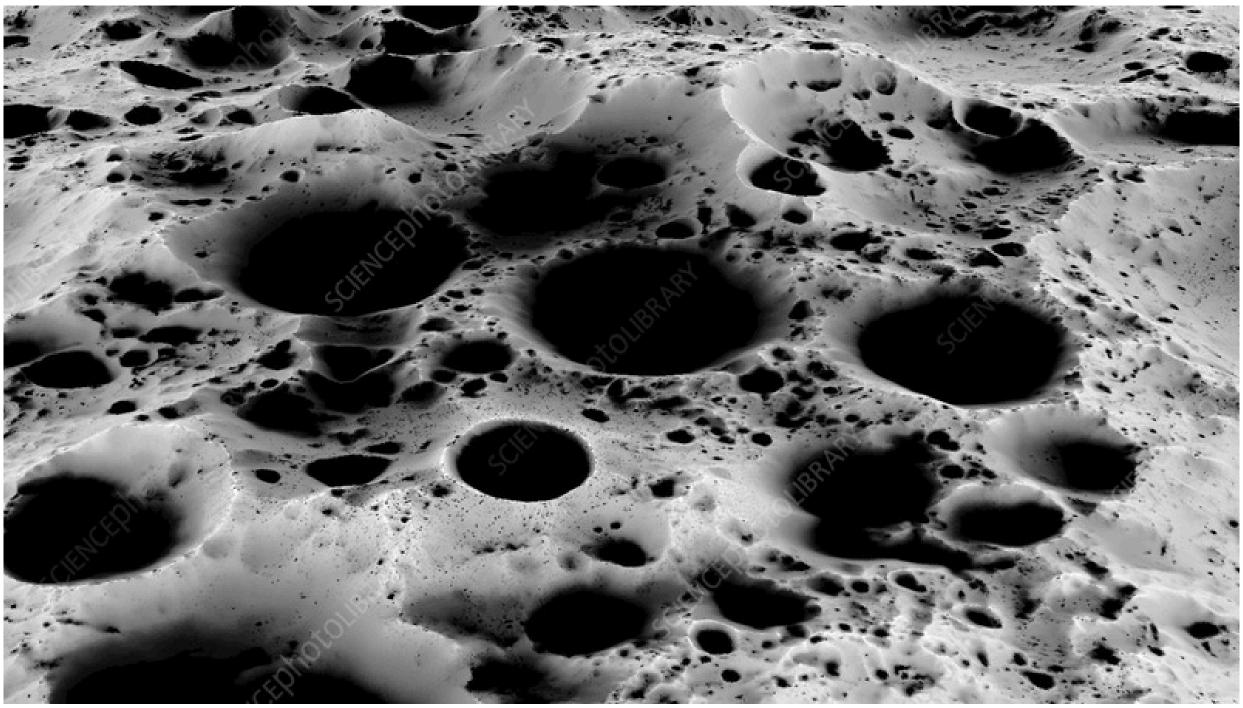
Selam Lunar Rover



Mission Definition Review (MDR)

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List of Acronyms

APXS	Alpha Particle X-Ray Spectrometer
ARC	Ames Research Center
cm	centimeter
CME	Coronal Mass Ejection
COTS	Commercial Off the Shelf
DC	Direct Current
DPMR	Deputy Project Manager for Resources
FMEA	Failure Mode and Effect Analysis
FY	Fiscal Year
GNC	Guidance, Navigation, Control
IMU	Inertial Measurement Unit
keV	Kilo electron Volt
LIDAR	Light Detection and Ranging
LOS	Line of Sight
LRO	Lunar Reconnaissance Orbiter
MCCET	Mission Concept Cost Estimation Tool
MIMU	Miniature Inertial Measurement Unit
MLI	Multilayer insulation
MPS	Modular Power System
nm	nanometer
NSS	Neutron Spectrometer System
OBC	On-board computer
OPM	Office of Personnel Management
OSHA	Occupational Safety and Health Administration
PPE	Personal protective equipment
PSR	Permanently Shadowed Region
RI	Reflective Index
SLC	Single-level cell
STM	Science Traceability Matrix
UHF	Ultra High Frequency
USD	U.S. Dollar

1. Mission Definition Review

1.1. Mission Statement

The Selam rover mission, named for the *Australopithecus afarensis* fossil known as "Lucy's Baby" and the team's recognition of mankind's status as Lucy's descendants who are "leaving the nest", has two science goals (Arneman 2006). The first mission goal is to determine the compositional state and distribution of volatiles such as water, hydrogen, and methane in the identified region "Nobile Rim 2." As an additional part of that goal, the mission aims to determine the state and composition encompassing elemental, isotopic, and mineralogic states as well as their lateral and depth distributions. This will be accomplished using a rover equipped with a drill for core sampling, which will increase scientific understanding of lunar polar volatiles within Nobile Rim 2's region and the distribution in comparison to other sites.

The second goal is to study the weathering of lunar concrete samples in the lunar environment. There are two parts to this goal: the study of combining Earth materials with lunar regolith and the study of the lunar environment's impact on pre-made concrete samples making use of lunar simulant. By performing these two studies, the scientific community will gain a better understanding of industrial applications of lunar regolith and simulants as well as performance parameters of concrete, with both Earth and Lunar materials, within Luna's permanently shadowed regions.

In combination the two science goals are stepping stones in Artemis's understanding of how mission sustainability on the moon may appear, as presence of water on the lunar surface may not only be used for human consumption, but also for the cooling of equipment, production of oxygen, and production of fuel (Williams, n.d.). Increased knowledge of volatile presence at the mission's site may allow for a more informed decision regarding where to conduct lunar research in the future due to presence of materials for processing into life support or required consumable materials such as fuel. The lunar concrete and control concrete undergoing evaluation also provides valuable insight into the building materials that may be used in tandem with Earth materials, as its exposure and final structural evaluation will allow a greater understanding of how such materials will fare in the lunar environment and which may be effective in future lunar exploration and construction.

1.2. Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
This mission aims to determinine the compositional state and distribution of volatiles in the identified region “Nobile Rim 2”, as well as to study the weathering and production of lunar concrete samples in the lunar environment.	Determine a method that utilizes a rover equipt with a drill for core sampling to identify the compositional state and quantity of lunar volatiles	Measure elemental, isotopic, and mineralogic resources at various depths and lateral distributions	Collect peaks of Na, Mg, Al, Si, Ca in the 500 - 750 nm range on each of the 6 core samples; one taken at each test site in the PSR	Wavelength Range:	500 - 750 nm	440 - 770 nm	Alpha Particle X-Ray Spectrometer (APXS)	Vehicle should maintain intrument position of <2 cm distance from scan target
				Integration Time:	3 hours	2 - 3 hours		
	Determine the water ice abundancy of Nobile Rim 2	Identify the Hydrogen (H) content of the lunar subsurface	Detect local and epithermal neutron flux at each test sites, as well as intermittently while traversing	Sensitivity:	0.5 - 1 w/w	0.5 - 1 w/w		Drill must collect a 2 cm diameter core sample for spectrometic analysis
				Spectral Resolution:	< 200 eV at 6.4 keV below ~ -5 deg C	< 200 eV at 6.4 keV below ~ -5 deg C		Vehicle will land within TBD meters of the designated landing zone within Nobile Rim 2 in the South Polar Region
	Determine the effect of the lunar environment on the chemical and physical structures of amples from Earth	Identify changes in mechanical properties and internal structures	Collect peaks of Si, Fe, Ca on each concrete sample; utilize tools to detect changes in tensile strength, density, permeability	Wavelength Range:	375 - 725 nm	350-750 nm	Neutron Spectrometer System (NSS)	
				Spatial Resolution:	20-30 nm	10 nm		Mission must collect TBD core samples at the 6 sampling locations
	Determine the feasibility of combining lunar regolith with Earth materials for future lunar concrete production	Identify chemical properties, mechanical properties, and physical performance	Collect peaks of Si, Fe, Ca on each combined concrete sample; Collect spectrometric data to detect new compounds	Integration Time:	1 s	1 s		
				Sensitivity:	0.5 wt% water-equivalent hydrogen	0.5 wt% water-equivalent hydrogen		Mission must collect TBD amount of Hydrogen samples throughout the traverse

Table 1. *Science Traceability Matrix*. Overview of mission objectives and science instrumentation.

The Selam mission aims to better understand the lunar composition of the Noble Rim 2 area through the objectives of developing a methodology that uses a rover equipped with a drill for core sampling to identify the compositional state (i.e. elemental, isotopic, mineralogical) of lunar volatiles. Studies like those by Kleinhenz et al. (2015) have demonstrated the efficacy of using drills for capturing volatiles in lunar regolith by minimizing loss during the collection process (2). Both Apollo and the more recent Lunar Reconnaissance Orbiter (LRO) missions show that there is an uneven distribution of volatiles due to reactions from drastically fluctuating temperatures between day/night. In addition to this, cometary impacts lead to introduction of new compounds, redistributed of original compounds, and reactionary phase fluctuations between compounds. By the development of a drill for core sampling, ground truth data can be created in order to more comprehensively understand the distribution cycles of these compounds in the region, and validate remote sensing data from previous missions.

The rover will be equipped with two instruments, the Neutron Spectrometer System (NSS) and the Alpha Particle X-Ray Spectrometer (APXS) that will aid in obtaining Selam's science. The NSS will utilize 375 to 725 wavelengths to detect hydrogen up to three feet into the lunar soil (National Aeronautics and Space Administration, n.d.). Once core samples are collected, the APXS will initiate a full 3-hour scan for Sodium, Magnesium, Aluminum, Silicon, and Calcium (Physical Research Laboratory, n.d.). They will also be combined with Earth concrete to observe the properties of lunar concrete. This is because if there has been a long-term presence of materials in lunar environments, there would be various forms of weathering on these structures. Regolith has been tested extensively which leads to reduced maintenance requirements. It is also possible to reduce the amount of upkeep of regolith as regolith varies in quality based on region. Some regions may have more advantages and may be able to prove better in some parameters. Regolith is already on the moon, so the need for transport to the moon is eliminated. Regolith will act as a temper within the composition of the concrete mix and the mission would like to see if it is effective as a building material within the lunar environment.

1.3. Mission Requirements

Design constraints and parameters of the spacecraft were given by the customer. Adherence to the following constraints is necessary and will outline the mission's overall requirements. With regard to mass, the rover shall not exceed a total of 85 kg including instrumentation. This includes samples collected during the mission. The vehicle itself, in its undeployed configuration, cannot exceed a volume of Length 1.5m x Width 1.5m x Height 1.5m. These two constraints cannot be exceeded under any circumstance due to the constraints of the primary launch vehicle.

The given budget for the mission is a total of $175M over the entire lifecycle of the mission and the rover must be ready for launch by September 1, 2028. The rover must be able to complete the mission's science objectives with a maximum of two scientific instruments. Any radioactive material used cannot exceed a maximum mass of 5g and the use of Radioisotope Thermoelectric Generator is prohibited. Furthermore, the mission lifespan requires the rover to operate for 180 days.

The power system serves to provide adequate power for the rover to complete the concepts of operations. To prevent short circuiting, the maximum power output at any given time through the power distribution board is 39.9 Watts. The power system will continue to power all necessary components to complete the mission utilizing solar power and a rechargeable battery.

Lastly, the rover's OBC will communicate with the moon orbiter to transmit science data from Selam at a rate of 2Mbps at most.

These requirements serve to guide the creation of the rover while maintaining within various constraints. Overall, the requirements will allow the team to complete science missions without risking mission cancellation or exceeding limitations.

Mission Requirements							
Req #	**Requirement**	**Rationale**	**Parent Requirement**	**Child Requirements**	**Verification Method**	**Relevant Subsystem**	**Requirement Met?**
Mission Requirements							
MR-1	The vehicle shall not exceed a cost of $175M.	Provided by Mission Document.	Customer	MEC-1, EPS-1, PAY-1, PAY2, CDH-1	Inspection	All	Met
MR-2	The vehicle shall be ready for launch by September 1st, 2028.	Provided by Mission Document.	Customer	MR-6, MEC-1, EPS-1, PAY-1, PAY2, CDH-1	Demonstration	All	Met
MR-3	Science objectives shall be achievable with no more than two science instruments	Provided by Mission Document.	Customer	PAY-2	Inspection	Payload	Met
MR-4	The vehicle shall not have a Radioisotope Thermoelectric Generator (RTG) or any derivative thereof.	Provided by Mission Document.	Customer	EPS-1	Inspection	Electrical Power System	Met
MR-5	Any radioactive material used for other spacecraft systems shall not exceed a cumulative mass of 5 g.	Provided by Mission Document.	Customer	MEC-1, EPS-1, PAY-1, PAY2, CDH-1	Inspection	All	Met
MR-6	The system shall have a mission lifespan of 180 days.	The mission necessitates this minimum amount of time to acquire sufficient data to satisfy the mission objectives.	MR-2	MEC-1, EPS-1, PAY-1, PAY2, CDH-1	Demonstration	System	Met

Mission Requirements (cont.)							
Req #	**Requirement**	**Rationale**	**Parent Requirement**	**Child Requirements**	**Verification Method**	**Relevant Subsystem**	**Requirement Met?**
Mechanical Requirements							
MEC-1	The vehicle shall not exceed a volume of Length 1.5m x Width 1.5m x Height 1.5m.	Provided by Mission Document.	MR-1, MR-2, MR-5, MR-6	TBD	Inspection	Payload	Met
Electrical Power System (EPS) Requirements							
EPS-1	The power system shall provide ample power to maintain operating conditions for the duration of the mission.	A certain amount of power will be needed to ensure all systems in the rover are operational.	MR-4, MR-6	EPS-1.1	Inspection	Payload, Command & Data Handling	Met
EPS-1.1	The system shall not exceed a power output of 40 W at a given moment while the rover is deployed.	A certain power output is needed to ensure systems are not damaged due to electronic failure.	EPS-1	TBD	Inspection	Payload, Command & Data Handling	Met
Payload Requirements							
PAY-1	The vehicle shall not exceed a total mass of 85kg.	Provided by Mission Document	MR-1, MR-2, MR-5, MR-6	TBD	Inspection	Payload	Met
PAY-2	The system shall integrate scientific instruments to complete scientific objectives.	Scientific instruments will allow for data to be collected to fulfill scientific objectives.	MR-3	TBD	Test	Payload	Met

Mission Requirements (cont.)							
Req #	**Requirement**	**Rationale**	**Parent Requirement**	**Child Requirements**	**Verification Method**	**Relevant Subsystem**	**Requirement Met?**
Command & Data Handling (CDH) Requirements							
CDH-1	The system shall send data to the orbiter.	Allow for data to be analyzed after being collected.	MR-1, MR-2, MR-5, MR-6	CDH-1.1	Test	CDH	Met
CDH-1.1	The system shall transmit data at a rate of at least 2Mbps.	Ensures that the orbiter can receive data during communication windows	CDH-1	TBD	Test	CDH	Met

Table 2. *System Requirements*. List of mission requirements, parent and children requirements, and their statuses.

1.4. Concept of Operations

Figure 1. *Concept of Operations.* Overview of Selam's 180-day mission plan.

The team's chosen system architecture for this mission is a lunar rover. The mission will begin with the lunar rover landing in the Nobile Rim 2 region which has been assessed to support the impact of vehicles landing during preparation for the VIPER mission. The rover will be deployed from the launch site to the first designated location where it will perform a systems check including instrument, telemetry, and communications calibration. The rover will also ensure it is completely charged, as it will not be able to charge inside of the PSR.

The rover will then begin a six-stage cycle of three phases. The first phase is ten days long, beginning at T+ 2 days. Firstly, it will traverse into the PSR, averaging 0.02 m/s, until it reaches the first science research site. This traverse is 1 - 2 km on average. The rover is expected to slow throughout the night and when traversing rough terrain to a TBD speed. Throughout the traverse, the rover will take intermittent NSS measurements. The NSS has an integration time of one second, so it can be conveniently utilized to obtain a broader scope of data.

The second phase occurs within the PSR, and will last one day. This phase aims to gain science regarding the presence of volatiles and their concentration below the surface, as well as the effect of the lunar environment on concrete samples. The NSS will take a TBD number of NSS measurements using a 375 - 725 nm wavelength. The drill will receive a 2-cm diameter core sample, and then the rover will extend the APXS within 2 cm of the sample to initiate a 3 hour sample period. It is TBD if the rover will collect multiple samples at certain test sites. The rover will go to sleep during this time to conserve energy. The rover will continuously expose the lunar simulant concrete samples to the lunar environment while gathering samples required to accomplish other research goals. The analysis of the lunar simulant concrete samples will occur toward the end of the mission following the exposure. The samples contain a variety of lunar simulants to be tested with criteria such as durability in extreme temperatures in comparison to typical concrete samples using solely Earth materials.

The third and final phase is around 15 days long. The rover first goes into Traverse Mode, similarly to Phase 1, as it moves out of the PSR and to its next respective site where it can recharge. Data collected regarding the composition of regions or abundance of water or other volatiles will then be transmitted in a fixed window of time (TBD) to an orbiter with a data rate of at least 2 Mb of data per second, which is based on the lower level CDH Communication subsystem requirements. This data will then be sent to Earth where it will be stored and later analyzed. Finally, the rover will go to sleep for 3-hour recharge periods in preparation for its next traverse into the PSR. These three phases should take approximately 30 days to complete and will repeat for all six test sites until End of Life at T+ 180 days.

Figure 2. Front-facing view of the model of the concept rover.

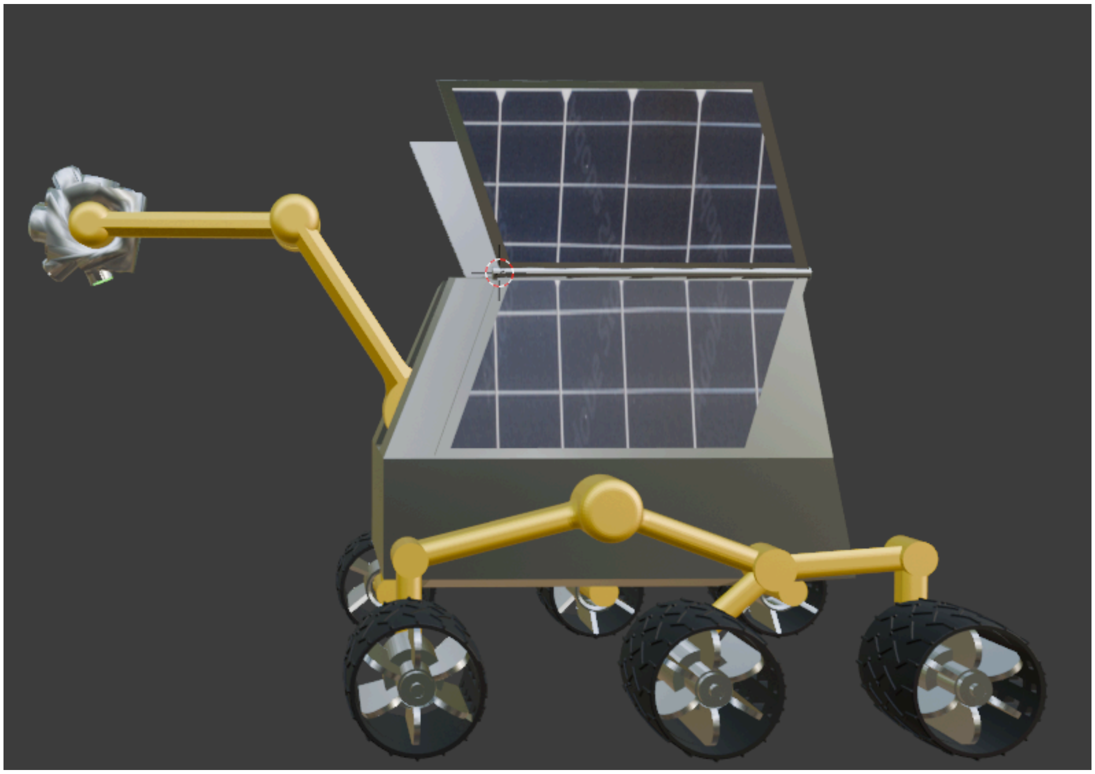

Figure 3. Side view of the model of the concept rover.

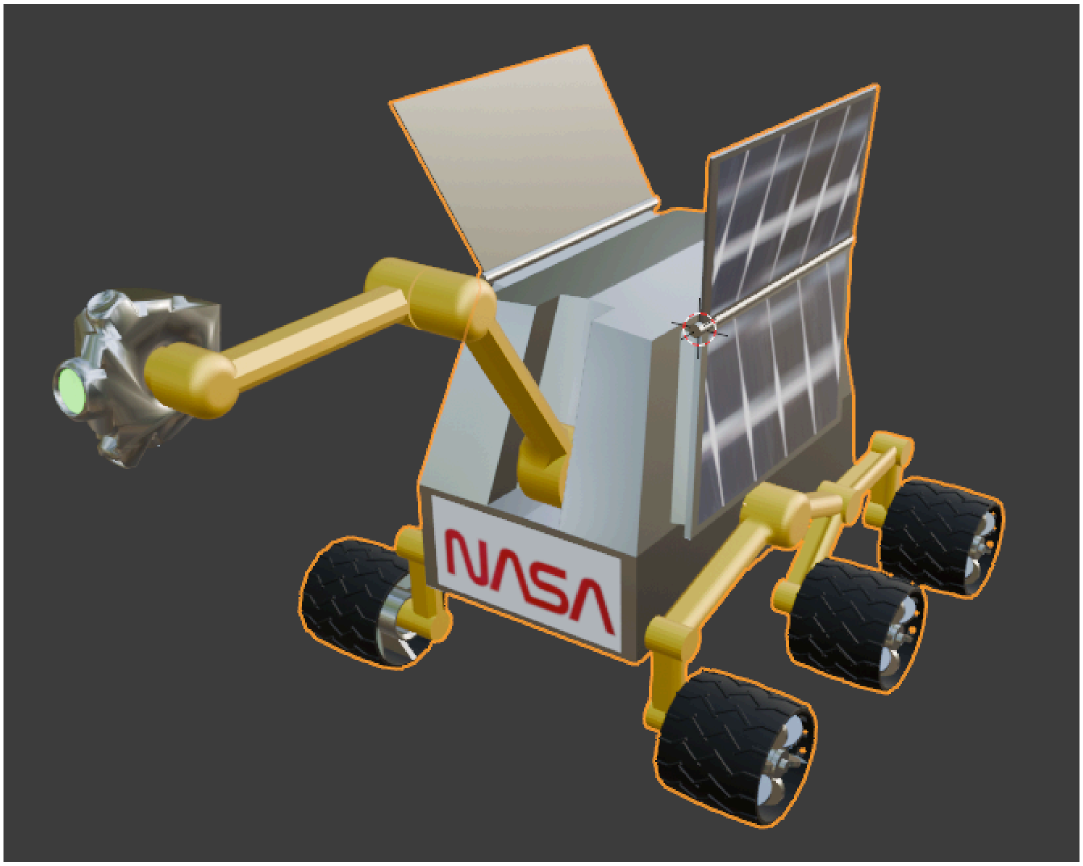

Figure 4. Isometric view of the model of the concept rover

The images above show preliminary sketches of the compacted version of the rover. The preliminary design above has dimensions of 1.5m x 1.5m x 1.5m in volume. This complies with the volume constraint given by the customer. The sketch includes two sets of foldable solar panels, the arm would be where the soil analysis would happen. A system of gathering soil is still being designed and is not included in this sketch.

1.5. MCA Team Management Overview

Team Selam’s structure is divided into three levels: Leadership, Functional Division, and Individual Role Groups. This is done in the Process-Based Organizational Structure, with the head of each subgroup reporting to the supervisor of the superior group. Major decisions are collaboratively discussed and voted on with the Project Manager, maintaining override authority. Tasks are divided and assigned to relevant groups based on technical requirements and availability of manpower.

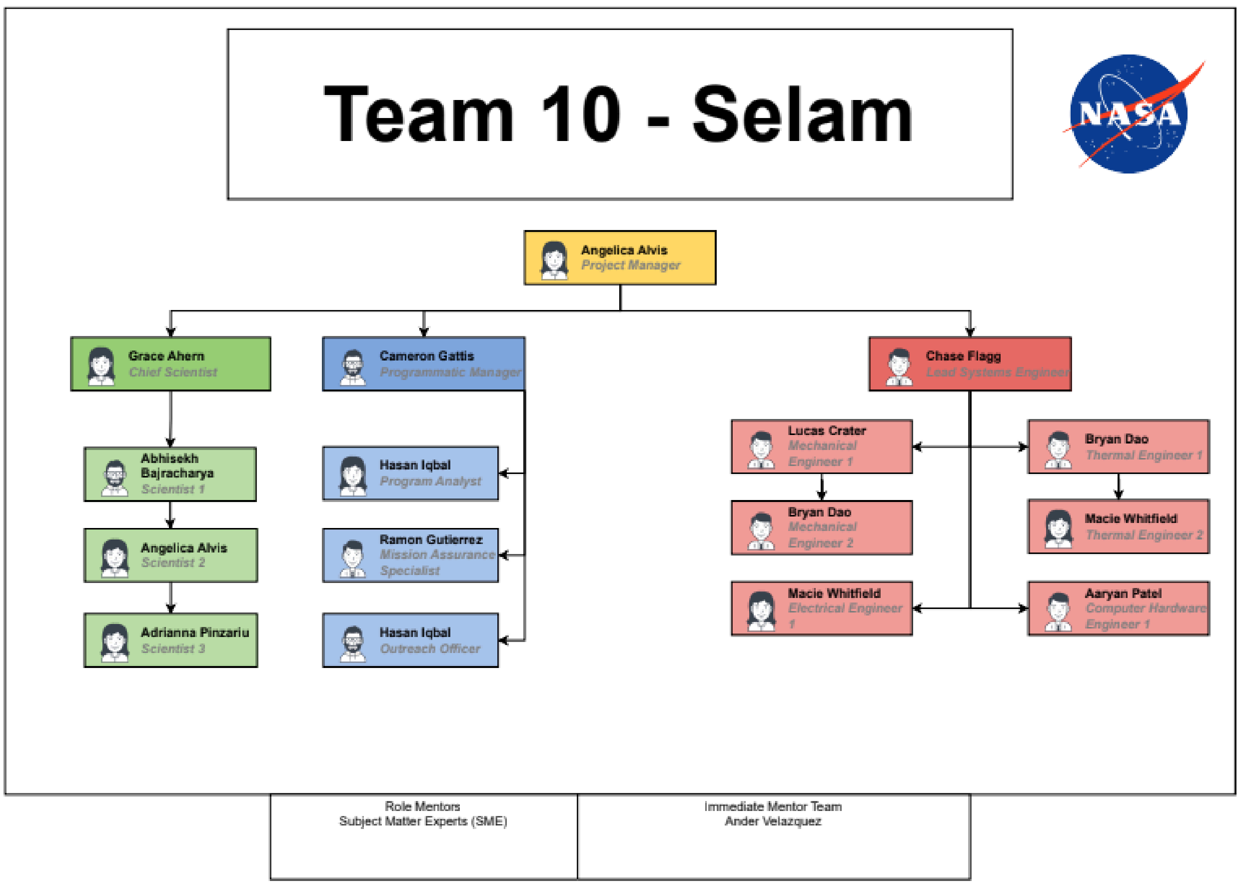

Figure 5. *Team Selam Organization Structure.* The organization is divided as above into various teams and cylinders of excellence.

As the core team has lost three personnel, and some personnel are less involved than others, which has created some difficulties that have had to be addressed within the team. When the team loses a team member, the remaining personnel in that Functional Division divide up the tasks which would have been assigned to that individual. In the event a team member does not provide the involvement necessary to complete a task up to the standard of leadership, leadership has stepped in and corrected the oversights, sometimes with the help of other Functional Divisions.

A budget cut of approximately 20% of the total budget also created an opportunity for Selam's mission members to flex innovation, communication, and adaptability. Each leader for every single Functional Division and Individual Role Group created a list of items that could perform similarly to the original, albeit with slightly less functionality, which would save costs. Leadership coordinated and discussed increases in risk which would and would not be acceptable while still ensuring mission success. Finally, each group discussed and agreed upon personnel reductions, which would save operating costs.

With all of these skills which have already been leveraged with the Selam mission, the team stands ready to move forward and see this mission to a successful completion. It has already demonstrated the flexibility, innovation, and strength to build out a mission on time, on budget, and on goal.

During this instance of difficulty, the Selam team was able to negate conflict and remain level-headed. However, the team still found it necessary to discuss how they prefer to address conflict. Overall, the team determined honesty and forwardness was crucial to resolving the conflict. The team has also experienced conflict with teammates not responding to messaging. Team leads have responded to this with added communication and clear expectations. In conclusion, the team has continued to work through these obstacles and worked to resolve all conflicts with communication.

1.6. Project Management Approach

With movement into Phase C, personnel will increase and this will necessitate a change in structure. While Selam will retain the three sections, they will become departments due to change in the amount of personnel, responsibility allocated, and increased oversight requirements. Department Heads will retain authority for hiring, termination, and allocation of personnel within assigned limits, subject to appeal for an exception to policy presented to and approved by the Project Manager. They will be allotted a working budget outside of equipment and personnel costs out of the margin funds and will have authority to spend it as required up to a certain amount before approval of the Deputy Project Manager for Resources (DPMR) is required to reassess budget concerns with their administrative team, which would then be presented to the Project Manager and Customer, if required.

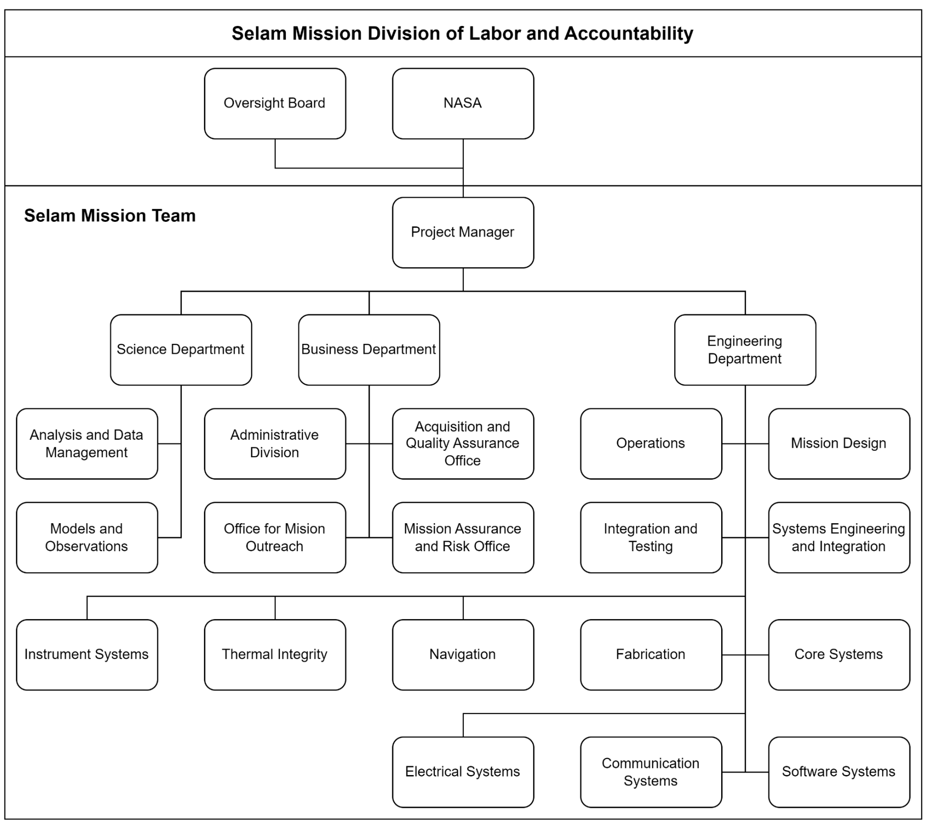

Figure 6. *Selam Mission Full Team Layout*. Overview of Selam's Department and Division structure.

The Science Department will consist of three personnel and two offices: Analysis and Data Management, and Models and Observations. Analysis and Data Management will be responsible for processing and archival of data generated during Phases C-D with the added requirement of dissemination and reporting during Phases E-F. Models and Observations will work with experts to model paths for the rover, ensure temperature and slope design ranges are validated, and be the scientific representative for outreach. The Chief Scientist will have, in addition to the previous authorities, the ability to change out scientific instrumentation to meet any changes in objectives or availability up to 120% the value of the instrument being replaced. Additionally, the Chief Scientist will act as the de-facto head

The Business Department will consist of four subgroups consisting of eight personnel which includes one management individual. The Office for Mission Outreach will consist of 3 personnel, of whom will develop and conduct the outreach operations for the mission. The Mission Assurance and Risk Office will consist of two personnel, provide risk analysis, coordinate risk mitigation and acceptance, and meet with other departments, outside experts, and the customer to make sure this is accomplished. The Acquisition and Quality Assurance Office will consist of a single person who will act as the mission’s purchasing agent, testing and validation coordinator, and as the business partner point of contact. The Administrative Division will comprise the rest of the personnel and will be responsible for pay and leave, benefits, travel, clearances, and any correspondence between outside agencies. The DPMR will function as the Department Head for the Business Department and will retain control and override authority on budget items in conjunction.This in turn will supervise financial obligations with the Project Manager.

The Engineering Department will consist of the majority of the personnel and offices with the mission. The majority of the twelve personnel will be broken into seven functional offices based around specific systems such as thermal and communications, as well as others. The Systems Engineering and Integration Office and the Integration and Testing offices will work with system teams and outside partners respectively to develop, test, and integrate systems into the Selam rover. Mission Design will work with the Science Department to set technology goals to meet mission requirements and with the Mission Assurance and Risk Office to mitigate risks and formulate a plan forward. The Operations Team will stand up during the later part of Phase D and work through the end of Phase F; they will be responsible for conducting actual operations and shutdown in conjunction with other facilities. The Chief Engineer will be responsible for the entirety of the department with an assistant management person to oversee the breadth of the requirements. They will also retain authority 25% of the annual budget margin to ensure mission development continues to occur on the correct timeline.

1.7. Manufacturing and Procurement Plans

Battery Storage

For energy storage, originally the B28-1100 Satellite Battery, 28-Volt Modular Battery (8S8P), was selected due to its large capacitance, minimum weight, operating power range, volume, autonomous heating system, etc. (satsearch, n.d.).

Due to budget restraints, the refined selection is the lesser storage version of this battery, the B28-825 Satellite Battery. The battery had the same features making it an optimal choice while minimizing cost. The lead time is 2 to 5 months.

If Ibeos is unable to produce the first two batteries, NanoPower BP8 by GOMSpace is another feasible option (GOMspace, n.d.). This option was another more cost effective choice which had a significantly lower mass, a two-stage battery passivation system, autonomous heating system, and still had adequate storage for the Salem mission. The lead time for this item is estimated to be 6 months as it is an off the shelf, unmodified component.

Power Distribution

For power distribution, the E28-200 was ultimately selected due to price constraints (Satsearch 2024). Originally, the Modular Power System (MPS) was selected, but due to its greater mass, volume, cost, etc. it was decided the simpler version (E28-200) would be adequate (satsearch 2024).

The E28-200 will convert the solar power and provide regulated 3.3, 5, and 12 V power in addition to unregulated 28 V battery power (Sat search, n.d.). The system contains I2C and SPI directives, regulations, and metrics handling interfaces in addition to under/over-voltage and over-current protection.

In the case this product is no longer viable, the MPS may be reconsidered or the VOLTA 1281 may serve as a valid supplement as it has many similar features (Argotec, n.d.). The lead time on these products is once again assumed to be approximately 6 months as the products are coming off the shelf, unmodified.

Power Generation

The 2NDSpace CORE-16, a 16U lateral solar panel, will generate renewable energy for the Salem mission. With an integrated thermal sensor and coarse sun sensor and averaging 30% efficiency, the 2NDSpace panels will produce 894.7 W, resulting in the battery charging in 2.22 hours assuming adequate solar rays. The panels will be deployed in a 1.5 by 1.5 meter region to maximize intake. These panels will be purchased off-the-shelf and will not be modified; likely resulting in a lead time of approximately 6-12 months.

Given this option fails, the secondary choice is Rocket lab's ZTJ. Optimized in low temperature environments and ready off-the-shelf, this product will be easily obtainable and suitable for this mission. Lead times are expected to range from 6-12 months as no in house modifications will be made. The structure for the solar panels will be the only additional time and was estimated to take less than an additional 12 months.

Guidance Navigation & Control

The LN-200S Inertial Measurement Unit (IMU) manufactured by Northrop Grumman was selected due to its reliability and its extensive flight heritage. Northrop Grumman specializes in space systems and defense and has a vast history working with NASA and in the space industry. The LN-200S has flown on many Mars missions including Spirit, Opportunity, Curiosity, and Perseverance. The LN-200S has proven to be reliable during these missions which can be attributed to its use of solid state components. Northrop's Navigation Systems Division is located in Woodland Hills, California and Northrop also has a development site for navigation, targeting, and self-protection in Rolling Meadows, Illinois. An IMU falls under the navigation divisions of both of these sites and is unclear where the component will be sourced from. Given that Team Selam is located at Ames Research Center (ARC) in Mountain View, California, it is assumed that the IMU will be sourced from Illinois in order to estimate the worst-case scenario lead time. Taking into consideration these parameters along with lead times from other IMU manufacturers, the estimated lead time of the component is 6 months.

In the event that the LN-200s IMU cannot be vended, the Miniature Inertial Measurement Unit (MIMU) from Honeywell Aerospace has been selected as the secondary contractor. This manufacture is also located within America, limiting its lead time in addition to the fact it currently needs no modifications. Lead time is estimated to be 6 months.

GSFL-16K 3D Flash LIDAR™ Camera manufactured by Advanced Scientific Concepts LLC was selected for the Selam Rover due to its high range of 1km and its ability to image through dust and total darkness. Advanced Scientific Concepts LLC invented and specializes in global shutter flash LIDAR and its wide range of applications, including space. They have worked to provide such technologies for NASA missions before, such as the OSIRIS-REx mission. However, this exact camera model has not flown on any missions, but it is manufactured as space grade, allowing the product to come unmodified and off the shelf. Since Advanced Scientific Concepts LLC is based out of the Santa Barbara, CA area, the estimated lead time for this component is 6 months with all parameters considered.

Structure

For the internal Nomex Honeycomb Core, Composite Envisions has been selected as the manufacturer. Composite Envisions has more than 30 years of experience working with space grade composites. Composite Envisions specializes in lightweight, high strength composites that are ideal for ensuring structural stability while keeping payload capacity in mind. The Nomex Honeycomb Core would be internal to the rover at a 25.4 mm thickness to provide ample structural strength for the rover. The expected lead time of the internal Nomex Honeycomb Core structure is 1 month. Alternative structural components that were researched for the rover include carbon fiber. Carbon fiber is another high strength, low weight composite that is fantastic for structurability.

TW Metals was selected as the manufacturer for the aluminum faceplates external to the rover. This manufacturer was chosen because they have been in business for over 100 years and have been known for responsive service and sound advice. TW Metals provides Aerospace grade aluminum that would be ideal for the external panels of the rover. The aluminum being used is Aluminum 6061 which is a very versatile, lightweight, medium strength alloy. The Aluminum 6061 sheets to cover the exterior of the rover will be 3mm in thickness to provide sufficient structural support to the rover. The expected lead time for the aluminum faceplates is 1 month.

Mobility

Maxon Group was selected to provide all the motors of the rover. Maxon specializes in customized electric drives ranging from biomedical applications to aerospace. These COTS motors were configured on the products website to provide the required torque and power needed for the mission. Maxon motors have flown on NASA missions before such as the Perseverance and Curiosity Rovers. Due to Maxon being based in Switzerland, and the product being currently out of stock, estimated lead time is 4 months.

Insulation

Sheldahl has been selected as a contractor to supply the materials for the multilayer insulation (MLI) of the spacecraft. Sheldahl was selected due to it's extensive experience developing in MLI materials which have flown on many NASA missions. Based out of Minnesota, Sheldahl specializes in engineering films, tapes and thermal coatings. As a secondary manufacturer, Dunmore Aerospace was selected to provide MLI materials. Dunmore specializes in providing films, foils, and fabrics for thermal control purposes. Similar to Sheldahl, Dunmore has an extensive history with NASA, providing thermal control materials for many spacecraft. Dunmore headquarters is located in Bristol, Pennsylvania.

The MLI itself will be fabricated at Kennedy Space Center's Thermal Protection System Facility (TPSF). The TPSF fabricates MLI blankets for NASA and commercial blankets. In general, they specialize in design, analysis, testing, and manufacturing of thermal control systems.

The fabrication of MLI necessitates the need for a dedicated clean room that qualifies as a Class 100,000. Any surface that may come into contact with the MLI blankets should be cleaned and workers should be dressed in laboratory smocks (Gilmore 2002, 198). Due to the complexity of the fabrication of MLI and the procurement time of the materials, lead time is estimated to be greater than 10 months.

Heaters

The manufacturer for the heaters for the rover is OMEGA. OMEGA has over 60 years of experience in thermal components. Several heaters will be required internally to the rover to ensure that all components are within their respective temperature ranges. These heaters are Commercial off the shelf which allows for fast procurement for the rover. The expected lead time for the heaters is 2 months.

For internal thermostats, Honeywell was chosen as the manufacturer. Honeywell is a reputable company that has worked with NASA for several decades. Several thermostats will be needed to monitor the internal temperature of the rover. The thermostats will also be used to control the heaters. The expected lead time for the thermostats is 3 months.

Thermal Surface Finishes & Paints

The rover utilizes aluminized kapton tape on external surfaces that are of similar materials to the MLI previously mentioned. Due to this the same primary and secondary manufacturers, Sheldahl and Dunmore are being selected. Due to the sensitivity of the indium tin oxide coating on the kapton, the film must be carefully applied. Since these are being ordered directly from the manufacturers, lead time is estimated to be 3 months.

The radiator surface of the panel will be painted with a white paint developed by the Illinois Institute of Technology Research Institute (IITR). The matte white paint, S13GP: 6N/LO-1, has been used on NASA missions before and presents attractive absorptivity and emissivity values for the rovers specific thermal control system.

On Board Computer

The RAD5545 SpaceVPX will support the rover, as it comes off the shelf, needing no modifications. The manufacturer BAE Systems will produce the product with no alterations. The delivery time will be minimal as it is in the U.S.. It is possible the product will need to be tested within extreme vibration and temperature conditions prior to mission. Considering these factors, the lead time is estimated to be 12-18 months.

The secondary manufacture choice is VersaLogic Manufactures. This company adds flexibility as it is capable of creating modified versions of the product. The company is also based out of America, limiting lead times.

Data Storage

The SLC NAND flash memory will be used to store data before communication with the orbiter and Earth. Two possible manufacturers include Kioxia and Micron, both based in America. Whichever producer can supply the piece for less money or quicker will be selected while the other will be considered the secondary supplier. There are currently no in-house modifications needed, and the product will be purchased off-the-shelf. The piece will require testing for extreme, cold temperatures adding to its lead time which is estimated to be 12-18 months.

Science Instrumentation

The Alpha Particle X-Ray Spectrometer has been utilized on the Sojourner, Curiosity, Chandrayaan-2 mission and recently used on the Chandrayaan-3 mission. For the former, creation of the instrument was slow, likely over 3 years, as the team were tasked with creating the design. The latter had a shorter lead time as it was based on the previous APXS, possibly 3 years. These numbers were estimated based on various sources discussing design start times and testing dates. Numbers could easily vary up to (plus or minus) two years. Given this information, the APXS will be expected to be produced by MDA Space within 2 years. Chandrayaan-2 was designed for the South Pole region, so it should need minimal modifications. Materials are theoretically more readily available than previously which will minimize manufacturing time (for Chandrayaan-2, the materials were not easily available causing slower development times).

The Neutron Spectrometer System's lead time is estimated to be 18 months based on VIPER's lead time. For VIPER's NSS, the critical design stage began in April 2020 and the final Rover Integration and Testing ended in October 2021, a span of 18 months (NASA Ames Research Center, 2024). VIPER experienced many setbacks due to COVID-19, so it is possible lead times could be further decreased. Lockheed and

AMES Research Center previously worked together to create the NSS, so optimally they will once again manufacture this product for the Salem Mission.

1.8. Risks and Safety

1.8.1. Risk Analysis

The Selam Mission currently has 24 active risks to mission, craft, and personnel. Two of the risks are being accepted by mission leadership, six risks are being researched for possible mitigation or resolution and the remaining sixteen risks have mitigation plans in place. Below is the table containing an overview of risks followed by explanatory paragraphs with amplifying information, mitigations, and plans. Risks were identified utilizing OSHA documentation, NASA Safety Office documents, and the Risk-Informed Decision Making process.

Selam Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Radiation	5	3	→	M	Radiation damages electronic components	Active
2	Very Low Temperatures	5	2	↓	R	Failure of motor and electrical components	Active
3	Regolith (grit)	5	3	→	M	Damage to open and mobile sections due to abrasion	Active
4	Low Light Conditions	5	3	→	R	Obstructions inhibit operations	Active
5	Static Build Up (Regolith)	2	2	→	M	Discharge damages electronics	Active
6	Moonquakes	1	5	→	A	Catastrophic collapse damages rover	Active
7	Planetary Protection	1	3	↓	R	Transport of contaminants to mission location	Active
8	Angle of Incidence of Solar Rays	5	2	New	M	Failure to charge batteries causes loss of operation	Active
9	Onboard Computer Failure	1	5	New	R	Failure causes potentially total loss of operation	Active
10	Single Wheel or Motor Failure	1	3	New	R	Failure may cause loss of fine control of rover.	Active
11	Dust on Solar Panels	2	4	New	A	Dust will impair efficiency of solar collection	Active
12	Thermal Systems Failure	1	4	New	M	Thermal Controls failing cause inability to maintain temperature ranges for equipment and mobility	Active

Selam Risk Summary (cont.)							
ID	**Summary**	**L**	**C**	**Trend**	**Approach**	**Risk Statement**	**Status**
13	Terrain Hazards	2	3	New	M	Terrain hazards cause damage to wheels, chassis, and instruments.	Active
14	Solar Deployment Failures	1	5	New	R	Failure to deploy will cause mission to be unable to recharge batteries	Active
15	Chemical	1	4	New	M	Chemicals cause corrosions and injury	Active
16	Cryogens	2	4	New	M	Cryogens cause injury and embrittlement.	Active
17	Electrical	2	4	New	M	Discharge damages electronics and causes bodily harm	Active
18	Fire	1	5	New	M	Fire causes bodily or component damage	Active
19	Heavy Machinery	1	5	New	M	Heavy machinery accidents cause damage and injury	Active
20	Noise	4	1	New	M	Prolonged loud noise damages hearing	Active
21	Sharp Items	1	2	New	M	destroy components and cause fatalities.	Active
22	Slips, Trips, Falls	1	4	New	M	destroy components and cause fatalities.	Active
23	Sterilizers	1	3	New	M	destroy components and cause fatalities.	Active
24	Vehicle Accidents	1	5	New	M	destroy components and cause fatalities.	Active

Table 3. Risk Assessments. Risk summary created based on NASA parameters and OSHA definitions.

Risk Criticality Matrix

LIKELIHOOD					
5	6, 9, 14, 18, 19, 24				
4	12, 15, 22	11, 16, 17			
3	7, 10, 23	13			1, 3, 4
2	21	5			2, 8
1				20	
	1	2	3	4	5
	CONSEQUENCES				

Table 4. Risk Criticality Matrix. Matrix based on Risk Table.

As the landing locations are lunar, and there is no magnetosphere, radiation presents a concern for the operability and survivability of the rover. There will be constant solar wind radiation, as well as the possibility of intermittent CME-related radiation and galactic cosmic rays (Vaniman et al. 1991). In spite of the hazard toward instrument uptime and overall function of the rover, these same aspects are desirable for the purpose of accomplishing the team’s second goal of studying the weathering of lunar concrete samples in the lunar environment. Radiation hardening on the system level where required prior to launch will aid radiation mitigation (Ladbury 2007, 3). In addition to the radiation hardening, the rover's presence within the PSR causes it to avoid direct LOS from the sun, providing some additional mitigation while in that zone.

While the rover's operation area within a PSR offers it some protection from radiation, the reduced solar exposure results in lower temperatures that present a hazard to the craft and equipment. Nobile Crater's average temperature near the selected landing zone within the PSR is less than 50K and between 125K and 175K along the crater rims (Schorghofer and Williams 2020, 10). This issue will be mitigated by radiation hardening of craft systems.

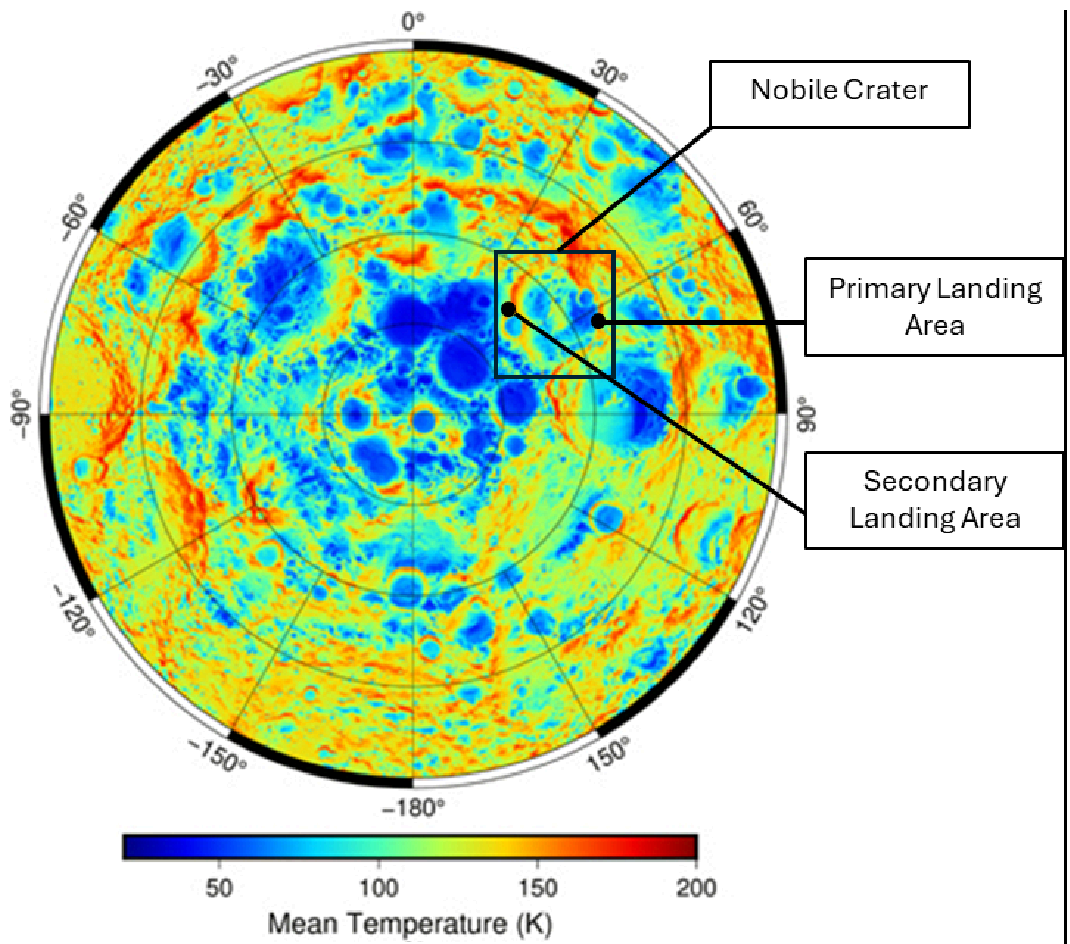

Figure 7. *Average Temperature of Lunar South Pole Surfaces*. The map shows the temperature average gradients for multiple lunar craters, showing the vast difference in temperature averages from the PSRs. (Schorghofer and Williams 2020, 10)

Surface dust, known as regolith, is a 45 μm to 100 μm "sharp and glassy" silt-like sand (Vaniman et al. 1991, 34). This dust can cause an electrostatic buildup and interfere with instruments. Additionally, due to its fineness, regolith has the potential to accumulate on the lander as time progresses, reducing its efficiency and lifetime. This issue will be mitigated by nonconductive construction and sealing.

The PSR's inherent very low-light conditions will cause potential risk during the landing phase at the landing site. This issue is yet to be resolved. The slopes of Nobile Crater, for both the primary and secondary landing sites, have an RI of greater than 0.5 (Magaña et al. 2024, 5-8). However, between the two sites, the Primary Landing Site has slopes measured at less than 10 degrees, while the Secondary Landing Site has measured slopes in excess of 10 degrees. The high surface RI could also potentially block the line of sight of the lander's instrumentation. These issues are mitigated by the mission being an immobile lander, thus making the slope traversal irrelevant. Line of sight issues are still being worked on at this time; however, due to the lack of high-resolution imagery, RADAR mapping, or surface scans, this problem cannot be thoroughly mitigated.

Static charges from regolith can interfere with sensitive electronics. When the moon travels through a cloud of electrical activity, the regolith is imparted with a static charge that can spark on the lander (The National Informal STEM Education Network, n.d.). These charges can be in excess of 1,000 volts (Ball 2024). This issue will be mitigated by nonconductive construction and sealing.

As the moon's core cools and shrinks, the above-ground settles causing moonquakes (Steigerwald 2024). This jostling can damage loose fittings, mobile parts, and dislodge rocks, causing slides that could damage the lander (Feehly 2023). Compared to earthquakes, moonquakes are on a similar scale, only with a longer duration. Because they are on a similar scale, technologies that have been developed on Earth can be incorporated to withstand moonquakes. Both automotive and buildings are developed to be able to absorb shock waves. Such absorbing technologies include thick blocks of rubber to reduce the overall stress the building encounters.

Planetary protection is a central aspect of NASA missions, to protect bodies within the solar system from cross-contamination. Given the clean construction environment, the transportation risk of Earthborn organisms is minimal, and as the mission will not return any samples to Earth, there is zero chance of contamination from Luna to Earth.

As the angle of incidence of solar rays is near perpendicular to the mission location, it poses a near certain minor risk to the mission. The angle of incidence can cause failure to recharge onboard batteries by not impacting optimally, causing loss of function by loss of power. Engineering will mitigate this risk by side-mounting the panels onto the rover at a near perpendicular angle.

Additionally, failure of the on-board computer (OBC) poses a very unlikely yet catastrophic risk to the whole mission. OBC failure can cause loss of control of the rover, which can snowball into loss of communication, loss of recharge capability, loss of movement, or any other action the rover is capable of. Per the Chief Engineer, this risk will be researched further for a risk management plan.

In terms of the single wheel or motor failure a very unlikely moderate risk to mission and equipment exists. Single wheel or motor failure can cause damage to rover mobility, which can cause a systems cascade due to immobility. Per the Chief Engineer, this risk will be researched further for a risk management plan.

Since there is a Dust on Solar Panels poses an unlikely severe risk to the rover. Dust on Solar Panels can impede functionality of solar cell collection, increasing the time required for recharge of batteries. The Project Manager has chosen to accept this risk likelihood and resource requirements.

Thermal systems failure poses a very unlikely severe risk to mission equipment. Loss of thermal control can cause runaway heating or cooling depending on the rover’s location and operating status. The Chief Engineer has chosen to accept this risk, low likelihood and resource requirements.

Terrain hazards pose an unlikely moderate risk to the rover. Terrain Hazards can cause damage to components and navigational issues which could cascade into power issues if obstructions are bad enough. GNC will mitigate this risk by terrain mapping ahead of rover path and levy orbital resources when available to ensure path viability.

Additionally, failure of solar cells to deploy pose a very unlikely and potentially catastrophic risk to the mission as a whole. Solar deployment failure would significantly inhibit recharge ability of the Selam rover, leaving the mission effectively dead in the water. Per the Electrical Engineer, this risk will be researched further for a risk management plan.

Risk by Subsystem															
Subsystem	Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mechanical	Locomotion		X	X			X	X		X	X		X	X	X
	GNC				X	X	X	X		X			X		X
	Chassis		X	X			X	X						X	
	Rocker		X	X			X	X						X	
Payload	Alpha Particle X-Ray Spectrometer (APXS)	X	X	X		X		X		X			X		X
	Neutron Spectrometer System (NSS)	X	X	X		X		X		X			X		X
Thermal	Thermal Control					X		X							
Electrical	Power Distribution	X	X			X		X		X			X		X
	Battery	X	X			X		X	X			X	X		X
	Solar Panel	X	X			X		X	X			X	X		X
CDH	OBC	X	X			X		X					X		X
	Data Storage	X				X		X		X			X		X
	Data Bus	X	X			X		X		X			X		X
	UHF Antenna	X	X			X		X		X			X		X

Table 5. Non-personnel related risks applicable to each subsystem.

1.8.2. Failure Mode and Effect Analysis (FMEA)

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
APXS	Instrument falls below operating temperatures.	Instrument is unable to operate.	1	Temperature should be verified to meet requirements prior to operation of the instrument.	5	Verify temperature of instrument prior to usage.	1	5	Create a mandatory checklist prior to instrument use.
	Radiation damages electrical components.	The instrument fails to take accurate data.	10	Electronics were inappropriately shielded.	5	Verify insulation from outside sources of radiation prior to launch.	5	250	Update rover routine to eliminate APXS evaluation and prioritize broad scans with NSS.
NSS	The helium filled gas-proportional counter (GPC) sensors helium escapes.	Renders NSS unusable.	7	Damage to rover and/or instrument.	1	Careful navigation of the rover.	8	56	The APXS could likely continue the majority of the science mission alone.
	Radiation damages electrical components	Instrument fails to take accurate data	10	Electronics were inappropriately shielded.	5	Verify insulation from outside sources of radiation prior to launch.	5	250	Complete failure of NSS will result in a rescope, granting the secondary science goal with the lunar concrete higher priority level.
Mobility	Grit enters mechanical components.	Vehicle becomes unable to move due to regolith.	8	Movement through the lunar surface disturbs regolith and incorporates it into mechanical components.	3	Indium tin oxide coatings reduce the risk of regolith clinging to mechanical components.	2	48	It is likely that the rover can drive with as few as two remaining motors. A more realistic minimum is three remaining motors.
	Vehicle does not move or the motor does not start.	Can only survey whatever site rover is upon. Unable to go in and out of PSR to charge.	9	Insufficient power supply to the subsystem.	2	Grant the system a higher priority level when power falls below operational minimums.	1	18	Create a contingency routine to override navigation in event of power falling below operational minimums in order to recharge the rover and resume normal operation.
Power Generation and Storage.	Solar panels are unable to produce energy.	Rover must have adequate power to complete science and move.	10	Dust prevents solar rays from entering panels.	6	Guarantee adequate power to operate panels without downtime .	3	180	Attempt to fully charge battery in sunniest, nearby region. Allowing as much time as needed to charge with disregard to the previous timeline.
	Power is not being stored.	Rover must have adequate power to complete science and move.	8	Extreme temperatures may shorten the lifespan of the battery.	2	Create a subassembly which reboots components.	3	48	Attempt to restart battery. Utilize a back-up power supply.
	Power is not being distributed to a subassembly.	Each subassembly must have adequate power to complete science and move.	8	PCDU is not responding or functioning properly.	2	Create a subassembly which reboots components.	1	16	Restart individual components not receiving power. Restart PCDU. Verify there is adequate power in battery at all times.
	Solar panel deployment failure.	Rover must have adequate power to complete science and move.	10	Lack of power to operate deployment mechanism. Regolith or grime in deployment systems.	4	Do not let power supply fall below the maximum instantaneous draw of 39.9W.	1	40	Restart deployment system. Verify power supply remains over set amounts.
CDH	ONC does not respond.	Rover cannot process, move, or store science data.	10	Programming or execution error.	1	Extensively test routines in various scenarios for stability.	1	10	Plan for a fail state detection that automatically exports all data to the orbiter in event of ONC failure during operation.
	Science data is not being written to storage.	Data is not written to onboard storage.	8	Low temperatures can result in failure to write data.	1	The system should have a second onboard storage that gets written simultaneously in event of failure.	1	8	Transmit program update to replace writing routine with direct relay routine.
	Science data is not being relayed to orbiter.	Data is stuck on onboard storage.	7	Build up of dust or radiation exposure may cause damage to communication systems.	3	Minimize radiation risk by operating the system within the PSR.	1	21	Consider ensuring that memory is externally accessible and may be retrieved by future missions.
Thermal	Heating components fail.	Vehicle leaves operating temperatures causing instrument failure.	9	Lack of power, connection failure, or short circuit.	4	Having redundant heating components.	1	36	There are two of each component to guarantee temperatures remain within the operational range.
	Cooling components fail.	Vehicle leaves operating temperatures causing instrument failure.	9	Lack of power, connection failure, or short circuit.	4	Having redundant cooling components.	1	36	Various components contain individualized cooling systems.
	Vehicle is unable to maintain functional temperatures.	Vehicle leaves operating temperatures causing instrument failure.	9	Heating and cooling components fail.	2	Prevention 3	1	18	Restart all electric components.
GNC	System stops responding.	Team is unsure of the vehicle location. Rover may become incapable of following predetermined path.	2	Lack of power, connection failure, or short circuit.	2	Create a subassembly which restarts components.	1	4	Another means of locating the rover must be determined.
	System is inaccurate or incapable of functioning correctly or fully.	Team is unsure of the vehicle location. Rover may become incapable of following predetermined paths.	2	Lack of power, connection failure, or short circuit.	2	Regular testing and calibration of components. Potential addition of a star tracker is under consideration but not confirmed.	1	4	Attempt to locate rover based on previous data transmissions.

Table 6. System failure evaluation alongside priority of address and solutions.

Key mission level failures included radiation, regolith, low-light conditions, low temperature, angle of incidence of solar rays, dust on solar panels, cryogens, and electrical failure. Tracing down these risks into individual subsystems, these lower-level risks were identified. For the science instrumentation, APXS and NSS, the main concerns were maintaining operational temperatures (26 degrees celsius), radiation, and regolith entering the instruments. Possible solutions to these risks include redundancies of heating and cooling components, inspection of subassemblies, and procedures being upheld and utilized.

For Power Generation, the concern of regolith or moon dust was difficult to address. Redundancy was considered to minimize this risk; by implementing a lithium-ion battery, there is a guaranteed reserve of power in the case the solar panels become dysfunctional. A change request form will be required to implement this decision.

In regards to mobility, the rover can remain functional with 2-3 motors. Redundancy is covered by the number of motors and wheels.

CDH and GNC had much lower risk priority numbers, conveying the team's ability to address any arising issues such as technology not responding. The action needed in response to this issue was to have a restart and calibration protocol in place. Another risk is low and high temperatures causing technology to malfunction or become inoperable. Redundancy was utilized to minimize the chances of this occurring. This is also true in the instance of the Thermal subsystem, redundancy minimizes the majority of risks.

1.8.3. Personnel Hazards

Chemicals pose a very unlikely, yet severe risk to personnel. Chemicals can cause damage to materials and cause injury. Along these same lines, cryogens also pose an unlikely but potentially severe risk by injury. Supervisors will mitigate this risk with mandatory training, ensure use of PPE, not allowing personnel to work with dangerous materials alone, and ensure proper keeping of hazardous materials.

In terms of the electricity, it poses an unlikely and severe risk to both equipment and personnel. Electrical can damage components and cause injury. Supervisors will mitigate this risk by providing mandatory training, implementing an auditable Tag-Out/Tag-In process with deenergized checks, required use of PPE, and not allowing personnel to work alone on systems that operate at or above 8 mA or 40 V (Csanyi 2016).

Fire poses a very unlikely though potentially catastrophic risk to both equipment and personnel. Fire can cause damage ranging from slight damage to components to total loss and cause injury from minor burns to death. Supervisors will mitigate this risk by having a fire response plan, ensuring basic fire fighting knowledge for all personnel, and communication with local responders when conducting high-risk evolutions.

Heavy Machinery poses a very unlikely and catastrophic risk to mission components, equipment, and personnel. Heavy Machinery can destroy components and cause fatalities. Supervisors will mitigate this risk by a training plan, a safety supervisor when heavy machinery is in operation, and only qualified personnel are authorized to use said equipment.

Additionally, noise poses a highly likely but near negligible risk to personnel. Noise has been shown to cause hearing loss (U.S. Bureau of Labor and Statistics, n.d.). Supervisors will mitigate this risk with mandatory training, ensure use of PPE, and require annual hearing assessments for personnel who work in high-noise areas.

Notably, sharp items pose a very unlikely and minor risk to components and personnel. Sharp Items can damage components and cause minor to major injury.

Employees will mitigate this risk by utilizing PPE, knowledge of the work environment, and basic first aid training.

As a slips, trips, and falls pose a very unlikely but severe risk to personnel. These height related accidents can cause injuries ranging from simple soreness, to compound fractures and death. Supervisors will mitigate this risk by implementing an OSHA approved training plan and require all relevant safety protocols to be followed where the risk of fall is in excess of four feet (Occupational Safety and Health Administration 2024).

Since there is a Sterilizers pose a very unlikely but moderate risk to personnel. Sterilizers can cause damage to components and cause injury from radiation. Supervisors will mitigate this risk by training and two-person integrity during sanitization operations.

In terms of vehicle accidents, they pose a very unlikely but potentially catastrophic risk to components, equipment, and personnel. Vehicle Accidents can cause fatalities and deal catastrophic damage to items other than personnel. Supervisors will mitigate this risk by requiring a license to operate all vehicles, require insurance and perform quarterly training for safety.

1.9. Schedule

1.9.1. Schedule Basis of Estimate

Mission timeline is based around a customer constraint that the mission must be ready to launch no later than September, 2028 and will operate for at least 100 days. Given a lead time of less than four years, Selam has opted to utilize simpler methods and tools to ensure delivery of a working craft on time and on budget. Selem is anticipated to enter Phase C in August of 2024. The Final Design and Fabrication Phase, Phase C, will see a complete design, fabrication, and production of hardware, and code software in preparation for integration. The System Assembly, Integration, Test, and Launch Phase, Phase D, assembly, integration, verification, and validation of the system, including testing of systems will occur. The Operations Phase, Phase E, is where the primary mission will occur to meet the initially identified need and to maintain support for that need. This phase is estimated to occur over at least 180 days. The Closeout Phase, Phase F, will see significant personnel downsizing as systems are switched off or transferred to other teams. Final reports are to be drafted, reviewed, and submitted. This phase is estimated to occur over 180 days.

With the mission slated to begin Phase C in mid to late August of 2024, the mission will be able to move directly into purchasing and funding requirements with some of the remainder of NASA’s discretionary spending. Then, there will be a quick turn around into a new FY which will allow for a new budget year to supply efforts unimpeded.

1.9.2. Mission Schedule

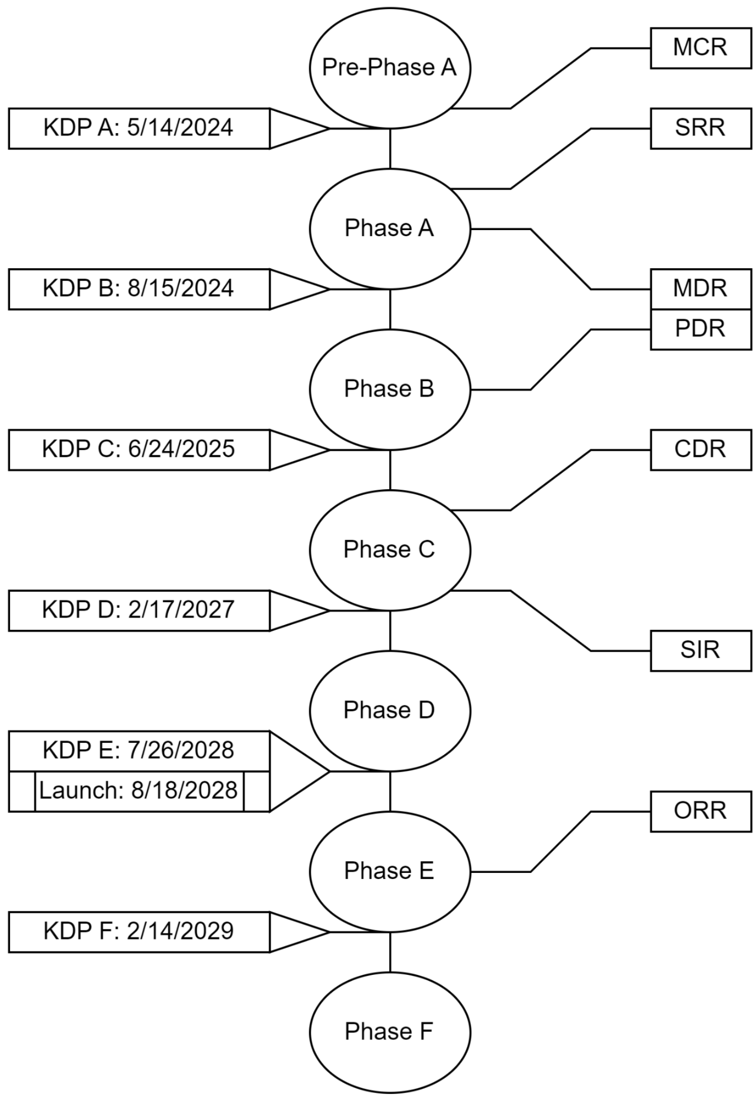

Figure 8. *Selam Mission Phase Overview*. Timeline of Selam mission phases and estimated key decision points.

After completing Phases A and B and achieving the milestone of Completing Rover Design and Testing on June 24th, 2025, the team moved onto Phase C of the mission life cycle: the Design and Fabrication. Phase C will begin on June 25th, 2025, with the first subtask belonging to the Engineering and Science teams. The task 3.1 is to design the rover, and it will take the two teams 126 days from June 25th, 2025 to October 28th, 2025 to complete. The next subtask is Hardware Production assigned to the Engineering Team. This task will take 134 days to complete, from October 29th, 2025 to March 11th, 2026. After the rover's design and hardware have been produced, the Engineering team must complete subtask 3.3, Coding the Software. This task will be completed in 294 days, from March 12th, 2026 to December 30, 2026. The coding of the rover will take longer than producing the design and hardware because of Team Selah's inclination towards Mechanical Engineering and design, and it was necessary to provide them with the remainder of the year to achieve this. With a schedule margin (3.5) of 48 days, the milestone of Phase C is achieved (3.6) on February 17th, 2027 to Complete the Design Integration.

Phase D will be launched on February 18th, 2027, which is to Test and Launch the mission. The Engineering team will be completing the subtasks 4.1 and 4.2 back-to-back. The first subtask 4.1 is the System Assembly and will take 76 days to complete, from February 18th, 2027 to May 4th, 2027. Afterwards, the subtask 4.2 is System Integration, and will be completed in 81 days, from May 5th, 2027 to July 24th, 2027. The Admin team will be in charge of 4.3 Verification and Validation, closely working with the Engineering and Science teams, and will complete this in 170 days, lasting from July 25th, 2027 to January 10th, 2028. Afterwards, the Admin and Engineering teams will be in charge of 4.4 System Testing which will occur from January 11th, 2028 to June 10th, 2028 for 152 days. The schedule margin (4.5) of this phase will be 45 days, and the Milestone (4.6) will be completed on July 26th, 2028, successfully Launching the System.

At this point in time, the system has been launched and the mission has lunged into Phase E of the mission life cycle. This phase will begin on July 27th, 2028, as the first of the two subtasks (5.1) will be completed by the Admin team to Complete the Primary Mission. This will take place for 135 days from July 27th, 2028 to December 8th, 2028. The aftermath will be carried by the Programmatics team, as they will have to Retain Support for the Mission (5.2) post-launch, utilizing methods such as Outreach. They will do this for 48 days from December 9th, 2028 to January 25th, 2029, spearheading into the final year of the mission. Phase E will be given a Schedule Margin (5.5) of 19 days, and the overall Milestone of Initially Identified Need (5.6) for the mission will be completed on February 14th, 2029.

The final Closeout phase of the mission, Phase F will begin on February 15th, 2029. The Engineering team will be in charge of the first subtask of Switching off all Systems (6.1), and will complete this in 26 days on March 12th, 2029. The remainder of the mission subtasks are to be handled by the Admin team. On March 13th, 2029 they will begin to Transfer all mission systems to other teams (6.2), completing this subtask in 92 days by June 12th, 2029. From June 13th, 2029 to July 25th, 2029, they will Draft Final Reports (6.3) for the mission in 43 days. Afterwards, they will take 31 days to Review all Final Reports (6.4) from July 26th, 2029 to August 25th, 2029. With a short Schedule Margin (6.5) of 24 days, the Final Reports for the mission will be submitted (6.6) on September 18th, 2029.

Selam Gantt Chart

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
3.1	Design Rover	Engineering, Science	Not complete	6/25/25	10/28/25	126	
3.2	Hardware Production	Engineering	Not complete	10/29/25	3/11/26	134	
3.3	Code Software	Engineering	Not complete	3/12/26	12/30/26	294	
3.5	Schedule Margin			12/31/26	2/16/27	48	
3.6	◆ Complete Design Integration		Not complete	2/17/27	2/17/27	1	
4	**Test and Launch**		0%	2/18/27	7/26/28	525	45
4.1	System Assembly	Engineering	Not complete	2/18/27	5/4/27	76	
4.2	System Integration	Engineering	Not complete	5/5/27	7/24/27	81	
4.3	Verification and Validation	Admin	Not complete	7/25/27	1/10/28	170	
4.4	System Testing	Admin, Engineering	Not complete	1/11/28	6/10/28	152	
4.5	Schedule Margin			6/11/28	7/25/28	45	
4.6	◆ System Launch		Not complete	7/26/28	7/26/28	1	
5	**Operations Support**		0%	7/27/28	2/14/29	203	19
5.1	Complete Primary Mission	Admin	Not complete	7/27/28	12/8/28	135	
5.2	Retain Support for Mission	Programmatics	Not complete	12/9/28	1/25/29	48	
5.5	Schedule Margin			1/26/29	2/13/29	19	
5.6	◆ Meet Initially Identified Need		Not complete	2/14/29	2/14/29	1	
6	**Closeout**		0%	2/15/29	9/18/29	216	24
6.1	Switch off Systems	Engineering	Not complete	2/15/29	3/12/29	26	
6.2	Transfer Systems to other Teams	Admin	Not complete	3/13/29	6/12/29	92	
6.3	Draft Final Reports	Admin	Not complete	6/13/29	7/25/29	43	
6.4	Review Final Reports	Admin	Not complete	7/26/29	8/25/29	31	
6.5	Schedule Margin			8/26/29	9/18/29	24	
6.6	◆ Submit Final Reports		Not complete	9/18/29	9/18/29	1	

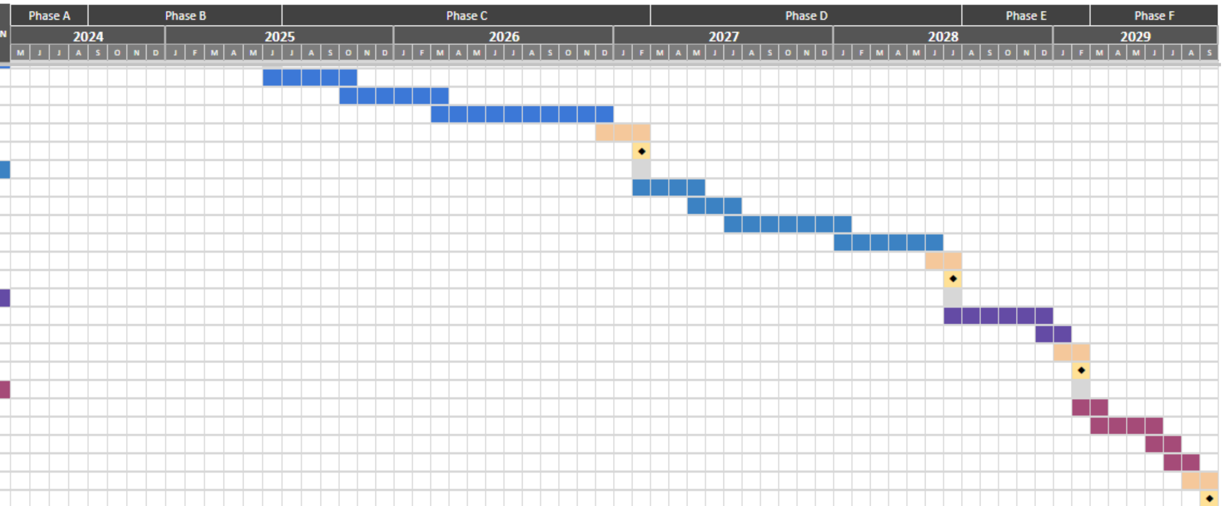

Figure 9. *Selam Mission Timeline*. Complete mission timeline.

1.10. Budget

1.10.1. Budget Overview

The budget allocated to the mission has been reduced to 175 million USD, which caused a rethinking of mission scope, technology planned for use, personnel, and other expenses. Selam's estimated cost at this time is roughly 166 million USD with a nine million USD reserve budget set aside for excess inflation, supply issues, and other *forces majeures* that could appear.

FINAL COST CALCULATIONS							
	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	
Total F&A	$ 1,130,000	$ 870,000	$ 870,000	$ 870,000	$ 870,000	$ -	$ -
Total Projected Cost	$ 36,972,258	$ 31,324,991	$ 31,772,424	$ 30,236,030	$ 29,675,545	$ 6,139,717	**$ 166,120,965**
Total Cost Margin	$ 14,117,000	$ 11,942,000	$ 12,001,000	$ 10,939,000	$ 10,822,000	$ 969,000	**$ 60,790,000**
	38.2%	38.1%	37.8%	36.2%	36.5%	15.8%	
Total Project Cost	$ 36,972,258	$ 31,324,991	$ 31,772,424	$ 30,236,030	$ 29,675,545	$ 6,139,717	**$ 166,120,965**

Table 7. Total Budget Cost. Estimated complete mission costs for duration.

1.10.2. Budget Basis of Estimate

The basis for this budget is based on multiple factors. Inflation rates for the next six years were assumed at 2.71% which is the average inflation rate for the past decade (U.S. Bureau of Labor and Statistics, n.d.). This rate was selected as it was the higher of the two, the other being the 25 year average rate of inflation, which was 2.33% (U.S. Bureau of Labor and Statistics, n.d.).

Cost estimates for equipment were developed using the Mission Concept Cost Estimation Tool (MCCET) which provides cost and schedule estimation for instrumentation and subsystems based on historical mission costs. The direct cost for structural parts was done utilizing Xometry from CAD files (Xometry, n.d.).

As the team has elected to be headquartered at Ames Research Center, and it is the furthest major NASA center, it provided upper ends on cost estimates for travel. Given the location of this NASA center, personnel detailed there are entitled to a 47% locality incentive pay to the provided salary rates (Office of Personnel Management 2023). Costs for flights were estimated utilizing an average of the highest per-coach-seat round trip tickets utilizing U.S. government preferred carriers: Delta and American Airlines. Per diem rates were calculated based on government provided rates (U.S. General Services Administration 2024). All costs are accounted as projected; however, with the cancellation of the VIPER mission, Selam will be filing requests for instruments and systems prior to any attempts to sell the rover. Any gear recovered from VIPER will not only lower Selam's budget, but recover costs for NASA while still seeing the benefit of the items, which will work towards enhancing the public opinion of NASA as stewards of taxpayer money.

1.10.3. Personnel Budget

Manning assigned to Selam will fluctuate with Mission Phase, and with that, administrative staff and management staff will fluctuate correspondingly. In Phases C and D, technical requirements will necessitate more engineering and technical personnel, this will mean additional administrative personnel and management. As launch approaches, engineering and technicians will ratchet down, as will their support personnel. This will be necessary due to the completion of the rover, associate lander, wraps, and testing. Finally, after the end of the active mission, science personnel will diminish while the remaining staff close out the mission and place the rover and associated items into layup.

Number of Personnel							
	Phase C	Phase C	Phase C-D	Phase D	Phase E	Phase E-F	
# People on Team	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Max**
Science Personnel:	3	3	3	3	3	2	**3**
Engineering Personnel:	10	10	10	10	8	8	**10**
Technicians:	12	12	12	12	10	10	**12**
Administration Personnel:	7	7	7	7	7	5	**7**
Management Personnel:	3	3	3	3	3	2	**3**
Total / FY	**35**	**25**	**35**	**35**	**31**	**27**	**35**

Table 8. Personnel by Fiscal Year. Anticipated personnel requirements for Selam Phases C-F.

Currently, the mission team is expected to be headquartered in and operate out of the Ames Research Facility in Mountain View, California. Due to this, personnel costs will be higher due to locality pay as prescribed by the OPM by 47.41% (Office of Personnel Management 2023). As seen in Table 10.2, accounting for this increased cost, and an additional twenty percent margin, total costs for salaries, and other employee benefits are expected to be around 32 million dollars through the end of the mission.

PERSONNEL							
	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Total**
Science Personnel	$ 349,000	$ 357,000	$ 366,000	$ 375,000	$ 384,000	$ 262,000	$ 2,093,000
Engineering Personnel	$ 1,164,000	$ 1,190,000	$ 1,220,000	$ 1,250,000	$ 1,024,000	$ 1,048,000	$ 6,896,000
Technicians	$ 1,047,000	$ 1,080,000	$ 1,104,000	$ 1,128,000	$ 970,000	$ 1,000,000	$ 6,329,000
Administration Personnel	$ 611,000	$ 630,000	$ 644,000	$ 658,000	$ 679,000	$ 500,000	$ 3,722,000
Project Management	$ 524,000	$ 537,000	$ 552,000	$ 567,000	$ 576,000	$ 384,000	$ 3,140,000
Total Salaries	$ 3,695,000	$ 3,794,000	$ 3,886,000	$ 3,978,000	$ 3,633,000	$ 3,194,000	**$ 22,180,000**
Total ERE	$ 1,035,000	$ 1,063,000	$ 1,089,000	$ 1,114,000	$ 1,018,000	$ 895,000	**$ 6,214,000**
Personnel Margin	$ 946,000	$ 971,000	$ 995,000	$ 1,018,000	$ 930,000	$ 818,000	$ 5,678,000
TOTAL PERSONNEL	$ 5,676,000	$ 5,828,000	$ 5,970,000	$ 6,110,000	$ 5,581,000	$ 4,907,000	$ 34,072,000

Table 9. Salaries. Cost per fiscal year for personnel based on locality pay.

1.10.4. Travel Budget

Travel will be central to ensuring mission success, and as such, 1.27 million USD is currently allocated to travel for collaboration between scientists, engineers and technicians, and project leadership. Additionally, funding has been set aside for the entire team to travel to Cape Canaveral for three days to view the launch in person. In the event of overruns, this could be reworked, saving 42 thousand dollars.

TRAVEL							
	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Total**
Total Flights Cost	$ 13,000	$ 28,000	$ 23,000	$ 6,000	$ 42,000	$ 9,000	**$ 121,000**
Total Hotel Cost	$ 28,000	$ 65,000	$ 64,000	$ 16,000	$ 158,000	$ 19,000	**$ 350,000**
Total Transportation Cost	$ 17,000	$ 36,000	$ 26,000	$ 8,000	$ 64,000	$ 11,000	**$ 162,000**
Total Per Diem Cost	$ 13,000	$ 28,000	$ 25,000	$ 6,000	$ 52,000	$ 9,000	**$ 133,000**
Travel Margin	$ 21,000	$ 47,000	$ 41,000	$ 11,000	$ 95,000	$ 14,000	$ 229,000
Total Travel Costs	$ 92,000	$ 204,000	$ 179,000	$ 47,000	$ 411,000	$ 62,000	**$ 995,000**

Table 10. Travel Expenses - Cost Type.Travel cost totals by fiscal year broken into associated cost types.

To further break down travel costs, during FY 1 and FY 2, science and management personnel will travel to NASA headquarters to coordinate with corporate, give presentations, iron out budgets, and network with other missions. During these years science, engineering and technician personnel will travel to Langley Research Center to aid in engineering development. Years FY 3 and FY 4 will see a migration of travel from Langley Research Center to Glenn Research Center and the Michoud Assembly Facility for testing and assembly respectively and Management will continue to travel to Headquarters. In FY 5, the entire team is currently slated to attend the launch over three days, and there will be a visit by management to Johnson Space Center to coordinate Phase E. FY 5 will see travel back to Langley Research Center to coordinate data analysis and give presentations and management will travel to headquarters and to Johnson Space Center to coordinate activities and address corporate concerns.

TRAVEL BY LOCATION							
Location	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Total**
Kennedy Space Center	$ -	$ -	$ -	$ -	$ 281,000	$ -	**$ 281,000**
Langley Research Center	$ 46,000	$ 52,000	$ -	$ -	$ -	$ 19,000	**$ 117,000**
Michoud Assembly Facility	$ -	$ 83,000	$ 77,000	$ 7,000	$ -	$ -	**$ 167,000**
Glenn Research Center	$ -	$ -	$ 39,000	$ -	$ -	$ -	**$ 39,000**
NASA Headquarters	$ 14,000	$ 11,000	$ 11,000	$ 12,000	$ 14,000	$ 12,000	**$ 74,000**
Johnson Space Center	$ -	$ -	$ -	$ 6,000	$ 10,000	$ 6,000	**$ 22,000**
National Travel for Outreach	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	**$ 66,000**
Travel Margin	$ 21,000	$ 47,000	$ 41,000	$ 11,000	$ 95,000	$ 14,000	$ 229,000
Total Travel Costs	$ 92,000	$ 204,000	$ 179,000	$ 47,000	$ 411,000	$ 62,000	**$ 995,000**

Table 11. Travel Expenses - By Location. Anticipated travel by location for Selam Phases C-F.

Travel for outreach was calculated off of the national averages from the 2024 highlights and corresponding values (U.S. Bureau of Labor and Statistics, n.d.). Pricing for rental remained the same across the board based on AVIS, a preferred vendor for the government (AVIS 2024). Flight costs were based on the 2023 national average for round trip coach class tickets (Pokora and Proctor 2023).

1.10.5. Outreach Budget

For effective outreach, the most effective is social media advertising, which would cost approximately 42 thousand dollars per year. The aforementioned travel would be broken up into six, four day trips nationwide for in person engagement. School program costs are nonexistent due to the fact that most of them are pitched and held without cost.

Part of Team Selah's effective outreach will be sponsored media marketing and posts. This includes $11,000 allocated for Youtube ads, $36,000 allocated for Instagram ads, $30,000 for Radio marketing, for the entirety of the mission, outside of the allocated budget for outreach traveling and venue expenses. The total Outreach budget of $250,000 for the entire mission is broken up by fiscal year, and equates to $46,000 per phase. The aforementioned travel would be broken up into six, four day trips nationwide for in person engagement. Tshirts showcasing the mission logo and name would cost $5,000 per the rate of 1000 tshirts. School program costs are nonexistent due to the fact that most of them will be pitched and held without cost.

OUTREACH							
	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Total**
Total Outreach Materials	$ 10,000	$ 15,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	**$ 125,000**
Total Outreach Venue	$ 20,000	$ 30,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	**$ 230,000**
Total Outreach Travel	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	**$ 66,000**
Total Outreach Services	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	**$ 150,000**
Total Outreach Personnel	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	**$ 360,000**
Outreach Margin	$ 30,000	$ 30,000	$ 40,000	$ 40,000	$ 40,000	$ 40,000	**$ 220,000**
Total Outreach Costs	$ 156,000	$ 171,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000	**$ 1,151,000**

Table 12. Outreach Expenses. Expected outreach costs for Selam Phases C-F.

1.10.6. Direct Costs

The direct cost of the mission is the largest part, coming in at 126.6 million USD. This is broken down into five subsystems, scientific instrumentation, manufacturing costs, and testing costs. These costs are broken down below.

DIRECT COSTS							
	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	**Total**
Mechanical Subsystem	$ 3,100,000	$ 2,600,000	$ 2,600,000	$ 2,400,000	$ 2,400,000	$ -	**$ 13,100,000**
Power Subsystem	$ 13,800,000	$ 11,500,000	$ 11,500,000	$ 10,800,000	$ 10,800,000	$ -	**$ 58,400,000**
Thermal Control Subsystem	$ 1,800,000	$ 1,500,000	$ 1,500,000	$ 1,400,000	$ 1,400,000	$ -	**$ 7,600,000**
Comms & Data Handling Subsystem	$ 1,600,000	$ 1,300,000	$ 1,300,000	$ 1,300,000	$ 1,300,000	$ -	**$ 6,800,000**
Guidance, Nav, & Control Subsystem	$ 1,000,000	$ 800,000	$ 800,000	$ 800,000	$ 800,000	$ -	**$ 4,200,000**
Science Instrumentation	$ 1,200,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ -	**$ 5,200,000**
Spacecraft Cost Margin	$ 12,000,000	$ 10,000,000	$ 10,000,000	$ 9,000,000	$ 9,000,000	$ -	**$ 50,000,000**
Total Spacecraft Direct Costs	$ 34,500,000	$ 28,700,000	$ 28,700,000	$ 26,700,000	$ 26,700,000	$ -	**$ 145,300,000**
Manufacturing Facility Cost	$ 4,400,000	$ 3,700,000	$ 3,700,000	$ 3,500,000	$ 3,500,000	$ -	**$ 18,800,000**
Test Facility Cost	$ 1,500,000	$ 1,300,000	$ 1,300,000	$ 1,200,000	$ 1,200,000	$ -	**$ 6,500,000**
Facility Cost Margin	$ 1,200,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ 1,000,000	$ -	**$ 5,200,000**
Total Facilities Costs	$ 7,100,000	$ 6,000,000	$ 6,000,000	$ 5,700,000	$ 5,700,000	$ -	**$ 30,500,000**
Total Direct Costs	$ 30,400,000	$ 24,700,000	$ 24,700,000	$ 23,400,000	$ 23,400,000		**$ 126,600,000**
Total MTDC	$ 23,300,000	$ 18,700,000	$ 18,700,000	$ 17,700,000	$ 17,700,000		**$ 96,100,000**

Table 13. Direct costs. Expected manufacturing and testing costs for Selam Phases C-F.

The mechanical subsystem consists of an aluminum chassis and rocker style suspension system derived from the Curiosity rover, these items will allow for easier navigation of the rough terrain, along with the six wheels and motors. Research is being done into the feasibility of small scale Nitol spring tires for additional flexibility and testing of new technology (Bazzi 2020). There are also LIDAR and an inertial measurement unit to assist in GNC. All of these items that are currently a part of this mission are either from government vendors or have been produced internally by NASA in the past, and thus costs are readily available.

Electrical subsystems include a solar array, power distribution unit (PDU) and batteries.

For communications and data handling there is slotted an onboard computer with data storage and interfaces for all systems, as well as a UHF communication suite. The RAD5545 produced by BAE is specifically for use in space environments and is radiation hardened as a standard. Memory will be a single-level cell NAND non volatile flash memory. The UHF suite will consist of a Ka-Band system for transmission and receiving of data to the orbiter as required by the customer. As all but the UHF system are from government vendors, costs for these items are readily available.

The thermal regulation system will consist of multilayer insulation, sourced from Sheldahl, which utilizes aluminized Kapton, which will enable retention of heat in the PSR and reflection of IR while in recharge and traverse modes. Omega heaters will augment the insulation, but due to the drastic temperatures, both of these items will require significant investment. Heavy duty Honeywell thermostats and Sierra Space heat switches will augment this process. The majority of these items will come from Kapton, and were priced as such.

Scientific instrumentation is the final direct cost physical item list. The two items are relatively cheap in the scope of mission equipment, however the cost assumes more than one of each due to the harshness of anticipated testing for the mission environment, as well as for integration testing.

Manufacturing costs will consist of roughly 15% of the direct costs, and will go into construction of the vehicle itself, manufacturing of the subcomponents, and post-initial test integration. After initial manufacturing of components, they will be tested in vacuum, high-radiation environments, vibration testing, and other system relevant subsystem testing. After this has been completed successfully, each will go into the parent system, such as power, and undergo the complete testing process again. Following successful testing here, the complete rover will be assembled from the components and will be tested a third time as a complete unit.

1.11. Scope Management

1.11.1. Change Control Management

The plan for change control processes implemented is relatively straight forward. This is important as a streamlined decision-making process minimizing bureaucratic delays, which can increase mission costs and hamper the achievement of timelines. Once the need for a change has been identified, either internally or externally (such as from the customer or lab), the relevant team leader will initiate the change process. In the event that the change is from customer feedback, this will start with the project manager. Following initiation, the need for change will be validated and added to the Change Log Tracker, which is an internal document allowing tracking of changes, or dispensed with. If the process is valid, the Program Manager will review the request, and consult with relevant team leadership to move forward, return for revision, or end the process. Once this has been satisfactorily achieved, the Change Request Form will be filled and submitted to the Customer by the Project Manager for approval, revision, or denial. Should the Customer approve the request or conditionally approve the request with changes, the Program Manager will disseminate the information and assign tasks to relevant teams to enact the change.

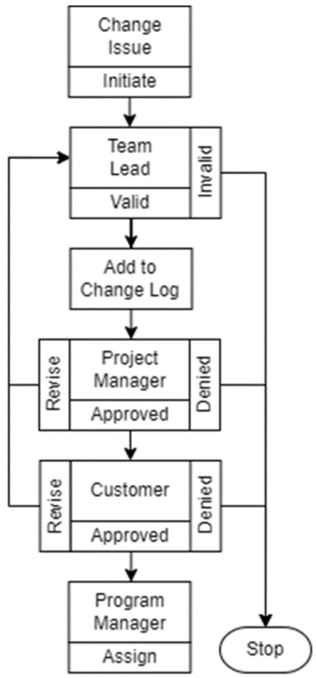

Figure 10. *Change Process.*

1.11.2. Scope Control Management

Scope control has been addressed in the same way as changes. Thus far, the only scope change originated from the customer in the form of a budget cut of 50 million USD from 225 million to 175 million. Mission scope has only changed in a descope direction thus far, and that was negligible due to where the team was designwise. In the event of attempted mission creep, the plan of Selam leadership is to first assess budget requirements and delta followed by a meeting between management and the customer to discuss allowing or nixing.

Descope requires more in depth processes. When the need to descope is communicated, each sub team leader will assess where changes can be made with the least amount of mission impact and annotation of any increases in risk. These items will be consolidated and brought before the Project Manager for ordering of change recommendations from least impact to most and present the recommendations to the customer for final approval or revisitation of descope necessity.

There is currently a budget reserve of nine million USD. In the event that is exhausted, priorities will be ensuring that the science goals are still accomplished, but any extra engineering may be reduced at increased risk. If the overrun is marginal, it will be handled at the personnel level with a reduction in personnel or reduction in travel. The last case, when both of the previous have been exhausted, would be removal of the secondary science objective and the associated infrastructure, but this is an absolute worst case, last resort scenario.

1.12. Outreach Plan

Selam’s outreach program will run throughout the entirety of the mission, including the closeout phase. Efforts will be made to tie Selam with Artemis in the publics’ mind as Selam is working to provide additional input and options for Artemis landing sites and future exploration development. Both online/social media and in-person outreach events must be held at each phase of the mission. Collection of metrics and feedback for the outreach efforts will be captured and revisited after each cycle in the mission phases. The unsponsored social media accounts will be run at no cost, per team’s discretion. There will be sponsored posts and ads that run year-long up to its cost online, coinciding with each phase to create hype and generate interest in the general audience; it will also generate excitement and anticipation for the mission and its discoveries.

Specifically, Social Media Outreach will consist of consistent non-sponsored uploads showcasing the mission and its development in detail. The team can leverage NASA’s social media channels and accounts to advertise the mission’s accounts in order to grow the initial audience. The team will utilize TikTok and Instagram Reels for short-form content, posting a minimum of twice per week. The team will also utilize Youtube and upload documentary-style videos per each phase in order to have an established video record for the entire mission. Sponsored Ads will also be utilized on Youtube, Instagram, and TikTok for the main purpose of getting engagement on each respective channel. These will consist of short-form, banner-style videos with the NASA and Selam mission logo and name clearly visible to grow familiarity with a general audience.

In-person outreach would consist of holding presentations and interactive workshops at K-12 schools, local libraries, and colleges. Partnership with high school and college STEM programs will be used to introduce students and intermix the mission with their educational programs.The Selam mission is also contemplating sponsoring an afterschool STEM program akin to the U.S. Navy’s Sea Perch involvement in working with children to learn about underwater robotics and how to create them and problemsove (United States Naval Sea Systems Command 2024).

Classic methods of outreach will happen as well, these consist of radio, television, and podcast interviews. Radio outreach will be targeted to the general public as it has the widest reach. Television ads will come in two separate groups: general public and targeted. The general public ads will, like the radio ads, be targeted to the average voter while the targeted ads will have more scientific weight behind them and will be targeted through channels such as Discovery, Science, and other educational channels and streaming content. An audio only version of the targeted outreach will be utilized in science podcasts.

Extended interaction will also play a major part in Selam's outreach campaign. Interviews on programs such as StarTalk, Impossible Engineering, How the Universe Works, and Deep Astronomy would feature interviews with mission scientists providing in depth analysis on how the mission will provide insight to what the team hopes to discover about the moon and the universe. Engineers and technicians would also be featured on some of the same programs to discuss the harsh environment Selam will operate in and the technical hurdles that will be overcome and how. This outreach will engage the casual scientific community at a higher level and put Selam's and NASA's objectives into the minds of listeners and viewers.

1.13. Conclusion

The Selam lunar rover mission will provide views of volatiles in the PSRs on schedule and on budget. Scientific instrumentation has been identified and validated to meet mission requirements. A full team structure for Phases C through F have been identified, validated, and budgeted for. All subsystems have been parted out to the subsystem level, production and manufacturing plans have been identified and a schedule ascertained. Risks to personnel, equipment, and mission have been identified and mostly resolved. Those that have not have a plan to move forward toward resolution. A budget cut was implemented at the customer's direction successfully. The budget cut did not result in a descope at the time, and everything is still occurring as intended.

Looking towards PDR, the Selam team will begin compiling data from previous deliverables, as well as feedback from outside agents. Following initial compilation, conflicts will be resolved and remaining risks will be addressed, manufacturing plans will be resolved, schedules will be revalidated, science goals will be affirmed, and the mission will continue to move forward.

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Appendix

Changes	
Change	**Cause**
Vehicle type	Change request submitted following a trade study.

RFAs and ADVs addressed		
RFA/ADV #	**Section #**	**Impact Summary for MDR**
MCR-RFA-1	1.4	Mission duration has been updated over the course of the program.
MCR-RFA-4	1.6	Design has been updated, including change of vehicle. A new CAD model has been added.
MCR-RFA-5	1.6	TRLs have been updated.
MCR-RFA-6	1.7	Design has been updated, including change of vehicle. A new CAD model has been added.
SRR-RFA-2	1.2	Instruments have been finalized and performance parameters updated.
SRR-RFA-3	1.4	Budget has matured.
SRR-RFA-4	1.4	Child and parent requirement columns are completed.
SRR-RFA-5	1.4	Met/unmet column are updated as of the MDR.

SRR-RFA-6	1.5.1	System overview has been updated. Is not in MDR, will be in PDR.
SRR-RFA-7	1.5.1	CAD model of the vehicle is included in 1.4.
SRR-RFA-8	1.5.1	Vehicle mass, volume, and power table are in progress. Currently requires component tracker completion.
SRR-RFA-10	1.5.2.2	Suspension and mobility has been remedied. The CAD has been updated to reflect the change.
SRR-RFA-12	1.5.2.2	Concept of Operations includes information that should have been included in this section of the SRR. Further detail will enter during the PDR.
SRR-RFA-17	1.5.3.1	Verification methods updated in section 1.3 in the MDR.
SRR-RFA-18	1.5.3.1	MVP table has been completed.
SRR-RFA-19	1.5.3.1	Trade studies were completed. This matured the decision making process for components in section 1.7 (MDR).
SRR-RFA-20	1.5.3.2	Details have been added regarding individual component choices (1.7 MDR)
SRR-RFA-21	1.5.3.2	TRL for power systems and CDH are at the end of power volume mass charts.
SRR-RFA-22	1.5.3.2	Mass volume power table is complete and ready for inclusion in the PDR.
SRR-RFA-23	1.5.3.3	Trade studies were conducted and are ready to include in the PDR.
SRR-RFA-28	1.5.7	FMEA is based on research conducted to complete the chart.
SRR-RFA-30	1.6	Risks identification table has been updated in the MDR.
SRR-RFA-31	1.6	Mitigation methods have been used to create the FMEA.
SRR-RFA-32	1.6	Overview is not in MDR however will be updated for PDR.
SRR-RFA-34	1.8	Conclusion of the MDR has been updated to address the direction provided by the MDR and the future direction of the project for the PDR.
SRR-ADV-1	1.2	Science section has been updated.
SRR-ADV-3	1.5.5.1	TBDs have been updated.
SRR-ADV-4	1.7.1	1.5 of the MDR has been updated to include conflict resolution strategies.