Mission Concept Review (MCR)

“CHILLY CHUMPS”

(MCA Team 09)

Cryogenic Hunters Investigating Lunar Locations Year-round - Cool Hilarious Uncharted Moon Prospectors Squad

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Table of Contents

Table of Figures

Table of Acronyms

Acronym	Definition
CDR	Critical Design Review
CNSA	China National Space Administration
ConOps	Concept of Operations
CSSL	Communication Systems Simulation Laboratory
MCR	Mission Concept Review
NASA	National Aeronautics and Space Administration
PDR	Preliminary Design Review
PSR	Permanently Shadowed Region
RTG	Radioisotope Thermoelectric Generator
SEE	Single Event Effect
SRR	System Requirements Review
STM	Science Traceability Matrix
TBD	To Be Determined
TBR	To Be Resolved
TRL	Technology Readiness Level
VIPER	Volatiles Investigating Polar Exploration Rover
WBS	Work Breakdown Structure

Mission Concept Review

1. Mission Statement

The goal of this mission is to study the composition of water-ice and other volatiles within the permanently shadowed regions of the southern pole on the moon. This is being done to measure the viability of long-term settlements on the moon that would use these resources to survive. The main resources that will be tested for will be water, hydrogen, and oxygen. The mission requires the team to collect data on several metrics of lunar water-ice behavior. Each science goal has different objectives, meaning the team will need to measure temperature, pressure, and flow rate measurements made during liquefaction and condensation; ice density, surface tension, and temperature during phase transitions of the water-ice; and the concentration and composition of water-ice in the first meter of regolith on one of the permanently shadowed regions. The data for this mission will be collected using instruments aboard a rover. Using a rover for the mission will increase the area of water-ice deposits that can be tested and allow for a wider range of the permanently shadowed region to be analyzed. Ultimately, this will allow for a breadth of data to be collected, allowing the mission to include research for the multiple aspects of the water-ice mentioned previously. By measuring the proportion and properties of water-ice at the Moon's South Pole, this mission aims to significantly advance our understanding of the Moon's formation and possible geological history, with potential for enrichment, especially drinking water, oxygen production, and fuel for future missions. This not only contributes advanced learning to scientific knowledge but also supports the long-term goal of putting man on the moon.

2. Science Traceability Matrix

Determining the presence and composition of water-ice deposits within the lunar regolith is the top priority of this mission. However, studying the ice itself presents an entirely new subset of challenges and introduces additional goals for this mission. The lunar ice-water deposits in PSRs will be studied to examine how partial-g and various particles held within the ice may affect the normal matter phases (solid, liquid, gas). Due to the majority of PSRs being unexplored, it is a goal to determine water ice abundance within the top meter of the regolith as well as other volatiles that may be found in these regions. Additionally, the effects of partial-g on the condensation of hydrogen and oxygen will also be studied during the liquefaction process. All of these goals and how they will be achieved is outlined in the Science Traceability Matrix (see *Table 1*). Accomplishing these goals will give insight into the moon's past as well as potential uses for the lunar ice in future missions and settlements.

Table 1. *Science Traceability Matrix (STM)*

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
Artemis Science Goal 6n: Study the conversion of water-ice to gaseous hydrogen and oxygen, and liquefaction of gasses for propellant storage	Investigate condensation of hydrogen and oxygen in partial-g during the liquefaction process	Identify the ideal conditions (temperature) under which hydrogen and oxygen condense	Measure gas and liquid temperatures, ambient temperature (during condensation), system pressure, partial pressures, gas and liquid density, and flow rates.	TBD-1	TBD-2	TBD-3	TBD-4	TBD-5
				TBD-1	TBD-2	TBD-3		
				TBD-1	TBD-2	TBD-3		
				TBD-1	TBD-2	TBD-3		
	Examine the influence of gravity on solid-liquid phase change of water ice including sedimentation of regolith in the liquid water.	Identify the presence of various regolith particles	Measure ice density. Measure the surface tension of liquid water and identify the boiling point of lunar water.	TBD-6	TBD-7	TBD-8	TBD-9	TBD-10
				TBD-6	TBD-7	TBD-8		
				TBD-6	TBD-7	TBD-8		
				TBD-6	TBD-7	TBD-8		

Artemis Science Goal 2a: Determine the Compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and with depth) of the volatile component in lunar polar regions.	Determine the water ice abundance of the Leibnitz Beta Plateau in or near a PSR, within the top 1 meter of regolith to at least +/- 5% accuracy	Identify the lunar regolith-to-ice ratio	Measure the average radius of the ice particulates as well as the overall shape.	TBD-11	TBD-12	TBD-13	TBD-14	TBD-15
				TBD-11	TBD-12	TBD-13		
				TBD-11	TBD-12	TBD-13		
				TBD-11	TBD-12	TBD-13		

3. Summary of Mission Location

Out of the 13 Artemis III Landing Sites (see *Fig. 2*), the Leibnitz Beta Plateau will be the mission location and landing site. Multiple factors have been considered when making this decision, such as terrain, permanently shadowed regions, illumination, and communication conditions. The topography of the Leibnitz Beta Plateau is favorable to the proposed rover mission due to its minimal slope changes, >8° [9]. The relatively flat terrain will allow the rover to move around easily and conduct scientific experiments without navigating extreme elevation changes. Along with the favorable terrain, the Leibnitz Beta Plateau is rich in permanently shadowed regions (PSRs). This is a key characteristic that was considered when choosing the mission location as PSRs are likely to host ice deposits, which is the focus of this mission. In fact, 78% of the PSR area located in the Liebnitz Beta Plateau is favorable to water-ice [14]. The chosen center for the 100m landing radius for this mission will be (-85.46°, 31.78°) due to this region covering the center of the PSR where ice deposits can be tested. A crucial third aspect that has been evaluated when choosing this location is the illumination of the selected area. The rover will use solar power as an energy source to conduct the proposed water-ice deposit experiments. Therefore, illumination of the mission location needs to be analyzed to ensure that enough sunlight can be harnessed to fulfill the needs of the rover. Although the Leibnitz Beta Plateau is a PSR-rich area, it also has areas of high illumination, partially due to its high elevation [14]. The chosen 100m radius covers both the PSR and the areas of high elevation where enough illumination is present to power solar panels. Arguably the most important consideration has been the communication conditions, specifically between the mission and Earth. A vast amount of data will be collected in this mission and due to its complexity, good communication is vital to mitigate any issues that occur over the duration of the mission and ensure success. The Leibnitz Beta Plateau is one of the best candidates for mission location when specifically considering its communicability as some areas of this region even reach maximum communication conditions of 100% (see *Fig. 1*). The Leibnitz Beta Plateau hosts reliable communication conditions along with fulfilling the mission's needs for ideal terrain, PSRs and high illumination areas, making it an ideal candidate for this mission and its experiments as seen by the data collected in the lunar south pole (see *Table 2*).

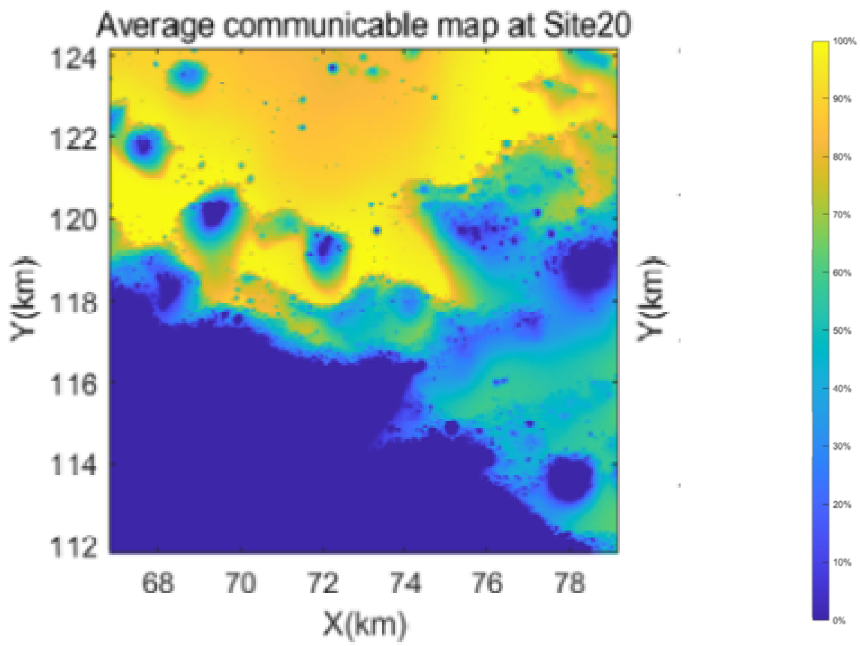

Figure 1. *Communicable Map of Leibnitz Beta Plateau* [9]

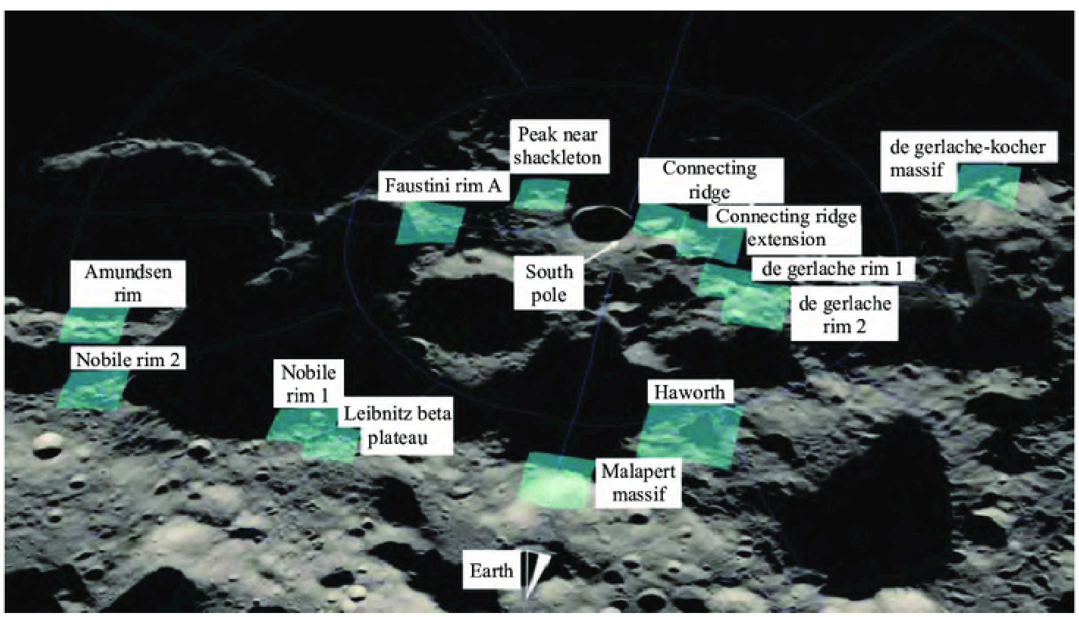

Figure 2. 13 pre-selected landing zones for the Artemis III landing mission [23]

Table 2. *Data of Leibnitz Beta Plateau with constraints of >8°, illumination >35% and communicable >40%* [9]

Location	Total Area with >8° slope (m^2)	Maximum Illumination (%)	Mean Illumination (%)	Maximum Com. (%)	Minimum Com. (%)
Leibnitz Beta Plateau	21760025	76.04	44.90	100.00	86.33

4. Mission Requirements

This mission must adhere to the customer constraints specified in the mission task document. As the vehicle is a secondary payload aboard a primary vehicle, there are mass and volume constraints that may not be exceeded by any amount. The vehicle's total mass shall not exceed 85 kg and shall not exceed a stored configuration volume of 1.5m in length, width, and height. Post-deployment, it is allowable for the vehicle to expand to a larger volume. Additionally, the total cost of the mission, including the cost of the system, salaries, travel, outreach, and other expenses, shall not exceed a total cost of $225 million. Since it is a secondary payload, launch and cruise costs are assigned to the primary payload. The vehicle must be ready for launch by September 1st, 2028 at Cape Canaveral, adjacent to the Kennedy Space Center. The customer has also imposed constraints on the science instrumentation of the vehicle. All of the mission's science objectives shall be achievable with no more than two science instruments in total. This includes duplicates and instrument suites with more than one instrument. Furthermore, the vehicle is prohibited from using a Radioisotope Thermoelectric Generator (RTG) and any derivative thereof. The total amount of allowable radioactive material is limited to a cumulative maximum mass of 5 g. If any of the customer constraints stated above are exceeded by any amount, the mission will be subject to cancellation.

The top-level mission requirements are shown below in Table 3. It outlines the top-level specifications, derived from the customer constraints and scientific traceability matrix (STM), that are necessary for a successful mission. Each requirement is uniquely identified and explained with a description and rationale. The parent requirements, requirements the specified requirement is derived from, and the child requirements, requirements derived from the specified requirement, are also shown for hierarchical and organizational purposes. In this report, most child requirements are listed as TBD and will be derived when major subsystem requirements are created. Additionally, the methods used to verify that requirements are met, the relevant subsystem, and the status of the requirements (not met/met) are also included. Currently, the status of the requirements remain blank as the mission is still in its concept phase.

Table 3. *Top Level Mission Requirements*

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
Mission Reqs							
MR-1	The vehicle shall be ready for launch by September 1st, 2028.	Provided by Mission Document.	Customer	TBD-16	Demonstration	All	Blank
MR-2	The vehicle shall launch from Cape Canaveral adjacent to the Kennedy Space Center.	Provided by Mission Document.	Customer	TBD-17	Demonstration	All	Blank
MR-3	The system shall operate within the 100 m radius landing location in Leibnitz Beta Plateau.	Provided by STM	Science Goal 2a	SYS-8 SYS-9 SYS-10	Demonstration	Payload	Blank
MR-4	The system shall measure water ice concentration within the top 1 meter of regolith to an accuracy of +/- 5%.	Provided by STM	Science Goal 2a	TBD-18	Demonstration	Payload	Blank
MR-5	The system shall investigate condensation of hydrogen and oxygen in partial-g during the liquefaction process.	Provided by STM	Science Goal 6n	TBD-19	Demonstration	Payload	Blank
MR-6	The system shall examine the influence of gravity on solid-liquid phase change of water ice including sedimentation of regolith in the liquid water.	Provided by STM	Science Goal 6n	TBD-20	Demonstration	Payload	Blank
MR-7	The system shall have a mission lifespan of TBD days.	The minimum amount of time to acquire sufficient data to satisfy the mission objectives.	MR-4 MR-5 MR-6	SYS-8	Demonstration	System	Blank
System Reqs							

SYS-1	The system shall not exceed a total mass of 85 kg.	Provided by Mission Document	Customer	TBD-21	Inspection	All	Blank
SYS-2	The system shall not exceed a volume of Length 1.5m x Width 1.5m x Height 1.5m for the stored configuration prior to deployment.	Provided by Mission Document	Customer	TBD-22	Inspection	All	Blank
SYS-3	The system shall not exceed a cost of $225M.	Provided by Mission Document	Customer	TBD-23	Inspection	All	Blank
SYS-4	Science objectives shall be achievable with no more than two science instruments.	Provided by Mission Document	Customer	TBD-24	Inspection	Payload	Blank
SYS-5	The system shall not have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof.	Provided by Mission Document	Customer	TBD-25	Inspection	Payload	Blank
SYS-6	Any radioactive material used by the system shall not exceed a cumulative mass of 5g.	Provided by Mission Document	Customer	TBD-26	Inspection	Payload	Blank
SYS-7	The system shall communicate with the primary mission orbiter for the duration of the mission lifetime (TBD).	Provided by Mission Document	Customer	TBD-27	Test	Communications	Blank
SYS-8	The system shall have sufficient power for its operation for the duration of the mission lifetime (TBD).	The system needs sufficient power in order to satisfy the mission objectives.	MR-3 MR-7	TBD-28	Test	Power	Blank
SYS-9	The system shall operate in the temperature ranges encountered in Leibnitz Beta Plateau.	The system needs to be capable of operating in extreme temperatures in order to satisfy the mission objectives.	MR-3	TBD-29	Analysis	Thermal	Blank

SYS-10	The system shall be capable of traversing the terrain in Leibnitz Beta Plateau.	The system needs to be able to traverse the terrain in order to satisfy the mission objectives.	MR-3	TBD-30	Test	Mechanical	Blank

5. Physical Environmental Hazards

5.1 Lunar Dust

Lunar dust is electrically charged which enhances its adhesive properties and it gets everywhere. It may reduce visibility on landing, cause difficulty when breathing, and contaminate equipment and specimens. Most dust has an average grain radius of approximately 70 μm, making it too fine to be seen by the human eye. About 10–20% of the dust particles have a radius smaller than 20 μm. Dust grains come in a wide range of shapes, from spherical to highly angular, though they are generally elongated. Lunar dust is characterized by low conductivity, enabling it to hold an electric charge. However, its conductivity can significantly increase with certain conditions: surface temperature, infrared (IR) light, and ultraviolet (UV) light. [1] These unique characteristics make lunar dust even stickier and a top priority for lunar exploration.

5.2 Extreme Temperature Fluctuations

The Moon experiences drastic temperature changes, with daytime temperatures reaching up to 123°C and nighttime temperatures dropping to -233°C. [27] This poses significant challenges for equipment functionality. The permanently shadowed regions (PSRs) at the lunar poles, which receive no direct sunlight, maintain consistently low temperatures year-round. This makes them ideal environments for the preservation of water ice. The primary heat sources for a permanently shadowed region (PSR) are thermal radiation and scattered sunlight, unlike non-PSR areas. This makes them extremely cold year-round, with temperatures between 25 K to 70 K; -415°F to -334°F. Because PSRs are exposed to the vacuum of space, they have the potential to hold water ice and other volatile compounds like ammonia and methane due to their extreme cold and darkness. [29] Should these deposits be verified, they could offer valuable resources to understand the origin of the moon.

5.3 Low Gravity

The Moon's gravity is about one-sixth of Earth's, which affects movement and the handling of objects. [24] Considerations must be made when designing vehicles for low-gravity environments. Wheels may have difficulty gaining traction on loose regolith due to the lower gravitational force, leading to slippage when navigating steep slopes. The lower gravity might allow for less payload because rovers need to be lightweight to carry necessary equipment. The reduced gravity might cause unexpected bouncing or hopping that must be taken into consideration. Anchoring systems may be less effective due to the lower gravitational pull.

5.4 Lack of Atmosphere

The virtual absence of an atmosphere on the Moon means there is no protection from harmful solar and cosmic radiation. Considerations must be made when designing vehicles for excursions in an atmosphere-less environment. Without an atmosphere to distribute heat, temperature regulation becomes more challenging. Temperature-sensitive equipment must be considered and thermal insulation must be prioritized. Without an atmosphere, vehicles will also be exposed to ionizing radiation. Shields must be included in the design to protect equipment.

5.5 Ionizing Radiation

Constant bombardment by solar and cosmic radiation is a major concern, requiring effective shielding and protective measures for equipment. Besides being a major health risk for biological beings and samples, radiation can also pose a challenge for vehicle design. Prolonged exposure to radiation can degrade sensitive equipment. They can destroy technology by corrupting data, causing memory errors, or even crashing systems with Single Event Effects (SEEs). [18] Radiation can affect the performance and accuracy of scientific instruments on the vehicle.

5.6 Micrometeoroid Bombardment

The Moon is continually hit by micrometeoroids, which can damage habitats, and equipment, necessitating robust protection systems. Micrometeoroids may cause structural impact damage on equipment. This can degrade or even destroy important equipment such as protective coatings, optics, and other vulnerable components.

5.7 Alien Lighting Conditions

The absence of atmospheric diffusion of sunlight creates unique lighting conditions that can disorient mission control and make it difficult to judge distances and navigate the terrain. Additionally, the low solar angle at the southern pole creates additional challenges such as long shadows and very bright conditions. [8] The darkness of the PSRs will pose a challenge as well.

5.8 Material Outgassing

Under high temperatures and vacuum conditions, organic materials such as polymeric materials can outgas. These outgassed products can degrade the performance of the system. Outgas products form a self-atmosphere and, in colder temperatures, will condense on sensitive surfaces which affect the performance of sensitive devices such as optical lenses and sensors. Additionally, vacuum insulation, used to insulate high-voltage devices, can outgas causing discharge breakdown. This can seriously affect the performance of the device and its reliability. [30]

6. System Evaluation Criteria

The primary criteria to be used in evaluating spacecraft subsystems will include performance evaluations, science objective criteria, and cost.

To ensure that the subsystems align with the mission's science objectives— (6n) the conversion of water-ice to gaseous hydrogen and oxygen, and liquefaction of gasses for propellant storage, and (2a) the compositional state (elemental, isotopic, mineralogic) and compositional distribution (lateral and with depth) of the volatile component in lunar polar regions— the qualitative evaluation criteria that will be considered will include mass, volume, pressure thresholds for science objective 6n. Additionally, budget, TRL, instrumentation requirements, and additional methods of subsystem tests will be used to evaluate and select spacecraft subsystems.

The technology maturity of spacecraft subsystems will be assessed with NASA's readiness assessment. This assessment is based on a scale of 1-9, in which an evaluation of 5 or higher is the goal. Adequacy, risk quantification, and technology issue assessment will all be part of the quantification process.

Communications subsystems will be evaluated using various models that account for system design verification, communication system performance, signal analysis, frequency management, and RF compatibility analysis. Facility access will be requested from the Communication Systems Simulation Laboratory (CSSL) for simulation performance analysis.

Thermal management subsystems will be evaluated based on their ability to maintain operational temperature ranges for all spacecraft components, considering the harsh thermal environment of space. Key criteria will include thermal control performance, material properties, energy efficiency, weight, and testing. Additional performance elevations for testing substems will also be at the component level, focusing on material and structure subsystems.

Based on mass and volume requirements for each subsystem, instrumentation requirements will be selected respectively. The total budget allocated for the spacecraft subsystems will be allocated according to the costs and schedule estimate of this MCR.

7. Concepts of Operations

The concept of operations (ConOps) for this mission task, shown below in *Table 4*, describes the procedures for a small and cost-effective robotic lunar surface reconnaissance mission. High-level goals such as spacecraft power management, instrumentation onboard the lunar spacecraft, navigation and terrain maneuverability, and data collection then transmission are addressed in this section.

First, the mission starts as the spacecraft lands on the surface and then it will get activated. For this mission, a rover was selected as the most dependable choice. The rover will also run a test and will do an initial assessment of its systems. To charge the rover, due to the fact that the primary launch vehicle only equips the rover with minimal power for transport, the rover will deploy solar panels to charge a full battery. Scientific tools will also be simultaneously deployed in efforts to start the analysis of the scientific goals, and those will begin calibration. The rover will be in a landing site that will ensure reliable communication with Earth's computers, at which this stage will be for.

After initial setup, the rover will traverse the moon's terrain and navigate between the PSR and the landing site, avoiding obstacles along the way. Finally, using scientific instruments, the rover will collect data and store them temporarily to ultimately transmit to the spacecraft orbiting around the moon. This orbiter acts as an intermediate point for data transmission before lastly transmitting back to Earth's scientists.

Table 4. *Operational phases in chronological order for the rover after landing at the landing site.*

Phase	Phase Name	Phase Description
1	Rover Activation	Rover boots up and performs a self-diagnostic test for initial setup
2	Component Deployment	Rover deploys solar panels and instruments for sample collection
3	Power Management	The rover charges to a full battery using the solar panels. Will enter low power status when the battery gets low and recharge.

4	Component Calibration	Sample collection instruments are calibrated
5	Communicate with Earth	Rover links to the orbiter around the Moon and the next steps with Earth are commanded to Rover
6	Navigate on the Moon's Terrain	Route planning is performed between PSR and the landing site
7	Sample Collection	Using scientific instruments to study the composition of volatile components and study the state of matter conversion in lunar polar regions
8	Data Storage and Transmission	Data is temporarily stored and transmitted to Earth for analysis

8. Alternative Mission Concepts

8.1. System Architecture

A rover was chosen to perform the tasks of this mission. Other vehicles such as an orbiter, lander, and hopper. Criteria of this system architecture trade study included feasibility, cost, risk, and data quality, and each vehicle was graded a score up to 3. The most important criteria were feasibility and data quality, being weighed at 30%. Feasibility is a very important criteria because it's related to the success of the mission, and data quality is important to fulfill the science goals and objectives.

The feasibility was graded based on the estimated Technology Readiness Level (TRL) for each system architecture using NASA's standard TRL definitions [13]. The orbiter was assigned a TRL 9 due to many successful lunar missions involving an orbiter, and going to the lunar south pole would not present any significant environmental change for the orbiter, meaning the TRL does not get reduced. However, there have been no surface missions to explore the permanently shadowed regions (PSRs) of the lunar south pole. Thus, a lander and rover were assigned a lower TRL, reflecting the new environment they would have to operate in. They were assigned TRL 7 and TRL 6 respectively. These are still quite high TRL scores so in terms of feasibility the rover, lander, and orbiter were given a score of 3. Since the hopper is a less mature technology, it was assigned TRL 5 and a score of 2.

Scoring the vehicles based on cost was challenging due to the widely varying costs of space missions, actual costs for our space could vary significantly from the cost of past missions. The cost of a rover mission is estimated to be nearly $195 million ($194,797,619) based on the programmatic team's budget estimate [6]. However, NASA's VIPER mission which will explore ice at the lunar south pole will have a lifecycle cost of $433.5 million [4]. Due to the high cost, the rover received a low score of 1 for the cost criteria. The lander also received a score of 1 due to CNSA's ~172 million cost of the Chang'e 4 mission [5]. The orbiter received a score of 2 due to the $72 million cost of the Lunar Trailblazer mission [18] and the hopper received a score of 3 due to the 41.6 million cost of the Micro Nova hopper [9].

For risk, the lander scored a 3 due to being a proven technology and the successful soft landing of the Chang'e 4 mission's lander in the Von Karman crater [14]. The orbiter also received a score of 3 because it was deemed to be a lower-risk mission since it avoids landing altogether. The rover received a risk of 2, indicating moderate risk due to the challenging terrain it will have to traverse. The hopper was deemed to be the highest risk, receiving a score of 1 since it's a less mature technology.

Finally, for data quality, the rover and hopper received a score of 3 due to their mobility, they can explore a larger area and gather data from multiple locations. The lander being stationary would only gather data from a single location, thus receiving a score of 1. Since the orbiter is not capable of meeting all the science goals in the Science Traceability Matrix (STM), it received a score of 0, meaning it fails to gather the necessary data for the required science.

In conclusion, the rover scored the highest based on the criteria in the system architecture trade study. This aligns with the team's initial decision to choose a rover for the mission. The hopper received a fairly high score as well due to lower cost and high data quality, but the team did not choose it due to it being a less mature technology with higher risks involved. The lander, although being a simpler mission, was not chosen since it would only be capable of gathering data from a single location. The orbiter was ruled out for scoring 0 in terms of data quality, failing to meet the science goals and objectives in the STM.

Table 5. *System architecture trade study*

System Architecture							
Criteria	**Explanation**	**Grade**	**Weight**	**Vehicle**			
				Rover	Lander	Hopper	Orbiter
Feasibility	How practical the vehicle is in the mission aspect	3 = High 1 = Low	30%	3	3	2	3
Cost	The monetary cost for each machine	3 = Least expensive 1 = Most expensive	20%	1	1	3	2
Risk	The possibilities of the multiple hazards that could be present because of the vehicle	3 = Lowest risk 1 = Highest risk	20%	2	3	1	3
Data Quality	Quality of the data that the rover will transmit to Earth	3 = High 1 = Low 0 = Fail	30%	3	1	3	0
		TOTAL	100%	80%	66.7%	76.7%	63.3%

8.2. Mission Location

When determining which of the 13 Artemis III Landing Sites will be optimal for this mission, various characteristics of each location were researched. The following criteria was used to evaluate each site: geological conditions, PSR size and quantity, illumination, and communication conditions. This criteria was used as the basis for the research because each of these factors affect the rover's ability to move, perform experiments, generate energy, and ultimately communicate the gathered data. After carefully considering each of these factors, the mission location was narrowed down to three landing sites: the Leibnitz Plateau, the Malapert Massif, and the Connecting Ridge. As mentioned previously, the Leibnitz Plateau has been finalized as the site for the mission, but both the Malapert Massif and Connecting Ridge were heavily considered during the research phase of this mission. Malapert Massif was a strong contender due to it having both large PSRs and high illumination, which is present for about 87-91% of the lunar year [2]. However, the communication conditions and terrain of the Malapert Massif were both less than favorable. The average communicable percentage at Malapert Massif is about 78.74%, which is a decrease from the Leibnitz Beta Plateau average of 86.33% [9]. Communication conditions must be favorable for this type of mission as a plethora of data needs to be collected and transmitted. The terrain of Malapert Massif could pose additional challenges to the mission because although it has some flat areas, the topography of the Massif suggests that the rover could be met with very steep slopes [25]. Due to these drawbacks, the Malapert Massif was ruled out when deciding on the mission location. When looking at the PSR-rich Connecting Ridge, the terrain seemed to be favorable and it provided the highest illumination out of the three sites [9]. However, the key issue with this location is its poor communication conditions. In fact, the communication conditions had ~52.53% uptime, which is concerning due to the vitality of information transmission [9]. For this reason, Connecting Ridge was also eliminated and the Leibnitz Plateau was chosen as the mission location.

9. Programmatics

9.1. Team Organization

Workload Delegation and Team Structure - Team 9's workload will be distributed based on the sub-team each member belongs to, focusing on their specific area of work. The team consists of 14 people divided into three sub-teams: Programmatics, Science, and Engineering. The delegation of work between teams and members of each team will be determined as a group led by the project manager. Within the subteams, the sub-team leaders, chief scientist, deputy project manager, and lead systems engineer, will discuss with the sub-team to delegate workload.

Programmatics: This is the main management team responsible for overseeing the schedule, cost, and outreach of the mission. They will handle tasks related to the mission's timeline and budget. Additionally, they will communicate with the Project Manager and the other sub-teams.

Science: Led by the Chief Scientist, this team handles research and analysis tasks. Responsibilities include researching mission requirements, selecting necessary instruments, and analyzing related data. Tasks should be evenly distributed among team members.

Engineering: This team is in charge of mission design, problem-solving, and documenting the design process. Their tasks include conducting first-order analysis to meet technical requirements, developing solution plans based on research, designing prototypes for science instruments, creating CAD models, and tracking budgets and milestones. They will report to the Lead Systems Engineer.

Team Preparedness and Support - If a team member feels unprepared for an assigned task, they are encouraged to ask for assistance. Each member should contribute as much time as possible to their tasks. If someone cannot complete their task, other team members should be ready to help. Otherwise, doing research in order to complete the task may be necessary.

Handling Differences in Opinion - When differences in opinion or ideas arise, the team will handle them through open discussion, ensuring that all viewpoints are heard and considered. Ultimately, it will come to either a team vote, a decision made by the sub-team leader, or a decision made by the project manager, depending on the scope of the issue/disagreement.

Time Commitment - Each role will require different time requirements, however an amount of time required to complete all work assigned to each person as well as roughly 3 hours a week for team meetings is required. However, some roles will require extra time. These are mainly the leadership roles of chief scientists, deputy project manager of resources, lead systems engineer, and the project manager. As these are management roles, extra time is necessary to complete the assigned task as well as the other tasks required from these leadership roles.

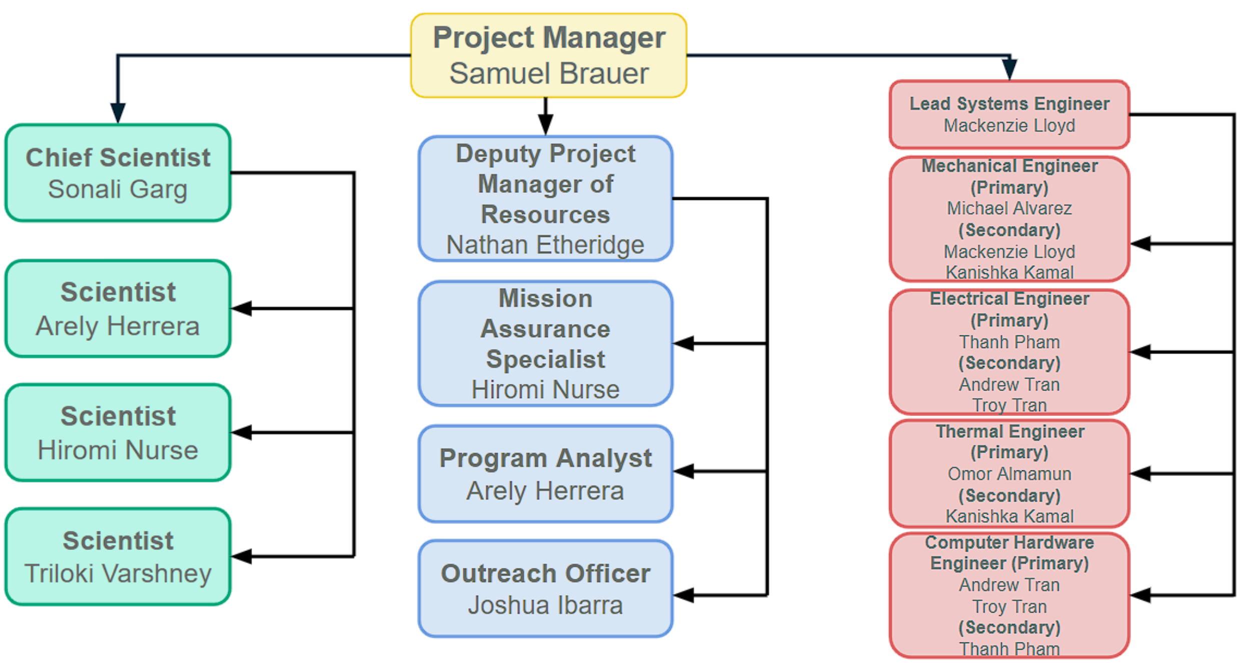

Figure 3. *Hierarchy of project team*

9.2. Cost and Schedule Estimate

Team 9's mission vehicle is scheduled for a launch by September 1st, 2028 from Cape Canaveral adjacent to the Kennedy Space Center. To meet this requirement and have the vehicle fully tested and prepared by the desired time, the schedule estimate in Table 6 consists of phases in which the mentioned tasks need to be completed for the mission vehicle to be fully prepared by the day of launch.

Table 6. *Schedule Estimate*

ID#	Task	Weeks[1]
1	Initial Construction and Software Development	100
2	Endurance/Environmental Testing	32
3	Test Launch and Validation	21
4	Launch Preparation and Travel	10
5	Launch	1
6	Lunar Exploration and Travel	20
7	Return and Analysis	40

The description of each of these tasks is provided below and listed in order of ID #:

1. Initial Construction and Software Development: Aligns with Phase C of the NASA Mission Life Cycle Timeline. This phase begins after the presentation of the team's PDR on the date of August 25, 2024. Includes the construction of the final design of the vehicle and the development of drivers and other software needed to ensure the efficient running of the vehicle. This task is allocated the greatest amount of time as it spans from the initial manufacturing of the mission vehicle for Team 9 to the completed hardware and software of the mission vehicle for later testing including major tasks such as the CDR.
2. Endurance/Environmental Testing: Aligns with Phase C-D of the NASA Mission Life Cycle Timeline. This task is designed to test the mission vehicle against the simulated harsh conditions of the lunar landing sight to ensure stability in the harsh conditions of the Moon.
3. Test Launch and Validation: Aligns with Phase D of the NASA Mission Life Cycle Timeline. This task is designed to test a simulated launch day experiment to analyze how the mission vehicle handles the launch and weather conditions of Cape Canaveral and validate its upcoming final launch.

4. Launch Preparation and Travel: Aligns with Phase D of the NASA Mission Life Cycle Timeline. This task prepares the mission vehicle for launch in Cape Canaveral and includes the transport of important materials and personnel to the landing site for validation and later launch viewing.
5. Launch: Aligns with Phase D of the NASA Mission Life Cycle Timeline. This phase includes the final launch of the vehicle from Cape Canaveral on September 1, 2028, and the analysis of the mission as it departs to the Moon after launch.
6. Lunar Exploration and Travel: Aligns with Phase E-F of the NASA Mission Life Cycle Timeline. The mission vehicle is expected to land in the selected landing spot approximately 3-4 days after launch by September 5, 2028. This phase monitors the mission vehicle while it is performing its mission task on the surface of the moon while also ensuring proper operation and sustainment of the vehicle for the duration of the mission period.
7. Return and Analysis: Aligns with Phase F of the NASA Mission Life Cycle Timeline. This phase includes the return and retrieval of data from the mission for the team to analyze and draw conclusions from.

With the current plan of the mission, the rough cost estimate of the Lunar Rover post-PDR and all of the required attachments can be split into its relevant phases and tasks according to the WBS and analyzed within *Table 7*.

Table 7. *Simple Cost Estimate of Mission by Phases* [34]

Mission Phase	**Phase C**	**Phase C-D**	**Phase D**	**Phase E-F**	**Phase F**	**Cumulative Total**
Year	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 4**	
Personnel Costs	$2,080,000	$2,134,090	$2,188,160	$2,242,240	$2,296,329	$10,940,819
Travel Costs[2]	-	$103,550	$517,750	$517,750	$517,750	$1,656,800
Mechanical Costs	$20,200,000	$10,100,000	$10,100,000	$15,400,000	-	$55,800,000
Electronic Costs	$14,500,000	$12,900,000	$20,100,000	$12,900,000	$12,900,000	$73,300,000
Operation Costs	-	-	-	$20,100,000	$33,000,000	$53,100,000
Phase Total	$36,180,000	$24,518,480	$31,777,670	$50,016,150	$47,554,630	$194,797,619

The description of each field of expense is listed below:

1. Personnel Costs: This field of expenses assumes a team of roughly 29 to 31 members throughout the duration of the project. The theorized team includes 7 Science Personnel, 10 Engineering Personnel, 7-10 Technicians, 4

Administration Personnel, and 1-2 Management Personnel. All costs associated with team personnel are based on the recommended salaries given by the Mission Task Document.

2. Travel Costs: This field of expenses encompasses the total travel costs of the entire team assuming a size of 29 members for both launch testing in Cape Canaveral and the final launch from Cape Canaveral on September 1, 2028. These costs utilize the US General Service Admissions FY 2023 Per Diem Rates for Cape Canaveral and include food, housing, and transportation costs for a 5-day trip for each member.[32] This field also includes the travel of team leads in Phase C-D to present data to NASA headquarters in Cape Canaveral or other miscellaneous tasks that require travel costs.
3. Mechanical Costs: This field of costs includes the price of mechanical manufacturing, development, and testing for the mission vehicle assuming the final design is used from the presented PDR. The estimate for this cost is based on the NASA VIPER Lunar Discovery mission which had similar requirements and parameters to the mission currently being undertaken.[33]
4. Electronic Costs: This field includes the cost of electrical manufacturing, development, and testing of instruments for the mission vehicle assuming the final design is used from the presented PDR. The estimate for this cost is based on the NASA VIPER Lunar Discovery mission which had similar requirements and parameters to the mission currently being undertaken.[33]
5. Operation Costs: This field includes the costs of operating the rover during launch and lunar exploration which is handled primarily by the technicians and engineering team during phases E-F. The estimate for this cost is based on the NASA VIPER Lunar Discovery mission which had similar requirements and parameters to the mission currently being undertaken.[33]

Using this rough estimation, the mission's total falls within the required limit of $225 Million considering all aspects of work on the mission. This estimation also considers that the aforementioned schedule is followed and the mission is completed efficiently and within the required time frame for launch in 2028.

10. Conclusion

The goal of the 14-member multidisciplinary group "CHILLY CHUMPS" is to investigate the characteristics of the water ice in the permanently shadowed area of the Lunar South Pole in order to learn more about the origins of the moon and possible resource opportunities for future human long-term settlements on the moon. The mission entails studying the temperature, pressure, density, and gravity of the water ice using a rover, which is currently the most suitable approach. The Leibnitz Beta Plateau has been selected as the landing site due to its advantageous topography, substantial water-ice volume, and dependable communication conditions. In a setting of financial and technical limitations, the mission also discusses an overview of the concept of operation and obstacles, such as lunar dust, extreme temperature fluctuations, and low gravity.

The next task for the team is to collaborate on creating the instrument performance specifications needed to accomplish the first research aim, which is to look at how hydrogen and oxygen condense in partial gas during the liquefaction process. Moreover, we will use the Science Traceability Matrix (STM) as a guide to do several studies on anticipated instrument performance, equipment needs, and mission requirements of the research objectives. Most of the team's time was being spent arranging, and everyone was adjusting to the new routine. We did not have much time to polish the study on certain mission requirements because the Mission Concept Review (MCR) was quickly approaching, thus additional research was put off until later. We would provide a more thorough version of the Top Level Mission Requirements Table if we had more time. In addition, the team will keep working on the System Requirements Review (SRR), which is the upcoming deliverable. To finish the SRR on schedule and with the best possible quality, the team will promptly schedule critical meetings and divide the work according to each person's responsibilities.

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Appendix

Appendix A. *Table of TBD/TBRs*

TBD / TBR #	Plans and Timeline for Resolution
TBD-01	Instrument Performance Requirements will be determined once the Instruments are finalized.
TBD-02	Instrument Performance Requirements will be determined once the Instruments are finalized.
TBD-03	Predicted Instrument Performance will be determined once the Instruments are finalized.
TBD-04	Instruments will be finalized once more research is conducted to determine the type of data that needs to be collected for each goal.
TBD-05	Mission Requirements will be finalized once Instruments are finalized.
TBD-06	Instrument Performance Requirements will be determined once the Instruments are finalized.
TBD-07	Instrument Performance Requirements will be determined once the Instruments are finalized.
TBD-08	Predicted Instrument Performance will be determined once the Instruments are finalized.
TBD-09	Instruments will be finalized once more research is conducted to determine the type of data that needs to be collected for each goal.
TBD-10	Mission Requirements will be finalized once Instruments are finalized.
TBD-11	Instrument Performance Requirements will be determined once the Instruments are finalized.
TBD-12	Instrument Performance Requirements will be determined once the Instruments are finalized.

TBD-13	Predicted Instrument Performance will be determined once the Instruments are finalized.
TBD-14	Instruments will be finalized once more research is conducted to determine the type of data that needs to be collected for each goal.
TBD-15	Mission Requirements will be finalized once Instruments are finalized.
TBD-16	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-17	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-18	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-19	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-20	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-21	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-22	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-23	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-24	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-25	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-26	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the

	next deliverable.
TBD-27	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-28	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-29	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.
TBD-30	Child requirements will be derived when major subsystem requirements, for Mechanical, Power, Thermal, CDH, and Payload, are created for the next deliverable.