Mission Definition Review (MDR)
Team 21
Habitability Explorer for Lunar Pits

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TABLE OF ACRONYMS

ADV	Advisory
ALSD	Apollo Lunar Surface Drill
APXS	Alpha Particle X-Ray Spectrometer
ARC	Ames Research Center
BRAILLE	Biologic and Resource Analog Investigations in Low Light Environments
BRB	Biosafety Review Board
BSL	BioSafety Level
CAD	Computer-Aided Design
CCB	Change Control Board
CER	Cost Estimating Relationship
CDH	Command and Data Handling
CDR	Critical Design Review
COSPAR	Committee on Space Research
CRF	Change Request Form
CRM	Continuous Risk Management
DPMR	Deputy Project Manager of Resources
DR	Decommissioning Review
DRR	Disposal Readiness Review
DTN	Disruption Tolerant Networking
EAP	Employee Assistance Program
ERE	Employee-Related Expenses
REMS	Rover Environmental Monitoring Station
F&A	Facilities & Administration
FHL	Flammable Hazard Level
FMEA	Failure Mode and Effect Analysis
FPGA	Field Programmable Gate Array
GN&C	Guidance, Navigation, & Control
HCS	Hazard Communication Standard
HELP	Habitability Explorer for Lunar Pits
HMST	Hazardous Materials Summary Table
HRL	Hazard Response Level
ISRU	In-Situ Resource Utilization
KDP	Key Decision Point
KSC	Kennedy Space Center
LHDAC	Lander Hazard Detection & Avoidance Camera
LIBS	Laser Induced Breakdown Spectroscope
LiDAR	Light Detection and Ranging
LND	Lunar Lander Neutron and Dosimetry Experiment
LRA	The Laser Retroreflector Array
LROC	Lunar Reconnaissance Orbiter Camera
LVMM	Lunar Volatile and Mineralogy Mapper
LVPS	Low Voltage Power Supply
MAKSI	Markov and Kalman State Identification
MAP	Mission Support Future Architecture Program
MCA	Mission Concept Academy

MCCET	Mission Concept Cost Estimate Tool
MCR	Mission Concept Review
MDAA	Mission Directorate Associate Administrator
MDR	Mission Definition Review
MG	Mission Goal
MLI	Multi-Layer Insulation
MMOD	Micrometeoroid and Orbital Debris
MOVE	Modal Optimized Vibration dust Eliminator
MPASS	Multi-Parameter Aerosol Scattering Sensor
MRR	Mission Readiness Review
NIRVSS	Near-Infrared Volatile Spectrometer System
NSS	Neutron Spectrometer System
OBC	Onboard Computer
ORR	Operational Readiness Review
ORSA	Organizational Risk Safety Assessment
OSHA	Occupational Safety and Health Administration
OSMA	Office of Safety & Mission Assurance
PDF	Probability Density Function
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PLAR	Post-Launch Assessment Review
PLZT	Photovoltaic effect of Lanthanum-modified lead Zirconate Titanate
PM	Project Manager
PP	Planetary Protection
PPE	Personal Protective Equipment
PTSD	Post-Traumatic Stress Disorder
R&D	Research & Development
RAD	Radiation Assessment Detector
REMS	Rover Environmental Monitoring Station
RFA	Request For Action
RIDM	Risk-Informed Decision Making
RPN	Risk Priority Number
SAMHSA	Substance Abuse and Mental Health Services Administration
SC	Spacecraft
SCI	Science
SIR	System Integration Review
SMA	Safety and Mission Assurance
SRR	System Requirements Review
SSD	Solid State Detectors
SRM&QA	Safety, Reliability, Maintainability and Quality Assurance
STM	Science Traceability Matrix
TBD	To Be Decided
TBR	To Be Revised
THL	Toxicity Hazard Level
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRR	Test Readiness Review

TRL	Technology Readiness Level
V&V	Verification & Validation
XRF	X-ray Fluorescence Spectrometer

1 MISSION DEFINITION REVIEW

1.1 Mission Statement

The objective of Habitability Explorer for Lunar Pits (HELP) is to send a rover into the Compton Pit, explore its characteristics, and determine its ability to sustain future human habitation. The rover is expected to obtain clear dimensions of the cave including deformations, points of stress, and terrain information. These measurements will be obtained using a terrestrial laser scanner device. Identifying overhangs and stress points will benefit astronauts, allowing them to detect potential hazards and enforce measures to prevent hazards or protect vulnerable areas from danger. The thermal environment inside lunar pits will likely differ that of the surrounding surface. The Compton Pit potentially presents areas that shield from solar radiation and the low thermal conductivity of the lunar regolith during nightfall, when extreme temperatures fluctuate. This pit is therefore a prime candidate to host habitable temperatures from day to night. The Rover Environmental Monitoring Station (REMS) will be used to assess temperature and an M-42 radiation detector will record critical radiation data from the pit. Regarding lessons learned from the Compton Pit, an advanced knowledge of lunar caves will be developed in terms of their conditions and what life can survive there. Further exploring the lunar environment also develops the understanding of what needs to be done to sustain life under extraterrestrial conditions.

The readily available amount of in-situ resources will be examined within a short distance surrounding the Compton Pit. A Near-Infrared Volatile Spectrometer System (NIRVSS) and a Neutron Spectrometer System (NSS) will be used to record measurements considering volatiles critical to supporting future habitability. Finding the presence of Silicon, Carbon, and Hydrogen will enhance understanding of the lunar environment in the vicinity of the Compton Pit. The presence of Oxygen and Hydroxyl will also be observed in regions outside the pit in order to decide if this area presents a suitable environment. Comparing data regarding temperature and radiation levels between these surface areas and the lunar pit itself will help draw differences that will lead to conclusions regarding other pits too. This mission will improve knowledge of other planets across solar systems with celestial bodies that share a similar landscape to the Moon. Obtaining an overall understanding of these pits will support future decisions that consider movements to sustain life on these comparable celestial bodies. Lunar caves are candidates for providing a stable environment for long-term lunar habitation, and the Compton Pit just might support human exploration on the Moon.

1.2 Science Traceability Matrix

To address the overarching science goals that have been established for this mission, several science goals have been defined. These objectives with consideration of customer restraints and each collect materials and data to fulfill the science goals. Analyzing the resulting data and samples obtained from these science objectives will pave the way for valuable mission discoveries regarding the Compton Pit and the lunar surface surrounding the pit.

The first science goal defined for this mission involves the mission's robotic system and how it will affect future research that will be conducted on the Moon's surface. To ensure that astronauts are efficiently prepared for the mission, two science objectives have been defined. The first objective requires determining the readily available amount of Oxygen and metals as in situ resources in the lunar regolith located around and inside the Compton Pit. The studies of lunar regolith stimulants can be used to determine the limits of the stimulants to validate key components for human survivability during sustained presence on the Moon (Chandra et al. 2010). The Apollo Lunar Surface Drill (ALSD) would be a suitable instrument to complete this goal. The system's purpose of gathering core samples to extract soil column samples and to create holes for emplacement of two heat flow probes in the lunar surface (National Air and Space Museum, 2021). The ALSD would be able to drill into the lunar surface and collect data measurements to fulfill this objective.

The second objective is to determine the amount of solar wind materials, water, and Hydroxyl molecules present in the lunar regolith located near or within the Compton Pit. Water is an important resource for future habitability. Although there may not be many water molecules, the process of combining Hydrogen and Hydroxyl molecules can be further studied to obtain water necessary to survive. The moon isn't able to protect itself from high levels of radiation, therefore we can identify surface regions that could be protected from inhabitable radiation levels. The Near-Infrared Volatile Spectrometer System (NIRVSS) acquires spectra between 1600-3400 nm, <15 nm resolution, and can identify key volatiles (solid and gas) and minerals while surface roving and subsurface drilling (Roush and Colaprete, 2015). It is designed to measure surface and subsurface water, carbon dioxide, and methane and is able to map the surface temperature and changes that occur at the landing site (Colaprete, 2022). NIRVSS would be efficient to collect similar minerals to past research experiments. A similar design or instrument would ensure proper data collection. Similarly, the Neutron Spectrometry System (NSS) will measure the amount of hydrogen-bearing materials near the surface at the landing site to determine the potential for water ice (NASA, PEREGRN-1-02). Together, both of these instruments are able to identify the H, O_2, H_2O, and OH molecules and assess how many of the materials at the surface have the potential to become water ice.

The second science goal defined for this mission determines the ability of the robotic system to provide and locate a safe habitat to protect individuals, equipment, and associated infrastructure. The first objective is to characterize the dimensions and deformations of the Compton Pit. The system will have to measure the depth, height, terrain variation, ease of access, and structural integrity of the pit. Mapping these physical features are imperative to determine conclusions for human habitation. Identifying dimensions and deformations is crucial for the safety of astronauts. Additionally, identifying overhangs and stress points will allow astronauts to detect potential hazards that could endanger personnel and equipment. These dangers should be identified to avoid or reinforce vulnerabilities to increase safety. A Light Detection and Ranging (LiDAR) system creates topographic maps that would identify terrain features, slopes, and potential obstacles. Sensing systems can identify potential hazards and allocate preparation to navigate risks and obstacles.

The second science objective is to measure temperature and radiation levels within the Compton Pit. This data will allow astronauts to make decisions regarding sustainability and survivability of the individuals and equipment that will be staying within the potential habitat area. An instrument such as the Multi-Parameter Aerosol Scattering Sensor (MPASS) would provide information about the particles in the environment in real time. Since it is an aerosol-detection system, it will categorize atmospheric particles and monitor them in real time to assess whether the environment is safe enough for life (NASA Technology Transfer Program). It is imperative that the cave remains below a radiation threshold to maintain a safe environment for human habitation.

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
“Develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon” - Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032	Determine the readily available amount of Oxygen and metals as in situ resources in the lunar regolith located around and inside the Compton Pit.	Identify Ilmenite, Pyroxene, Olivine, Anorthite, Mg-rich silicates, and Anorthitic Plagioclase.	Collect spectral signatures of Ilmenite, Pyroxene, Olivine, Anorthite, Mg-rich silicates, and Anorthitic Plagioclase present 10 cm below the surface in a 3km area.	Drilling Depth:	10 - 30 cm below the ground	20 - 30 cm	Apollo Lunar Surface Drill (ALSD)	Identify and process lunar resources, including water and oxygen.
				Drilling Speed:	15:21 - 23:40 mm/s	10:43 - 13:50 mm/s		
				Control and Operation:	Cordless, battery-operate d motor with specialized drill bits and modular core stems	Cordless, battery-operated motor with specialized drill bits and modular core stems		
				Material Compatibility:	100 - 300 K	450 - 550 K		
	Determine the amount of solar wind materials, water, and Hydroxyl molecules present in the lunar regolith located around and inside the Compton Pit.	Identify Hydrogen (H) Oxygen (O2), water (H2O), and Hydroxyl (OH) molecules measure the amount of hydrogen-bearing materials near the surface at the landing site to determine the potential for water ice.	Collect spectral signatures of H, O2, H2O, and OH in the 10-30 nm range over a 3km area.	Wavelength range:	1600-3400 nm	1300-2500 nm	Near-Infrared Volatile Spectrometer System (NIRVSS)	Measure subsurface water, CO2, and CH4; Analyze the composition and structure of the surface and subsurface
				Integration time:	1 s-1	712 bits per sample		
				Sensitivity:	Thermal and epithermal neutrons	Thermal and epithermal neutrons		
				Spatial Resolution:	H2O: 20-30 nm NH3 : 10-20 nm CO2 : 10-20 nm CH4 : 20-30 nm	<20 nm and <50 nm		
			Detect water ice and other volatiles to better than 0.5% mass fraction within a 10m radius	Wavelength range:	1 ev- 1 keV	<0.3 ev - 1 keV	Neutron Spectrometer System (NSS)	Detect water ice and other volatiles on sunlit portions of mission site during the day.
				Integration time :	<= 550 cts/s	<= 511 cts/s		
				Sensitivity:	80/ cm^2	80/ cm^2		
				Sample rate:	1/s	1/s		
Life Support & Habitat: mLSH1 - “Provide safe and	Characterize the depth, height, terrain variation, ease of	Define the dimensions and deformations of	Collect and map the dimensions, deformations, terrain,	Wavelength range:	400m	450m	RIEGL VZ-400 V-Line 3D Terrestrial	Map the interior of the pit, develop point clouds for

enduring habitation systems to protect individuals, equipment, and associated infrastructure” (Lunar Exploration Analysis Group (LEAG) Habitation: HAB-SAT Report, Priority Objectives)	access, structural integrity, temperature, and radiation levels within lunar pits/caves to determine the viability of human habitation.	the lunar pits/caves.	overhangs, and stress points in a 35m or greater range.	Integration time:	110,000 measurements/sec	122,000 measurements/sec	Laser Scanner	data analysis.
				Sensitivity:	4mm precision, 5mm accuracy	Precision, 3mm, accuracy 5mm		
				Spatial Resolution:	5mm	4mm		
		Identify the Galactic Cosmic Ray flux in the Compton Pit, measure variation in its diurnal, seasonal, and solar cycle, and measure temperature variation.	Detects temperature measurements between 273K and 373K and radiation levels that exceed 25,000 millirems.	Temperature range:	273-373 K	143-343 K	Rover Environmental Monitoring Station (REMS)	Collect dosimetry and temperature data in the Compton Pit to determine habitability.
				Integration time:	1 s	1 s		
				Sensitivity:	2 K	1 - 4.5 K		
				Resolution:	2 K	2 K		
				Detection range:	0.1 MeV - 15 MeV	0.06 MeV - 18 MeV	M-42 Radiation Detector	
				Integration time:	300 s	300 s		
				Sensitivity:	0.5 MeV	0.5 MeV		
				Counts per second:	0.5 cnt/s	0.4 cts/s		

Figure 1: Science Traceability Matrix

1.3 Mission Requirements

The budget for the mission has undergone descoping from $425 million to $300 million. The schedule for launch is March 1, 2030. To sufficiently meet customer constraints and demonstrate that the HELP mission is capable of meeting science requirements, the Mission Timeline section outlines major milestones the HELP team will follow to increase mission confidence. The goals for HELP involve hydrogen sampling, mineral sampling, and mapping. The HELP rover will search for hydrogen in the lunar regolith, and will use a spectrometer system to determine whether the hydrogen is in the form of free hydrogen, water, or hydroxyl. All are important in-situ resources for human habitation. In addition, the mission rover will use its spectrometer to find other important minerals on the Moon, such as Iron and Pyroxene.

The HELP spacecraft will also evaluate the Compton Pit to determine its suitability for future human habitation. It will evaluate whether or not the Compton Pit exhibits constant temperatures throughout the Moon's orbit, and whether it might provide protection for humans from solar radiation. It will also map the inside of the pit and gather data to inform next steps in regards to planning future habitation of the Moon.

Req #	Requirement	Rationale	Parent Req	Child Req	Verification method	Relevant Subsystem	Req met?
MG-1	The mission shall develop a precursor lunar robotic mission that will define future scientific activities for astronauts to conduct on the Moon.	-	-	All	Demonstration	-	Met
MG-2	The mission shall evaluate an environment that may provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure on the Moon.	-	-	All	Demonstration	-	Met
PM-1	The mission shall fall within outlined customer constraints concerning budget, schedule, and spacecraft specifications.	-	MG-1 MG-2	PM-1.1 PM-1.2 PM-1.3	Demonstration	-	Met
PM-1.1	The mission shall have a cost cap of $300 to expend.	-	PM-1	-	Test	-	Met
PM-1.2	The spacecraft shall be ready for launch by March 1st, 2030.	-	PM-1	-	Analysis	-	Met
PM-1.3	The mission shall follow the NASA Mission Life Cycle and will coordinate documents to pass the required gate reviews.	-	PM-1	-	Analysis	-	Met
SCI-1	The readily available amount of in-situ minerals and metals shall be measured in the lunar regolith located near the Compton Pit.	To support in-situ resource utilization (ISRU) efforts and prepare for future human missions by analyzing critical elements for life support and construction.	MG-2	SCI-1.1 SCI-1.2	Demonstration	Payload	Met
SCI.-1.1	The amount of Ilmenite, Pyroxene, Olivine, Anorthite, Mg-rich silicates, and Anorthitic Plagioclase shall be quantified in the lunar regolith near the Compton Pit.	To identify essential mineral resources needed for oxygen extraction and building materials.	SCI-1	SCI-1.1.1 SCI-1.1.2	Test	Payload	Met

SCI-1.1.1	Spectral signatures of Ilmenite, Pyroxene, Olivine, Anorthite, Mg-rich silicates, and Anorthitic Plagioclase shall be collected from the lunar regolith.	To verify the presence of key minerals over a 3 km area, enabling resource mapping in the vicinity of the Compton Pit.	SCI-1.1	-	Test	Payload	Met
SCI-1.1.2	Spectral data will be collected in the 350-500 nm range.	To target the specific wavelengths where these minerals exhibit distinct spectral features, ensuring accurate identification.	SCI-1.1	-	Test	Payload	Met
SCI-2	The amount of solar wind induced materials shall be measured in the lunar regolith near the Compton Pit.	To evaluate the potential for extracting water and other essential materials for future missions and habitation on the Moon.	MG-2	SCI-2.1 SCI-2.2	Demonstration	Payload	Met
SCI-2.1	The amount of Hydrogen (H), Oxygen (O2), water (H2O), and Hydroxyl (OH) molecules shall be quantified in the lunar regolith located near the Compton Pit.	To map the availability of water and essential gasses in the surrounding area, critical for life support and fuel production.	SCI-2	SCI-2.1.1	Test	Payload	Met
SCI-2.1.1	Spectral signatures of H, O2, H2O, and OH molecules shall be collected in the 2.8-3.0 μm range.	This wavelength range is critical for detecting water and hydroxyl molecules, enabling resource assessment for ISRU.	SCI-2.1	-	Test	Payload	Met
SCI-3	The depth, height, terrain variation, ease of access, structural integrity, temperature, and radiation levels of the Compton Pit shall be characterized.	To assess the viability of lunar pits/caves for future human habitation, supporting exploration and habitation goals.	MG-2	SCI-3.1 SCI-3.2	Demonstration	Payload	Met
SCI-3.1	The dimensions and deformations of the Compton Pit shall be quantified.	To create a detailed topographical map of the cave and surrounding area, ensuring it meets the criteria for human habitation and exploration.	SCI-3	SCI-3.1.1	Demonstration	Payload	Met
SCI-3.1.1	The dimensions, deformations, terrain, overhangs, and stress points of the Compton Pit shall be mapped over a 35 m or greater range.	To ensure the structural integrity of the site and assess potential hazards or areas for safe habitation.	SCI-3.1	-	Test	Payload	Met
SCI-3.2	Temperature and radiation levels shall be measured within the Compton Pit.	To ensure that the environment is suitable for human habitation, with acceptable levels of radiation and manageable temperature variations.	SCI-3	SCI-3.2.1 SCI-3.2.2	Demonstration	Payload	Met

SCI-3.2.1	Temperature measurements shall be detected between 273K and 373K.	To support NASA's Lunar Exploration objectives by exploring the feasibility of using lunar pits/caves as future habitat locations for astronauts.	SCI-3.2	-	Test	Payload	Met
SCI-3.2.2	Radiation levels that exceed 25,000 millirems shall be measured.	To ensure that the Compton Pit is capable of supporting living organisms.	SCI-3.2	-	Test	Payload	Met
SC-4	The spacecraft shall determine the amount of in-situ resources and readily available volatile materials present on the lunar surface in the area surrounding the Compton Pit.	To evaluate the available resources near the Compton Pit given it's a potential location for human habitability.	MG-1	SC-4.1 SC-4.2 SC-4.3 SC-4.4 SC-4.5 SC-4.6	Demonstration	-	Met
SC-4.1	The spacecraft shall traverse the lunar surface from the landing site to the Compton Pit.	-	SC-4	SC-4.1.1	Demonstration	-	Met
SC-4.1.1	Mechanical system shall traverse the jagged and uneven lunar surface sufficiently.	To ensure the spacecraft doesn't get stuck or tip over in its transit from landing site to the Compton Pit.	SC-4.1	-	Test	Mechanical	Met
SC-4.2	Payload instruments shall collect samples from the lunar regolith surrounding the Compton Pit.	To ensure science requirements are successfully met by obtaining the necessary science measurements from the lunar surface regolith.	SC-4	-	Demonstration	Payload	Met
SC-4.3	The Data Handling system shall store science measurements obtained by the payload instruments on the lunar surface regolith.	To ensure the science measurements obtained are securely stored and are recorded efficiently in an organized way.	SC-4	-	Test	CDH	Met
SC-4.3.1	Communications components shall relay data stored from the lunar surface regolith to Earth ground control.	To ensure lessons learned can be drawn from the recorded data and further research on the Moon can be done in the future.	SC-4	-	Test	CDH	Met
SC-4.4	Guidance, navigation, and control system shall circumvent significant obstacles impeding the spacecraft's path from its landing site to the Compton Pit.	To ensure the spacecraft successfully travels from the landing site to the Compton Pit and avoids significant craters and other threatening landmarks.	SC-4	-	Test	GN&C	Met
SC-4.5	Power system shall store energy during daylight hours to power spacecraft components.	To ensure the spacecraft has enough energy to travel, collect measurements, and traverse into permanently shadowed regions.	SC-4	-	Test	Power	Met

SC-4.6	Thermal system shall maintain component operational temperatures during major temperature fluctuations between shaded and lit areas.	To limit stresses and strains placed on system components from extreme lunar temperatures.	SC-4	-	Test	Thermal	Met
SC-5	The spacecraft shall monitor environmental conditions, including potential hazards, while exploring the Compton Pit.	To ensure that the cave is a safe and viable location for habitation, with minimal risks from environmental factors such as micrometeorite impacts or landslides.	MG-1	SC-5.1 SC-5.2 SC-5.3 SC-5.4 SC-5.5 SC-5.6 SC-5.7	Demonstration	-	Met
SC-5.1	The spacecraft shall traverse into the Compton Pit via an accessible sloped surface ramp.	To ensure that astronauts or robotic systems can access the cave with minimal risk, supporting long-term missions.	SC-5	SC-5.1.1	Demonstration	-	Met
SC-5.1.1	Mechanical systems shall be capable of traversing a sloped surface.	To ensure that the spacecraft can travel into the Compton Pit without getting stuck or tipping over.	SC-5.1	-	Test	Mechanical	Met
SC-5.2	Payload instruments shall evaluate the environmental conditions and habitability of the Compton Pit.	To ensure science requirements are successfully met regarding the Compton Pit, and the pit's habitability is subsequently determined.	SC-5	-	Demonstration	Payload	Met
SC-5.3	Guidance, navigation, and control system shall conduct sequential operations to traverse the robot into the Compton Pit.	To ensure the robot efficiently makes its way into the Compton Pit via the pit's accessible ramp.	SC-5	-	Test	GN&C	Met
SC-5.4	Power system shall store enough energy to explore the Compton Pit for distinct periods of time in permanently shadowed regions.	To ensure the spacecraft can explore darker areas of the pit without running out of energy.	SC-5	-	Test	Power	Met
SC-5.5	Thermal system shall maintain operational temperatures of the spacecraft while exploring the Compton Pit.	To ensure system components won't fail due to potential extreme temperatures in the Compton Pit.	SC-5	-	Test	Thermal	Met
SC-5.6	The Data Handling system shall store science measurements recorded by the payload instruments in the Compton Pit.	To ensure science measurements recorded by the payload instruments are stored efficiently and in an organized manner.	SC-5	SC-5.6.1	Test	CDH	Met

SC-5.6.1	Communications components shall relay data recordings taken in the Compton Pit to mission ground control.	To ensure lessons learned are drawn from the data stored by the spacecraft's payload instruments.	SC-5.6	-	Test	CDH	Met
SC-5.7	The spacecraft shall complete decommissioning protocols at the end of the HELP mission timeline.	To ensure planetary protection protocols are followed sufficiently.	SC-5	SC-5.7.1	Demonstration	-	Met
SC-5.7.1	Power system shall complete passivation protocols to deplete extra stored energy.	To ensure the spacecraft doesn't explode due to energy build-up in the Compton Pit, which would make the pit uninhabitable.	SC-5.7	-	Test	Power	Met

Figure 2: Mission Requirements Table

1.4 Concept of Operations

The HELP mission's concept of operations begins when the rover lands on the lunar surface. The goal is to land inside the Compton crater at a spot 300m outside of the edge of the Compton Pit. Upon landing, pre-checks of all instrumentation onboard will be run to ensure everything is operating as it should be.

Once all instrumentation is checked and powered on, the rover begins its traverse to the entrance of the pit. Since the rover will land so close to the entrance, it is expected to only take 1 Lunar day to reach the entrance of the pit, where it will document the dimensions and structure presented by the pit and cave below ("Lunar Roving Vehicle", 1972). Once it reaches the entrance of the pit, it will begin collecting data from the lunar surface concerning in situ resources and other important molecules, including Oxygen, Hydrogen, and Hydroxyl. This soil evaluation is estimated to take approximately 14 days, based on the time required for the Chandrayaan-3 rover to obtain similar measurements ("Chandrayaan-3", 2024). It will also obtain science measurements concerning temperature and radiation as well.

Once this data is collected, the rover will make its descent into the pit. Once it reaches the bottom, it will repeat the soil, temperature, and radiation evaluations, as well as conduct cave mapping. Mapping the cave will allow the team on Earth to understand the dimensions, deformations, terrain, overhangs, and stress points in the cave. The cave mapping process is expected to take approximately a month to completely collect all of the necessary data. The largest caves typically take around 27 days to be completely mapped; therefore, a month is given in case the cave found within the pit is larger than predicted (Gibb, 2021). Once all of the data has been collected, it will then be organized and documented correctly for further research and analysis. The entire Concept of Operations is shown in Figure 3.

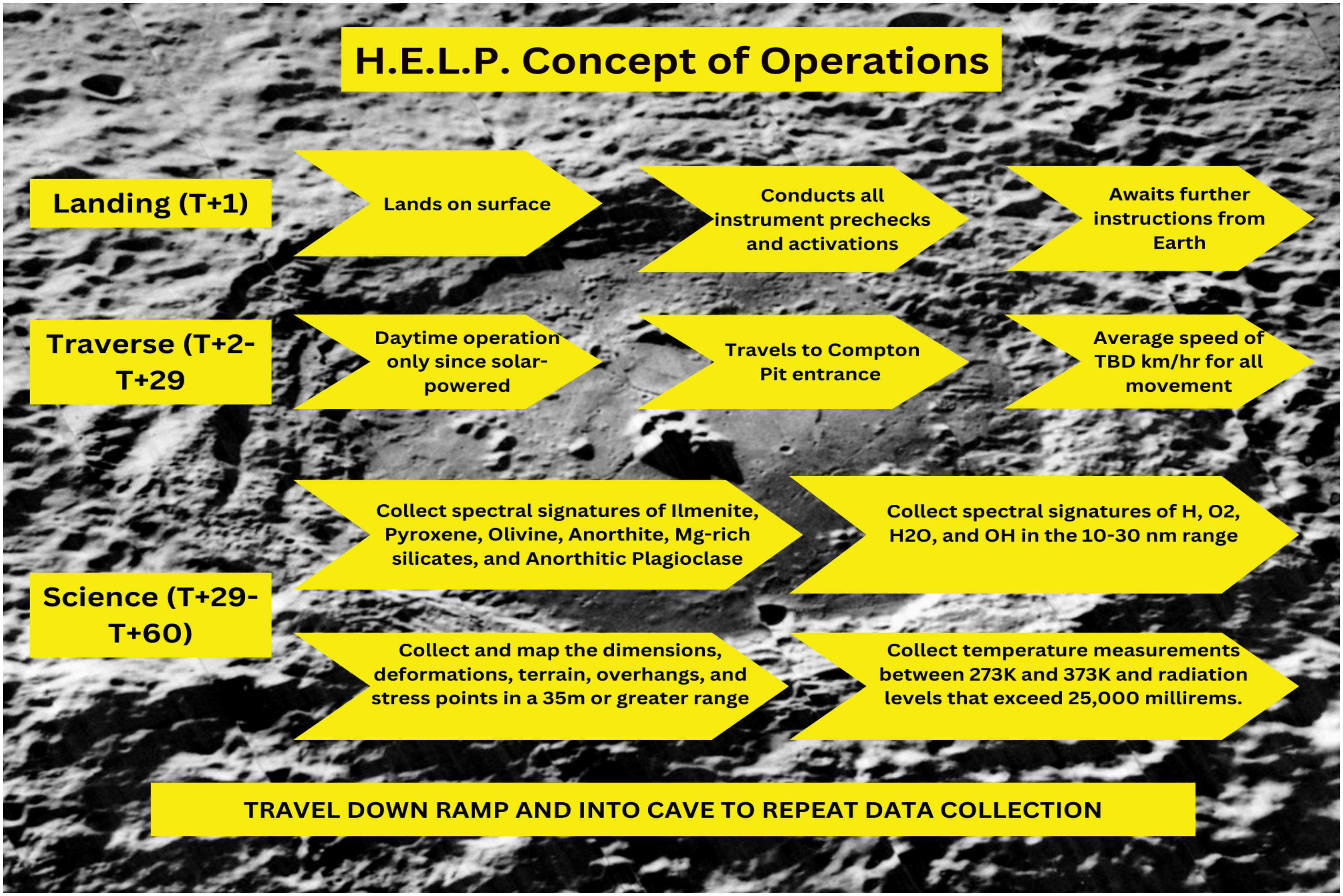

Figure 3: HELP Concept of Operations

1.5 MCA Team Management Overview

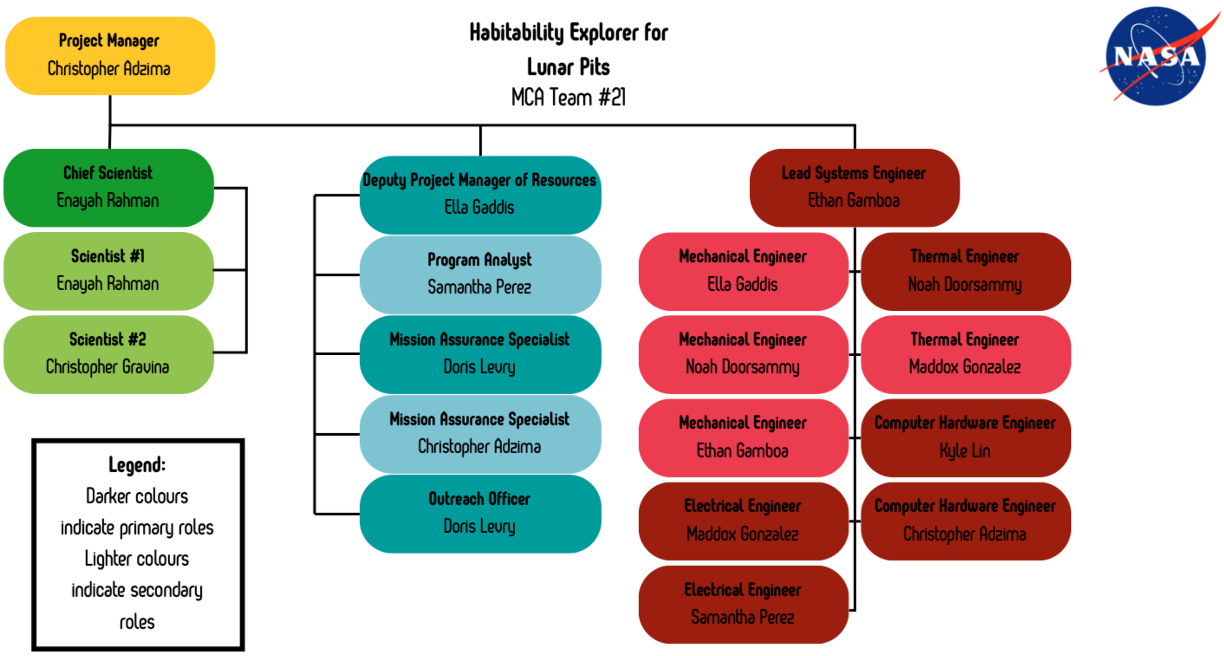

Figure 4: Team Organization Chart

The HELP Team is presently equipped to handle this mission. In order to efficiently manage the workload, the organizational structure now includes designating specific leads and sub-teams for Science, Programmatics, and Engineering. Designating each sub-team as responsible for its own area has prevented overlap and ensured that the mission's many components are moving forward simultaneously. Even with a smaller team, a balanced workload is maintained by allocating any additional or new duties according to each individual's skill and availability.

The HELP mission decision-maker is the Project Manager (PM), but in most cases involving trade studies, the PM delegates the decision to a deliberation lead with greater knowledge of the decision being made. This lead is either the Chief Scientist or the Lead Systems Engineer. These roles are responsible for understanding each alternative presented by subteam members and documenting an analysis of the options presented to make an informed decision. The leads also relay the decision alternatives and thought process to the PM so that the PM clearly understands the decision-making process and can share necessary information with other subteams impacted by the decision. This process is continuously iterated as RIDM and CRM are completed to evaluate options, assess related risks, and reconsider decisions to ensure mission safety and assurance.

Adapting to an unexpectedly reduced team size is a continued challenge for the HELP team. Regarding this specific mission, the main Program Analyst dropped forcing the role to be transferred to spreaded across the other members as shown in the new team management chart.

Passive communication is also a continued problem, where team members perform their duties without regularly updating the group. On occasion, this has led to misunderstandings regarding the assignment status of each member. To overcome this, the emphasis has changed to proactive communication and regular check-ins, allowing all members to participate successfully and stay informed about one another's progress. Throughout the project's difficult stages, the team mentor has remained impartial and balanced while offering wise counsel and assisting with decision-making and dispute resolution as needed.

To prepare for the completion of the MDR document and clarify task division, a task breakdown sheet was implemented for this assignment. This task breakdown assigned sections of the MDR document to members of the HELP team, thereby clarifying expectations for the document and how each member can contribute. The breakdown of sections and document tasks can be reviewed in Appendix D, in a figure known as the MDR Task Breakdown Table. After these tasks were initially assigned, each team member approved their designated tasks.

1.6 Project Management Approach

The HELP mission team can be divided amongst individual subteams, of which each plays a significant role in ensuring the mission is successfully completed. Understanding the connections and communication between these specialty groups and the responsibilities that employees carry in relation to their subteam is incredibly important for reassuring all necessary aspects of the HELP mission will efficiently be addressed.

After researching analogous discovery-class missions, it’s estimated that approximately 30-50 team members are necessary to complete the HELP mission (Yost, 2021). Further evaluating the HELP mission and its necessary subdivisions led to the establishment of the subteams outlined in Figure 5. A total of 38 team members are divided amongst five specific categories of personnel, including scientists, engineers, technicians, administration, and management. An additional 8 members are dedicated to completing outreach related expenditures. Therefore, the entire HELP mission carries a team of 44 members, and each team member plays a role outlined in the categories specified in Figure 5.

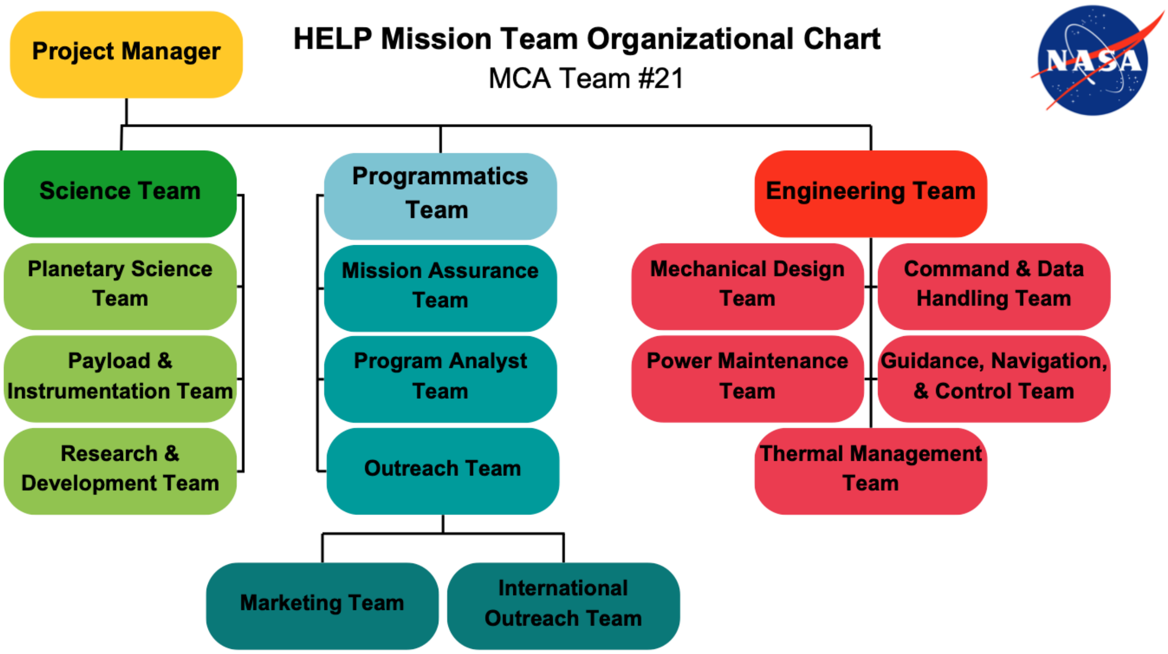

Figure 5: HELP Mission Team Organization Chart

	Phase C	Phase C	Phase C	Phase D	Phase D	Phase D	Phase E-F
Team	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	FY 7
Project Manager:	1 - Management	1 - Management	1 - Management	1 - Management	1 - Management	1 - Management	1 - Management
Science Team							
Chief Scientist:	1 - Scientist	1 -Scientist	1 - Scientist	1 - Scientist	1 - Scientist	1 - Scientist	1 - Scientist
Planetary Science Team:	4 - Scientist	3 - Scientist	2 - Scientist	1 - Scientist	1 - Scientist	0	4 - Scientist
Payload & Instrumentation Team:	3 - Scientist 1 - Technician	4 - Scientist 1 - Technician	4 - Scientist 1 - Technician	3 - Scientist 3 - Technician	3 - Scientist 3 - Technician	4 - Scientist 3 - Technician	1 - Scientist
R&D Team:	4 - Scientist	4 - Scientist	5 - Scientist	1 - Scientist	1 - Scientist	1 - Scientist	4 - Scientist
Engineering Team							
Lead Systems Engineer:	1 - Engineer	1 - Engineer	1 - Engineer	1 - Engineer	1 - Engineer	1 - Engineer	1 - Engineer
Mechanical Design Team:	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	3 - Engineer 2 - Technician	3 - Engineer 2 - Technician	3 - Engineer 2 - Technician	0
Power Maintenance Team:	2 - Engineer 1 - Technician	2 - Engineer 1 - Technician	2 - Engineer 1 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	0
Thermal Management Team:	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	0
Command & Data Handling Team:	2 - Engineer 1 -Technician	2 - Engineer 1 -Technician	2 - Engineer 1 -Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	2 - Engineer 2 - Technician	1 - Engineer 1 - Technician
Guidance, Navigation, & Control Team:	1 - Engineer 1 - Technician	1 - Engineer 1 - Technician	1 - Engineer 1 - Technician	2 - Engineer 1 - Technician	2 - Engineer 1 - Technician	2 - Engineer 1 - Technician	1 - Technician
Programmatics Team							
Deputy Project Manager of Resources:	1 - Administration	1 - Administration	1 - Administration	1 - Administration	1 - Administration	1 - Administration	1 - Administration
Mission Assurance Team:	3 - Administration	3 - Administration	3 - Administration	2 - Administration	2 - Administration	2 - Administration	2 - Administration
Program Analyst Team:	3 - Administration	3 - Administration	3 - Administration	3 - Administration	3 - Administration	3 - Administration	2 - Administration

Figure 6: Personnel Mission Life Cycle Division Chart

Of the 38 total team members contributing to the HELP mission, 1 is dedicated to management, 12 are scientists, 10 are engineering, 8 are technicians, and 7 are administration. This division of labor is specifically outlined for Phase C, and can be further observed in Figure 6 to understand how each category is separated amongst the individual subteams. As the mission progresses, mission staff are redistributed to address more pressing concerns in some areas while others have a smaller workload. Since Phase D primarily focuses on the manufacturing and testing of the spacecraft and system components, an increase in engineering and technician personnel is necessary. Phase D also sees a drop in scientist personnel, since most of the planetary science and payload instrument research should be completed, assuming the engineering team is moving forward with established designs and verification and validation (V&V) plans.

By modeling Phase C and its distribution of personnel, the subteams outlined in Figure 5 can be further examined to identify the specific role an individual plays in the completion of the HELP mission. For example, the 10 engineering professionals are divided amongst the Engineering Team, the 12 science professionals are divided amongst the Science Team, the 7 administration personnel are divided amongst the Programmatics Team, and the 8 technicians are distributed between both the Science and Engineering Teams. These divisions are displayed in Figure 6. Understanding how each of these broad categories of subteams organizes its staff and designates authority helps one understand how the HELP mission is coordinated.

The Science Team carries the responsibility of ensuring instrumentation is implemented to meet the mission science requirements outlined in Figure 1. The Planetary Science Team consists of more staff towards the beginning of the mission under the first fiscal year of Phase C, since it’s responsible for researching the Compton Pit, risks associated with the pit, and environmental risks on the Moon. This subteam is allowed much autonomy to cover any necessary bounds in relation to mission hazards and environmentally-based risks. However, they must also communicate their discoveries throughout the Science Team, Engineering Team, and Mission Assurance Team to ensure risks are continuously monitored and tracked throughout Phase D. The amount of Planetary Science Team personnel sees an increase in Phases E and F to draw lessons learned from the recorded data and the corresponding lunar environment. The Payload & Instrumentation Team researches and implements solutions for integrating the instrumentation technology into the HELP spacecraft design. This team is responsible for making sure the mission’s science requirements are met, therefore, they will receive help from technicians when the time comes to manufacture and test payload instruments. This team coordinates its payload research and integration so recovery and redundancy protocols are thoroughly discussed between personnel regarding what each payload instrument contributes to the spacecraft.

The Payload & Instrumentation team heavily communicates with the Research & Development (R&D) Team. The R&D Team is also allowed a significant amount of autonomy regarding decision making and testing strategies. This team is responsible for raising the Technology Readiness Level (TRL) of system components, which subsequently will raise the TRL of the entire HELP mission rover. This team collaborates heavily with the Engineering Team, and will handle much of the

V&V-related testing as well. The R&D team plays a more significant role in Phase C, where it researches manufacturing plans for spacecraft equipment, as well as in Phases E and F to conduct research following the collection and analysis of science measurements.

The Programmatics Team plays a significant role in the entirety of the HELP mission. The Mission Assurance Team is responsible for researching mission-related risks, tracking risks discovered by the Science and Engineering Teams, outlining and helping implement mitigation plans, and continuously monitoring risk status to ensure each is properly addressed. A comprehensive knowledge of mission processes and components is preferable for this position, due to the heavy reliance of mission success on risk mitigation and acceptance. The Program Analyst Team is represented by two subcategories: the Cost Budgeting Team and the Schedule Management Team. One administrator will address the mission schedule, while two will address the mission cost. These two teams will work closely together to monitor the mission's budget and scheduling, and ensure that they remain within range of the established customer constraints[1]. The Cost Budgeting Team holds most of the autonomy regarding budget distribution between other subteams. A consultative system is in place that sees subteams discussing their ideal budget with the Cost Budgeting Team, but ultimately the program analyst personnel have the final say as to how much money is allocated to a given subteam. Therefore, the Cost Budgeting and Schedule Management Teams must continuously monitor mission costs and scheduling setbacks that might impact the current standard, leading to significant changes that might involve descoping.

The amount of administration personnel remains consistent for the entirety of Phase C, however, throughout Phase D the amount of administrators in the Mission Assurance Team decreases to 2. Most of the risks that threaten the mission have already been established prior to Phase D, and mitigation plans should already be in place to help lower the likelihood of risk scenarios occurring. Therefore, it is fitting that a decrease in personnel is seen in this subteam. This transition can be visualized in Figure 6. In Phases E and F, the Program Analyst Team is downsized instead, since major cost and scheduling issues aren't as prevalent past mission launch.

The Outreach Team consists of 8 total members, and it has been split into the Marketing Team and the International Outreach Team. These members aren't included in Figure 6, but are still important factors associated with the HELP mission. The Marketing Team consists of 4 of these members, each of which have different programming and social media responsibilities in relation to formatting a HELP mission website, establishing HELP social media accounts across LinkedIn, Instagram, X, and Facebook, as well as sending informational emails. This team will travel for educational programs across the nation, so it is expected that marketing personnel work well with children. The International Outreach Team is composed of the other 4 members. Each member of this team will attend virtual and in-person conferences with representatives across the globe. It's preferable that these personnel are fluent in several languages, and are comfortable traveling and sharing mission-related information with a host of other cultures and regions.

[1] The total mission budget constraint is $300 million, and the mission launch date is March 1, 2030.

The Engineering Team is the most complex in that it includes a variety of subteams, of which each is responsible for addressing a major subsystem of the HELP spacecraft and plans for subcomponent V&V. The Mechanical Design Team begins with four members, two of which are engineers and the other two technicians. This team researches and designs the mechanical-related components such as wheel treads, spacecraft mechanical structures, and material preference. This team must examine these factors, estimate costs, and discuss them with the Cost Budgeting Team to receive an associated subsystem budget cap. Heading into Phase D, the personnel in this team is increased to include an additional technician to deal with the unique manufacturing design of the spacecraft architecture. This team must also communicate constantly with other Engineering Team subteams and the Lead Systems Engineer to organize the integration of other system subcomponents onto the mechanical hardware design of the spacecraft.

The Power Maintenance Team identifies sources of power for the rover to efficiently run on the lunar surface. This team begins with two engineers and one technician, but gains an additional technician during Phase D to address the testing associated with the solar panels and batteries. Related personnel must have a knowledge of circuitry and wiring as they implement these energy sources into the spacecraft design. The Thermal Management Team must recognize and analyze areas of heat transfer to address the extreme temperature range present on the Moon. This team must consider conductive heat transfer, radiation heat transfer, and convection heat transfer if it’s relevant and how each affects the system (Gilmore 2002). They must also research thermal control solutions such as paint, multi-layer insulation (MLI), and radiators. Two engineers and two technicians are designated to this subteam for the entirety of the mission. Similar to the Mechanical Design Team, the Power Maintenance and Thermal Management teams must coordinate their work amongst the other Engineering Team subteams and the Lead Systems Engineer, as well as discuss their related cost cap with the Cost Budgeting Team.

The Command & Data Handling (CDH) Team plays a significant role in that it ensures science data is properly recorded and stored once it is obtained from the lunar site. This team must establish communication connection systems between the rover and ground control, and obtain the frequency licensing necessary to minimize interference (Bapna, Martin, and Whittaker n.d.). The data collected must be properly stored to be transmitted via this communication. Two engineers are assigned to this team, and a total of two technicians enforce these requirements heading into Phase D. In comparison to other teams in Phase D, the CDH Team continues to have an engineer and a technician in Phases E and F to ensure this data is transmitted and collected efficiently at this critical time.

The Guidance, Navigation, & Control (GN&C) Team also incorporates a communication aspect to receive ground system commands and navigate across the lunar surface. One engineer works with one technician throughout Phase C, and one engineer is added to the team in Phase D to further implement system commands to be utilized in system operations on the lunar surface. They will work closely with the Payload & Instrumentation Team and other Science Team subteams to enforce the

HELP Concept of Operations, involving an in-depth plan mapped out for when the rover reaches the lunar surface. This plan is outlined in Figure 3. Similar to the CDH Team, one technician is available in Phases E and F to address any critical issues that arise concerning system navigation. Again, each of these teams is also responsible for understanding the costs associated with their subcomponents and working below the cost cap assigned by the Cost Budgeting Team.

Verification and validation (V&V) involves confirming the requirements outlined by the customer and each of the other subteams are properly addressed and met throughout the mission timeline (Day n.d.). The V&V process is enforced by each of the engineering subteams outlined in Figure 5, as well as the Payload & Instrumentation Team. Mission validation is completed earlier in the Mission Life Cycle in Phase B in order to ensure requirements remain stagnant throughout the mission timeline. In Phase D, teams addressing this process will clarify verification protocols involving inspection, analysis, demonstration, and testing to each of the spacecraft subsystem components. In outlining these methods, the TRL of system subcomponents will be raised and mission uncertainties will be alleviated. Officials guaranteeing V&V are awarded much autonomy to outline V&V strategies, but they must also maintain constant communication and consider process costs with the Cost Budgeting Team before beginning the V&V process of a subcomponent.

Decision making is an important factor to consider when addressing mission task division and significant decisions in order to move forward with the mission. The one management position, the Project Manager (PM), is the decision-maker responsible for making these major decisions. Similar to the decision making process in-place with the Cost Budgeting Team, the PM will discuss major decisions with representatives from the Science, Engineering, and Programmatics Teams, but will essentially have the final say in an outcome[2]. The representative of the Science Team is the Chief Scientist from the scientist personnel, that of the Engineering Team is the Lead Systems Engineer from the engineering personnel, and that of the Programmatics Team is the Deputy Project Manager of Resources (DPMR) from the administration personnel. When conducting trade studies across subteams, the PM will delegate the decision to a deliberation lead instead. Deliberation leads will be one of these three team representatives, and they'll be responsible for having more knowledge in relation to the trade study being conducted. Therefore, these leads can make more informed decisions considering RIDM processes. These leads must also explain their decision to the PM, as well as communicate the necessary changes that must occur amongst the other subsystems for its integration to be conducted smoothly.

1.7 Manufacturing and Procurement Plans

The spacecraft's solar panels will be contracted and sourced from The Boeing Company's Spectrolab. If the Boeing company is unable to provide the solar panels, then SolAero Technologies will be contacted. The Boeing Company's Spectrolab is the world leader in high efficiency solar panels, with a substantial amount of experience in spaceflight. Spectrolab panels have additionally assisted in previous NASA missions, as

[2] This decision structure can be defined as consultative decision-making.

well as commercial and military satellites.The power distribution system will be provided by Northrop Grumman. Northrop Grumman will be able to supply highly customizable power distribution systems, which will allow for seamless integration for the spacecraft. Additionally, Northrop Grumman has experience in government and commercial space missions, making them a great resource to contract the power distribution unit (PDU). In the event Northrop Grumman is unable to supply the power distribution unit, Lockheed Martin will be contacted instead. Lastly, the solid state battery will be contracted from Panasonic. Panasonic is a global leader in battery technology, and will be able to provide batteries with high energy densities, long cycle life, and great temperature tolerances. These characteristics make Panasonics' solid state battery the ideal candidate for the spacecraft's power storage unit. Solid Power will be contacted in the event that Panasonic is unable to supply the batteries.

The Thermal Management System requires a variety of different components to seamlessly work together in order to ensure that the temperature within the spacecraft does not fluctuate extremely. The heating/cooling units will be contracted from Lockheed Martin. These units designed by Lockheed Martin have the ability to maintain precise temperature control, as well as experience in multiple missions, making Lockheed Martin a reliable candidate. Northrop Grumman will be contacted in the event Lockheed Martin is unable to provide the units. The MLI Coating will be manufactured in house with NASA resources. This is due to the fact that the MLI coating will require precise control over the production process, which ensures that the coating meets the expected requirements for the thermal management system. Fluid Loops will be supplied by Jacobs Engineering Group. Jacobs Engineering Group has significant experience in integrating fluid loops into thermal management systems for similar applications to the spacecraft. The Aerospace Corporation will be contacted in the event that Jacobs Engineering Group is unable to provide the fluid loops. Heat pipes will be utilized in conjunction with fluid loops, and contracted by Sierra Nevada Corporation. Sierra Nevada has experience in space missions, specifically involving integrating heat pipes into thermal management systems, making them the perfect candidate to supply the heat pipes. General Dynamics Corporation will be contacted in the event Sierra Nevada is unable to provide the Heat pipes. Radiators are another integral component of the thermal management system, and will be contracted from The Boeing Company. Boeing has the ability to manufacture advanced radiators for aerospace applications, making them the ideal candidate to source the radiators from. Raytheon Technologies Corporation will be contacted as a backup to Boeing. Lastly, the thermal management systems heat exchanger will be contracted from Teledyne Technologies Incorporated. Teledyne Technologies has experience with heat exchangers in aerospace applications, and can guarantee reliable and efficient thermal control systems. Aerojet Rocketdyne will be contracted in the event Teledyne technologies is unable to supply the heat exchangers.

Mesh Wheels will be utilized on the spacecraft, and contracted from Northrop Grumman Corporation. Northrop Grumman has experience in creating solutions for spacecraft mobility in aerospace applications, and has the ability to engineer lightweight, durable wheels. The spacecrafts' wheels will be contracted from Sierra Nevada Corporation in the event Northrop is unable to provide the wheels. In regards to the spacecrafts' communications and data handling, an onboard computer is vital to the success of the mission. The onboard computer will be contracted from Lockheed Martin Corporation. Lockheed's onboard computers provide a reliable computing power, and are ideal for aerospace applications due to their radiation tolerance. Raytheon Technologies Corporation will be contracted to provide the onboard computer if Lockheed Martin is unable to. Lastly, the spacecraft needs a means of storing information. This will be possible through the use of Electronic Data Storage. The spacecrafts' electronic data storage will be contracted through Teledyne Technologies Incorporated. Teledyne has the ability to provide high capacity data storages that are resilient against radiation exposure, making them the ideal candidate for this mission. Leidos Holdings Incorporated will be relied on to provide the Electronic Data Storage in the event Teledyne is unable to.

Many scientific instruments will be utilized during this mission, and contracted by TELEDYNE TECHNOLOGIES INCORPORATED, and in the event that TELEDYNE TECHNOLOGIES INCORPORATED cannot manufacturer some instruments then RAYTHEON TECHNOLOGIES CORPORATION will manufacture the rest. Both these contractors specialize and have experience making tech, making them a great choice for making the scientific instruments. In all, both companies have the ability to manufacture the ProSEED, NIRVSS, NSS, M-42, REIGL, and REMS that this mission is looking for.

Mechanical subsystems are very important for this subsystem and therefore Northrop Grumman Corporation will be chosen to manufacture these items. Northrop Grumman Corporation is a very reliable company and has experience in manufacturing the items needed for this mission. In the case Northrop Grumman Corporation isn't able to manufacture the mechanical subsystem then Sierra Nevada Corporation will be contacted as the backup supplier.

The mechanical subsystems estimated lead time will be from March 2027 until January 2028. The Northrop Grumman Corporation will work on manufacturing this subsystem the full amount of time in phase D due to how important the mechanical part is. If Northrop Grumman Corporation isn't able to complete the manufacturing of the mechanical subsystem then the backup supplier Sierra Nevada Corporation will take over and may take until march 2028.

The thermal subsystems estimated lead time will be between March 2027 to December 2027. Lockheed Martin, Jacobs Engineering Group, Aerospace Corporation, Sierra Nevada Corporation, The Boeing Company, and Teledyne Technologies Incorporated will work on manufacturing specific thermal subassemblies used throughout the spacecraft. Each subassembly will be integrated within each subsystem to ensure optimal efficiency throughout the mission. NASA resources will be used to manufacture the MLI coatings specifically on the exterior of the spacecraft while the other subassemblies are being manufactured. This time frame allows the specific manufacturers to deliver the subassemblies in a timely manner, provide time to use backup suppliers if needed, and allows for the integration of the thermal subassemblies throughout each subsystem.

The CDH subsystems estimate lead time will be between March 2027 to December 2027. Boeing Company’s Spectrolab, Panasonic, and Northrop Grumman Corporation will be the primary manufacturers of this subsystem. These companies will need this time in order to make sure each CDH subassembly is manufactured correctly and works efficiently. In the case these companies don’t work out, the backup suppliers will take over and most likely take an extra month until January 2028.

The Scientific instruments subsystems estimated lead time will be between March 2027 to October 2027. TELEDYNE TECHNOLOGIES INCORPORATED will be in charge of manufacturing these instruments and will need this allocated time in order to test each instrument and make sure it's working efficiently. In the case that TELEDYNE TECHNOLOGIES INCORPORATED cannot manufacture the scientific instruments then RAYTHEON TECHNOLOGIES CORPORATION will take over. RAYTHEON TECHNOLOGIES CORPORATION may take an extra month and finish in November 2027, due to late notice. Both companies would be responsible for manufacturing efficient ProSEED, NIRVSS, NSS, M-42, REIGL, and REMS that this mission is looking for.

The power subsystems estimated lead time will be between March 2027 to December 2027. The Boeing Company, Northrop Grumman, and Panasonic will work on manufacturing specific power subassemblies used throughout the spacecraft. This time frame allows the specific manufacturers to deliver the subassemblies in a timely manner, provide time to use backup suppliers if needed, and allows for the integration of the power subassemblies throughout each subsystem. The power subsystem will be used throughout the interior such as the batteries and power distribution system, while the solar panels are used on the exterior of the spacecraft. Additional time was provided for the power system due to the significant importance of the subsystem itself and to allow time for the specific integration between the power, thermal, and mechanical subsystems.

1.8 Risks and Safety

1.8.1 Risk Analysis

A variety of risks threaten the safety and success of the HELP mission. These risks represent the probability that an event or scenario negatively impacts either the technical, safety, cost, or schedule aspects of this mission. Baselining strategies to identify, research and mitigate these risks is absolutely necessary for minimizing the risks present within each subsystem. In order to conduct risk management efficiently, the HELP team will abide by a handful of steps outlined by Risk-Informed Decision Making (RIDM) and Continuous Risk Management (CRM) protocols. Interpreting these protocols and integrating their processes into HELP’s risk management system will foster sufficient risk mitigation techniques that will hopefully lead to eventual risk acceptance.

The first steps taken to effectively identify and mitigate risks relate specifically to

RIDM[3]. This process can be divided between several key milestones. The first milestone involves reviewing stakeholder and mission expectations to derive performance measurements for the mission, which are further used in trade studies that evaluate multiple decision alternatives. Constraints were established by consulting the MCA Mission Task Document and assessing stakeholder constraints[4]. The HELP STM further formatted these constraints with performance measurements and requirements that abide to stakeholder criteria and mission science objectives. Various decision alternatives were then found by the science and engineering teams to be used in trade studies. This step is sufficiently completed by outlining risks in a Risk Summary Table based on the components considered in trade studies and other risks considered for the mission.

The second milestone of the RIDM process involves mitigating the risks outlined previously. Strategies used to estimate these performance expectations included similarity or analogous estimation methods, parametric estimation methods, and testing estimation methods. The testing methods have and will prove especially effective for improving a component's Technology Readiness Level[5] (TRL) in preparation for the mission. If a risk is deemed too costly to address given the mission timeline and budget, or seemingly has no solutions to addressing the problem, then previous decisions made in the earlier stages of the RIDM process will be reconsidered to better advance this mission.

To begin mitigating these risks, possible solutions must first be researched. The CDH subsystem is subject to multiple risks, one of which involves the passivation process necessary to complete HELP's decommissioning plan. This particular risk is outlined in Figure 7, as well as several other CDH-related risks. Point failures in communication and standard procedures present opportunities for the passivation process to either default early and disrupt the mission timeline or prevent this energy depletion process from ever occurring due to autonomous recovery systems (Hull n.d.). This single point of failure will be mitigated by including redundant hardware and thorough software programs that ignore a passivation initiation message that occurs prior to the disposal phase of the mission (Hull n.d.). In addition, the CDH subsystem will be programmed using a disposal mode of operations to disable any autonomous recovery systems during the final decommissioning phase as well (Hull n.d.).

Communication continues to be a point of concern for spacecraft interaction due to alternative spacecraft and satellite interferences. The surplus of space systems that separate the Earth from the Moon carry their own radio-frequency waves as specified in Figure 7, meaning there is potential for those signals to override messages received from the HELP spacecraft. This risk is being addressed by obtaining frequency licensing

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[3] The RIDM process involves evaluating a set of established performance measurements to help decision-makers make informed decisions (Homayoon Dezfuli et al. 2011).
[4] Stakeholder constraints are outlined in the MCA Mission Task Document. These constraints provide limits for mass (350 kg), dimension (2m x 1.25m x 1.25m), and design (must explore a lunar cave and get surface science measurements).
[5] The HELP team recognizes the importance of raising the TRL level of every subcomponent of the mission system, given the standard that the lowest TRL often represents the TRL of the entire system, and TRL plays a crucial role in risk evaluation and uncertainties in relation to the mission.

and allocation, which takes approximately two to three years to confirm (Bapna, Martin, and Whittaker n.d.). The CDH Team outlined in Figure 5 is actively working to address this potential issue. In addition, the X-Band High-Gain Antenna is being researched to coordinate with phased arrays to address failure modes that might occur in communication (Hong 2023).

The payload subsystem carries several instruments of which their operation is crucial to the success of the HELP mission. Furthermore, there are a variety of risks related to this subsystem outlined in Figure 7 that will be continuously expanded on and addressed. The LiDAR device is a complex device that returns large amounts of mapping data to be analyzed. The data it collects relies on laser technology to map surrounding areas. When alternative light sources interfere with this technology, the LiDAR detector may become damaged or incorporate these faulty light signatures into an incorrectly mapped representation ("Advanced Techniques for LiDAR Interference Avoidance" 2024). An ultra-narrow interference filter is being implemented to address this issue, due to its durability and ability to ignore certain wavelengths of light ("Thin-Film Interference Filters for LIDAR" 2017). Additionally, the massive amount of data that LiDAR returns presents potential issues with data handling procedures. To ensure the data is efficiently recorded and analyzed, an Onboard Computer (OBC) will work with an electronic data storage bank to ensure data is efficiently stored.

Micrometeoroid and orbital debris (MMOD) presents potential concern to the payload subsystem as well. Despite there being a low possibility that the spacecraft is struck by a micrometeoroid, the resulting consequences from the impact are severe. Major injuries to the payload subsystem may prevent the necessary science measurements from being recorded. In order to address these scenarios, a system similar to Markov and Kalman State Identification (MAKSI), an onboard fault detection system, which applies continuous and estimations (Washington 2000). This system actively evaluates any damages sustained by impacts (Arnold et al. 2009). These sensors and redundant protocols are also important for addressing instrument failures that don't occur due to MMOD. Payload devices and optical features are susceptible to extreme conditions on the Moon such as temperatures and lunar dust too. In order to reduce uncertainties of failures that might occur due to these conditions, the instruments must be tested and analyzed under similar environmental conditions to raise their TRL. These experiments will be run at facilities such as NASA's Ames Research Center, which hosts Lunar Lab and Regolith Testbeds (Hoover 2023).

Mechanical subsystem risks are prevalent in relation to MMOD, obstacles impeding navigation, and lunar dust. Impacts from micrometeoroids can potentially impact the HELP spacecraft, leading to significant damages to the mechanical subsystem that may prevent it from being able to travel to the Compton Pit. In order to mitigate this concern, a multi-layered surface damage detection sensory system is being applied to the mechanical structure. This system utilizes software to pin-point surface damage on the rover and its extent (Williams et al. n.d.). Impact craters and resulting debris present additional concerns regarding navigation across the lunar surface. During the HELP spacecraft's trek from the landing site to the Compton Pit, it may encounter meteoroid debris or impact craters that represent significant obstacles to its traversal system. In unfortunate scenarios, these obstacles may cause the robot to become stuck, preventing it from visiting the pit. In order to address this navigation risk outlined in Figure 7, mire mesh wheels are utilized on the HELP rover to effectively traverse the lunar regolith. These wheels are flexible, allowing them to conform to lunar surface features while still being durable (Kilkenny 2017). Simulations will be run to test drive the wheels on a simulated lunar surface ("Designing Rovers for the Moon's Extreme Environment" 2022). Not only will these tests help justify the robot's traversal ability, but they'll also raise the TRL of the wheels.

The mechanical subsystem can also be potentially affected by lunar dust. Lunar dust threatens many subsystem failures. This dust has an electrostatic charge, and is incredibly sharp due to the Moon's lack of water and air, substances that are responsible for smoothening rocks on the Earth's surface ("Designing Rovers for the Moon's Extreme Environment" 2022). The electrostatic property of the dust causes it to settle on mechanical hardware and seals, potentially causing severe degradation (Kaczmarek 2021). To mitigate these risks, dust-resistant seals and materials are being studied and compared. The aluminum alloy being used in the spacecraft design is durable and will be molded tightly to hardware to prevent dust intervention. Additionally, labyrinth seals are applied to system motors, and Teflon seals to the wire mesh wheel motors in order to protect these components from dust. These seals can also withstand extreme temperatures, and will further be tested at the Kennedy Space Center to simulate lunar dust and temperature conditions (Tabor 2020). These tests will subsequently raise the TRL levels of the mechanical system components interfaced with these seal solutions.

The power subsystem is also heavily impacted by lunar dust and other lunar environmental extremes. The dust's electrostatic property allows the dust to latch onto power components such as the HELP system's solar panels. As particles layer these power components, their signals become muffled, lowering the magnitude of any energy provided via the power devices ("How Dangerous Is Lunar Dust for Humans and Equipment? And Can It Also Be Put to Good Use?" 2021). A photovoltaic effect of lanthanum-modified lead zirconate titanate (PLZT) dust removal ceramic is being applied to these system components to help remove attached dust. The PLZT emits electrostatic traveling waves to clear dust that has settled on solar panels after consuming ultraviolet light (Jiang et al. 2019).

Several other environmental characteristics of the Moon pose major risks to the power subsystem. Due to the Moon's orbital relationship with the Sun, some areas of the Moon are lit while others remain in darkness. The HELP spacecraft relies on solar panels for energy, therefore spending long periods of time in these dark regions is not possible since it will eventually run out of power. This concern limits the amount of time the HELP spacecraft can travel in these areas, which includes dark, secluded areas of the Compton Pit. Given that the allotted time for rovers to remain in permanently shadowed areas is 50 hours (Wetzel, 2021), a plan outlined in Concept of Operations clarifies how the HELP spacecraft charges for enough time in sunlight and has limited, estimated movement while in permanent darkness.

The Moon's thin exosphere also causes severe radiation due to its lack of a consistent magnetic field. This radiation has the potential to cause severe damage to HELP's power subsystem. Cosmic radiation has been known to wipe the memory of computer chips, cause electrical systems to fail, and lead to brittle wires that break easily ("Designing Rovers for the Moon's Extreme Environment" 2022). In order to address issues of radiation in the power subsystem, electrical wires are shielded with insulation to prevent them from becoming brittle ("Designing Rovers for the Moon's Extreme Environment" 2022). In the event that wires do become faulty, the system's electrical flow has been programmed to be rerouted around damages and still reach its required destination (Beale n.d.). Preemptive shielding is also applied to the solar panels and other hardware components to protect them from degradation induced by cosmic rays (Beale n.d.). Using Corning type 7940 artificial fused silica, a thickness of 6 thousandths of an inch is layered over these components (Waddel n.d.). This specific thickness has been identified due to its greater power protection and lesser tendency to limit energy production from light (Waddel n.d.).

The thermal subsystem is also subject to major threats imposed by the lunar environment. The surface temperature on the Moon varies immensely depending on a region's lighting conditions. Due to the thin atmosphere on the Moon, known as the exosphere, the lunar surface is minimally insulated (Sharp and Urrutia 2023). This leads to temperatures that range from 121°C in the light to -133°C in the dark (Barry, n.d.). In the Compton Pit, permanently shadowed areas might reach extreme temperatures up to -246°C. This extreme flux in temperature may induce severe stresses and strains on the spacecraft's thermal technology, which heavily impact the functionality of thermal, electrical, and payload components (Beale n.d.). The Thermal Management Team is integrating a type of Kapton electrical heater known as the Omega Polyimide Heater Kit to address colder temperatures. To address the extreme heat, thermoelectric coolers and fluid loops are also included in the spacecraft design. These solutions are compact, and help monitor the temperature of system components and maintain operable temperatures (NASA, 2024). Integrating several solutions in regards to temperature control will improve system redundancy as well.

Similar to the mechanical and power subsystems, the thermal subsystem is also threatened by lunar dust and its tendency to settle on spacecraft components. The layers of dust that build up on thermal devices reduce the spacecraft's ability to maintain insulation across the system body ("How Dangerous Is Lunar Dust for Humans and Equipment? And Can It Also Be Put to Good Use?" 2021). This scenario may eventually lead to robot systems failing, an event that would certainly prevent science measurements from being recorded. The PLZT technology used for the power subsystem will similarly be implemented into thermal components to mitigate this significant lunar dust issue. Applying this technology across multiple spacecraft subsystems allows the Thermal Management and Power Maintenance Teams to follow similar testing protocols to raise the TRL of this lunar dust mitigation technique.

As tests are completed for the technical subsystems and instrumentation, probability density functions[6] (pdfs) will be created in coordination with Monte Carlo

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[6] A probability density function (pdf) is a figure, or graph, that displays the probability of outcomes that occur for a given performance measurement when assessing an alternative (Homayoon Dezfuli et al.

shells to better understand uncertainties surrounding the performance parameters of each alternative. These strategies will address both aleatory[7] and epistemic[8] uncertainties. This process will be incredibly important for RIDM and pruning alternatives and for CRM when risks are further reconsidered, testing is repeated, and this process is iterated.

The third major milestone that will complete what HELP's RIDM process looks like includes establishing risk tolerances for the performance measurements and risks being considered and finally making a decision following the trade study process outlined previously. The risk tolerances assigned to the various performance measurements heavily impacted whether or not an alternative was selected. The size of these tolerances depended on the priority ranking of the measurement being evaluated. Measurements that are critical to our science objectives, especially ones spectrometer related, were given lower risk tolerances in order to eliminate components that generated the most uncertainty in relation to meeting necessary requirements. Customer constraints and failures that impacted larger pieces of the mission system were also considered when establishing these ranges of acceptance. A Risk Matrix helps visualize what risks have higher uncertainty ranges. A risk's probability of success directly affects the risk's place in the matrix by judging the risk's likelihood and consequence. This matrix is further inspected to assign priority for addressing one risk over another.

Completing this RIDM process allows the HELP team to move forward with necessary CRM protocols. The CRM strategies used are responsible for managing the risks that have been outlined in the RIDM process, and can be broken down into five critical steps. These steps are continuously repeated throughout the timeline of this mission concept to constantly check for new risks, mitigate ones already researched, and eventually accept risks once they've been mitigated sufficiently. It's important to note that no risk can be completely eliminated - accepting a risk implies that its likelihood of occurring has been reduced significantly to the point where other options present higher likelihood and the probability of the related scenario recorded has been minimized to the greatest degree possible.

The first step implemented from CRM involves identifying mission concerns based on the selected alternatives from RIDM. Next, the Risk Summary Table analyzes the likelihood of each risk scenario occurring, and the rated consequence of its impact on the mission system. The HELP team's Mission Assurance Specialists have assigned values to these two variables, L and C, in Figure 7. These values were determined based on several uncertainties potentially observed by the risks outlined in Figure 7. These uncertainties consider the uniqueness of the risk in relation to other missions, the cross-cutting character or impact the risk will have on other system components, the

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2011). These figures are normally used to compare uncertainties in the success of a component being compared in a trade study.

[7] Aleatory uncertainties are random and can't be alleviated by completing testing and analysis (Homayoon Dezfuli et al. 2011).

[8] Epistemic uncertainties are not random and can be reduced by learning more on a topic through testing (Homayoon Dezfuli et al. 2011).

complexity of the component being considered for the risk, the propagation potential of the risk to segway into greater faults in the mission concept, and the detectability of the risk if it were to occur. The severity assigned to likelihood and consequence is restricted to a number 1 to 5, with 1 being low likelihood or low consequence, and 5 being high likelihood and high consequence. Risks with the highest likelihood and consequence levels will be prioritized throughout this mission, whereas risks of lower value will be addressed secondhand and aren't be represented in the Risk Matrix seen in Figure 8.

The third step of CRM involves addressing each of the risks established in Figure 7. These risks are either being actively researched, mitigated, accepted, or watched. The current status, or plan, of each risk is represented in the eighth column of Figure 7. At this current stage of the mission timeline, the newly established risks are being researched to better understand the circumstances that might bring about the risk scenario and what can be done to minimize the uncertainty in relation to each risk. After this process, mitigation strategies will begin to be implemented for each risk.

The fourth step will see the severity and progress of each risk tracked continuously throughout the mission timeline. The Mission Assurance Specialists have and will communicate with the engineering, science, and programmatics subteams to monitor and receive updates on risks to individual mission components. New risks will be appended to Figure 7, major priority risks will be addressed in Figure 8 to lower their likelihood of occurring, and the progress of these risks will be monitored until the point where it might be deemed possible to accept a risk as is in preparation for the mission.

Maintaining planetary protection (PP) for this mission requires certain guidelines be met. The HELP spacecraft is categorized as a Category IIa mission by Committee on Space Research (COSPAR) policy standards, therefore risks are present in relation to the spacecraft's bioburden, probability of contamination, and organic inventory ("Editorial to the New Restructured and Edited COSPAR Policy on Planetary Protection" 2024). In order to properly address these potential issues of concern, strict guidelines and documentation will be developed that clarifies strategies for quantifying HELP's probability of contamination and chemical impact on the Moon. Researching and devising control plans for each of these areas of concerns will minimize the uncertainty in relation to planetary protection risks.

Regarding documents that will be formalized to ensure these procedures are efficiently executed, a PP Mission Categorization Proposal will be issued to specify that the HELP mission is a Category IIa mission, given that it will be completed below the 86°N latitude line at the Compton Pit (DeLoach 2022). A PP Requirements Document will then be formatted with requirements and relevant compliance, non-applicable, and non-compliance statements that clarify the mission's plans for abiding to the requirements. In addition, a scheduling system will be clarified for providing necessary planetary protection documentation. Next, a PP Implementation Plan will be developed that follows guidelines for a Category IIa mission. This document will follow the HELP mission across the entire project life-cycle; it will include how the mission abides to requirements and considers necessary risks (DeLoach 2022).

One potential concern outlined in Figure 7 is that intensive organic inventories on the HELP spacecraft will lead to contamination of the Compton Pit. This risk will be addressed by working in a sterile facility for the entirety of spacecraft production. Personnel will be required to follow sterilization procedures and planetary protection guidelines will be followed (Greicius, Jackson, and Hartono 2020). A PP Organic Inventory will be conducted to monitor organic materials on the HELP spacecraft that exceed 0.1 kg in mass (DeLoach 2022), as well as estimate the extent to which organic materials may be released into the lunar environment.

A Pre-Launch PP Report will also be filed that quantifies the spacecraft's volatile organic materials, propellent residuals, and combustion products that may be emitted by spacecraft systems (DeLoach 2022). Similarly, a Post-Launch PP Report will be conducted that will include any alterations to the previously quantified amounts due to launch. An End-of-Mission PP Report will be conducted during the decommissioning phase of the mission to again assess the spacecraft system's emitted or stored amount of volatile organic materials, propellent residuals, and combustion products to ensure it remains at a viable amount (DeLoach 2022).

Completing this End-of-Mission PP Report involves carrying out the HELP Decommissioning Plan and ensuring planetary protection guidelines are followed. Without thorough plans for decommissioning, a risk arises as seen in Figure 7 that potentially sees the spacecraft exploding due to energy build-up (Hull n.d.). Passivation appears to be an efficient strategy that relieves onboard sources of energy and disables sources of energy generation (Hull and Schonberg 2022). While there are no propellant systems present on the HELP rover, the spacecraft's solid-state battery energy must be depleted during the decommissioning phase (Caldwell 2024b). However, initiating the passivation process to relieve these concerns raises several risks in relation to the spacecraft system.

Risks considering budgeting and scheduling must also be addressed to ensure this mission is carried out successfully. For one, the mission schedule can potentially be impacted by severe testing delays. The recent budget descope has led to several descoping processes in relation to the mission payload instruments and cost evaluation of the HELP mission. The payload changes signify more testing must be completed to confirm the addition of these new components, as well as raise their corresponding TRL. Setbacks in testing may build upon each other to a point where the mission launch date is unachievable. Reevaluating and retesting procedures are necessary in case instruments fail under lunar conditions or are discovered to not meet system requirements. The Mars Curiosity Rover is a good example as to why it's important to begin this testing phase early. In order to mitigate this potential issue, the HELP team has already conducted trade studies for these new instruments, and has developed plans to travel to testing facilities to monitor the manufacturing and testing process. The completed procedures will follow guidelines outlined by NASA for testing while maintaining risk control protocols too ("NASA Systems Engineering Handbook" 2007).

The Program Analyst Team will be working extensively with the Cost Budgeting and Schedule Management Teams to conduct mission cost and budget evaluations continuously to monitor the status of the mission and enforce the mission constraints regarding the budget and mission schedule[9]. In addition, an in-depth budget revaluation was conducted to alleviate descoping concerns, therefore the budget available now is considerably more accurate. Margin percentages mentioned in the Budget Basis of Estimate allow room for uncertainties in relation to cost and budgeting risks too.

In the event that personnel are not prepared to undergo this testing, or there are equipment availability issues, there is a risk for the mission schedule to be impacted. These resource constraints may lead to significant milestones being missed throughout the mission timeline. To mitigate this particular risk, resource allocations will continuously be monitored by the Program Analyst Team, and mission tasks will be assigned priorities in order to coordinate the distribution of resources. Strategies to navigate this process will be implemented from NASA's Scheduling Management Handbook, which provides advice on how to adapt to changes and unforeseen circumstances ("NASA Schedule Management Handbook" 2011).

Many scenarios that heavily impact mission schedules also greatly affect mission costs. If technical difficulties were to occur, or devices or materials suddenly become higher in demand, the mission cost may threaten to surpass the recently descoped mission budget constraint of $300 million. This concern is why it's incredibly important to establish margins early on in the mission life-cycle - these boundaries allow for some leeway to occur in relation to cost increases. In order to further manage these unexpected costs, budget assessments and emergency funds will be allocated. The margins specified in the Budget Basis of Estimate will help accommodate any unexpected expenditures that occur throughout the mission. The importance of procedures like these becomes clear when observing scenarios such as the James Webb Space Telescope, a device that experienced cost growth due to unforeseen challenges ("The Role of Satellites in Enabling Emerging Technologies" 2015). Cost risks will further be mitigated by conducting proactive risk assessments such as failure modes and effects analyses (FMEA). The FMEA section clarifies the highest priority risks that threaten the success of the HELP mission. The corresponding Figure 9 also outlines the individual spacecraft systems and components that are affected by each risk as well.

Personnel safety and professional experience also present opportunities for risk throughout the HELP mission. Staff turnover may occur and skill gaps may be present throughout mission personnel. To alleviate these risks, a program similar to Mission Support Future Architecture Program (MAP) has been implemented to address workforce availability concerns in this mission's Project Management Approach and to award employee and contractor performance when cost and schedule requirements are met ("NASA's Management of the Space Launch System Booster and Engine Contracts" 2023). The Space Launch System program outlines lessons learned that help to prioritize certain techniques over others in relation to this MAP program ("NASA's Management of the Space Launch System Booster and Engine Contracts" 2023). Safety is also a major concern regarding personnel and testing procedures. Since personnel will be working often with HELP instruments to raise TRLs and assess a device's ability to withstand harsh environmental conditions, component failure is

[9] The mission cost cap is $300 million, and a hard launch date has been set for March 1, 2030.

certainly a possibility. Safety protocols regarding Personal Protective Equipment (PPE) will be followed at testing facilities, safety equipment will be up-to-date, and safety guidelines will be strictly followed in order to address these risks ("Occupational Safety and Health" 2024). The HELP team is implementing a safety plan that aligns with safety strategies and procedures outlined in the NASA Systems Safety Handbook (Dezfuli 2014).

Mission outreach risks must also be considered when evaluating concerns of the entire mission. Risks are present in relation to foreign engagement and garnering public support. To address potential limits placed on international engagements, virtual conferences have been organized with foreign countries to discuss lessons learned and significant mission discoveries. An Outreach Plan has been formalized that involves sending mass amounts of informational emails as well. The Mars Perseverance mission followed similar steps successfully, and their use of virtual outreach led to greater mission interaction worldwide (Cook and Good 2021). Public support also plays a critical role in mission exposure and budgeting support. The benefits of prioritizing public support are prevalent when analyzing the Apollo Program and its proactive approaches for outreach and mission awareness (Ostovar 2024). The HELP Outreach Team will schedule educational events regularly with school systems across the nation, and has planned televised mission updates and broadcasts that allow the public to view mission progress real-time.

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Safety - Planetary Protection	1	4	↓	M	Given that the Moon is sensitive to extraterrestrial disturbances, organic inventories might contaminate potential lunar habitation sites visited by the HELP spacecraft, thereby impacting the habitability of the Compton Pit and the nearby landing site.	The spacecraft will be manufactured in sterile facilities, in which workers are expected to follow sterilization protocols. A PP Organic Inventory report will also monitor the mass of organic materials on the spacecraft. (11/13/24, CA)
2	Safety - Decommissioning	1	5	↓	M	Given that a spacecraft stores residual energy over long periods of time when left running a spacecraft explosion may occur due to energy build up impacting the Compton Pit, thereby damaging a potential habitability site on the Moon.	Passivation processes are being implemented that address premature passivation messages and autonomous recovery protocols that might prevent passivation from occurring. (11/14/24, CA)
3	Power - Lighting Conditions	2	4	↓	M	Given that the Moon has permanently shaded areas that receive zero light from the Sun, solar power cannot be continuously stored by the robot in these areas impacting the robot's solar panels negatively to limit the extent to which the robot can remain in these areas.	The HELP mission Concept of Operations clarifies how long the rover remains in potential permanent darkness regions of the Moon in comparison to areas where the system can charge itself. (11/13/24, CA)
4	Power - Radiation	2	4	↓	M	Given that the Moon has a very thin atmosphere, the lunar surface has little protection from cosmic radiation which can cause significant damage to electrical systems thereby wiping computer chip memory and short-circuits in system wiring.	Insulation will protect wires and computer chips from being significantly affected by radiation, and rerouting electrical connections addresses faulty wiring issues. (11/13/24, CA)
5	Power - Lunar Dust	2	4	↓	M	Given that lunar dust is present on the Moon and it carries an electrostatic charge, it will stick to objects not electrically grounded on the Moon such as the HELP spacecraft, which might damage system assemblies carrying electronics and reduce energy generated from solar panels.	The photovoltaic effect of lanthanum-modified lead zirconate titanate (PLZT) dust removal technique is being implemented to remove dust from energy sources using electrostatic traveling waves. (11/13/24, CA)

6	Thermal - Lunar Dust	2	4	↓	M	Given that lunar dust is present on the Moon and it carries an electrostatic charge, it will stick to objects not electrically grounded on the Moon such as the HELP spacecraft, thereby covering thermal radiators and causing them to produce less heat for other subsystems.	The photovoltaic effect of lanthanum-modified lead zirconate titanate (PLZT) dust removal technology is being implemented to remove dust from thermal components using electrostatic traveling waves. (11/13/24, CA)
7	Thermal - Temperature	2	5	↓	M	Given that lunar surface temperatures vary from 40K to 250K, an object on the Moon may be subject to two polar opposite temperatures depending on the location of the Sun, impacting spacecraft components, by creating large heat fluxes that induce thermal stresses, strains, and distortions on science instrumentation and other components.	A Omega Polyimide Heater Kit will be used to address colder temperatures, and a thermoelectric cooler will be used with fluid loops to address the extreme heat. (11/13/24, CA)
8	Mechanical - Lunar Dust	2	3	↓	M	Given that lunar dust is present on the moon and it carries an electrostatic charge, it will stick to objects not electrically grounded on the Moon such as the HELP spacecraft and might erode mechanical components that haven't been properly sealed.	Dust-resistant seals such as the labyrinth and Teflon seals are being used to protect mechanical components from lunar dust. (11/13/24, CA)
9	Mechanical - Navigation	2	3	↓	M	Given the heavily cratered and uneven terrain present on the Moon, there may be significant obstacles such as rocks and craters between the identified landing site and the Compton Pit impacting the HELP rover's wheel traction, thereby leading to problems with path planning and issues of getting physically stuck in one place on the lunar surface.	A wire mesh wheel design is being used to account for steep slopes and jagged regolith. These wheels will be tested through simulations to model how they'll function on the lunar surface. (11/13/24, CA)
10	Mechanical - Micrometeoroid and Orbital Debris (MMOD)	1	3	↓	M	Given that the Moon has a very thin atmosphere, micrometeoroid and orbital debris may impact the lunar surface in and around the Compton Pit potentially threatening the HELP spacecraft's mechanical architecture by striking the spacecraft directly.	A multi-layered damage detection system is being applied to the robot architecture to locate damage and assess its magnitude. (11/13/24, CA)

11	CDH - LiDAR Data Handling	2	3	↓	M	Given the large amount of data returned by LiDAR simultaneous localization and mapping (SLAM), the LiDAR system used on help may produce a surplus of data information while mapping the Compton Pit overloading the CDH subsystem, thereby making it difficult for the subsystem to handle and record all the necessary data.	An Onboard Computer and electronic data storage bank will be used to handle the mass amounts of data recorded by the RIEGL LiDAR device. (11/13/24)
12	CDH - Communication Interference	1	3	↓	M	Given the variety of active communication systems that remain active in the space between the Earth and the Moon, there may be communication interferences that impact the radio-frequency waves emitted by the CDH subsystem, thereby interfering with the data being recorded by HELP's payload subsystem.	Frequency allocation and frequency licensing are being addressed by the CDH Team. This process will be completed well before mission launch, as it will take up to a few years. (11/13/24, CA)
13	CDH - Passivation Communication	1	4	↓	M	Given that passivation processes are controlled via communications systems one single erroneous line due mission operations initiating passivation would impact the HELP mission collection entirely thereby relieving the spacecraft of its power and preventing it from completing the mission.	The CDH Team is programming protocols into the HELP system that ignore early passivation messages that occur prior to when passivation should actually occur. (11/13/24, CA)
14	CDH - Passivation and Autonomous Recovery Systems	1	2	↓	M	Given that autonomous recovery systems are in place on the HELP spacecraft, they may constantly default the system to an active state preventing passivation procedures, and thereby preventing the HELP mission from completing its end of mission protocols.	The process of disabling the HELP's autonomous recovery system is being addressed by the CDH Team by programming a disposal mode of operations that disables Autonomous Recovery Systems past a given mission milestone. (11/13/24, CA)
15	Payload - LiDAR - Light Interference	2	4	↓	M	Given the severe difference in lighting conditions on the Moon based on the location of the Sun, light will be reflected and received at different angles on the lunar surface impacting the light received by LiDAR, thereby damaging the LiDAR's light reception system or creating confusing data that affects LiDAR's mapping techniques.	An ultra-narrow interference filter is being integrated into the RIEGL LiDAR device to filter out unnecessary wavelengths of light. (11/13/24, CA)

16	Payload - Micrometeoroid and Orbital Debris (MMOD)	1	3	↓	M	Given that the Moon has a very thin atmosphere, micrometeoroid and orbital debris may impact the lunar surface in and around the Compton Pit potentially threatening the HELP spacecraft by striking the spacecraft directly or impeding its path from the landing site to the pit.	A system similar to MAKRI is being implemented that continuously addresses the state of the payload instruments. This system will help identify and assess MMOD damage. (11/13/24, CA)
17	Payload - Instrument Failure	2	5	↓	M	Given that the lunar environment presents extreme conditions such as severe temperatures, radiation, and lunar dust, these conditions are difficult to replicate on the Earth impacting the trade studies conducted for payload instruments thereby causing failure uncertainties as to how instruments will function on the Moon.	Testing facilities plans have been outlined at the Ames Research Center to raise the TRL of the payload instruments in simulated lunar environments. (11/13/24, CA)
18	Budget - Schedule Delays	4	5	↑	M	Given that scheduling often goes hand-in-hand with cost planning, major setbacks in scheduling due to instrument scrapping and retesting will heavily increase the HELP mission estimated cost, thereby pushing this mission's necessary allocated value to over the cost constraint.	Recent budget descoping has caused subsystem changes that have raised risks in relation to testing. Component trade studies have been completed, and subsequent testing will be done as soon as readily possible. (11/14/24, CA)
19	Budget - Unanticipated Cost Increases	2	4	↓	M	Given the complexity of our space mission, unanticipated cost increases may happen due to unexpected technical challenges, delays, or resource demands in the HELP mission, leading to exceeding the budget and compromising the mission's ability to be completed within financial limits.	Periodic financial evaluations are to be completed and enforced to monitor and control unforeseen expenses. In addition, an extensive budget revaluation was completed to provide a more accurate mission budget estimate. (11/14/24, CA)
20	Schedule - Testing	3	5	↑	M	Given that testing will have to be completed on the spacecraft's instruments, setbacks may occur when a device is reevaluating to not be sufficient enough to be used in the HELP mission, leading to deadline delays thereby affecting the launch date of the mission.	Descoping has caused changes in payload instrumentation, so some delays have occurred in relation to testing. In completing trade studies and testing at facilities like KSC and ARC, components can be confirmed and the mission can confidently move forward. (11/14/24, CA)

21	Schedule - Resource Constraints	2	4	↓	M	Given that scheduling depends on the resources available for testing and development phases, resource constraints can lead to delays and restrictions on equipment readiness or facility access. This would delay key milestones in the HELP mission's timeline and push the launch date back, affecting the mission objectives.	Resource allocations will be handled by the Program Analyst Team to make sure there is sufficient personnel, time, and equipment for high priority tasks. Scheduling will be adjusted as needed to prevent delays. (11/14/24, CA)
22	Outreach - Lack of Support	1	2	↓	M	Given that mission success and lessons learned relies on public and shareholder support of the mission failing to stress the importance and impact of the HELP mission for space exploration impact data recorded by the spacecraft in that the subsequent lessons learned won't be efficiently documented and shared across school systems and major shareholders.	Educational programs will help raise awareness of the HELP mission in school systems, and public broadcasted conferences will help raise public awareness as well. (11/14/24, CA)
23	Outreach - International Engagement Limitations	1	2	↓	M	Given the global interest in the HELP mission, limited international outreach efforts may restrict the HELP missions's ability to create a global engagement and learning, thus affecting international partners by reducing the HELP mission's collaborations.	Virtual sessions will be scheduled with foreign entities, and informational emails will be sent with important mission-related content. (11/14/24, CA)
24	Personnel - Testing	2	5	↓	M	Given that personnel will be testing system components in extreme conditions, risks are present in relation to system failure and lack of safety protocols impacting personnel safety thereby threatening the health of any engineering or science professionals conducting testing procedures.	Safety protocols employed such as PPE and enforced in testing facilities as well as other safety protocols to ensure personnel are properly protected. (11/14/24, CA)
25	Personnel - Staff Turnover & Skill Gaps	2	3	↓	M	Given the specialized skills needed for critical tasks, high staff turnover or skill gaps may result in operational delays or knowledge loss, leading to a decrease in the quality and continuity of mission outcomes and increasing training costs and loss of time.	Mitigation strategies similar to MAP are being implemented that ensure personnel are efficiently appropriated and mission contributors are awarded for their work. (11/14/24, CA)

Figure 7: HELP Mission Risk Summary Table

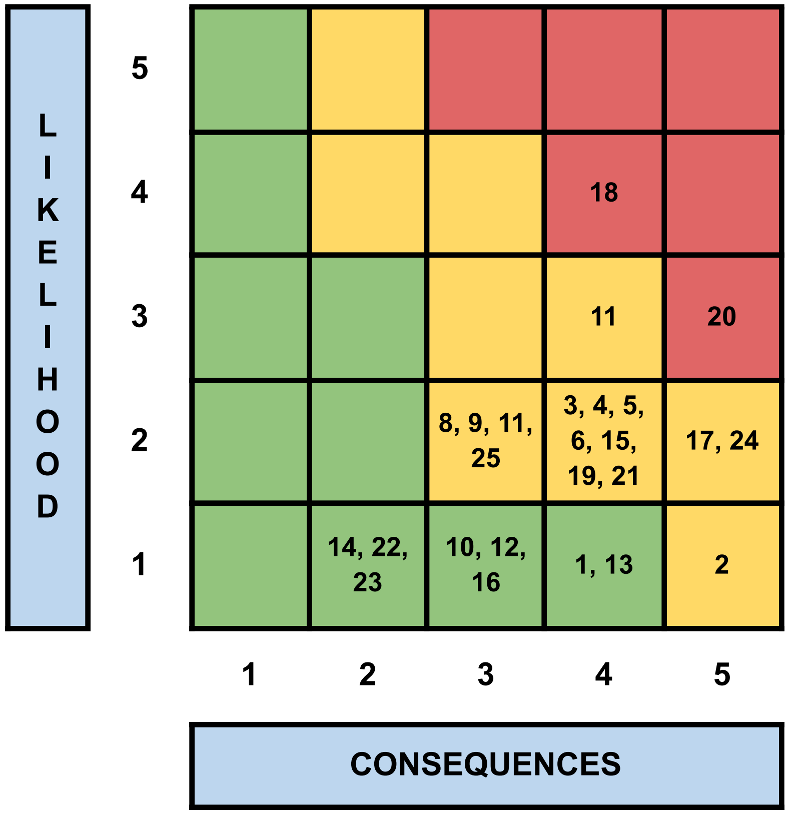

Figure 8: HELP Mission Risk Matrix

1.8.2 Failure Mode and Effect Analysis (FMEA)

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Safety	Planetary Protection: Contamination of lunar habitat	Damage to habitability and ecosystem	8	Improper containment of organic inventories	2	Assess spacecraft organic materials and containment	5	80	Examine the effects of contamination, carry out emergency sterilization, and update safety procedures.
	Decommissioning: Energy buildup causing explosion	Damage to lunar environment and assets	9	Residual energy during decommissioning	3	Develop passivation techniques	6	162	Update passivation techniques, implement robotic decommissioning, and carry out an emergency energy release.
Power	Lighting Conditions: Inability to store solar power	Reduced operational capacity	7	Permanently shaded areas on the Moon	4	Design long-duration storage systems	4	112	Increase battery capacity, look into adding more solar panels, and switch to backup energy sources.
	Radiation: Electronics damage due to radiation	Loss of communication and control	8	Lack of adequate shielding	3	Research and integrate shielding material	5	120	Install emergency shielding, swap out damaged parts, and incorporate adaptive radiation systems.
	Lunar Dust: Short circuits and panel damage	Loss of power generation	7	Electrostatic attraction of dust	4	Add dust removal technologies	6	168	Replace broken parts, improve dust repulsion techniques, and use dust removal systems to clean the impacted components.
Thermal	Lunar Dust: Heat dissipation inefficiency	Overheating of systems	8	Dust accumulating on and inside the thermal radiators	5	Develop dust repelling techniques	6	240	Upgrade thermal materials, implement alternative cooling systems, and clean dust frequently.
	Temperature: Structural stress and distortion	Failure of critical systems	9	Extreme temperature fluctuations	4	Apply thermal insulation and heaters	5	180	Redesign critical systems, put active temperature regulation in place, and fix stressed components.
Payload	Instrument Failure: Inability to replicate lunar conditions	Unreliable instrument performance	8	Harsh lunar environment conditions	5	Establish robust testing protocols	4	160	Use backup instruments, increase redundancies, and validate alternative ground-testing simulations.
Budget	Schedule Delays:Cost overrun due to rescheduling	Exceed project budget and timeline	7	Instrument scrapping and resetting	4	Develop contingency budget plans	5	140	.Reassess the scope of the mission, allocate emergency funds, and renegotiate contracts with stakeholders.

Schedule	Testing: Missed deadlines for mission launch	Compromised mission timeline	8	Insufficient time for testing	4	Streamline testing procedures	4	128	Prioritize critical tests, implement streamlined testing protocols, and request timeline extensions
Personal	Testing: Failure in maintaining safety protocols	Compromised testing integrity	7	Inexperienced or insufficient staff	3	Cross-train personnel for critical tasks	4	84	Rotate experienced personnel, provide intensive training, and enforce stricter safety checks.

Figure 9: Failure Mode and Effect Analysis Table

The Failure Mode and Effect Analysis (FMEA) section will focus on the most critical risks identified in the Mission's Risk Matrix. Specifically, the most severe risks with high priority to their potential impact on mission success. The failures discussed are related to safety, power, thermal, conditions, payload performance, and schedule management.

SAFETY RISKS

The mission's habitability and scientific integrity are directly threatened by contamination of the lunar habitat (RPN: 80,000). Future habitation plans and lunar ecosystems may be jeopardized if inventories are not kept under control. Emergency containment and sterilization must be put into place right away if this risk continues. Furthermore, if unchecked, the energy buildup during spaceship decommissioning could result in catastrophic explosions (RPN: 162,000). To ensure safe decommissioning, this calls for a strong passivation system that includes remote robotic intervention and emergency energy release.

POWER MANAGEMENT RISKS

Solar power restrictions are caused by constant lunar shade (RPN: 112,000). This can lead to possible operational downtime if this risk is not addressed. Including energy storage devices, adaptive solar technologies, and backup power sources will help mitigate this issue. Additionally, radiation-induced damage to electronics could cut off control and communication lines (RPN: 120,000). The mission must switch to emergency electronic replacement and implement adaptive radiation-resistant components in the event that radiation shielding fails.

Two major hazards are increased by lunar dust: power system short circuits (RPN: 168,000) and thermal radiator overheating (RPN: 240,000). Essential hardware can experience irreversible damage if the dust accumulation is not controlled. For the mission to continue, it requires proactive measures such as installing dust removal equipment, improving protective coatings, and starting real-time hardware diagnostics.

THERMAL REGULATION RISKS

Spacecraft systems are under tremendous thermal stress due to the Moon's drastic temperature swings (RPN: 180,000). Instrument failure and structural deformation may result from these situations if left unchecked. It will require the use of active heating systems, sophisticated thermal insulation, and regular hardware checks to make sure systems stay reliable and functional. Structural elements need to be modified and verified with simulated stress testing in order to withstand these harsh conditions.

PAYLOAD & SCHEDULE RISKS

The scientific goals of the mission may be jeopardized if instruments fail due to the inability to replicate lunar conditions in testing facilities (RPN: 160,000). There needs to be improved instrument testing procedures, alternate simulations, and thorough redundancy strategies in place. In addition, schedule delays brought on by testing or rescheduling mistakes might cause expenses to rise and the mission timeline to be derailed (RPN: 140,000). In order to prevent these setbacks, emergency funds, quicker processes, and stakeholder renegotiations need to be set in place.

PERSONNEL & SAFETY PROTOCOLS

Personnel not following safety protocols during testing is another major risk that must be closely monitored and prevented (RPN: 84,000). In order to reduce the chances of this risk, the HELP Team must have cross-functional staffing, constant employee training, and strict adherence to safety regulations. If this safety regarding personnel continues to be an issue, external consultants might be required.

Final Analysis of FMEA Risk Priority Numbers

The risks with the highest Risk Priority Numbers (RPN) represent the most important dangers to the mission's success and will address the risks that receive immediate attention. The maximum RPN for safety, which is related to energy accumulation during spacecraft decommissioning, is 162,000. The greatest RPN in the Power category, 168,000, is ascribed to panel damage and short circuits brought on by lunar dust. The maximum RPN for Thermal is 240,000, which is associated with inefficient heat dissipation brought on by dust buildup. The maximum RPN in the Payload category is 160,000, which is associated with instrument failure brought on by the inability to simulate lunar conditions. Last but not least, the Schedule category has the highest RPN at 140,000, which is the result of testing and rescheduling errors. These values highlight the areas that need the greatest focus in order to successfully reduce mission risks.

1.8.3 Personnel Hazards

Maintaining personnel safety is critical to the success of the HELP mission. Personnel hazards may occur in a variety of circumstances, and they threaten the mental and physical health of mission personnel. These hazards may occur in relation to physical, chemical, biological, ergonomic, and psychological circumstances. By applying protocols outlined by the Office of Safety & Mission Assurance (OSMA) and the Occupational Safety and Health Administration (OSHA), and understanding the breadth of hazards that put personnel at risk throughout this mission, mitigation strategies have been outlined to ensure safety and health are preserved.

Physical hazards can be described as any hazard that may cause physical harm or injury to an employee due to any physical factors or conditions present in mission facilities ("Physical Hazards and Risks" n.d.). These hazards include but aren't limited to tripping hazards, machine-related incidents, cranial injuries, noise exposure, prolonged vibration, radiation exposure, electricity exposure, and extreme temperatures ("Physical Hazards and Risks" n.d.). For the HELP mission, physical risks are most certainly prevalent, especially in manufacturing and testing facilities. While completing testing procedures at KSC, ARC, and other facilities, spacecraft components will be examined under extreme conditions that mirror those present on the lunar surface. These tests are absolutely necessary to raise the TRL level of the system, but they also threaten employee safety. Being exposed to noise or machine vibrations over long periods of time can also lead to temporary or permanent disabilities in hearing and other functions of the body (“Physical Hazards and Risks” n.d.). These hazards especially exist in manufacturing facilities, where scientists, engineers, and technicians will work closely with machinery across long periods of time to monitor their production.

Chemical hazards include any substance that may induce negative physical and health effects to either people or to the environment due to its chemical properties (Reyes 2024). These hazards are dangerous to the human body, especially if they make contact with the human eye and skin, or make their way into the human respiratory system. Unfortunately, chemical hazards will be frequent throughout Phases C and D of the HELP mission in manufacturing and testing facilities. Since HELP mission facilities are required to maintain sterilization protocols to meet planetary protection guidelines, disinfectants and cleaning materials pose dangers due to frequent exposure. In addition, welding fumes that emanate from spacecraft manufacturing processes may cause respiratory issues leading up to lung disease and cancer (Reyes 2024). Oil and gasoline are fluids often utilized in manufacturing machinery that present chemical hazards as well.

Biological hazards are hazards that threaten the health of people and all other living organisms. Common biological hazards include bacteria, viruses, molds, and fungi (“Biological Health Hazards” 2021). These hazards not only threaten the planetary protection protocols outlined in Risk Analysis, but they pose national threats similar to the COVID-19 pandemic that occurred just previously in 2020. Any viral hazard that reaches the severity of the Coronavirus disease threatens the entirety of the HELP mission, therefore precautionary measures must be in place to address those circumstances if they were to arise.

Ergonomic hazards consider workplace conditions that cause wear and tear to an employee’s musculoskeletal system. These particular hazards cause repeated strain on the human body, often involving heavy lifting, awkward posture, prolonged stationary positions, and forceful motion (“Identifying and Addressing Ergonomic Hazards Workbook” n.d.). Employees subject to these ergonomic hazards often develop extremely uncomfortable conditions, including stiffness, swelling, sensitivity, weakness, and difficulty moving (“Identifying and Addressing Ergonomic Hazards Workbook” n.d.). Manufacturing equipment is not lightweight - workers that attempt to move or force around heavy objects during spacecraft manufacturing and testing will quite possibly be subject to ergonomic strain. In striving to meet mission deadlines, HELP administratives and technical employees might also feel inclined to work overtime. This may lead to employees spending extended periods of time in uncomfortable seated or working positions, or attempting to handle too much at once, leading to increased musculoskeletal stress.

Psychological hazards, also known as psychosocial hazards, include any factors in the work environment that cause stress to a person’s physical or mental well-being (Manawis 2024). In a high-stress/high-stakes environment such as the one presented by the HELP mission, personnel might be subject to long shifts, fatigue, and anxiety. Allowing an unhealthy, toxic work environment to fester in which leadership positions are unreliable or work relationships involve bullying or discrimination may cause low morale, depression, Post-Traumatic Stress Disorder (PTSD), or other prevalent mental health issues (Manawis 2024). These types of hazards, especially those negatively affecting mental health, directly impact the health of mission personnel and are often the cause of employee turnover[10], job dissatisfaction, and decreased productivity ("Mental Health in the Workplace: Supporting Employee Well-Being" 2024).

It's important to understand the role that OSMA and OSHA play in improving workplace conditions in order to properly address personnel hazards. OSMA emphasizes the importance of abiding by NASA Safety and Mission Assurance (SMA) and Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) protocols throughout the entirety of the mission timeline (Bishop 2024a). NASA's SMA system includes many safety disciplines and programs that will prove useful for mitigating the personnel hazards outlined for this mission. In addition, the NASA SRM&QA Office handles the standardization of policies regarding safety, problem reporting, software assurance, and system assurance and assessment ("IMPLEMENTATION of the RECOMMENDATIONS of the Presidential Commission on the Space Shuttle Challenger Accident" n.d.). HELP's Mission Assurance Team will work closely with this office to handle risk management policies in relation to personnel hazards.

Similar to OSMA, OSHA outlines specific guidelines that help address hazards present throughout the NASA Mission Life Cycle. These guidelines cover subdisciplines that range from monitoring hazardous energy to maintaining test operations safety (Bishop 2024b). By promoting OSHA techniques concerning training, outreach, education, and assistance, the HELP mission will minimize risks and their resulting consequences ("About OSHA " n.d.).

One particular SMA system that will be implemented in the HELP mission is its comprehensive Safety Culture (Bishop 2024c). This program outlines five guidelines to be followed to promote an inclusive, comfortable environment in which employees feel comfortable voicing their safety concerns and confident that their safety and health is prioritized. As long as the criteria outlined below is continuously followed and prioritized throughout the mission, risks can be identified early by those actively working in manufacturing, testing, and other mission facilities.

The first piece of criteria involves reporting safety threats to the necessary authorities (Bishop 2024c). In order for this guideline to be met, leadership must establish a trust with their sub-teams that sees members confident the safety concern will be properly addressed. The second guideline sees an award system established for bringing safety concerns to light (Bishop 2024c). Professionals will never be punished for voicing their concerns, especially when their intentions are to create a safer, healthier environment. The third criteria of flexibility ensures that early mitigation systems are put in place to address unexpected safety risks that occur along the

[10] Personnel turnover was a risk outlined in Risk Analysis that sees a lack of employees present to complete the mission due to them leaving the mission team or improper planning and training.

mission timeline (Bishop 2024c). Implementing programs that take precautionary measures early-on in the mission will ensure major schedule setbacks don't occur given unfortunate events. The fourth piece of criteria considers learning, and the importance of mission personnel understanding helpful resources they can use to share their experiences and learn from others (Bishop 2024c). The fifth and final guideline for following this Safety Culture system is employee engagement (Bishop 2024c). In order for this program to efficiently identify hazards and safety concerns, there must be employee buy-in from mission managers and sub-team personnel.

Guidelines outlined by OSHA are especially useful for managing the physical and chemical hazards associated with this mission. To protect employees from energy-inflicted injuries and other machine-related physical or chemical injuries, Lockout/Tagout procedures will be in place. The Lockout/Tagout system sees locks placed on faulty equipment to isolate their functionality within the production line, and tags used to inform employees as to why the lock was utilized (Bishop 2024b). Flammability hazards will be heavily monitored and assigned Flammable Hazard Levels (FHL) (Lewis 2023b). A Fall Protection Program will be implemented that ensures fall hazards are identified earlier and mitigated accordingly (Bishop 2024b). Regulations will be set in place that make Personal Protective Equipment (PPE) a mandatory requirement for personnel in manufacturing and testing work environments. PPE sees protective equipment such as safety goggles, ear-plugs, and head-gear used to protect the eyes, face, and head (Bishop 2024b). In addition, respiratory devices and protective clothing and shields will always be available, especially in areas of the workplace where physical, chemical, and biological hazards are prevalent (Bishop 2024b). Gloves and knee padding are but a couple PPE resources that will help prevent ergonomic hazards as well ("Ergonomics - Solutions to Control Hazards" n.d.).

While PPE acts as one mitigation solution to resolving physical and chemical hazards, it doesn't sufficiently mitigate it completely. The HELP mission will abide by the Hazard Communication Standard (HCS), which establishes guaranteed communication of potential chemical hazards to mission personnel by outlining plans to communicate these issues (Reyes 2024). An inventory of all chemicals involved in the mission will be documented, tracked, and assigned a Toxicity Hazard Level (THL) in order to ensure all grounds are covered (Reyes 2024). Enforcing employee training is critical in order for this system, as well as other mitigation techniques, to be as effective as possible. The HELP mission will follow OSHA's Safety Training and Certification procedures to develop employee knowledge on how to handle dangerous chemicals, production-line machinery, and how to use mitigation strategies such as PPE to improve mission safety (Bishop 2024b).

Regarding biological hazards, the HELP administrative team will work closely with NASA's Biosafety Review Board (BRB) to identify and control any biological concerns present in the HELP mission. The biological payloads present within manufacturing and testing facilities will be examined, and any biohazardous materials present will be assigned a NASA BioSafety Level (BSL) (Lewis 2023a). Similar to the system in-place to track chemicals across mission facilities, a tracking system will also be used to monitor biohazards. Together, the BSL, THL, and FHL combine to make a

Hazard Response Level (HRL) used in coordination with a comprehensive Hazardous Materials Summary Table (HMST) (Lewis 2023b). This table will compile all of the chemical, biological, and flammable hazards present throughout the HELP mission (Lewis 2023b).

In terms of ergonomic hazards, workplace machinery and set-ups will be designed or rearranged to minimize ergonomic strain presented by awkward body positions and heavy lifting (“Ergonomics - Solutions to Control Hazards” n.d.). Requirements will be set in place to enforce machinery-use for any heavy lifting. A job rotation system will also be implemented, especially in manufacturing and testing facilities, that sees employees complete rotations around several tasks that target different muscle groups (“Ergonomics - Solutions to Control Hazards” n.d.). Personnel will have the variability to adjust work schedules and work pace, and will be provided with small periods of recovery time throughout the work time to relax strained muscles (“Identifying and Addressing Ergonomic Hazards Workbook” n.d.).

Psychological hazards will be mitigated by promoting mental health awareness, completing team-wide assessment surveys, and providing relative training modules that give instructions on how to identify and maintain good mental health. Digital training modules will be required for all mission personnel to complete. These modules will promote diversity and inclusivity, provide advice on how to manage mental health, and tips on how to identify symptoms of psychological hazards in the workplace (Manawis 2023). The HELP mission will conduct Organizational Risk Safety Assessments (ORSA) to receive discrete employee feedback. ORSA is a tool that utilizes on-site interviews and surveys to gauge the opinions of mission personnel regarding mission safety and well-being (Bishop 2024b). HELP personnel should feel comfortable utilizing this resource to voice safety and mental health concerns, whether it be regarding themselves or a coworker. The Substance Abuse and Mental Health Services Administration (SAMHSA) outlines Employee Assistance Programs (EAP) that the HELP administration will share with mission personnel and emphasize their importance. EAPs offer services that assist employees with addressing personal problems that might involve health, finances, social anxiety, or substance abuse (“Provide Support” 2023).

These mitigation strategies involving training, protection equipment, employee resources, surveys, and hazard tracking will be emphasized constantly throughout the entirety of the HELP mission. Similar to Risk Analysis, personnel hazards must be monitored continuously and updated accordingly as new hazards come to light. Personnel safety is of the highest priority, not just for ensuring mission success but for maintaining physical and mental well-being as well.

1.9 Schedule

1.9.1 Schedule Basis of Estimate

There are several assumptions and restrictions that have been laid out in order to obtain an accurate schedule basis of estimate. A constraint made by the customer includes the budget of $300 million, the costs of staff, software, hardware, and science is deducted from this budget. The spacecraft must be completed and be ready to launch by the deadline of March 1st, 2030. The time of travel, part of Phase C, will also be added on to the assumptions, which will be approximately four weeks, traveling from their respective locations to Cape Canaveral, FL. In order to obtain a time frame for how long each phase will last, another discovery class mission, the Lucy Mission, was used as an analogous mission and based on its template, several time estimations and assumptions were used for phase C and D of the HELP mission. The schedule will assume that Phases C and D will be longer compared to the analog mission because of a longer time of preparation for the launch date. This allows the Phases C and D for the HELP to be extended by 200% as the ratio from the Lucy mission was used to justify this. Based on the Lucy mission, it will also use the fiscal calendar in order to keep track of finances. After the completion of both Phases C and D, the HELP mission will then move onto Phase E, the Post-Launch Assessment Review (PLAR), which uses the Apollo mission as reference. The Apollo mission was used for this estimate to find out how long it takes to reach the moon. Phase F, finally, which allows the closeout to begin, meaning the rover is decommissioned and reports will be finalized, which will approximately take a day. Both Phases E and F require staff to travel which lands around a week's worth of time.

Thus, the following assumptions and restrictions are laid out:

1. The deadline of the completion of the spacecraft is March 1st, 2030.
2. The HELP mission will be using the fiscal calendar for financial tracking.
3. There will be a 200% increase for Phase C and D based on the Lucy mission.
    a. Approximately one year was given for Phase C and Phase D respectively from the Lucy mission.
    b. Three years is given for Phase C and Phase D respectively for the HELP mission.
4. Phase E’s PLAR will take three days based off of the Apollo mission.
5. Time will be set aside for staff travel to Cape Canaveral, FL.
    a. Three weeks will be set aside for Phase C.
    b. One week each will be set aside for both Phases E and F.

All assumptions are based on these restrictions and analog missions such as the Lucy mission and Apollo mission have been used as references for the scheduling of the HELP mission.

1.9.2 Mission Schedule

The mission schedule can be broken down into four primary phases: Phase C, Phase D, Phase E, and Phase F. Each of these phases marks a significant milestone range of NASA’s Mission Life Cycle past NASA’s approval of this mission’s implementation (Deiss, 2023). Understanding the task and subtask breakdown within each of these phases and the amount of time needed to efficiently complete each helped contribute to the creation of the schedule timeline depicted in Figures 10 and 11. These tasks are also specifically divided amongst mission life cycle phases, which can be observed in Appendix C, the Mission Life Cycle Phases Table.

The first major category specified in Appendix C is Phase C, otherwise known as Final Design and Fabrication. In evaluating the project breakdown of this phase, two major milestones must be considered and completed. The first of these two milestones for review is the Critical Design Review (CDR). The CDR is incredibly important in that it clarifies and finalizes robot architecture designs. This involves a complete explanation of how the instrumentation is manufactured, how individual subsystems of the robot are constructed, and how comparable instrumentation will be analyzed and considered for future robot implementation. The document must also specify how each subsystem will effectively interact with one another to allow the robot to collect all of its desired science measurements. It clarifies the interface between the mechanical, power, electrical, and computer hardware subsystems, and how each plays a role in getting the rover to traverse across the lunar surface and ensure the instrumentation functions according to plan.

Given the importance of this document and the role it plays in defining complete designs for robot architecture and instrumentation, other discovery-class missions were considered to evaluate an efficient time estimate for when this review should be drafted and submitted. The Lucy Mission, a discovery-class mission, played a crucial role in determining a time estimation for not only this particular document, but for the entirety of Phases C and D, which can be observed in Figures 10 and 11. While the Lucy Mission is still active, both of its Phases C and D are marked as complete. The timeline for Phase C was October of 2018 to August of 2020, and the timeline for Phase D was October of 2020 to October of 2021 (“Timeline”, 2024). The end of Phase D marks the vehicle launch of the mission. For the Lucy Mission, both of these phases were approximately a year in length.

The set mission launch date for HELP is March 1, 2030. This launch date creates a Phase C and D completion timeline that extends six years in total. Using the phase split presented in the Lucy Mission as a template for when the phases will be completed for this mission, it is assumed that Phases C and D for HELP will each take approximately three years total in time. The ratio from Lucy Mission launch to this mission launch helped formulate this assumption. Further division within these phases was derived from both the Lucy Mission and documentation summarizing deliverables and expectations for missions completing the NASA Mission Life Cycle (Deiss, 2023).

Based on the life cycle timeline expectations for the CDR and its completion within Phase C, an estimate was generated not just for when the CDR takes place, but also for its individual subtasks, and those related to the System Integration Review (SIR) as well. The CDR is often completed at some point halfway into Phase C, therefore it was estimated that it should be completed over a year into Phase C, during January of 2026. Similar assumptions were made about its individual subtasks, as well as the SIR which is often much later towards the end of Phase C. In this case, it’s estimated it will be done by January of 2027. Given that this is a rough estimate, a phase margin was specified that allows an extra 31 days for this phase to accommodate obstacles that inhibit progress in Phase C.

Next, Phase D is often referred to as System Assembly, Integration & Test, and Launch & Checkout. The task breakdown represented in Phase D was assigned timeline due dates using a similar assumption strategy to that used in Phase C. Considering this phase deals with the manufacturing, assembly, integration, and testing of the robot, many of the major task deadlines consider test and operational readiness. This is marked as a Key Decision Point since it determines the capabilities and how prepared the instruments are for the mission. The Test Readiness Reviews (TRRs) are set to have an estimated completion time in January of 2027, followed by a set Operational Readiness Review (ORR) deadline for February of 2029, and a Mission Readiness Review (MRR) deadline for January of 2030. The order of these documents is important, since each segways into the next, modeling a predecessor system. Again, the end of Phase D marks mission launch at Cape Canaveral, FL, on March 1, 2030. Therefore, the completion of these assignments beforehand is crucial to confirming spacecraft readiness regarding safety and capability.

Phase E marks Operations and Sustainment of the mission. This phase encompasses post-launch evaluation, and the most important piece of the mission: where the robot collects necessary data. The Post-Launch Assessment Review (PLAR) is given a rough estimate of nine days to be completed, which involves evaluating the efficiency of the launch and its completion and how it can be improved. The estimated travel time for the spacecraft to reach the moon and begin operation is three days, modeled after the time taken for the Apollo spacecraft to travel a similar distance ("Journey to the Moon", 2017). The process of HELP carrying out its mission once landing on the lunar surface is outlined in the Concept of Operations. Once the mission is complete, the robot then completes its decommissioning process outlined by the Decommissioning Review (DR), marking the closing stages of the robot's role in completing its mission.

In Phase F, otherwise known as Closeout, a Disposal Readiness Review (DRR) is conducted to construct the robot to dispose of itself based on the plans outlined in the document. This process should be very short, so it is given a day. Next, completing the final mission report is the final step in completing this mission. Approximately a month is given to baseline this report, draw conclusions from the data, document lessons learned from this mission, and draft areas for future exploration and improvement. This report will verify whether or not the Compton Pit is suitable for human habitation in the future, and will provide a surplus of information regarding the surface conditions adjacent to the pit. The final date estimated for this mission to be completed is June of 2030.

A Gantt chart outlining the tasks and major milestones in Phases C, D, E, and F is below.

ID#	TASK	START	END	DAYS	MARGIN
1	**Draft and submit Critical Design Review**	12/23/24	1/23/26	397	32
1.1	Develop detailed designs of necessary hardware and software	12/23/24	7/23/25	213	
1.2	Further explain how subsystems effectively interface	12/23/24	10/23/25	305	
1.3	Explain how the instrumentation is analyzed and considered for future implementation	12/23/24	10/23/25	305	

1.4	Continue updating plans for operations, risks, and anticipated procedures for manufacturing	12/23/24	1/23/26	397	
1.5	Key Decision Point: Submit Production Readiness Review (PRR) for necessary instrumentation	12/23/24	1/23/26		
1.6	Schedule Margin	12/23/25	1/23/26	32	
1.6	◆ Submit Critical Design Review	1/23/26	1/23/26	1	
2	**Draft and submit System Integration Review**	1/23/26	3/1/27	403	31
2.1	Finalize design plans and plans for integrating the subsystems and instrumentation	1/23/26	11/23/26	305	
2.2	Baseline how each subsystem will operate	11/23/26	1/30/27	69	
2.3	Begin outlining the process of Verification & Validation (V&V)	11/23/26	1/30/27	69	
2.4	Schedule Margin	1/30/27	3/1/27	31	
2.5	◆ Submit System Integration Review	3/1/27	3/1/27	1	
3	**Begin and Complete Test Readiness Reviews (TRRs) of Instrumentation and System**	3/1/27	3/1/28	367	30
3.1	Manufacture system components and then assemble and integrate them	3/1/27	1/1/28	307	
3.2	Inspect instrumentation and system capability to obtain science measurements	1/1/28	3/1/28	61	
3.3	Key Decision Point: Assess instrumentation with prototypes to determine TRR	1/1/28	3/1/28	61	
3.5	Schedule Margin	2/1/28	3/1/28	30	
3.6	◆ Complete Test Readiness Reviews (TRRs) of Instrumentation and System	3/1/28	3/1/28	1	
4	**Draft and Submit Operational Readiness Review (ORR)**	3/1/28	2/1/29	338	32
4.1	Test instrumentation and instate confidence in its usage	3/1/28	5/1/28	62	
4.2	Key Decision Point: Begin V&V of subsystem and instrumentation results	3/1/28	5/1/28	62	
4.3	Finalize operations plans and procedures	5/1/28	2/1/29	277	
4.4	Baseline plans for decommissioning and disposing of the robot after mission completion	5/1/28	2/1/29	277	
4.5	Schedule Margin	1/1/29	2/1/29	32	
4.6	◆ Submit Operational Readiness Review (ORR)	2/1/29	2/1/29	1	
5	**Draft and Submit Mission Readiness Review (MRR)**	2/1/29	1/1/30	335	31
5.1	Baseline and verify V&V results	2/1/29	1/1/30	335	
5.2	Prepare launch and confirm spacecraft flight/launch capability	5/1/29	1/1/30	246	
5.3	Perform safety review assessing launch and mission safety	5/1/29	1/1/30	246	
5.4	Confirm spacecraft safety and capability readiness	5/1/29	1/1/30	246	
5.5	Schedule Margin	12/1/29	1/1/30	31	
5.6	◆ Submit Mission Readiness Review	1/1/30	1/1/30	1	
6	**Complete Launch Readiness Review (LRR) and Launch Vehicle (LV)**	1/1/30	3/1/30	60	29
6.1	Complete Launch Readiness Review	1/1/30	2/1/30	32	
6.2	Schedule Margin	2/1/30	3/1/30	29	
6.3	◆ Launch Mission at Cape Canaveral, FL	3/1/30	3/1/30	1	

7	**Draft and Submit Critical Events Readiness Review**	3/1/30	4/19/30	50	1
7.1	Key Decision Point: Conduct vehicle launch performance assessment	3/1/30	4/1/30	32	
7.2	Activate science instruments upon landing	3/4/40	3/4/30	1	
7.3	Collect data measurements concerning surface features	3/4/30	3/18/30	15	
7.4	Visit Compton Pit and cave map the pit dimensions and structural features	3/19/30	4/19/30	32	
7.5	Collect measurements concerning cave temperature and radiation	3/19/30	4/19/30	32	
7.6	Schedule Margin	3/19/30	4/19/30	32	
7.7	◆ Submit Critical Events Readiness Review	4/19/30	4/19/30	1	
8	**Draft and Submit Decommissioning Review**	4/19/30	5/6/30	18	6
8.1	Begin process of decommissioning the robot systems	4/19/30	5/1/30	13	
8.2	Outline potential upgrades for future missions	4/19/30	5/1/30	13	
8.3	Conduct safety review	4/19/30	5/1/30	13	
8.4	Key Decision Point: Compile and Document Collected Data Efficiently	4/19/30	5/1/30	13	
8.5	Schedule Margin	5/1/30	5/6/30	6	
8.6	◆ Submit Decommissioning Review	5/6/30	5/6/30	1	
7	**Complete Disposal Readiness Review (DRR)**	5/6/30	6/6/30	32	6
7.1	Conduct robot disposal according to outlined plans	5/6/30	5/7/30	2	
7.2	Ensure Organized Documentation and Draw Conclusions Based on the Collected Data	5/6/30	5/7/30	2	
7.3	Baseline and write up the mission final report	5/6/30	6/1/30	27	
7.4	Draft and capture lessons learned based on data collected (determine habitability of Compton Pit and the supply of resources available in the vicinity)	5/6/30	6/1/30	27	
7.5	Schedule Margin	6/1/30	6/6/30	6	
7.6	◆ Submit Disposal Readiness Review and Conclude Mission	6/6/30	6/6/30	1	

Figure 10: Mission Schedule Gantt Chart

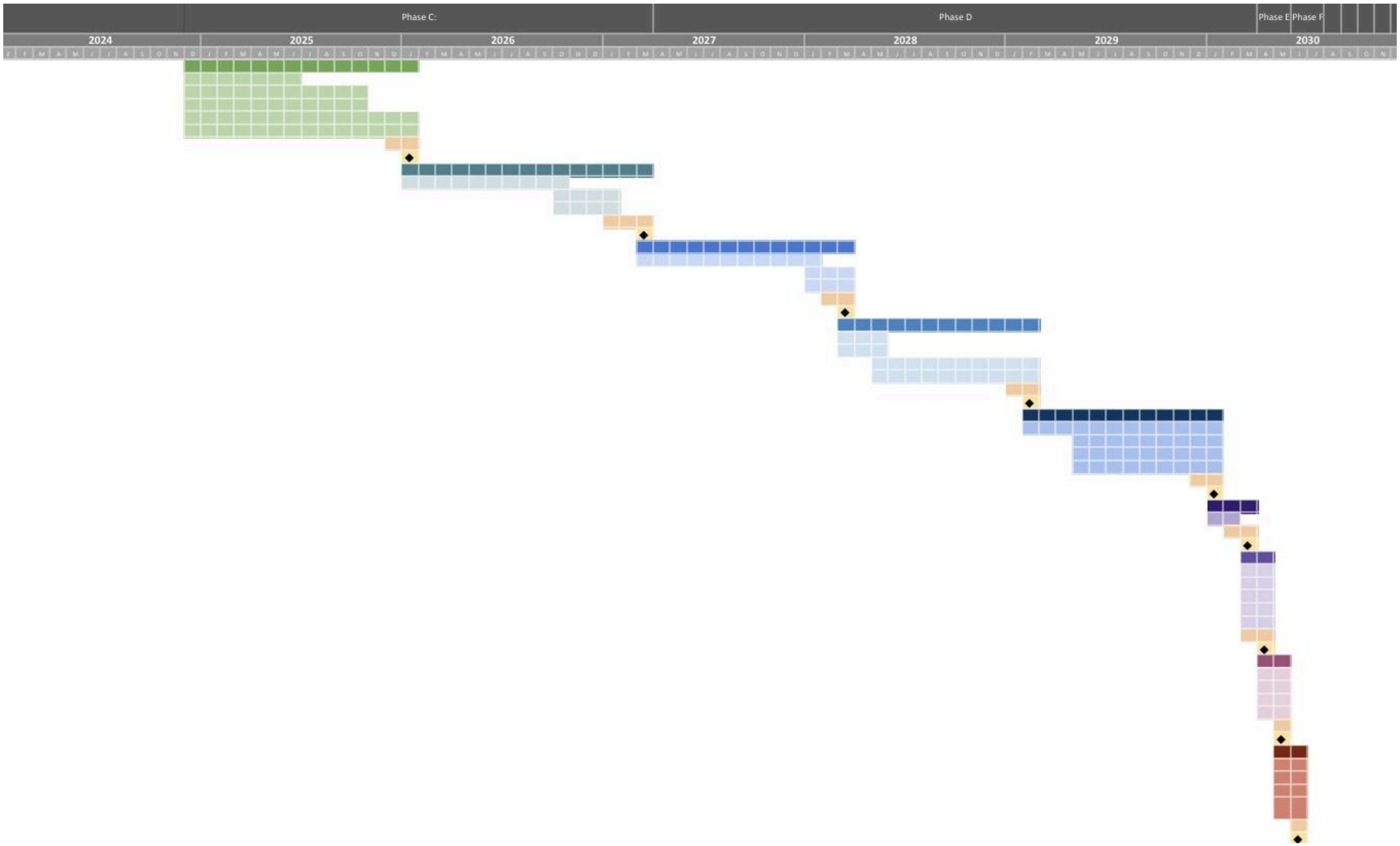

Figure 11: Gantt Chart Deadlines and Margin

1.10 Budget

1.10.1 Budget Overview

The original budget set for the HELP mission was $425 million, however the mission budget was cut to $300 million. To account for this, the mission cut certain outreach efforts and streamlined direct costs to downsize to a final cost of $296,660,064.

	Personnel	Travel	Outreach	Direct Costs	Final Costs
SRR	$24,598,492	$320,151	$7,818,078	$270,259,070	$317,429,546
Descoped	$26,352,130	$480,932	$6,792,483	$249,974,344	$296,660,064

Figure 12: Budget Overview Breakdown Table

1.10.2 Budget Basis of Estimate

The budget estimated for the HELP mission was driven by customer constraints and further evaluated by considering factors concerning personnel, travel, outreach, and direct costs. In finding estimates for each of these subcategories, a total budget estimate was subsequently found by adding the designated amounts necessary for the completion and success of each subcategory. The NASA L'SPACE Budget Template and Mission Concept Cost Estimation Tool (MCCET) were two extremely useful resources that were used to help provide estimates for the HELP mission budget, and several assumptions were made while utilizing them.

An important basis for the budget estimate calculated is that the budget only encompasses processes specific to Phases C-F of the NASA Mission Life Cycle. This assumption means that any costs spent in phases Pre-Phase A, Phase A, and Phase B of the mission are negligible regarding the overall budget estimate, and are therefore not included in the total budget estimate. In other words, once the Preliminary Design Review (PDR) for the HELP mission is submitted and approved, and technology plans are sufficiently outlined and completed, mission processes then incorporate cost estimates.

In addition, the budget estimates for the entire mission life cycle are assumed to be divided amongst six years. This division is based on the cost constraint of $300 million[11] placed on the HELP mission. Assuming the mission budget remains below this value, costs are distributed amongst six years for Phases C and D, and one year for Phases E and F. The first year of Phase C sees no budget contribution from direct costs, since manufacturing doesn't occur before the submission of the Critical Design Review (CDR). This particular document submission also impacts the second year of Phase C too, with very minimal budget contribution to manufacturing and testing. Since

[11] The mission cost constraint of $300 million is an amount descoped from the original $425 million specified by the customer in the MCA Mission Task Document.

all manufacturing and testing must be completed before mission launch, during the final year of the mission it’s assumed that there won’t be any budget contribution from manufacturing and testing costs as well.

Margin contributed significantly to the budget estimate calculated for this mission. This variable was incorporated into the estimated value of each individual subcategory. A personnel margin of 15% was added to the overall personnel cost, a travel margin of 15% was added to the overall travel cost, an outreach margin of 50% was added to the overall outreach cost, a spacecraft cost margin of 50% was added to the direct cost of the mission, and a facility cost margin of 50% was added to the manufacturing and testing facility costs. These cost margins helped designate extra funds to each subcategory in order to ensure its completion in the mission given the mission cost constraint of $300 million.

The concept of margin alleviates stress related to exceeding a mission cost constraint. Margin acts as a placeholder for any unexpected funds that must be delegated to a certain subcategory throughout a mission, whether it be personnel, travel, outreach, or spacecraft-related. These unexpected funds account for improper budget estimations at the early stages of the mission that don’t consider unpredictable cost necessities including the need for more personnel, travel opportunities to mission events, outreach activities, or additional testing when manufactured components fail under the required conditions. These are but a few examples of how margin designates extra room for unexpected cost expenditures.

The cost margin of 15% chosen for the personnel and travel costs indicates that only a small amount of change is predicted in these two subcategories. A smaller margin represents a smaller amount of money designated to cover any unexpected expenses in relation to that mission subcategory. An outreach cost margin of 50% was used because it's assumed that there is still much to change regarding the mission outreach. The spacecraft and facility cost margin of 50% is a value recommended when considering both of these expenses, since unfortunately much can change regarding the mission subsystems and its manufacturing and testing, especially as more data is revealed and TRLs are evaluated.

Considering the personnel subcategory of the budget estimate, several assumptions were made concerning the salaries of each available mission position. Scientists and engineers are assumed to have a salary of $80,000/year, technicians and administration are assumed to have a salary of $60,000/year, and mission managers are assumed to have a salary of $120,000/year[12]. In addition, an employee-related expenses (ERE) percentage of 28% was also integrated into the personnel cost estimation. These expenses ensure that mission employees are provided with benefits and insurance during their time working to support the HELP mission.

There were several assumptions made while estimating travel costs as well. The travel cost estimation assumes flight costs of $1,348 (“City Pair Program (CPP)”, 2024). It is assumed that this value incorporates a week’s stay, and includes round-trip pricing.

[12] These salaries are clarified in the MCA Mission Task Document.

The trip to Miami, FL is from Tallahassee, FL, and the trip from Miami, FL is to La Crosse, WI. These trips were used since they're the highest flights to and from Miami, FL within the United States ("City Pair Program (CPP)", 2024). Hotel costs are assumed to be the highest rate in Miami, FL at a value of $911 ("FedRooms", 2024). This price coincides with the round-trip dates; therefore, the mission representative can stay at the hotel throughout the week. Car rental transport is approximated at the highest rate in Miami, FL at a value of $316 ("Expedia", 2024). It is assumed that the car will be rented for six days as well. The per diem costs for food are all estimated at Cape Canaveral, FL at a value of $208 a day for March ("FY 2025 Per Diem Rates for Cape Canaveral, Florida", 2024). This per diem rate is multiplied by a factor of six, since it is assumed representatives will be staying over six days. This rate is also the highest per diem rate throughout the year, and it occurs during March, when the mission launch takes place. Assuming these costs, one single trip should cost approximately $3,823, excluding travel margin and inflation.

The outreach subcategory also incorporated several assumptions to estimate its total budget calculation. A total of 8 outreach personnel are necessary to coordinate the HELP mission's outreach plan, and it's assumed that they will contribute to the mission for the entirety of HELP's mission life cycle. This is due to the consistent need for community outreach, providing mission updates, and sharing lessons learned. Of these 8 personnel, there is one website designer, one email marketing specialist, two social media chairs, two conference executives, and two traveling agents. The website designer is assumed to have a salary of $107,000/year ("Web Designer Salaries" 2024). The email marketing specialist is assumed to have a salary of $60,000/year (Perlson 2024). The two social media expects are assumed to have salaries of $95,000/year each (Sonnenberg 2023). The four community outreach specialists, which includes both the conference executives and traveling agents, are assumed to have salaries of $63,000/year ("Community Outreach Specialist" 2024).

Additional assumptions are made when calculating outreach material, venue, travel, and service costs. Outreach venues hosting educational sessions are estimated to cost $400 for each session, with associated outreach materials pricing in at $100 ("Orbital Outreach" 2023). In order to organize these events, it's assumed that flights will be from Boston, MA to Houston, TX and back, and outreach trips will occur over a duration of three days. Round trip flights are estimated at $846 assuming these locations ("City Pair Program (CPP)", 2024). Rental car transportation is estimated at $110 for three days ("Expedia", 2024). The per diem food costs in Houston are also assumed to be $128, the highest per diem rate across the year ("FY 2025 per Diem Rates for Houston, Texas" 2023). Outreach services must also be considered for the outreach plan to be sufficiently fulfilled. The HELP mission educational website is estimated to cost $15,400/year based on its content and design structure ("Armia Systems Website Estimator" n.d.). The process of mass-sending information emails to organizations across the globe is estimated to cost $310/month, which adds up to $3720/year ("Amazon Simple Email Service Pricing" n.d.). Each virtual event hosted is assumed to cost $10,000/event (Russell 2021), and virtual conferences are assumed to be twice as expensive at $20,000/event (Marom 2024). Finally, it's assumed that

$5,000/year is necessary to maintain social media accounts such as YouTube and Instagram (Video Visionary 2024).

Regarding final cost calculations, a facilities and administration (F&A) margin of 10% was assumed to incorporate margin for spacecraft costs without the spacecraft cost margin mentioned previously. This additional F&A margin acts as an added facilities buffer that ensures direct costs will be efficiently addressed without stress in relation to exceeding the mission cost constraint. This is a standard value for F&A that was included in the Budget Template.

When calculating direct costs for the system, especially in relation to the mechanical, thermal control, CDH, GN&C, and payload subsystems, the MCCET was an incredibly useful tool that evaluated mass, maximum power draw, and design life to determine the mission's direct costs. The MCCET provides a variety of formulas provided through the resource to be manipulated depending on these variables. The mass, power, and design life variables are often found online with specifications regarding the outlined subcomponents of each subsystem. The values returned by these formulas were assumed to be accurate, and these values are represented in the Budget Template and are divided across five years.

For example, when evaluating the mechanical subsystem, the total mass of the subsystem was found by adding the masses of all necessary materials and components of that subsystem. Then, the maximum amount of power was found for each mechanical component, such as the rover's wheels, and was further added together to find a total power amount. These two values were entered into the corresponding subsystem Cost Estimating Relationship (CER) equation to approximate the amount of money needed for the mechanical subsystem.

Inflation was also a significant factor that impacted both the Budget Template estimation and the MCCET estimation. In formulating the total cost of the mission in the Budget Template, an inflation rate increase was incorporated that sees a 2.6% inflation increase with each passing year of the mission. This basis for inflation was baselined by the Budget Template, and it especially impacted the direct costs that are more specifically addressed towards the end of Phase C and most of Phase D. Inflation also affected the total cost values returned from MCCET. An inflation rate of 154.44%[13] was applied to the CER value in the calculator to determine the final estimated cost. These costs were then used in the Budget Template to estimate the total estimated cost of the mission, $296,660,064.

[13] The inflation rate of 154.44% is the default inflation rate for 2023.

1.10.3 Personnel Budget

PERSONNEL								
Science Personnel	$ 960,000	$ 984,960	$ 1,009,920	$ 517,440	$ 529,920	$ 542,400	$ 924,800	$ 4,544,640
Engineering Personnel	$ 800,000	$ 820,800	$ 841,600	$ 1,034,880	$ 1,059,840	$ 1,084,800	$ 184,960	$ 5,641,920
Technicians	$ 480,000	$ 492,480	$ 504,960	$ 776,160	$ 794,880	$ 813,600	$ 138,720	$ 3,862,080
Administration Personnel	$ 420,000	$ 430,920	$ 441,840	$ 388,080	$ 397,440	$ 406,800	$ 346,800	$ 2,485,080
Project Management	$ 120,000	$ 123,120	$ 126,240	$ 129,360	$ 132,480	$ 135,600	$ 138,720	$ 766,800
Total Salaries	$ 2,780,000	$ 2,852,280	$ 2,924,560	$ 2,845,920	$ 2,914,560	$ 2,983,200	$ 1,734,000	**$ 17,300,520**
Total ERE	$ 775,898	$ 796,071	$ 816,245	$ 794,296	$ 813,454	$ 832,611	$ 483,959	**$ 4,828,575**
Personnel Margin	$ 417,000	$ 427,842	$ 438,684	$ 426,888	$ 437,184	$ 447,480	$ 260,100	**$ 2,595,078**
TOTAL PERSONNEL	$ 3,972,898	$ 4,182,174	$ 4,396,822	$ 4,384,338	$ 4,598,378	$ 4,817,519	$ 2,864,637	$ 26,352,130

Figure 13: Personnel Budget

	Phase C	Phase C	Phase C	Phase D	Phase D	Phase D	Phase E-F
# People on Team	FY 1	FY 2	FY 3	FY 4	FY 5	FY 6	FY 7
Science Personnel:	12	12	12	6	6	6	10
Engineering Personnel:	10	10	10	12	12	12	2
Technicians:	8	8	8	12	12	12	2
Administration Personnel:	7	7	7	6	6	6	5
Management Personnel:	1	1	1	1	1	1	1

Figure 14: Personnel Distribution

The HELP personnel budget is representative of the total amount of personnel needed to complete the HELP mission, with the addition of salaries and ERE costs. The personnel costs can be examined in Figure 13, and the personnel distribution between each year of the HELP mission can be observed in Figure 14.

The total budgeted amount for personnel is $26,352,130. This amount is derived from salaries, ERE, and personnel margin. There are five categories of professionals in the HELP team: scientists, engineers, technicians, administration, and management. Each category is assigned a certain salary: scientists and engineers are given a salary of $80,000/year, technicians and administration are given a salary of $60,000/year, and management is given a salary of $120,000/year[14]. The total salaries for a given year incorporates the inflation rate for that given year. Since inflation rises 2.6% each year, it can be observed in comparing Figures 13 and 14 that estimated salaries for the same amount of personnel rises across multiple years. The total ERE in relation to these positions is calculated by applying the ERE rate of 28% to the total salaries estimated for a given year. ERE is important in that it covers insurance and other employee-related necessities. A personnel margin of 15% is also applied to the total salary amount for a year to account for unexpected expenses in relation to personnel expenditures.

When examining Figure 14, it can be determined that a total of 38 personnel are necessary to complete the HELP mission. In comparison to other Discovery-class missions, this number is realistic, since a typical mission of this caliber has from 30-50 members (Yost, 2021). However, this amount is not constant - depending on the Phase of the mission, the amount of personnel designated to one of the professional categories may increase or decrease depending on the major priority processes associated with that given phase.

During Phase C, there are 12 professionals with a scientist role, 10 with an engineering role, 8 with a technician role, 7 with an administration role, and 1 management professional. Phase C, also known as the Final Design and Fabrication Phase, focuses on finalizing the robot architecture design of the HELP mission rover ("NASA Systems Engineering Handbook" 2007). Design characteristics must address the lunar environment and the science measurements to be obtained to ensure that science requirements are met. Therefore, in comparison to other mission life cycle phases, this phase carries the most members fulfilling the scientist role. The 10 engineering professionals focus on completing the individual subsystem design, and work with the 8 technicians to develop plans for interface control between the subsystems to outline the entire spacecraft design. It's crucial that these plans are finalized for the Critical Design Review (CDR), which has an estimated submission time during January of 2026 when referencing Figure 10 ("NASA Schedule Management Handbook" 2011).

For the entirety of Phase D, there are 6 professionals fulfilling scientist roles, 12 with an engineering role, another 12 with an engineering role, 6 with an administrative role, and 1 management personnel that still remains. Phase D is often referred to as the

[14] These salaries are clarified in the MCA Mission Task Document.

system assembly, integration and test, and the launch and checkout phase. The drop in scientists signifies that the mission is moving on to manufacture and test the components outlined previously in the CDR. The remaining scientists will focus on research in the R&D Team and integrating payload instruments in the Payload & Instrumentation Team. Seeing as there's an increase in manufacturing, the engineering and technician roles see an increase in personnel. Subsystem teams will be manufacturing the coordinating their interfacing strategies with the rest of the subsystems, and the V&V Team will be completing verification protocols to ensure these components effectively meet the science and system requirements. The spacecraft architecture must be completed within this phase, therefore an increase in engineering-related personnel is absolutely necessary ("NASA Schedule Management Handbook" 2011).

During Phases E and F, it's anticipated that 10 professionals will fulfill scientist roles, 2 members will be engineers, 2 will be technicians, 5 will be administration, and 1 will undertake the management position of the mission. These phases are depicted as the operations phases, due to the entirety of the science measurements and mission requirements being fulfilled throughout the completion of these two phases ("NASA Schedule Management Handbook" 2011). The increased number of scientists is necessary to analyze the data recorded by the HELP mission rover and ensure that the science requirements have been met by the mission. Without the scientists drawing conclusions and releasing discoveries concerning these measurements, the associated lessons learned can't be shared, defeating the purpose of outlining mission science requirements. The decrease in engineering and technicians is necessary given that all of the manufacturing must be completed by this mission phase. However, communication and data handling procedures must still be maintained in order to ensure the science measurements are efficiently stored.

Administration plays a critical role throughout the entirety of the mission. Mission assurance positions must research and mitigate risks surrounding the mission environment and spacecraft technology, program analysts must track the mission cost and schedule and make sure they remain within mission constraints, and executive leads must organize operations within their specific subteam. During Phases C and D, these processes are continuously iterated, therefore the amount of administration personnel remains almost the same (Dezfuli et al. 2011a). The reason the number slightly drops from 7 to 6 members is that by this time the Cost Scheduling Team will have already designated budgets for specific sub-teams to manage with their associated margins. Progressing into Phases E and F, administration is still necessary for ensuring mission decommissioning occurs smoothly, and lessons learned are shared efficiently. The continued decrease in administration personnel to 5 signifies the continued reduced need for the Cost Budgeting Team, considering cost and scheduling primarily focuses on practices that lead up to mission launch.

The one management personnel represents the HELP mission Project Manager (PM). The PM is responsible for coordinating communication between each of the subteams, making top-level decisions, providing support for each subteam whenever it's necessary, and ensuring the mission cost and schedule remain within the specified constraints (*NASA Space Flight Program and Project Management Handbook* 2014). Therefore, the PM remains present throughout the entire mission to help conduct the NASA Mission Life Cycle and assist other personnel where assistance is needed.

1.10.4 Travel Budget

TRAVEL								
Total Flights Cost	$ 8,088	$ 8,088	$ 13,480	$ 8,088	$ 8,088	$ 77,812	$ 5,392	**$ 123,644**
Total Hotel Cost	$ 5,466	$ 5,466	$ 9,110	$ 5,466	$ 5,466	$ 51,016	$ 3,644	**$ 85,634**
Total Transportation Cost	$ 1,896	$ 1,896	$ 3,160	$ 1,896	$ 1,896	$ 10,428	$ 1,264	**$ 22,436**
Total Per Diem Cost	$ 7,488	$ 7,488	$ 12,480	$ 7,488	$ 7,488	$ 109,824	$ 4,992	**$ 152,256**
Travel Margin	$ 3,441	$ 3,441	$ 5,735	$ 3,441	$ 3,441	$ 37,362	$ 2,294	**$ 56,859**
Total Travel Costs	$ 26,379	$ 27,065	$ 46,251	$ 28,436	$ 29,122	$ 323,679	$ 20,329	**$ 480,932**

Figure 15: Travel Budget

Single Trip Cost Distribution	
Flight Cost	$1,348
Hotel Cost	$911
Transportation Cost	$316
Per Diem Cost	$1,248

Figure 16: Cost Breakdown for an Individual Travelling

The HELP mission travel budget ensures mission travel is efficiently covered. Mission travel includes business trips to visit testing and manufacturing facilities, trips to attend Key Decision Points (KDPs) in Washington, D.C., and travel to conduct and observe the HELP mission launch on March 1, 2030. The total travel budget is outlined in Figure 15, and is further divided into more specific costs in Figure 16 as well.

The total travel budget for this mission is $480,932. This number does not incorporate any travel expenditures associated with outreach travel. In the Budget Basis of Estimate, it is established that one single person traveling costs approximately $3,823. This number does not incorporate travel margin or inflation. These trips are all based on travel from Tallahassee, FL to Miami, FL and from Miami, FL to La Crosse, WI. A travel margin of 15% is applied to this total travel estimate as well, so any unexpected travel expenditures are incorporated into the total travel budget. In addition, inflation impacts the costs displayed across the HELP mission timeline. With inflation rising 2.6% every year, the travel pricing outlined for each year is steadily increasing, even between mission fiscal years where the amount of travel remains the same.

Owing to the fact that there are six payload instruments addressing the science requirements outlined by the HELP mission[15], it's anticipated that mission representatives will have to visit associated contractor facilities to monitor the progress of related testing and manufacturing procedures. Therefore, the $3,823 is multiplied by a factor of six for the first two years of Phase C to address contractors organizing these plans and developing verification protocols. Moving into the final year of Phase C, additional travel is included to compensate for KDPs. A KDP event sees the Mission Directorate Associate Administrator (MDAA) travel to Washington D.C. at NASA headquarters to officially sign-off on the mission moving forward[16]. Since the PM designates the role of deliberation lead to either the Chief Scientist, Deputy Project Manager of Resources (DPMR), or Lead Systems Engineer to be a key decision-maker in the HELP mission, all four are expected to travel for this event. It is expected that the PM will act as the MDAA for this mission's KDPs, however, the other leadership positions must advise decisions to move forward, and support the consultative decision process outlined previously for this mission.

Moving into Phase D, inflation continues to rise, causing larger travel costs. In addition, six mission representatives are again expected to visit contractor facilities throughout the year to monitor the spacecraft manufacturing progress. Now that the mission has transitioned into the manufacturing phase, each of these facility visits will monitor the spacecraft production process, rather than outlining plans for production as done previously in Phase C. During the final year of Phase D, two major events see a major increase in travel cost estimation. Since the final year of Phase D indicates another KDP, the traveling price of $3,823 is again multiplied by a factor of four to address all leadership positions attending the confirmation event. Additionally, the mission launch is set to take place on March 1, 2030. It is anticipated that all mission personnel, including scientists, engineers, technicians, administrators, outreach officials, and the manager, will attend this event. Therefore, the single trip cost of $3,823 is

[15] The mission's science requirements are outlined in the HELP mission STM.
[16] The role of the MDAA at these KDPs is outlined in the MCA MIssion Task Document.

multiplied by a factor of 44 to address round trip travel for this significant mission event, leading to the fiscal year travel total amounting to $323,679.

During Phases E and F, much less travel is expected. Mission engineering representatives aren't responsible for visiting manufacturing and testing facilities, since these processes should have been completed before mission launch. The only significant travel requirement[17] within this timeframe is the KDP that occurs at the end of Phase E. Consequently, travel for this fiscal year amounts to $20,329, which covers travel for the four mission representatives[18]. This value includes travel margin and the inflation rate for that given year.

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[17] Mission travel outlined in the MCA Task Document indicates that travel is necessary to Washington D.C. at the end of Phases C, D, and E to address KDPs.
[18] The four mission representatives are the PM, Chief Scientist, Lead Systems Engineer, and DPMR.

1.10.5 Outreach Budget

OUTREACH								
Total Outreach Materials	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	**$ 9,000**
Total Outreach Venue Costs	$ 4,800	$ 4,800	$ 4,800	$ 4,800	$ 4,800	$ 4,800	$ 4,800	**$ 28,800**
Total Outreach Travel Costs	$ 13,200	$ 13,200	$ 13,200	$ 13,200	$ 13,200	$ 13,200	$ 13,200	**$ 79,200**
Total Outreach Services Costs	$ 64,120	$ 64,120	$ 64,120	$ 54,120	$ 54,120	$ 174,120	$ 94,120	**$ 474,720**
Total Outreach Personnel Costs	$ 609,000	$ 609,000	$ 609,000	$ 609,000	$ 609,000	$ 609,000	$ 609,000	**$ 3,654,000**
Outreach Margin	$ 346,310	$ 346,310	$ 346,310	$ 341,310	$ 341,310	$ 401,310	$ 361,310	**$ 2,122,860**
Total Outreach Costs	$ 1,038,930	$ 1,065,942	$ 1,092,954	$ 1,103,797	$ 1,130,419	$ 1,360,441	$ 1,253,023	**$ 6,792,483**

Figure 17: Outreach Budget

Over the course of the mission, the HELP outreach budget is projected to reach roughly $6.8 million. The outreach plan, which attempts to ensure strong community engagement, educational activities, and distribution of mission updates to stakeholders and the general public, served as the basis for this cost estimate. The outreach budget was determined by examining the costs of persons, services, venues, travel, materials, and an extra margin to cover unanticipated costs.

The cost estimates for outreach were derived from sources with industry rates for salaries, travel, venue, rentals and web tools. For instance, the Armia website cost estimator and the Amazon SES pricing calculator were used to ensure accuracy. For the travel event cost, outreach programs in Houston, TX were used in relation to the estimations as benchmarks ("City Pair Program (CPP)" 2024).

By coordinating the outreach strategy with these budgetary estimates, the HELP mission guarantees effective resource utilization while attaining maximum impact. This comprehensive budget helps the mission achieve its objectives of encouraging community engagement and sharing project lessons to the public.

MATERIALS

The total per year is $1,500 allocated for outreach materials such as kits and hands-on activities.

VENUE COSTS

The cost of venues is $400 per event. The annual venue fee for a 12-month period of one event each month comes to $4,800. These expenses are predicated on projections from institutions like the Space Center Houston.

TRAVEL COSTS

Travel expenses between Boston and Houston are approximated. The cost of each vacation includes round-way airfare of $846, three-day vehicle rentals of $110, and $128 for per diem. The annual travel cost, including monthly excursions, comes to $13,200.

SERVICE COSTS

Among the services offered are virtual events, instructional email campaigns, and the creation and upkeep of the HELP educational website. Based on comparable web development projects, the estimated annual cost for website development and maintenance is $15,400.

- Email campaigns: $3,720 is spent annually at a rate of $310 per month.
- Virtual Events: Virtual news conferences cost $20,000 per, while virtual Zoom meetings cost $10,000 per event. Every year, four virtual events with a combined budget of $120,000 are organized.

PERSONNEL COSTS

Costs of Outreach Staff: Outreach needs eight staff members, including social media managers, email marketing experts, website designers, and outreach representatives. The following is an estimate of personnel salaries:

- $107,000 a year for a website designer
- Specialist in Email Marketing: $60,000 per year
- (2) Social Media Experts: $95,000 a year each
- (4) Executives and Outreach Agents: $63,000 a year $609,000 is the entire yearly personnel cost.

MARGIN COSTS

The entire margin is $2.1 million, which includes a 50% buffer to cover unforeseen costs.

1.10.6 Direct Costs

The direct costs of this mission include the cost of manufacturing, testing, and assembling the mechanical system, power system, CDH system, thermal system, and all science instrumentation. The total direct costs for this mission totals $249,974,344, with the total cost of manufacturing, testing, and facility cost estimate being $61,454,782 of this. The individual subsystem direct costs are further explained in the associated subsection below. All subsections, excluding power, had a Cost-Estimating Relationship (CER) that could be used in the Mission Concept Cost Estimating Tool (MCCET). There is no CER for Power, so all costs were calculated from off-the-shelf items.

MECHANICAL

The mechanical subsystem includes the main body of the rover as well as the wheels and motors that allow it to move. To determine these, trade studies were conducted. Aluminum alloy 2219-T851 was chosen due to its low cost, high strength, and low density. Wire mesh wheels were chosen due to their low cost, lack of mass, and high performance and durability. A trade study for specific motors has not yet been conducted, but it is estimated that the max power should not exceed 89.5 watts, split between 4 motors, and the mass of the entire mechanical system will not exceed 50 kilograms. With these variables, and by using the mechanical Cost-Estimating Relationship and the MCCET tool, the final manufacturing cost of the mechanical subsystem was estimated to be $22,999,998. This cost was divided between phases C and D, since all manufacturing happens in these phases. Facility testing costs for the mechanical subsystem totaled $6,900,000.

POWER

The power subsystem consists of all electronics used to power the rover. It was decided to use solar power as the source of power since similar missions like

Chandrayaan-3 operated using solar power. Power collected from solar cells will be stored in batteries and used to power all components of the rover.

To estimate the cost of this subsystem, costs of the intended off-the shelf items were found. The triple junction solar cell that will be used is manufactured by SatSearch. This type of solar cell is very expensive, with each 4cm X 8cm cell costing $450. The mission intends to use 625 of these cells since the power draw will be 166V. This total cost is $281,250. To store this power draw, batteries will also be needed. 8 22V batteries cost about $6920. That means that the total cost of the power subsystem is $287,634, which is split between Phases C and D.

CDH

The CDH subsystem makes sure the rover has an instrument in order to send and receive information in order to communicate with Mission Control. The rover also has a method of handling and gathering information. An Onboard Computer (OBC) will be responsible for tracking mission data and communicating with Mission Control.

To find the costs of the CDH, Mission Concept Cost Estimate Tool (MCCET) was used on a X-band high gain antenna, receiver dishes, transponders, and phased arrays. These tools were based on the prices of each subsystem to cost a total of $22,700,000. This total price was split and roughly gave an estimate of $400,000 and $2,800,000 for each part of Phase C respectively and $5,000,000, $11,000,000, and $3,500,000 for Phase D.

THERMAL

The objective of the thermal management system is to maintain a specific temperature range inside of the interior of the spacecraft to ensure that all components and electronics can operate efficiently and effectively. Any extreme temperatures caused by the harsh environment will damage the electronics and put our mission at risk.The thermal management subsystem has a variety of subassemblies to meet the pre established requirements including passive and active systems. A combination of the MCCET, CERs, and budget estimation tools was used to calculate specific cost of each subassembly and the total budget allocated for the thermal subsystem. A total estimated budget of $4,700,000 will be used between Phases C and D.

The cost of each passive subassembly uses the CERs and MCCET tools to calculate the estimated cost using the mass of the thermal assembly. The passive subassemblies include MLI coatings, adhesive tapes, thermal switches, radiators, and thermocouples with an estimated cost of $1269, $418, $164, $1134, and $154, respectively. The total estimated cost of the passive subassemblies is $3139.

The cost of each active subassembly uses the CERs and MCCET tools to calculate the estimated cost using the mass of the thermal assembly. The active subassemblies can be broken down into active heating and cooling systems. The active heating system chosen for this mission was the Omega Polyimide Heater Kit with an estimated cost of $237. The active cooling systems used for this mission include thermoelectric coolers and fluid loops with an estimated cost of $237 and $826, respectively. The total estimated cost of the active subassemblies is $1300.

Based on both passive and active thermal subassemblies, the total estimated cost based on mass is $4439. After inflation, the total cost of the system (without wraps) is $684,170. The remainder of the budget for the thermal management system will be used on the cost associated with management, systems engineering, product assurance, integrating, and testing.

INSTRUMENTATION

The instrumentation of the rover is used to collect science data and achieve mission goals. Accordingly, there are many parts to the instrumentation, each with its own budget. To estimate the budget of the instrumentation, the CER and MCCET tool was used. The exception to this is the RIEGL VZ-400 V-Line 3D Terrestrial Laser Scanner, which is considered an off-the-shelf product with a price available from the manufacturer.

The price of the RIEGL VZ-400 V-Line 3D Terrestrial Laser Scanner was $100,000 as of 2024. The estimations for the other instruments are as follows. NIRVSS was estimated to cost $6409.66; the NSS cost $1042.99, the ALSD was estimated to cost $11,266; the REMS cost $117,023.95, and the M-42 cost $970.05. Since the REMS was developed to work on Mars, parts such as the wind measurement system will be removed, reducing mass and power consumption.

In total, the estimated cost for the instrumentation adjusted for inflation with manufacturing and testing costs added is $18,508,879.61. Although this budget has been significantly downscoped, there is room to reduce costs further while increasing the ability to achieve mission objectives.

1.11 Scope Management

1.11.1 Change Control Management

One of the first things the team implemented to communicate about changes was a specific change control chat in Discord. It was decided that this would be the simplest way of keeping track of changes that were made by submitting Change Request Forms (CRFs). Anything regarding RFAs or ADVs was discussed in the associated subteam's chat. A Google Sheet regarding all RFAs and ADVs received throughout the academy, as well as their completion statuses, is being kept and updated as frequently as possible.

To request changes, the associated subteam discussed among themselves as well as the project manager about the necessity of the proposed change. Once a change was decided upon as being necessary to the success of the mission, the project manager submitted a CCB form, which was communicated about in the team's change control Discord channel and stored in the team's change control folder in the Google Drive. Submitting a CCB is also a program requirement for any major changes to already-outlined decisions regarding science and engineering. The goal is to keep all team members as informed as possible about possible, requested, and implemented changes.

The team received many additional RFAs and ADVs from the System Requirements Review (SRR). The first RFA implemented was a “met” column needed to be added to the mission requirements table. This was added and included in this document's mission requirements table, which is in Section 1.3. The second RFA implemented was addressing any future changes the team might make. This was discussed in the change control management section of the MDR. The final RFA implemented was that a breakdown for all costs and personnel should be completed. This had not been finalized prior to SRR completion, but due to the budget cuts and descoping, this was finalized and will be further discussed in the sections dedicated to mission costs.

Several RFAs received will not be implemented in the MDR due to the fact that there are no sections for them. These include the following: adding more detail to the mechanical requirements, lack of completion of the mechanical overview, more power requirements, more details in the power subsystem overview, providing TRLs for the power subsystem, adding necessary components to the CDH system, fixing the TBDs in the STM table, adding a requirements table for the payload subsystem, lacking sources regarding the payload, and improving the N^2 chart. These RFAs will be addressed further in the PDR.

Many ADVs were requested following the SRR as well, the first being to expand on narratives and SRBs, which will be done so in the schedule-related sections of the MDR. The second ADV received was to discuss the change request process within the academy. This was done so in the change control management section. The final ADV received was to provide the page number for each section and subsection in the table of contents. This is done so in the MDR and will be for the PDR as well.

Like the RFAs, there are many ADVs received that do not pertain to the MDR. These include the following: completing the power subsystem overview table, reconsidering usage of a solid-state battery, and rewriting the thermal system requirements to be more specific to the mission statement. These will be implemented in the PDR as needed.

A table listing all of the RFAs and ADVs received throughout the academy is included in Appendix A.

1.11.2 Scope Control Management

Scope, or more specifically project scope, can be defined as the necessary work performed to deliver a product, service, or result given specified guidelines or constraints (Grant 2021). For the HELP mission, scope encompasses the processes and components necessary to manufacture, test, and launch and rover spacecraft and record science measurements while remaining within strict customer constraints[19]. In

[19] The customer constraints for the HELP mission include ones in relation to mass, dimension, cost, and schedule, and are outlined in the MCA Mission Task Document.

the event that this scope changes, whether it be via downscoping or increasing scope, scope control strategies must be in-place from the beginning of the mission in order to ensure the scope change is addressed and the mission is still successfully completed.

In preparation for any scope changes that may occur, the HELP management and administration professionals have a plan in-place with realistic project goals that minimize procedure complexities (Millhollan 2008). Manufacturing in-house instruments for the spacecraft payload may produce new, innovative technology to be used on the lunar surface, but it will also result in lower TRL levels. In-house components carry higher levels of uncertainty, therefore they require extensive testing to raise the TRL of the entire spacecraft system. Therefore, the HELP Engineering and Science Teams have identified plenty of contractors to contact for payload instruments and system components to prioritize simplicity where it can be implemented. These contractors are outlined in the mission Manufacturing and Procurement Plans.

Defining preliminary scope is also a priority for successful completion of the HELP mission. To receive official approval for scope plans with contractors and clients, endorsement documents will be signed between contracted organizations to clarify boundaries and plans for moving forward with manufacturing and testing (Millhollan 2008). Sponsor acceptance of mission goals must also be confirmed. In the event that mission requirements are met within their constraints with extra breathing space for cost and scheduling, it’s best advised that the mission team move forward with the current procedures in place rather than attempting to expand on the components already initially outlined (Millhollan 2008). This way, as long as mission requirements are sufficiently met, sponsors and customers are satisfied.

Lead will be implemented to plan out the entire budget and scheduling of the HELP mission. Lead involves mapping out every step of a mission timeline (Avantika Monnappa 2024). Incorporating this strategy makes it easier to address scope changes since the mission plans can be directly observed and analyzed. The HELP mission has already outlined the entire mission schedule, seen in Figure _, as well as in Appendix C, where each phase of the NASA Mission Life Cycle is separated by distinct dates. The Budget Overview also clarifies the current mission budget, and how funds are distributed amongst different categories of the mission[20].

Scope change requests must also be considered when evaluating the scope of a project (Millhollan 2008). Changes in scope might occur in relation to cost, scheduling, spacecraft mass, or spacecraft dimensions. Any mission variable subject to customer constraints might be inflicted by a scope change at some point along the mission timeline. Typically, mission teams must reevaluate mission plans and make changes accordingly to address these scope changes. However, in some circumstances, the HELP team might deem it necessary to submit scope change requests to these customers to reevaluate their constraints and make exceptions for components that might veer slightly outside of the specified scope range. For these requests to be submitted, HELP mission management must communicate extensively with team leads from the Science, Engineering, and Programmatics Teams.

[20] Mission categories associated with the budget include, personnel, travel, outreach, and direct costs.

In order for a scope change request to be approved, it must be justified, with clarified evidence as to why the additional scope is necessary for mission success. If this situation were to occur, the HELP team would evaluate the situation, conduct necessary trade studies, provide a variety of potential options for customers to choose from, and give detailed advice on each option and the mission results that might occur given that one of the options is chosen. For this reason, in the event of a scope change, the sub-teams outlined in Figure 5 must assess their individual mission contribution and report whether or not they'd be inclined to submit a scope change request to their administrative lead. These sub-team updates will then be communicated to management through the team leads, followed by further discussions before finally making a decision regarding scope change request submission.

Downscoping involves customer constraints tightening or decreasing in magnitude, and it often occurs in relation to a mission's cost or schedule. Given a schedule downscope, the HELP mission will consider two possibilities: project crashing and fast-tracking. Project crashing involves evaluating costs and adding an increased amount of resources to fast-forward the mission timeline (Avantika Monnappa 2024). This process can only occur if there is enough leftover budget margin available to allocate money for additional resources. Fast-tracking involves rescheduling tasks to be completed in parallel rather than serially, or one after another (Avantika Monnappa 2024). As opposed to project crashing, fast-tracking would reallocate mission personnel to other or additional tasks to be completed at once. Depending on the funds available, additional personnel may be temporarily added to the mission as well, especially for schedule descoping that occurs during Phase D. Between these two schedule downscoping solutions, fast-tracking will be prioritized over project crashing. While fast-tracking introduces the increased risk of rushing work and testing that might increase component uncertainty, it is much less expensive than project crashing (Avantika Monnappa 2024).

Budget downscoping can and has been addressed by completing an in-depth budget reevaluation that sees mission subsystems and budget allocation reexamined. The HELP mission was previously subject to a significant budget descope from $425 million to $300 million. In order to address this scope change, the HELP mission budget was analyzed and recalculated. This process was completed due to the fact that the entire mission budget had not been established yet, therefore budgets for each subcategory had to be found first before completing downscoping procedures. Completing these estimates saw a total budget estimate of $317,429,546.

Next, each mission subsystem was re-examined to identify potential areas of budget downscoping. Given that the science requirements outlined in Figure 1 drive the HELP spacecraft design, the payload subsystem was examined last when analyzing each subsystem. However, ultimately it was chosen amongst two other subsystems, the power and GN&C subsystems, to further be analyzed. These three subsystems either carried budgeted values deemed unnecessarily high or carried over extensive redundancies. The power subsystem reevaluated its off-the-shelf costs to reduce budget estimates from $9,920,000 to $287,634. This impressive recalculation occurred due to minor miscommunications in regards to the MCCET tool. In the payload subsystem, two instruments, the Lunar Lander Neutron and Dosimetry (LND) device and the Radiation Assessment Detector (RAD) had previously been outlined to complete the same job: obtaining radiation measurements. Further research was completed to reevaluate the implementation of these two instruments, and the M-42 radiation detector was integrated instead. This instrument is introduced at a higher TRL level and it meets science requirements outlined in the HELP mission STM. Following these changes, the HELP mission successfully downscoped from $317,429,546 to $296,660,064, which is beneath the descoped cost cap of $300 million. Given similar situations in which budget downscoping occurs, a similar procedure will be followed.

In the case scenario where scope is increased, and additional funds are available in comparison to the previously outlined budget, the budget of each individual section of the mission can be increased. A dramatic increase in budget can be allocated to increasing the mission objectives by adding or upgrading instruments. The change to instrumentation requires additional funding in each section of the mission to support manufacturing, testing, personnel, and other costs. Another option is to add a novel experiment to the mission. This would be useful as the environmental conditions of Compton Pit are unique, and bringing an experiment can fast-track the long-term goal of sustaining humans in the pit, as it can be used to field test the cave conditions[21] being considered when developing a long-term base on the Moon.

However, more modest funds can be implemented in as effective a manner. One option is to invest in promotional material to educate the public about the HELP mission. This would increase public awareness about the prospect of permanent habitation on the Moon, but was determined to be an ineffective use of funds due to not directly contributing to mission objectives. Another potential upscoping scenario would involve an extension in the mission schedule, allowing more time for testing to be completed and personnel to generate stronger confidences in their individual tasks. Should scheduling upscoping occur, this will be the most effective course of action.

1.12 Outreach Plan

The HELP mission aims to garner public attention through various outreach events including virtual information sessions and presentations, conventions panels, and educational events.

Firstly, HELP will establish an educational site that can be referenced in all future outreach efforts, to attract interested parties to more information on the mission and its goals. This site will be the first place that will receive updates throughout the lifecycle of the mission, including information about the launch, data received, etc. This site will be linked to any social media handles held by the mission(Youtube, Instagram, etc.). Social media will be used to announce outreach efforts, display the turn out of these events, and any relevant mission information. In addition, the site will contain an email

[21] In order for the Compton Pit to present a habitable environment for humans, it must maintain habitable radiation levels and temperature levels. Its infrastructure must also be examined to determine its accessibility and stability, and it would be preferable if volatile resources were to be readily available nearby as well.

subscription to update on avid followers about mission updates and outreach events more efficiently.

The HELP mission plans to utilize virtual presentations and sites to reach a larger national audience.The outreach team plans to host 10 different virtual information sessions via Zoom to update the public and shareholders on the lifecycle of the mission leading up to launch. These sessions would serve to give the public an in-depth view into the outlined goals of the HELP mission and how it will be achieved. Moreover, HELP will host eight virtual news conferences. Four of these conferences will precede the launch to give the community some final updates, and increase interest in the mission's objectives. Two more will be held after the payload has landed and will update on the current conditions. The remaining two conferences will occur after the mission has finished, and will relay the conclusions reached based on the data collected by HELP.

HELP has devised several avenues to open the mission up to community engagement such as school presentations and space center activities. The HELP Outreach Team will be reaching out to schools in different districts to put together presentations to increase interest in the mission from underrepresented communities. These events will occur about once a month, and will use hands-on activities to engage students to follow the mission. In addition, the HELP mission will commission an event at Space Center Houston about once a month, reaching up to 250 students per session to show what HELP aims to achieve and increase interest in current and future missions.

1.13 Conclusion

The HELP mission MDR baselines the programmatics associated with the HELP mission. The mission budget and schedule are explicitly defined, along with corresponding budget and schedule basis of estimates that include the assumptions made in calculating costs and defining project deadlines. The mission launch date of March 1, 2030 fits within the mission schedule provided. The total estimated budget of $296,660,064 has been broken down and categorized into mission travel, personnel, outreach, and direct costs. Risk mitigation has improved since the SRR to now include personnel hazards. All of the risks outlined previously in risk analysis have been addressed with mitigation strategies. These strategies have helped lower the likelihood and consequence of most risks, seen in the HELP Risk Matrix. The highest priority risks can now be visualized in a FMEA table as well, in which risks and their consequences are more explicitly defined. Cost and scheduling risks threaten the HELP mission to the greatest degree, especially considering the recent downscoping that has occurred in the budget constraint from $425 million to $300 million. Scope and change control has been outlined accordingly in this document to address future revisionary, advisory, and descoping changes. These plans define how the HELP team prepares for changes and tackles circumstances introducing downscoping or increased scope. Regarding mission science, the payload was further reexamined following the budget descope to implement a M-42 radiation detector, and research improved science requirements that prepare the integration of a new drilling instrument.

While most of the mission programmatics have been clarified, there are still several areas of this document that would be improved given more time. The mission outreach plan would be more explicitly defined, along with risks outlined in the mission FMEA table. In addition, more engineering-related tasks would have been completed in order to prepare the Preliminary Design Review (PDR). Science requirements and replacing the ALSD in the STM will be assigned the highest priority heading into the PDR. Spacecraft overview and requirements will also be prioritized, along with providing Computer-Aided Design (CAD) drawings. Following the SRR feedback, much of the HELP team's focus will be on improving the present status of mission engineering, and addressing RFAs and ADVs assigned for the team to implement since the completion of the Mission Concept Review (MCR). Defining these goals leading into the PDR will prepare the HELP team to submit a complete, comprehensive PDR document.

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DECLARATION OF GENERATIVE AI

During the preparation of Section 1.7, Chat GPT was used to weigh the pros and cons between contracting specific components for each subsystem at specific companies against others. After using this tool/service, the content was reviewed and edited as needed, and full responsibility is taken for the content of the deliverable.

APPENDIX A: RFA/ADV Table

RFAs and ADVs			
RFA ID	**Section #**	**Action**	**Implemented?**
MCR-RFA-1	1.2	Instrumentation shall not be selected until columns 1-4 are defined with no TBDs/TBRs. Trade studies must be conducted for each instrumentation selection.	Yes
MCR-RFA-2	1.4	Include a requirements table.	Yes
MCR-RFA-3	1.5	The team needs to address Planetary Protection Concerns.	Yes
MCR-RFA-4	1.5	The team should address the risk associated with their specific pit.	Yes
MCR-RFA-5	1.7	The team must determine an alternative method of analyzing samples that does not rely on transportation of the rover back to Earth, as the primary vehicle does not have any further purpose after transportation to the moon is complete.	Yes
MCR-RFA-6	1.8	Change your alternative design concepts to be "alternative system concepts".	Yes
SRR-RFA-1	1.4.	Add a met column. Review requirements verification methods. Add engineering requirements. - KS	Yes
SRR-RFA-2	1.5.2.1	Add detail to the mechanical requirements as directed.	Yes
SRR-RFA-3	1.5.2.2	Add the mechanical overview, TRL discussions, mass/power/dimensions table, and trade studies.	PDR
SRR-RFA-4	1.5.3.1	More requirements should be added (see feedback). - KG	PDR
SRR-RFA-5	1.5.3.2	More detail is needed in this section. - KG	PDR
SRR-RFA-6	1.5.3.2	No TRLs are provided. - KG	PDR
SRR-RFA-7	1.5.3.3	Trade studies are needed for the other subassemblies. - KG	PDR
SRR-RFA-8	1.5.4.2.	Add necessary components to your CDH system - OBC, redundant OBC, Storage Unit, Data processing unit (DPU), Signal Amplifier, Power Conditioning and Distribution Unit (PCDU), Software and Firmware, Thermal Management, Interface Modules, Clock and Timing Module, Error Detection and Correction Module and Environmental Sensors. - KS	PDR
SRR-RFA-9	1.5.5.2	Consider revising to show a more comprehensive view of your specific system. - RH	PDR

SRR-RFA-10	1.5.5.2	Fix the TBD's in the MVP table. - RH	PDR
SRR-RFA-11	1.5.5.2	Add TRL scores. - RH	PDR
SRR-RFA-12	1.5.6.1	Add requirements table	PDR
SRR-RFA-13	1.5.7	Lack of sources. Redundancy parts not mentioned in requirements or components/parts tables. - KS	PDR
SRR-RFA-14	1.5.8.	Add Block diagram. Improve N^2 chart. Include sources. - KS	PDR
SRR-RFA-15	1.7.1	Any future changes the team might make should be addressed. - HG	Yes
SRR-RFA-17	1.7.2	Please provide a breakdown for all your cots and personnel throughout all phases C-F. Additionally, please make sure to include a specific total cost and explicitly state that it falls under budget. - NC	Yes
MCR-ADV-1	1.3	Discuss how the site(s) of-interest are favorable to carry-out this specific mission's science objectives.	Yes
MCR-ADV-2	1.4	Format the requirements to be SMART requirements.	Yes
MCR-ADV-3	1.5	The team should separate or clarify the risk from ConOps. Although addressing the importance of the risk the rover can experience is vital, the team should only address the risk and not mention details in how the rover needs to operate.	Yes
MCR-ADV-4	1.6	The team should consider criteria for ALL subsystems, and how criteria related to cost, volume, time, and TRL will inform decision-making.	Yes
MCR-ADV-5	1.9.2	Restructure the budget section to clearly separate the four categories: outreach, direct costs, transportation, and personnel.	Yes
SRR-ADV-1	1.5.3.2	Complete the table and add a narrative. - KG	PDR
SRR-ADV-2	1.5.3.3	Reconsider using a solid-state battery. - KG	PDR
SRR-ADV-3	1.5.5.1	Rewrite your requirements to be more specific to the mission statement. - RH	PDR
SRR-ADV-4	1.7.3	Please expand on narratives and SRB's - NC	PDR
SRR-ADV-5	1.7.4	Discuss the Change Request Process within the academy.	Yes
SRR-ADV-6	1.7.4		
SRR-ADV-7	Table of Contents	Please provide the page number for each section and subsection. - NC	Yes

APPENDIX B: TBD/TBR Table

TBD/TBR #	Plans and Timeline for Resolution
N/A	N/A

APPENDIX C: Mission Life Cycle Phases Table

1	**Phase C: Final Design and Fabrication**	12/23/24	3/1/27
1.1	Major Milestone 1: Draft and Submit Critical Design Review (CDR)	12/23/24	1/23/26
1.1.1	Develop detailed designs of necessary hardware and software	12/23/24	7/23/25
1.1.2	Further explain how subsystems effectively interface	12/23/24	10/23/25
1.1.3	Explain how the instrumentation is analyzed and considered for future implementation	12/23/24	10/23/25
1.1.4	Continue updating plans for operations, risks, and anticipated procedures for manufacturing	12/23/24	1/23/26
1.1.5	Key Decision Point: Submit Production Readiness Review (PRR) for necessary instrumentation	12/23/24	1/23/26
1.2	Major Milestone 2: Draft and Submit System Integration Review (SIR)	1/23/26	1/30/27
1.2.1	Finalize design plans and plans for integrating the subsystems and instrumentation	1/23/26	11/23/26
1.2.2	Baseline how each subsystem will operate	11/23/26	1/30/27
1.2.3	Begin outlining the process of Verification & Validation (V&V)	11/23/26	1/30/27
1.3	Schedule Margin	1/30/27	3/1/27
1.4	◆ Completion of Phase C	2/1/22	3/1/27
2	**Phase D: System Assembly, Integration & Test, Launch & Checkout**	3/1/27	3/1/30
2.1	Major Milestone 3: Complete Test Readiness Reviews (TRRs) of Instrumentation and System	3/1/27	3/1/28
2.1.1	Manufacture system components and then assemble and integrate them	3/1/27	1/1/28
2.1.2	Inspect instrumentation and system capability to obtain science measurements	1/1/28	3/1/28
2.1.3	Key Decision Point: Assess instrumentation with prototypes to determine TRR	1/1/28	3/1/28
2.2	Major Milestone 4: Draft and Submit Operational Readiness Review (ORR)	10/1/27	2/1/29
2.2.2	Test instrumentation and instate confidence in its usage	10/1/27	3/1/28
2.2.3	Key Decision Point: Begin V&V of subsystem and instrumentation results	3/1/28	5/1/28
2.2.4	Finalize operations plans and procedures	10/1/27	2/1/29
2.2.5	Baseline plans for decommissioning and disposing of the robot after mission completion	5/1/28	2/1/29

2.3	Major Milestone 5: Draft and Submit Mission Readiness Review (MRR)	2/1/29	1/1/30
2.3.1	Baseline and verify V&V results	2/1/29	1/1/30
2.3.2	Prepare launch and confirm spacecraft flight/launch capability	5/1/29	1/1/30
2.4	Key Decision Point: Complete Safety and Mission Success Review	1/1/28	1/1/30
2.4.1	Continuously update risks	1/1/28	1/1/30
2.4.2	Perform safety review assessing launch and mission safety	5/1/29	1/1/30
2.4.3	Confirm spacecraft safety and capability readiness	5/1/29	1/1/30
2.5	Major Milestone 6: Launch Vehicle (LV)	1/1/30	3/1/30
2.5.1	Key Decision Point: Complete Launch Readiness Review (LRR)	1/1/30	2/1/30
2.5.2	Major Milestone 7: Launch Mission at Cape Canaveral, FL	3/1/30	3/1/30
2.6	Schedule Margin	3/1/30	3/1/30
2.7	◆ Completion of Phase D	3/1/27	3/1/30
3	**Phase E: Operations and Sustainment**	3/1/30	5/6/30
3.1	Major Milestone 8: Complete Post-Launch Assessment Review (PLAR)	3/1/30	3/10/30
3.1.1	Key Decision Point: Conduct vehicle launch performance assessment	3/1/30	4/1/30
3.2	Major Milestone 9: Complete Critical Events Readiness Review	3/4/30	4/19/30
3.2.1	Activate science instruments upon landing	3/4/30	3/4/30
3.2.2	Collect data measurements concerning surface features	3/4/30	3/18/30
3.2.3	Visit Compton Pit and cave map the pit dimensions and structural features	3/19/30	4/19/30
3.2.4	Collect measurements concerning cave temperature and radiation	3/19/30	4/19/30
3.3	Major Milestone 10: Complete Decommissioning Review (DR)	4/19/30	5/1/30
3.3.1	Begin process of decommissioning the robot systems	4/19/30	5/1/30
3.3.2	Outline potential upgrades for future missions	4/19/30	5/1/30
3.3.3	Conduct safety review	4/19/30	5/1/30
3.4	Key Decision Point: Compile and Document Collected Data Efficiently	3/4/30	5/1/30
3.5	Schedule Margin	5/1/30	5/6/30
3.6	◆ Completion of Phase E	3/1/30	5/6/30
4	**Phase F: Closeout**	5/6/30	6/6/30
4.1	Major Milestone 11: Complete Disposal Readiness Review (DRR)	5/6/30	5/7/30
4.1.1	Conduct robot disposal according to outlined plans	5/6/30	5/7/30
4.2	Ensure Organized Documentation and Draw Conclusions Based on the Collected Data	5/6/30	5/7/30

4.2.1	Baseline and write up the mission final report	5/6/30	6/1/30
4.2.2	Draft and capture lessons learned based on data collected (determine habitability of Compton Pit and the supply of resources available in the vicinity)	5/6/30	6/1/30
4.3	Schedule Margin	6/1/30	6/6/30
4.4	◆Completion of Phase F and Mission	5/6/30	6/6/30

APPENDIX D: MDR Task Breakdown Table

Sub-topic	Assigned To	Pages Expected	Progress	Due
Complete Trade Studies for ProSEED and LVMM	Enayah Rahman, Chris Gravina	0	Complete (1)	11/6/24
FINALIZE STM	Enayah Rahman, Chris Gravina	1	Complete (1)	11/7/24
Budget Overview	Samantha Perez	0.5	Complete (1)	11/7/24
Budget Basis of Estimate	Chris Adzima	2	Complete (1)	11/7/24
Project Management Approach	Chris Adzima	3	Complete (1)	11/9/24
Outreach Plan	Doris Levry	5	Complete (1)	11/10/24
Personnel Budget	Chris Adzima	2	Complete (1)	11/10/24
Travel Budget	Chris Adzima	2	Complete (1)	11/11/24
Mission Statement	Chris Adzima	0.5	Complete (1)	11/12/24
Mission Schedule	Ella Gaddis	2	Complete (1)	11/12/24
Risk Analysis	Chris Adzima	5	Complete (1)	11/13/24
Outreach Budget	Doris Levry	2	Complete (1)	11/13/24
Schedule Basis of Estimate	Kyle Lin	2	Complete (1)	11/13/24
Manufacturing and Procurement Plans	Ethan Gamboa, Maddox Gonzalez	4	Complete (1)	11/14/24
Direct Costs (Mechanical)	Ella Gaddis	1	Complete (1)	11/14/24
Direct Costs (Power)	Ella Gaddis	1	Complete (1)	11/14/24
Direct Costs (CDH)	Kyle Lin	1	Complete (1)	11/14/24
Direct Costs (Thermal)	Noah Doorsammy	1	Complete (1)	11/14/24
Direct Costs (Payload)	Enayah Rahman	1	Complete (1)	11/14/24
Direct Costs (Comprehensive Narrative)	Ella Gaddis	1	Complete (1)	11/14/24
Mission Requirements	Chris Adzima	1	Complete (1)	11/15/24
Concept of Operations	Ella Gaddis, Samantha Perez	2	Complete (1)	11/15/24
MCA Team Management Overview	Doris Levry	1	Complete (1)	11/15/24
Personnel Hazards	Chris Adzima	2	Complete (1)	11/16/24
Failure Mode and Effect Analysis (FMEA)	Doris Levry	2	Complete (1)	11/17/24
Change Control Management	Ella Gaddis	2	Complete (1)	11/17/24
Scope Control Management	Chris Adzima, Enayah Rahman	2	Complete (1)	11/17/24
Conclusion	Chris Adzima	0.5	Complete (1)	11/18/24
References	Chris Adzima	0	Complete (1)	11/18/24

Declaration of AI	Anyone Who Uses AI	0	Complete (1)	11/18/24
Appendix	Whole Team	0	Complete (1)	11/18/24
Mission Definition Review (MDR)	**Team 21**	**49.5**	**Complete: 100%**	**11/18/24**