Rewritten Requirements Document

1.0 LunarGEM Program

- **The entire LunarGEM project, including the design, launch vehicle, upper stages, mission hardware, software, and all other parts and services required for the mission, shall cost less than US$425 million.**

  Rationale: NASA's Discovery Program guidelines impose a maximum cost of $425 million for each mission.

- **LunarGEM shall launch within 36 months of contract awarding.**

  Rationale: NASA's Discovery Program imposes a 36-month project start-to-launch time limit.

- **The contractor shall meet NASA Structural Design and Verification Requirements.**

  Rationale: NASA Structural Design and Verification Requirements specify design loads, factors of safety and margins of safety, design and stress analysis requirements, and structural materials criteria.

- **The lunar landing sites shall be selected based on recommendations of the mission science team.**

  Rationale: LunarGEM geological researchers are responsible for ensuring the seismic vehicle distribution is capable of meeting the mission science objectives.

- **The mission shall follow NASA orbital debris assessment and guidelines per NASA Safety Standard (NSS) 1740.14.**

  Rationale: NASA Management Instruction 1700.8 states "NASA's policy is to employ design and operations practices that limit the generation of orbital debris, consistent with mission requirements and cost effectiveness."

1.1 Spacecraft

- o **The spacecraft shall be launched to Earth orbit using a launch vehicle selected by the NASA Discovery Program.**

  Rationale: NASA's Discovery Program office will be responsible for procuring and manifesting the launch vehicle that best meets project requirements for payload capability, reliability, and cost.

- o **The spacecraft shall maintain communications in transit to lunar orbit.**

  Rationale: The time period while the spacecraft is in transit to lunar orbit shall be used to verify the functionality of the spacecraft.

- o **The spacecraft shall be compatible with the all launch vehicle interfaces and comply with size restrictions of the payload fairing.**

  Rationale: The mission will implement a current rocket design for which there are set dimensions for the payload. The spacecraft should also be designed to function in accordance with the deployment capabilities of the launch vehicle payload fairing to ensure proper release from the launch vehicle.

- **The LunarGEM spacecraft shall comply with NASA-STD-5017, Design and Development Requirements for Mechanisms.**

  Rationale: NASA-STD-5017 establishes uniform design and development requirements for the design of mechanisms whose correct operation is required for safety or program success.

- **All flight hardware shall be designed so that it is capable of being stored, under controlled conditions, for as long as two years.**

  Rationale: Possible launch delays should not compromise mission success due to hardware problems such as battery degradation.

- **Flight hardware shall meet electrical workmanship requirements per NASA-STD-4003, NASA-STD-8739.1, and NASA-STD-8739.3.**

  Rationale: Proper electrical workmanship is necessary to meet performance, safety, and electromagnetic compatibility requirements.

- **Spacecraft assembly shall be performed in a class-100,000 clean room.**

  Rationale: Foreign object and dust particle contamination of flight hardware must be minimized to reduce the possibility of hardware failure.

- **The spacecraft contractor shall define adequate safety margins to be incorporated into the design.**

  Rationale: Safety margins must be considered during all phases of the mission.

- **The mass of LunarGEM shall be within the capacity of the launch vehicle selected by the NASA Discovery Program.**

  Rationale: The Discovery Program budget will affect the launch vehicle choice, indirectly affecting the maximum launch mass.

1.1.1 OTV

- **The OTV spacecraft shall perform course corrections during trans-lunar coast.**

  Rationale: Small ΔV corrections will be necessary to maintain the desired trajectory to the moon.

- **The OTV shall provide the ΔV required enter lunar orbit.**

  Rationale: A ΔV is necessary for lunar orbit insertion of the LunarGEM spacecraft.

- **The thermal control subsystem (TCS) shall monitor and control temperatures of components on the lunar seismic vehicles and the OTV.**

  Rationale: Seismometers and other sensitive mission hardware must be protected from the temperature extremes of space and on the day and night sides of the moon.

- **The Guidance Navigation and Control (GNC) subsystem of the OTV shall monitor and control the attitude and trajectory of the OTV.**

  Rationale: The OTV must have the ability to correct its trajectory as needed to ensure that it enters the target window for injection into lunar orbit.

1.1.1.1 OTV Propulsion

- **The OTV propulsion subsystem shall provide attitude and course correction burns for the OTV.**

  Rationale: Course corrections are necessary to preserve the correct trajectory in order to achieve lunar orbit insertion. During the transit phase of the mission, attitude control is necessary to maintain pointing accuracy and to control spacecraft temperature distribution.

- **The OTV propulsion subsystem shall provide the ΔV necessary for lunar orbit insertion.**

  Rationale: Once earth-lunar transit is complete, the OTV must perform a prescribed ΔV in order to be placed in the desired lunar orbit.

1.1.2 Communication

- **The communication subsystem shall provide data uplink and downlink between Earth-based groundstations and the LunarGEM spacecraft.**

  Rationale: Control inputs from Earth groundstations must be received by LunarGEM spacecraft, and telemetry and data must be received by Earth groundstations.

1.1.3 LunarGEM

- **LunarGEM shall be vacuum-rated per NASA standards.**

  Rationale: Vacuum environment problems such as hardware out-gassing must be considered during the design phase.

- **LunarGEM shall provide micrometeoroid protection for all critical system hardware.**

  Rationale: Damage from micrometeoroids could cause significant spacecraft damage and possible mission failure.

- **LunarGEM shall provide adequate protection from all forms of Van Allen belt, solar, and other forms of radiation.**

  Rationale: Hardware damage resulting from excess exposure to radiation could cause a spacecraft failure.

- **LunarGEM shall be able to operate in the range of temperatures between 2.7K up to 320K, encountered in transit to the Moon.**

  Rationale: Temperature variations could result in failure of electronics and other critical systems.

- **LunarGEM shall provide adequate protection for the entire range and types of radiation that are known to exist on the lunar surface.**

  Rationale: Hardware damage resulting from excess exposure to radiation could prevent data collection and transmission and possibly result in a mission failure.

- **LunarGEM shall be operational in the entire range of temperatures encountered the Moon's surface.**

  Rationale: Hardware temperature variations could result in failure of electronics and other critical systems.

- **LunarGEM shall protect critical hardware from lunar dust contamination.**

  Rationale: Lunar dust contamination could adversely affect critical mechanical systems and other essential hardware.

- **The LunarGEM spacecraft shall be electromagnetically compatible with external interfaces**

  Rationale: All spacecraft systems, subsystems, and equipment must be compatible with external interfaces in order to meet LunarGEM operations and performance requirements. External interfaces include interfaces with transportation systems, RF systems, and other vehicles.

- **The LunarGEM manufacture and assembly processes shall abide by the NASA Planetary Protection Policy.**

  Rationale: Although the lunar environment is not likely to support life, efforts must be made to mitigate the possibility of lunar contamination by LunarGEM.

1.1.3.1 Lunar Descent

- Requirements do not exist.

1.1.3.1.1 Lunar Descent Propulsion

- **The descent stage propulsion subsystem shall control the descent velocity and attitude of each seismic vehicle.**

  Rationale: A method to reduce the descent velocity of each seismic vehicle is necessary to ensure that the descent velocity is within operational limits. Spacecraft attitude must also be maintained and corrected during descent for proper placement of each seismic vehicle.

1.1.3.2 Lunar Seismic Vehicle

- **Lunar seismic vehicles shall separate from the OTV after lunar orbit insertion and descend to the surface of the moon.**

  Rationale: The nature of the mission requires that the OTV remain in orbit while lunar seismic vehicles descend to the lunar surface. Once on the surface, lunar seismic vehicles will begin lunar surface operations.

- **The lunar seismic vehicle shall secure the seismometers to the moon's sub-regolith rock.**

  Rationale: The top surface of the moon is mainly composed of loose rock, known as regolith, which may damp out seismic waves from within the internal structure of the moon. It is necessary to securely attach the seismometers to the sub-regolith rock in order to obtain accurate seismic data.

- **The structure of the seismic vehicle shall withstand descent, landing, and placement on the lunar surface.**

  Rationale: The structure of the seismic vehicles will be exposed to extreme conditions.

- **Once calibrated, the lunar seismic network shall operate for six months, with the potential for an extended mission.**

  Rationale: Six months is the minimum amount of time necessary to record sufficient seismic data.

1.1.3.2.1 Seismometers

- **The seismometers shall be calibrated once emplaced on the lunar surface.**

  Rationale: Calibration will ensure that the seismometers record accurate data.

- **LunarGEM shall deploy a globally-distributed network of seismometers on the moon.**

  Rationale: A globally-distributed network allows lunar seismic activity originating from any location on the moon to be catalogued and characterized. Previous seismic sensors on the moon were restricted to small areas near the six Apollo landing sites on the lunar near-side, preventing the creation of a complete statistically-accurate data set for the moon.

- **LunarGEM seismometers shall be five times as sensitive to seismic waves as the Apollo passive seismometers.**

  Rationale: Apollo seismometers experienced a great deal of error, limiting the intensity of seismic waves that could be detected. Increased sensitivity shall allow seismic activity of lower intensity to be studied.

1.1.3.2.2 Communication

- **The communication subsystem shall forward recorded data from each seismometer to Earth groundstations.**

  Rationale: Collecting data from globally-distributed seismometers is necessary to meet the objective of LunarGEM

1.1.3.2.3 GNC

- **The GNC subsystem of each seismic vehicle shall monitor and control the descent trajectory and vehicle orientation.**

  Rationale: The seismic vehicle will need to descend with the appropriate velocity, angle, and orientation relative to the surface of the moon. A GNC subsystem will enable the seismic vehicle to determine if any corrections are necessary and will command the propulsion subsystem accordingly.

1.2 Communications

- **Ground station software shall process data from the seismic network.**

  Rationale: Upon receipt of telemetry and data from the communications subsystem, it will be necessary to decode the seismic data for distribution to the science community.

1.3 Launch Vehicle (subsystem to LunarGEM Project)

- **The launch vehicle shall place the Orbital Transfer Vehicle (OTV) on a trans-lunar trajectory from Low Earth Orbit (LEO) to Low Lunar Orbit (LLO).**

  Rationale: The launch vehicle, not the LunarGEM spacecraft, will provide the ΔV necessary for trans-lunar injection.