https://www.nasa.gov/space-technology-mission-directorate/tdm/mars-oxygen-in-situ-resource-utilization-experiment-moxie/

NASA Science Editorial Team. (2024, August 6). How we land on mars. *NASA Science*. https://science.nasa.gov/planetary-science/programs/mars-exploration/mission-timeline/how-we-land-on-mars/

Peters, E. (2024, December 5). *NASA identifies cause of Artemis I Orion heat shield char loss*. NASA. https://www.nasa.gov/missions/artemis/nasa-identifies-cause-of-artemis-i-orion-heat-shield-char-loss/

Polymer Process. (2024, April 7). *Carbon fiber reinforced polymer: Advantages, uses, and properties*. Polymer Process. https://polymer-process.com/carbon-fiber-reinforced-polymer/

Sanchez, E. (2024, December 4). *How long can humans survive without air?* Scientific Origin. https://scientificorigin.com/how-long-can-humans-survive-without-air

Warren, P., Raju, N., Ebrahimi, H., Krsmanovic, M., Raghavan, S., Kapat, J., & Ghosh, R. (2022). Effect of sintering temperature on microstructure and mechanical properties of molded Martian and Lunar regolith. *Ceramics International*, *48*(23), 35825–35833. https://doi.org/10.1016/j.ceramint.2022.07.329

Appendix

Outreach Page

Figure 1

Graphic flyer