Mission Concept Review - Team 27

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Table of Acronyms

Abbreviation	Definition
CC	*Customer Constraints* 7
SCI	*Science* 7
SC	*Spacecraft* 7
SPRT	*Standard Platinum Resistance Thermometer*. .11

1. Mission Concept Overview

1.1. Mission Statement

Through past and current lunar exploration, it has been found that the Earth's Moon had volcanic activity about 3.8 to 3 billion years ago.[1] During volcanic eruptions, magma would reach the surface and, while subjected to the lower surface temperatures, began to harden into a crust layer. During this process, the magma carried on flowing under the surface, and tubes were formed. As the eruptions subsided, the magma would eventually exit the subsurface entirely and leave hollowed lava tubes. Throughout the years the Moon's surface experienced impacts from micrometeorites hitting the surface, which created a number of lunar pits and caves that can allow entry into the lava tubes. Current data suggests that lunar pits and caves can protect humans and equipment from extreme fluctuations in temperature and radiation, which would allow long-term habitation of humans for future exploration on the moon.[2]

This mission aims to determine if the Mare Ingenii lunar pit is a viable option for sustained human presence on the Moon. The first science goal is to define the scientific activities that the astronauts will conduct on the Moon. Astronauts will collect data from tests that will define the temperature needed to extract a 10% yield of oxygen from the lunar regolith, define the strength and direction of magnetic fields correlated with lunar swirls, and identify the amount of radiation present in order to determine the radiation's effects on the microclimate of the lunar pit. The second science goal is to determine the safety of lunar pits and caves for prolonged human habitation. Data will be collected on the characteristics within the Mare Ingenii lunar pit in order to define the depth, height, variations in terrain, and entry access. The structural integrity will be determined by sourcing the thickness and structural data acquired from muon imaging. By using one spacecraft, the data collected can be used to provide a better understanding of how the current solar system and planets formed and a better solar system and planet formation timeline.

1.2. Science Traceability Matrix

The science objectives for the mission are split between two main goals, which are listed below:

i) Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon.[3]

ii) Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure.[4]

[1] Heng-Ci Tian et al., "Surges in volcanic activity on the Moon about two billion years ago," Nature Communications 14 (2023). `https://doi.org/10.1038/s41467-023-39418-0`.

[2] Raymond P. Martin and Haym Benaroya, "Pressurized lunar lava tubes for habitation," Acta Astronautica 204 (2023): 157-174, `https://doi.org/10.1016/j.actaastro.2022.12.013`.

[3] Committee on the Planetary Science and Astrobiology Decadal Survey et al., Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (Washington, D.C.: National Academies Press, 2023), `https://doi.org/10.17226/26522`.

[4] Lunar Exploration Analysis Group (LEAG), "The Lunar Exploration Roadmap: Exploring the Moon in the 21st

Below, Figure 1 shows the Science Traceability Matrix of the mission.

Science Goals	Science Objectives	Science Measurement Requirements	
		Physical Parameters	Observables
"Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon" - Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032	Determine if 10% of oxygen (O2) can be pulled from regolith in lunar conditions.	Define the amount of heat needed on the lunar surface for regolith to be heated to the correct temperature to produce a 10% yield of oxygen.	Obs. 1
	Determine the location of any potential surface magnetic fields within and around the Mare Ingenii lunar pit, specifically those correlated with lunar swirls.	Identify the magnitude and direction of magnetic fields present in a range of 15km.	Detect magnetic fields in the 0-5000nT range over an area of 10km.
	Determine the effect of radiation on temperature, humidity, and pressure within lunar pits to determine if they can sustain human life.	Identifty the percentages of Alpha, Beta, and Gamma radiation within and surrounding the Mare Ingenii pit in a 10km area.	Obs. 3
"Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure" - (Lunar Exploration Analysis Group (LEAG) Habitation: HAB-SAT Report, Priority Objectives	Characterize the depth, height, terrain variation, and ease of access within lunar pits/caves to determine the viability of human habitation.	Define the characteristics of the Mare Ingenii pit within a vertical distance of 55m and a diameter of 180m.	Obs. 1
	Determine the structural integrity within the Mare Ingenii lunar pit to determine if it can support human life.	Define the thickness and structure of the Mare Ingenii pit utilizing the flux of muons.	

Figure 1: The Science Traceability Matrix of the mission.

Beneath the first goal, the first objective is to determine if 10% of oxygen (O2) can be pulled from the regolith in lunar conditions. As noted in the Lunar Exploration roadmap, a primary goal of lunar missions is to establish a permanent human presence on the moon. This means that to avoid commuting supplies back and forth between the Earth and the Moon, necessary supplies for human life must be created on the Moon. This includes oxygen, which has been found to be able to be drawn from lunar regolith via using extreme amounts of heat.[5]

The second objective is to determine the location of any potential surface magnetic fields within and around the Mare Ingenii lunar pit, specifically those correlated with lunar swirls. The measuring of the Moon's magnetic fields can be useful in determining the formation of the Moon as well as its composition. As the Planetary Decadal Survey states, it is a high priority to understand the formation of the universe and the Moon itself. The landing

Century: Themes, Goals, Objectives, Investigations, and Priorities" (Lunar and Planetary Institute, 2016), https://www.lpi.usra.edu/leag/roadmap/US-LER_version_1_point_3.pdf.

[5]Diane L. Linne et al., "Lunar Production System for Extracting Oxygen from Regolith," Journal of Aerospace Engineering 34, no. 4 (July 2021): 04021043, https://doi.org/10.1061/(ASCE)AS.1943-5525.0001269.

site of this mission is the Mare Ingenii lunar pit, which is well known for its lunar swirls that create weak magnetic fields.[6]

The last objective of the first goal is to determine the effect of radiation on temperature, humidity, and pressure within lunar pits to determine if they can sustain human life. As stated before, the primary goal of lunar missions is to establish a lasting human presence on the moon. Thus, it is important to understand the risks of long-term exposure to any radiation present on the moon. Measuring the amount of Alpha, Beta, and Gamma radiation in the Mare Ingenii pit will provide knowledge of if the area would be safe for humans to live and establish a base.

As for the second science goal, the first science objective is to characterize the depth, height, terrain variation, and ease of access within the lunar pits/caves to determine the viability of human habitation. It is a requirement of the customer that the landing site be analyzed to see if it would make a good potential base location for humans. This is why this objective strongly relates to the goal of providing safe habitation systems to protect equipment and individuals. This objective is about seeing if the landing site will be easily accessible for astronauts, and if the location will also be large enough to support a base.

Lastly, the final science objective pertaining to this goal, and the final objective overall, is to determine the structural integrity within the Mare Ingenii lunar pit to determine if it can support human life. If this landing site were chosen as a place to build a human settlement, it would be crucial to ensure that the pit would not collapse, as the base would be within the pit. The structural integrity of the pit will be determined via using muons from cosmic rays. Muons form when cosmic rays interact with the lunar surface. This will be measured by observing the flux of muons through the surface of the pit.[7]

1.3. Summary of Mission Location

Three potential pit locations were selected before the final potential location where the mission will be collecting data. Aside from the geographical location, criteria that were considered when selecting potential locations were terrain slopes, existence of lunar swirls, entry conditions of the pit, shadow existence within pits, depth of the pit, lava tube existence, and unique features. The three selected potential locations are the Mare Ingenii, Mare Tranquillitatis, and Copernicus 10 pits.

The Mare Ingenii site is located on the outer edge of the South Pole-Aitken basin on the moon. There are distinctive lunar swirl patterns known to be in the region, however the

[6] Ian Garrick-Bethell, James W. Head, and Carle M. Pieters, "Spectral Properties, Magnetic Fields, and Dust Transport at Lunar Swirls," Icarus 212, no. 2 (2011): 480–92, https://doi.org/10.1016/j.icarus.2010.11.036.

[7] Timo Enqvist et al., Exploration of Lunar In Situ Resources Can Be Conducted by Applying Density-Sensitive Cosmic-Ray-Based Geophysical Muon Imaging Method Called Muography, 2021, https://www.researchgate.net/publication/355782028_Exploration_of_Lunar_In_Situ_Resources_Can_Be_Conducted_by_Applying_Density-Sensitive_Cosmic-Ray-Based_Geophysical_Muon_Imaging_Method_Called_Muography.

mare deposits may be thin in the region.[8] The slopes in the region range from about zero to five degrees, allowing for multiple possible landing sites within 5 km of the pit, although the pit itself contains slopes of around 20 degrees.[9] The pit is near the center of the crater Thomson M. Depths of the pit are projected to range from 39m to 64m. The range in depth is due to the nature of the sloping talus that covers most of the pit floor. Additionally, it has a very pronounced funnel that exposes numerous layers. There is an overhang of at least 10-20m on the west and south sides.[10] Lastly, the location is known to have the potential for many lava tubes within the pit.

The Mare Tranquillitatis region, more commonly known as the sea of tranquility, represents the largest shield volcano on the moon, and was the site of Apollo 11.[11] It is a known location for research on basalt, and effects of lateral and vertical mixing processes within the mare.[12] It is a smooth and relatively flat location, although slopes near the pit get much steeper. The pit has a depth of about 105m at the bottom of the funnel, and about 80 m depth along the walls.[13] There are no slopes, only vertical walls that lead to the floor, with overhangs on the east, west, and north sides. This results in variable shadows depending on the moon's position relative to the sun. Finally, the location is generally known for the presence of lava tubes.

The Copernicus 10 pit is located in the Copernicus crater, which is located in the Mare Imbrium region on the northern hemisphere of the moon. The crater is known for having several central peaks, with research showing that extensive olivine has been detected in the upper parts.[14] The slope in the crater is around two to five degrees, not including the central peaks.[15] This leaves plenty of potential landing locations around the pit. The pit itself has a sloped entrance that is projected to be nearly transversable to the floor. There are no shadows in the pit allowing for the continuous use of solar power to operate the device.

Ultimately, the Mare Ingenii location was selected for three main reasons. First, the terrain is within the requirement of less than ten degrees for the specific landing site. This also offers ideal conditions for surface experimentation. The second reason is the strong po-

[8] Salari, Giulia, Gloria Tognon, Francesca Zambon, Cristian Carli, Federico Tosi, Lorenza Giacomini, Jean-Philippe Combe, et al. "Spectral Analysis of Mare Ingenii Basin (Lunar Farside)." Journal of Geophysical Research: Planets 128, no. 12 (December 21, 2023). https://doi.org/10.1029/2023JE007963.

[9] Lunar Reconnaissance Orbiter Camera. "Pits." Accessed October 3, 2024. https://www.lroc.asu.edu/atlases/pits/6.

[10] Ibid.

[11] "Mare Tranquillitatis." Accessed October 3, 2024. https://science.nasa.gov/image-detail/20100528/.

[12] Staid, Matthew I., Carlé M. Pieters, and James W. Head. "Mare Tranquillitatis: Basalt Emplacement History and Relation to Lunar Samples." Journal of Geophysical Research: Planets 101, no. E10 (October 1, 1996): 23213–28. https://doi.org/10.1029/96JE02436.

[13] Lunar Reconnaissance Orbiter Camera. "Pits." Accessed October 3, 2024. https://www.lroc.asu.edu/atlases/pits/3.

[14] Pieters, Carle M., and Don E. Wilhelms. "Origin of Olivine at Copernicus." Journal of Geophysical Research: Solid Earth 90, no. S02 (February 15, 1985): C415–20. https://doi.org/10.1029/JB090iS02p0C415.

[15] Lunar Reconnaissance Orbiter Camera. "Pits." Accessed October 3, 2024. https://www.lroc.asu.edu/atlases/pits/54.

tential for a lava tube within the pit, this helps ensure that there will be a lava tube present to conduct experiments. Lastly, it was chosen due to the unique lunar swirls in the region, which will offer a valuable research opportunity that will be explored during the mission.

1.4. Mission Requirements

The following table outlines the Mission Requirements in a "flow-down" structure, beginning with the fundamental constraints and limits outlined by the customer constraints (CC) outlined by the customer L'SPACE, and then branching out to its corresponding requirements whether it be a science (SCI) or spacecraft constraint (SC). Each level of flow corresponds to its color; a darker shade of color signifies a higher level of flow, while a lighter shade signifies a lower level of flow within a foundation.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem
CC - 0.0	The mission shall adhere to customer constraints.	Parameters outlined in document, in relation to the given constraints and requirements	N/A	All	Analysis	All
CC - 0.1	System must adhere to mass constraint of 350 kg	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.2	System must adhere to dimension constraint of 2 m x 1.25 m x 1.25 m during transit	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.3	System must explore the lunar/pits caves and perform surface science operations	Defined by the customer (L'Space)	CC - 0.0		Scientific Review	Payload
CC - 0.4	System must not exceed cost constraint of $425M	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.5	System must be ready to launch by March 1st, 2030, at Cape Canaveral.	Defined by the customer (L'Space)	CC - 0.0		Inspection	Payload
CC - 0.6	System cannot have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof; System must not exceed radioactive material cumulative mass of 5g	Defined by the customer (L'Space)	CC - 0.0		Inspection	Electrical, Structural, Mechanical
CC - 0.7	System will be transported on a separate, primary vehicle launch (rocket) with power sufficient during transport. No scientific data will be collected during transit	Defined by the customer (L'Space)	CC - 0.0		Inspection	Structural
CC - 0.8	System shall arrive at target destination adhering to landing site constraints: given a 100m diameter landing zone, it shall not exceed a slope of 10 degrees, and should traversal be necessary to the science site or lunar cave, it must no be no further than 5 km from the landing zone (only applicable for mobile vehicle)	Defined by the customer (L'Space)	CC - 0.0		Analysis	Structural, Mechanical
CC - 0.9	System shall communicate data to Earth via relay of spacecraft orbiting the Moon; the spacecraft must be able to communicate with the orbiting spacecraft directly, and the primary mission orbiter which shall remain in a circular polar orbit of 100km during the mission's lifespan	Defined by the customer (L'Space)	CC - 0.0		Demonstration and Test	Electrical, Communication, Mechanical
CC - 0.10	System shall undergo analog testing in a comparable volcanic environment; drop testing is necessary should the landing site not have a traversable entrance, and tether or winch system	Defined by the customer (L'Space)	CC - 0.0		Test and Analysis of all drop-tested systems	All

Figure 2: This table lays out the mission requirements. The complete table is extensive and can be viewed in its entirety in the Appendix section of this report.

1.5. Physical Environmental Hazards

The exploration of lunar pits, specifically in the Mare Ingenii region, presents unique environmental challenges due to the Moon's harsh and varying conditions. Exploring the

Lunar pit Mare Ingenii will be exposing the mission to a harsh radiation environment from the cosmic rays hitting the moon. The cosmic rays are high energy charged particles that travel through space; they can come from sources such as blackhole jets, stellar winds, and gamma-ray bursts to name a few. The origins of tracking where the cosmic rays come from cannot be easily traced back to their origin when they hit on the moon's surface since they are deflected by intergalactic magnetic fields and charged particles colliding within those magnetic fields forming other different particles which are speeding at near light speeds spiraling through the universe. Cosmic rays are a problem when it comes to electronics for the rover. The effect of the radiation on the electronics depends on the type of electronics such as battery, solar cells, sensors, wires, etc. Due to the radiation effects, the instruments on the rover will have degraded performance overtime to the point where in the future it would be unrepairable. When it comes to measuring the data, the radiation effects would introduce noise in the output data which would affect the readings and analysis of the particular objective that needs to be accomplished for the mission. To limit and extend the lifespan of the instruments, the radiation effects of the electronics that will be used for the rover has to be well understood by testing the instruments in a radiation environment on the earth before sending it to the moon to study the effects in depth.

Radiation exposure for future lunar habitation will pose significant health risks for humans during the stay at the moon. The radiation dose limits for humans differ for various body parts, with more sensitive tissue, such as eyes and blood-forming organs requiring sticker protection measurements and shielding. Age also plays a significant role in how radiation dose affects a particular individual. Younger and older individuals are most sensitive to radiation effects than adults. The rapidly dividing cells make them more susceptible to the damage effects of ionizing radiation causing mutations and an increased risk of developing cancer later in their life. To minimize the effects of radiation for future lunar habitation the rover will take necessary data such as the radiation dose per hour inside the cave that has been selected for the mission to study about the radiation effects within the cave. This will be useful since the primary goal of the mission is to study the caves in depth so a habitation is built inside the cave to protect the individuals from the constant radiation exposure.

Other physical hazards that exist are micrometeoroids, which travel at very high velocity and aren't easily detectable due to their size and shape. They are a hazard for rovers and habitats as they can easily damage surfaces, potentially causing puncturing, cratering, or abrasion, which can degrade instruments, solar panels,protective coatings and exposed elements of structures and instruments.

The structural design and integrity of spacecraft exploring Mare Ingenii must also account for physical characteristics such as the pit has several physical hazards that must be accounted for in determining the spacecraft's structural design and integrity. Some hazards such as its 10-20 m overhanging properties on the Western and Southern ridges of the pit, impose a challenge that would require an alternative route, or safety protocols implementation to ensure the structural integrity of such spacecraft/personnel during a free-fall drop. Another factor to consider in regard to its overhanging properties is the amount of sunlight available within the pit as some systems such as its electrical system may be dependent on solar energy.[16]

In addition, rim-to-floor depths range from 15m to 65m, with the lowest elevation being at -3,672.5m and the highest elevation (the surrounding area) being at -3,635.0m. The incline of the terrain must be considered as well, in order to ensure safe passage and investigation. Fortunately, the slope is negligible at the slope (degree) of 24-20 degrees, when approaching from the Northern ridge, leading at a downwards slope South.[17]

Not only is the terrain uneven, but its composition: lunar regolith, is extremely sharp, and fine. Based on its precarious properties, the spacecraft's navigation and structural systems (electrical, mechanical, communications, etc.) must be protected from such lunar regolith micron particles and razor-like edges.[18]

Another measurable factor to consider is temperature; although interestingly the pit's temperature is stable, remaining at a steady 290K throughout the lunar night, due to the insulating properties of the lunar regolith.[19]

1.6. System Evaluation Criteria

The following specific criteria will be used to assess several options for the spacecraft and its aspects and instrumentation. Only one spacecraft will be used for the mission. This will allow for easier control of the spacecraft's makeup as well as its functions. Additionally, using only one spacecraft will help to stay within the mission's mass, dimensions, and budget constraints. For reiteration, the constraints are as followed:

i) Mass = 350 kilograms

ii) Dimensions = 2 meters by 1.25 meters by 1.25 meters

iii) Budget = $425 million

These constraints, as established by the mission, will be of ultimate priority in terms of criteria for the spacecraft.

The spacecraft will also be evaluated and manufactured in terms of the research objectives decided. The spacecraft will need an instrument that will test the lunar regolith for signs of oxygen using heat. Therefore, the instrument must include a function to create and control heat. The source of the heat and how that heat will be produced will be assessed. Additionally, the same instrument or a different instrument must have a function that can detect any possible oxygen produced from the heating of the lunar regolith. Moreover, the spacecraft must be able to detect and analyze the weather conditions and climates of the lunar pit explored. These weather conditions include the temperature, pressure, and

[16] "Pit Atlas: Mare Ingenii Pit."
[17] Christensen et al., "JMARS."
[18] Noble, "The Lunar Regolith."
[19] Hovrvath et al., "Thermal Environment of Lunar Pits and Caves: Implication for Future Lunar Missions and Volatiles."

humidity. Thus, the spacecraft as well as its instrumentation must be able to withstand and operate in these conditions. The aspects that will allow for this will be assessed. A thermometer, pressure sensor, and humidity sensor must be included as instrumentation. Lastly, the spacecraft must be able to detect possible magnetic fields on the moon in relation to lunar swirls. An instrument, such as a magnetometer, should allow for this.

Alongside the research objectives, other specific science objectives also play a crucial role in the criteria for the spacecraft. The spacecraft must be able to define the structural characteristics of the lunar pit, such as the pit's dimensions, type of terrain, and landscape. Instruments included in the spacecraft must have functions that allow these characteristics to be detected and analyzed. Furthermore, the structural integrity of the lunar pit will be assessed. Thus, instruments, such as the Silicon Photomultiplier (SiPM), can allow for such a function on the spacecraft. The instrument's dimensions and placement on the spacecraft will be assessed.

1.7. Concept of Operations

The primary and miniature rover should have a mass of less than 350kg and dimensions no larger than 2 m x 1.25 m x 1.25 m. The vehicles shall be ready by March 1st, 2030, and project costs shall not exceed $425M. After the successful creation of the vehicles, analog testing at Black Point Lava Flow in Arizona will be conducted. Since the miniature rover will be lowered using a winch system, a drop test will not be necessary.

Upon landing at the Mare Ingenii, less than 5 km from the pit (-35.9494, 166.0559), the vehicles will test the telecommunication systems, scientific instruments, and telemetry capabilities.[20] The telecommunication system of the primary rover shall use a medium-frequency communication band between 1 to 2 GHz. This will allow the rover to communicate with a nearby satellite using L-band radio frequencies.[21] Alternatively, the miniature rover shall use a low-frequency communication band to send data to the primary rover. The vehicles will wait for their first command from the ground operations team.

The primary rover will move to the outer rim of the Mare Ingenii pit. A test of the winch system shall be run to ensure its functionality in the lunar environment. Afterward, the miniature rover will be lowered about 40m into the Mare Ingenii pit.[22] Once safely inside the pit, a pulse check is performed to ensure the continued safety of the miniature rover.

While inside the pit, the miniature rover will test the microclimate by measuring the environment's temperature, humidity, and pressure. The temperature and humidity can be collected using a Platinum Resistance Thermometer (SPRT) and a Novel Solid-State Hu-

[20] "Pits Atlas: Mare Ingenii Pit." n.d. LROC. Accessed October 3, 2024. https://www.lroc.asu.edu/atlases/pits/6.

[21] "9.0 Communications - NASA." 2024. NASA Ames Research Center, Small Spacecraft Systems Virtual Institute. https://www.nasa.gov/smallsat-institute/sst-soa/soa-communications/.

[22] Whittaker, William. 2011. "Technologies Enabling Exploration of Skylights, Lava Tubes and Caves." https://www.nasa.gov/wp-content/uploads/2017/07/niac_2011_phasei_whittaker_lavatubesandcaves_tagged.pdf.

midity Sensor.[23] The pressure will be measured using a Pressure-Temperature instrument, which will be an alternative means of temperature gauge if the SPRT fails.[24] The collected data will then be sent to the rover above through telemetry, which will be relayed to the satellite and the team on Earth. Lastly, using a transverse bucket wheel, the miniature rover will collect regolith samples into a holding tray.[25]

After safely recovering the miniature rover using the winching system, the primary rover will collect regolith samples from the Mare Ingenii. The sample-collecting process will involve using a hammer and collection tube to safely store regolith for transportation to Earth.[26] This collected sample will allow for later testing to work towards hydrogen reduction of lunar regolith to help with oxygen production in later lunar missions.[27]

The primary rover will then maneuver about 42km to the Southwest to reach the lunar swirls inside the Thomson crater within the Mare Ingenii.[28] A drive tube will then extract moon soil samples from the lunar swirls and nearby for further analysis. These and the previous samples from the Mare Ingenii pit and outer rim will be delivered to Earth to further understand the moon's potential magnetic fields.[29]

Once all planned tests have been completed, data has been received, and samples have been sent, the rovers will have completed the planned mission tasks. The primary and miniature rovers will then be decommissioned and disposed of using the steps laid out by the DRR which will be developed in time.[30]

1.8. Alternative Mission Concepts

The process for selecting the mission chosen was the result of filtering through initial ideas, starting from the means of exploration to the elimination of landing sites and scientific ob-

[23] "Novel Solid-State Humidity Sensor." n.d. NASA Technology Transfer Program. Accessed October 4, 2024. https://technology.nasa.gov/patent/MFS-TOPS-80.

[24] "Pressure-Temperature (PT) Instrument." n.d. Accessed October 4, 2024. https://cloud1.arc.nasa.gov/crystalface/WB57_files/PTnoaa.pdf.

[25] Linne, Diane L., Jason M. Schuler, Laurent Sibille, Julie E. Kleinhenz, Anthony J. Colozza, Homer J. Fincannon, Steven R. Oleson, Nantel H. Suzuki, and Landon Moore. 2021. "Lunar Production System for Extracting Oxygen from Regolith." Journal of Aerospace Engineering 34 (4): 04021043. https://doi.org/10.1061/(ASCE)AS.1943-5525.0001269.

[26] Allton, J. H. n.d. "LUNAR SAMPLES: APOLLO COLLECTION TOOLS, CURATION HANDLING, SURVEYOR III AND SOVIET LUNA SAMPLES." Accessed October 4, 2024. https://www.nasa.gov/wp-content/uploads/2019/04/02_allton_corrected_apollo.pdf.

[27] Hegde, Uday, Ramaswamy Balasubramaniam, Suleyman Gokoglu, Kathleen Rogers, Michael Reddington, and Lara Oryshchyn. 2011. "Hydrogen Reduction of Lunar Regolith Simulants for Oxygen Production." In 49th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition. Orlando, Florida: American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2011-608.

[28] Denevi, Brett. 2012. "The Swirls of Mare Ingenii." LROC. June 21, 2012. https://www.lroc.asu.edu/images/530.

[29] Rizk, Bashar. 2010. "Reiner Gamma Constellation Region of Interest." June 29, 2010. https://www.lroc.asu.edu/images/193.

[30] Blythe, Michael. 2014. "NASA Space Flight Program and Project Management Handbook." https://ntrs.nasa.gov/api/citations/20150000400/downloads/20150000400.pdf.

jectives. In the initial meeting, various methods of exploration were discussed and articulated, considering which options were feasible and which were not. To start, the focus was placed on what spacecraft would be used for data collection. The initial idea involved deploying both a rover and a drone-like craft: the rover would explore the surface, and the drone would provide aerial reconnaissance, giving us a bird's-eye view of the terrain. This would help map geological features and enhance situational awareness for the rovers navigation. Although the drone was heavily considered, it was ultimately ruled out because the moon has no atmosphere, making flight impossible. For the drone to function in these conditions, it would need a finite propulsion system to maintain flight, which would quickly run out, rendering it unfeasible for long-term exploration. The drone would have to rely entirely on this system, leading to limited operational capacity and increased mission complexity. It was the conventional choice, to settle on the rover, as it was a more efficient and sustainable solution and surface exploration. It had the perfect balance between simplicity and mission success possibility.

After the spacecraft was established, a down-selection process was implemented to narrow down the potential landing sites. Factors such as thermal stability, structural integrity, ease of access, and scientific potential were considered. By analyzing these features from multiple angles and ensuring each option was balanced between mission goals and its technical feasibility, the process of elimination was guided. Various pits were evaluated, assessing their drawbacks and identifying reasons for exclusion. **Mare Tranquillitatis Pit** was initially appealing due to its known lava tubes, which offer valuable insights and potential for future human habitats. Lava tubes are very valuable for natural protection from cosmic radiation and shelters from extreme temperature fluctuations, deeming them as prime candidates for human habitation. However, the pit's depth made it logistically challenging for rover deployment and data collection. The pit's steep walls would call for advanced mechanisms for the descent into the pit, further increasing mission complexity. In the retrieval of the drone as well, this causes issues, presenting a high risk factor that outweighed the scientific gains. **Copernicus 10** also posed potential, with its ramp providing smooth access for the rover. This looked very convenient, as the rover could find its way into the pit with ease. However, issues arose with the lack of shadows, which, while beneficial for solar-powered equipment, could lead to overheating if the rover was exposed to sunlight for extended periods. Additionally, uncertainty around the slope presented a logistical challenge for navigation.

There were inconsistencies around entryways into the pits, to find a stable slope was complex, hindering the possibility of safe navigation. **The Rutherfurd Pits** were also deeply considered, with their gentle slopes (less than 10 degrees) being particularly attractive for scientific exploration. Unlike others, which presented accessibility challenges, this location did not include issues related to geographical movement. Yet, uncertainty regarding the structural features and the harsh conditions at the lunar poles posed problems for potential human habitation. Harsh conditions were identified as extreme cold and prolonged periods of darkness, which raised concerns about the possibility of long-term stability. The issue with stability is mainly in regards to power generation, as the option of using solar energy would be limited, and the rover would have to heavily lean on using batteries during extended lunar nights. These cons ultimately outweighed the potential of the pit, causing it to be ruled out. Lastly, **Southwest Mare Fecunditatis Pit** was considered for its location in the highland region and its significant potential for geological exploration. It contained scientific valuable materials that held high value, adding a lot of weight to make it the choice of exploration. Upon further examination, the 45-degree funnel leading into the pit raised concerns about the rover's ability to land safely and would restrict access to scientifically valuable areas, making it less suitable for the mission objectives. Regardless of the weight of valuable materials being considered, the terrain would negate this being something to look for, as access was difficult. After considering these factors, it became clear that **Mare Ingenii Pit** was the best choice for exploration. It presented itself with manageable terrain, moderate slopes, and accessible areas that were able to ensure the rover could be displayed smoothly and effectively, with substantial scientific interest.

In the context of scientific objectives, the value of the top 3 options examined, rather than eliminating those deemed unfit, as a means of choosing the focus. Firstly, it had to be established whether it was possible to extract oxygen from the lunar regolith under realistic lunar conditions. Oxygen is not only crucial for life but also as a component of rocket fuel; hence, this objective became all the more vital. If oxygen could be extracted directly from the lunar regolith, that would transform human space exploration by drastically reducing the need for costly resupply missions from Earth. This would allow missions to be much more self-sustaining, with longer durations – realizing the objective of a permanent lunar base. Under consideration are various methods for extracting oxygen: molten salt electrolysis and carbothermal reduction. In these processes, the regolith's chemical components are split apart, releasing the oxygen. But all these methods need to be checked in real conditions of the Moon, which, due to features such as low gravity, extreme fluctuations of temperatures, and vacuum, may present a serious obstacle to their application. Overcoming this barrier will support not only NASA's goals regarding advanced in-situ resource utilization but also some ground-laying toward leveraging similar technologies on Mars or other planetary bodies. Further, such success could also be extended to possible life support systems and mechanisms of propulsion of spacecraft, enabling deeper space travel in a more feasible and cost-effective way.

Apart from oxygen extraction, the second focus of this study is to explore the microclimates of the lunar caves that may offer some natural protection from extreme conditions on the Moon-high-contrast temperature swings and radiation from the Sun. Lunar caves often created by ancient lava tubes provide a unique opportunity for a base with built-in protection from the environment. By studying microclimates of these caves regarding temperature stability, humidity levels, and potential air circulation, the suitability of these caves for long-term human habitation can be determined. These caves offer relatively stable environments that would decrease the need for expensive and complex artificial habitats and hasten building sustainable outposts on the Moon. It might also hasten the plans for permanent bases since the natural shelters would be easing some of the construction logistics and energy needs. Furthermore, understanding how such caves work as natural insulators could help develop designs for future habitats not only on the Moon but on Mars and beyond. Studying these microclimates may also provide insight into the

Moon's geological past and thermal evolution, as these caves represent untouched environments which have remained relatively insulated from surface processes for millions of years.

The third priority was an investigation into localized magnetic fields associated with lunar swirls, mysterious patterns on the Moon's surface often linked to magnetic anomalies. These magnetic fields are even thought to offer some natural protection from harmful cosmic and solar radiation, which constitutes one of the largest risks associated with long-term human presence in space. If such regions with substantial magnetic fields can be pinpointed, they may offer a form of natural radiation shielding and decrease the reliance on heavy artificial radiation shielding, thereby giving these locations a decided advantage when choosing the placement for future lunar bases. This is important not only for understanding the Moon's geological history and its interaction with the solar wind but also for uncovering the mechanisms that may have created these localized magnetic fields. This research provides valuable information about the Moon's past and enhances the ability to design future habitats with integrated radiation protection. This knowledge would also aid NASA in its broader objectives of ensuring astronaut safety during long-duration missions, particularly as exploration efforts expand toward Mars and other destinations in the solar system. The investigation of such magnetic fields would also unlock new secrets for strategic design of spacecraft and radiation shielding. Better comprehension of how the natural magnetic fields can interface with the solar wind may provide an enabling technology that allows its exploitation on future spacecraft and surface habitats, possibly significantly reducing mass and the complexity of the radiation protection systems. The enhanced study of the magnetic fields associated with lunar swirls further combines in a greater way to explore the geological evolution of the Moon, since these features are important in delivering clues about the magnetic field history of the Moon and its general role in the solar system.

1.9. Programmatics

1.9.1. Team Organization

The following will be the framework that Team 27 will use to improve team organization in this project.

Workload Delegation

To ensure that tasks are divided up evenly, the below workflow will be followed:

i) The tasks will be inputted into a spreadsheet with their roles and responsibilities.

ii) The team members will sign up for their preferred task by putting their name next to the task.

   a) In the event that two or more members desire the same task, they will independently decide between themselves how they will resolve this issue.

iii) If there are still tasks that are left blank after every team member has signed up, then another round of signing up will occur with team members choosing to take up another task.

Decision Making

Time-sensitive decisions: There will be decisions that will have a time limit to them and need to be decided as soon as possible. The following will be how they are decided.

i) A poll will be created with a time limit and it will be up to each member of the group to make sure that they input their answer into the poll before the time limit is reached.

ii) Then the team will proceed with the solution that the team members voted on.

Split Opinion: There will be times where opinions are split on an issue. The following will be how it will be resolved.

i) There will be a poll created to break the tie between the opinions.

ii) If there are still split decisions then a new poll will be created and the opinion with more than 50% will be the one that the team will follow through with.

Communication

In every team, communication is the most important quality a team should have to succeed in any endeavor. The following are some key principles that the team will follow to facilitate communication.

i) *Regular Meetings*: The team has agreed to meet at least once a week to discuss tasks and resolve any issue.

ii) *Speak up*: Every team member will communicate with the team in an open and honest manner about what they can and cannot do (or can no longer do).

iii) *Empathy*: Team members must be able to see from another member's point of view and understand their situation.

1.9.2. Cost and Schedule Estimate

The overall budget for the mission task is under $450 million dollars, which includes three major phases.[31] This encompasses the robotic system development, system assembly and launch, operations and decommissioning.[32]

[31] Yost, B., and National Aeronautics and Space Administration. 2021. "NASA SSRI Knowledge Base | Explore." `https://s3vi.ndc.nasa.gov/ssri-kb/`.

[32] "SEH 3.0 NASA Program/Project Life Cycle." NASA, July 26, 2023. `https://www.nasa.gov/reference/3-0-nasa-program-project-life-cycle/`.

i) Robotic System Development (phase C & D): This first phase involves the creation of our mechanical, and electrical subcomponents, propulsion, payload systems and thermal systems into an overall working system. Afterwards, completing rigorous testing on the system to mimic its lunar conditions is needed in order to fix or change anything that might hinder our data collection and overall functionality. Some testing that can be performed would be thermal vacuum testing, vibrational[33] and overall environmental testing.[34] In order to integrate our system with the launch vehicle, multiple checks and launch tests will need to be done. These tests make sure that all systems are robust enough to handle the intense launch, space travel, and landing conditions of the lunar surface. Each one of these components must function perfectly in harsh conditions, as even a slight malfunction could lead to mission failure. The integration process will also involve coordination with the launch vehicle provider to ensure smooth harmony. The cost for this phase will include[35]:

a) A group of highly qualified individuals to take on this phase will include multiple engineers of all disciplines, scientists and managers.

(5) Engineers (mechanical, electrical, systems, software, computer)	$80,000 per engineer
(3) Scientists	$80,000 per scientists
(2) Managers	$120,000 per manager

Figure 3: This table lists who will be necessary to hire, along with their corresponding salaries.

b) Each specific component or part that needs to be used in the design (and any additional fabrication methods to make parts).

Overall System Assembly	$80 M
Testing	$20 M
Launch Support	$10 M

Figure 4: The above table details components of the design and their corresponding costs.

c) Travel costs for the mission would involve:

[33] "Satellite Vibration Testing." Crystal Instruments. Accessed October 6, 2024. https://www.crystalinstruments.com/satellite-vibration-testing#:~:text=The%20vibration%20test%20systems%20consists,critical%20test%20for%20satellite%20qualification.

[34] Space Environmental Testing at the NASA Space Power Facility. Accessed October 6, 2024. https://www.nasa.gov/wp-content/uploads/2015/11/space-testing.pdf.

[35] National Aeronautics and Space Administration. 2015. NASA Cost Estimating Handbook. February.

Potential Part Manufacturer Facility Visits	Per each staff member - $200 - 400
Travel to Launch Site (Kennedy Space Center)	Per each staff member - $400 - $700
Conference Travel (To present mission data and findings)	About 3 staff members from the team $300 - $600

Figure 5: This table focuses on travel costs.

ii) Operations (phase E): This phase focuses on data collection and analysis from our lunar robotic system. Throughout the entire mission, it will be necessary to monitor how the robot is functioning, controlling it from ground system controls and fixing any obstacles it may face. After this, collecting data is crucial as to achieve the scientific research objectives. The data for this phase will be transmitted continuously back to Earth where the scientists will analyze it to uncover new insights about the lunar surface. Any anomalies encountered during operations must be addressed swiftly to avoid any miss interruptions in the data transmission. Along with staff personnel, the following will be necessary:

Ground System Maintenance	$24 M
Data Analysis Software	$14 M
Communication - Deep Space Network (DSN)	$20 M

Figure 6: This table focuses on resources needed to handle data of the mission properly.

The DSN will play a vital role in ensuring uninterrupted communication with the spacecraft, particularly during these critical moments of the mission, such as landing and data transmission.[36] Additionally, the data analysis software will need to be configured enough to process large amounts of specific data in real-time, which allows the researchers to come to a conclusion quickly.

iii) Decommissioning (phase F): This final phase includes deactivating the robotic system, making sure the system is done with data collecting and preserving it. To undergo all closeout operations and create final documents or reports it will cost about

[36] Monaghan, Heather. "What Is the Deep Space Network?" NASA, September 29, 2023. `https://www.nasa.gov/directorates/somd/space-communications-navigation-program/what-is-the-deep-space-network/`.

$3M. During this phase we will also involve archiving the mission data for future use, as it ensures that nothing is lost in the transition. The final reports will be conducted as a comprehensive record of the current mission's achievements and challenges, while offering valuable lessons for the future lunar explorations.

TASK [7]	START	END
Phase C Preliminary Design	9/15/24	10/13/25
System Design	9/15/24	10/30/24
Fabrication	10/30/24	6/27/25
System Testing	7/20/25	9/13/25
Reviews CDR, PRR, SIR	9/14/25	10/14/25
Phase D System Assembly	10/12/25	7/24/27
System Integration	10/14/25	11/29/25
Assembly of Spacecraft	11/29/25	2/26/26
System Testing	2/26/26	4/26/26
Launch(earth to Mare Ingenii)	5/14/26	7/25/27
Phase E/ FOperations	7/25/27	7/28/27
Surface Ops	7/25/27	7/28/27
Transmit Data	7/25/27	7/28/27

Figure 7: This figure documents the start and end dates of mission tasks and phases.
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1.10. Conclusion

In summary, Team 27 has selected three potential lunar sites – Mare Ingenii, Mare Tranquillitatis, and Copernicus 10. These lunar locations holds fascinating science to be explored individually as well as alongside each other, ranging from magnetic fields corresponding to lunar swirls, to pulling concentrations of oxygen from regolith, to analyzing radiation and its effect. Additionally, the dimensions of the pits, their accessibility and ability, and analyzing structural integrity will be focused on in order to determine whether a lunar pit is able to support human life. Unique environmental conditions will play a part in impacting the exploration and explorers of these lunar pits, such as harsh radiation dependent on the rover's electric components and physical hazards like micrometeoroids. Thus, the team will strive to maintain a structural design of a rover that will avoid physical and environmental threat, as well as damaging the pits themselves. Team 27 will abide by the required metrics and limitations outlined by the mission, as well as its budget and timeline. The team will utilize the work of individuals varying from engineers to scientists, data-handling resources and software, and record these items to ensure logistical (and general) mission success. To ensure the completedness of the mission, the team will utilize thorough and effective organization by means of delegating tasks, making decisions together, and communicating frequently.

If the team had more time, it is likely that topics such as specific instrumentation for the mission would have been discussed early, researched further, and potentially introduced in the MCR. Additionally, more in-depth research on more complex and advanced-level research topics, when considering interesting science to explore as ideas brought by individual members and presented, could have been performed. Team 27 will continue to check in and meet with one another weekly to make progress on the mission, including the focus on the System Requirements Review.

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Declaration of AI in the Writing Process

Team 27 did not utilize AI for any part of the Mission Concept Review.

Appendix

[1] Full Mission Requirements Figure.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem
CC - 0.0	The mission shall adhere to customer constraints.	Parameters outlined in document, in relation to the given constraints and requirements	N/A	All	Analysis	All
CC - 0.1	System must adhere to mass constraint of 350 kg	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.2	System must adhere to dimension constraint of 2 m x 1.25 m x 1.25 m during transit	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.3	System must explore the lunar/pits caves and perform surface science operations	Defined by the customer (L'Space)	CC - 0.0		Scientific Review	Payload
CC - 0.4	System must not exceed cost constraint of $425M	Defined by the customer (L'Space)	CC - 0.0		Inspection	All
CC - 0.5	System must be ready to launch by March 1st, 2030, at Cape Canaveral.	Defined by the customer (L'Space)	CC - 0.0		Inspection	Payload
CC - 0.6	System cannot have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof; System must not exceed radioactive material cumulative mass of 5g	Defined by the customer (L'Space)	CC - 0.0		Inspection	Electrical, Structural, Mechanical
CC - 0.7	System will be transported on a separate, primary vehicle launch (rocket) with power sufficient during transport. No scientific data will be collected during transit	Defined by the customer (L'Space)	CC - 0.0		Inspection	Structural
CC - 0.8	System shall arrive at target destination adhering to landing site constraints: given a 100m diameter landing zone, it shall not exceed a slope of 10 degrees, and should traversal be necessary to the science site or lunar cave, it must no be no further than 5 km from the landing zone (only applicable for mobile vehicle)	Defined by the customer (L'Space)	CC - 0.0		Analysis	Structural, Mechanical
CC - 0.9	System shall communicate data to Earth via relay of spacecraft orbiting the Moon; the spacecraft must be able to communicate with the orbiting spacecraft directly, and the primary mission orbiter which shall remain in a circular polar orbit of 100km during the mission's lifespan	Defined by the customer (L'Space)	CC - 0.0		Demonstration and Test	Electrical, Communication, Mechanical
CC - 0.10	System shall undergo analog testing in a comparable volcanic environment; drop testing is necessary should the landing site not have a traversable entrance, and tether or winch system	Defined by the customer (L'Space)	CC - 0.0		Test and Analysis of all drop-tested systems	All

MG - 1.0	The mission shall conduct scientific research on the Mare Ingenii Pit in relation to the sustainability of human infrastructure.	In conjunction with the Mission Goal: "Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon" and ""Provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure"	CC - 0.0	SCI - 1.1 SCI - 1.2 SCI - 1.3 SC - 1.4	Demonstration	All
SCI - 1.1	The mission shall conduct analysis and research of lunar regolith.	Analysis of lunar regolith for utilization of matter in terms of lunar mission sustainability.	MG - 1.0	SCI - 1.1.1	Demonstration	Science, Communication, Mechanical
SCI - 1.1.1	The mission shall determine if 10% of oxygen (O2) can be pulled from the regolith in lunar conditions.	To determine the regolith's sustainability in terms of colonial/mission infrastructure.	SCI - 1.1		Analysis	Science, Communication,
SCI - 1.2	The mission shall investigate magnetic fields within and around the Mare Ingenii Pit	To observe and analyze the abnormal magnetic fields	MG - 1.0		Analysis and Modeling	Science, Communication
SCI - 1.3	The mission shall analyze the viability of human habitation within the lunar pit.	To identify the plausibility of lunar colonial/mission infrastructure.	MG - 1.0	SCI - 1.3.1 SCI - 1.3.2 SCI - 1.3.3	Analysis	Science
SCI - 1.3.1	The mission shall determine the properties of radiation on temperature, humidity, and pressure within the pit.	To determine the pit's sustainability in terms of colonial/mission infrastructure.	MG - 1.0		Analysis	Science, Communication, Mechanical
SCI - 1.3.2	The mission shall identify and characterize the depth, height, terrain variation, and ease of access within the lunar pit.	To determine the lunar pit's infrastructure and identify its strengths and weaknesses for colonial/mission infrastructure.	SCI - 1.3.1		Analysis	Science, Navigation, Communication
SCI - 1.3.3	The mission shall analyze the lunar pit's structural integrity.	To determine the lunar pit's infrastructure and identify its strengths and weaknesses for colonial/mission infrastructure.	SCI - 1.3.1		Analysis	Science
SC - 1.4	The mission shall utilize a spacecraft for the duration of the mission and to fulfill mission research.	Mission requires a method of conducting research in a controlled and measurable manner.	MG-1.0 SCI - 1.1	SC - 1.4.1 SC - 1.4.2 SC - 1.4.3	Demonstration	All

SC - 1.4.1	The spacecraft shall be able to traverse the lunar terrain in regards to its mission.	The Mare Ingenii Pit has a diameter of 130m; the spacecraft must be able to traverse the pit to fulfill its mission.	SC - 1.1	SC - 1.4.1.1 SC - 1.4.1.2	Demonstration and Testing in (CC-0.10)	Structural, Mechanical, Navigation
SC - 1.4.1.1	The spacecraft will be remotely piloted to navigate the lunar terrain via cameras.	In order to navigate the spacecraft, a visual representation is needed to guide the device forward.	SC - 1.1		Demonstration	Structural, Mechanical, Navigation
SC - 1.4.1.2	The spacecraft mobility parameters must be able to withstand the traversal conditions of the lunar plane.	The terrain of the lunar surface is very harsh with its sharp rocks, and micron-sized regolith dust. Its mobility features must be able to withstand these conditions.	SC - 1.1		Demonstration	Structural, Mechanical, Navigation
SC - 1.4.2	The spacecraft shall have sufficient power to maintain mission operations.	Spacecraft functionality is derived off its power.	SC - 1.1		Demonstration	Electrical
SC - 1.4.3	The spacecraft shall transmit and receive data to the corresponding entities for research and data collection.	Data obtained by the spacecraft must be transmitted to the research team (orbiter, space station, etc.) to be analyzed for scientific research. Must adhere to the CC - 0.9 restriction.	SC - 1.1		Demonstration	Communications
SC - 1.4.4	The spacecraft will be equipped with scientific instruments to accomplish its mission tasks.	Data collection of scientific tools/instruments is crucial composing it into data that can be researched/analyzed.	SC - 1.1	SC - 1.4.4.1 SC - 1.4.4.2 SC - 1.4.4.3 SC - 1.4.4.4 SC - 1.4.4.5	Demonstration	Science, Mechanical, Electrical
SC - 1.4.4.1	The scientific instrument shall be able to manipulate and measure lunar surface temperatures.	In order to accomplish the requirements outlined in SCI-1.1.1, the spacecraft must be able to measure surface temperature (or even manipulate) to identify the amount of heat needed for lunar regolith to produce 10% yield of oxygen.	SC - 1.4.4		Demonstration during Analog Testing	Mechanical, Electrical, Communications
SC - 1.4.4.2	The scientific instrument shall detect magnetic fields in the 0-5000nT range over an area of 10km.	In order to accomplish the requirements outlined in SCI-1.2, the spacecraft must be able to measure the magnetic fields within the area.	SC - 1.4.4		Demonstration during Analog Testing	Mechanical, Electrical, Communications

SC - 1.4.4.3	The scientific instrument shall detect radiation percentages of Alpha, Beta, and Gamma radiation.	In order to accomplish the requirements outlined in SCI-1.3.1, the spacecraft must be able to measure the radiation within the area.	SC - 1.4.4		Demonstration during Analog Testing	Mechanical, Electrical, Communications
SC - 1.4.4.4	The scientific instrument shall be able to determine terrain characteristics.	In order to accomplish the requirements outlined in SCI 1.3.2, the spacecraft must be able to identify the depth, height, and ease of access within lunar pits.	SC - 1.4.4		Demonstration during Analog Testing	Mechanical, Electrical, Communications, Navigation
SC - 1.4.4.5	The scientific instrument shall be able to measure muon flux variations.	In order to accomplish the requirements outlined in 1.3.3, the spacecraft must be able to penetrate and measure the amount of muon flux variation.	SC - 1.4.4		Demonstration during Analog Testing	Mechanical, Electrical, Communications

[2] TBD/TBR Resolution Table.

TBD / TBR #	Plans and Timeline for Resolution
1	Thermal Control: The plans for thermal control of the vehicles from the lunar environment will be determined during the System Design with an expected resolution date of October 30, 2024.
2	Decommissioning: The vehicles shall be decommissioned using a procedure deemed appropriate by the Decision Authority. This process will be determined during the Reviews of the CDR, PRR, and SIR, which will be resolved by October 14, 2025.
3	Anomalies: Anomalies could occur while maneuvering the vehicles, using the winching system, communicating between vehicles and/or to the satellite, gathering and transporting samples, environmental factors, and possible overheating/overcooling. These factors will be tested and resolved after conducting System Testing in Phase D, with an expected resolution date of April 26, 2026.
4	Coordinates of Landing Site: The coordinates of our landing site have yet to be determined. The slope shall be less than 10 degrees, and the coordinates shall be within 5 km of the Mare Ingenii Pit. This will be resolved during the Reviews of the CDR, PRR, and SIR with a resolution date of October 14, 2025.