SKYF-RP-19-0051
Revision -
Released Date: 2019-04-08

LunIR Redacted Orbital Assessment Report (ODAR)

Contract Number NNH16CO94C

This report is presented in compliance with NASA-STD-8719.14, APPENDIX A.

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APPROVALS

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Released by:

Pamela Craig	Configuration & Data Management	2019-04-08

REVISION HISTORY LOG

Revision	Released Date	Change Description / Change Authority / Sections Affected
-	2019-04-08	Initial Release created from the released Rev – of the SKYF-RP-16-0031 LunIR ODAR with all proprietary and export data removed

SUMMARY: LUNIR ORBITAL DEBRIS ASSESSMENT REPORT

A self-assessment provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14.

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-2								No Debris Released in GEO. See note 1.
4.4-1								No LEO, GEO orbit.
4.4-2								No LEO, GEO orbit.
4.4-3								No planned breakups. See note 1.
4.4-4								No planned breakups. See note 1.
4.5-1					☒	☐	☐	No LEO, GEO orbit.
4.5-2					☒	☐	☐	No LEO, GEO orbit.
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-2	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-3	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-4	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.6-5	☐	☐	☒	☐	☒	☐	☐	No Earth orbit.
4.7-1	☐	☐	☒	☐	☒	☐	☐	No Re-entry.
4.8-1					☒	☐	☐	No tethers used.

Note 1: Since this is a secondary payload, there will not be analysis of the launch vehicle applicability.

DAS Version or Other Software/Models Used

The LunIR Program used Systems Toolkit 10 to prepare data for this ODAR.

Table of Contents

1 INTRODUCTION

1.1 Purpose

This is the Orbital Debris Assessment Report (ODAR) for the LunIR Program. The purpose of this report is to assess the debris generation potential and the mitigation options. This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in Sections 1 through 8 below for LunIR. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

This report will be updated as necessary in accordance with NPR 8715.6B.

A summary of the requirements with their compliance is located in a table in the front of the document.

1.2 Scope

This document shows the compliance of LunIR with the requirements of NPR 8715.6B, "NASA Procedural Requirements for Limiting Orbital Debris". The orbital debris assessment covers the following topics according to NASA-STD 8719.14A, and indicates the sections that are not applicable to the LunIR mission:

- Program Management and Mission Overview
- Spacecraft Description
- Debris Released During Normal Operations
- Intentional Breakups and Potential for Explosions
- Potential for On-Orbit Collisions
- Post Mission Disposal Plans and Procedures
- Spacecraft Reentry Hazards
- Assessment for Tether Missions

1.3 Software and Models Used

No specific debris assessment software was used for this assessment, due to the unusual orbits.

2 PROGRAM MANAGEMENT AND MISSION OVERVIEW

2.1 Responsible Personnel

NASA Mission Directorate: AES, Advanced Exploration Systems
NASA Program Domain Lead: Andres Martinez, NASA HEOMD / AES
LunIR Program Manager: Chris McCaa / Lockheed Martin Space
LunIR Contract Program Manager: John Ringelberg / Lockheed Martin Space
LunIR Systems Engineer: Gaylene Langley / Lockheed Martin Space
LunIR Mission Systems Engineer: Selena Hall / Lockheed Martin Space
Foreign government or space agency participation: None.

2.2 Mission Description

Launch Vehicle: Space Launch System (SLS) / EM-1
Launch Site: KSC**Launch Date (Scheduled):** Mid 2020 [TBR]
Primary SLS Payload: Orion
Secondary Payloads (Deployed): LunIR and 12 other 6U CubeSats
LunIR Mission Duration: 30 to 100+ days
Operational Orbit: Lunar Flyby; **Reason:** Lunar imaging

LunIR Project Schedule

Selection by NASA:	March 2015
Contract ATP:	July 2016
Preliminary Design Review:	June 2017
Critical Design Review:	November 2017
Secondary Payloads Verification	8/23–9/13/2019 [TBR]
Pre-Ship Review	11/27-12/4/2019 [TBR]
Arrival at KSC for SLS/MSA Integration:	12/19/2019 [TBR]
SLS EM-1 Launch	TBD[6/26/2020]

LunIR will be one of thirteen 6U CubeSat secondary payloads installed on the SLS/EM-1 MPCV Stage Adapter (MSA). Following launch and the upper stage Trans Lunar Injection (TLI) maneuver, Orion (the primary SLS payload) will separate from the Interim Cryogenic Propulsion Stage (ICPS). After a 30 minute coast, the ICPS will perform safing and blowdown to fully empty the propellant tanks. Upon completion, ICPS will re-orient to its disposal burn attitude and conduct a disposal burn using its Attitude Control System (ACS) engines to target a heliocentric orbit via Lunar flyby. The ICPS will then send a signal to the Secondary Payload Deployment System (SPDS) which will then sequentially deploy all the secondary payloads, including LunIR, based on a pre-loaded deployment sequence. With the current SLS/ICPS trajectory, this deployment sequence lasts from approximately T0 + 4 hrs to T0 + 6 1/2 days, covering a distance from Earth between 36,500 km and 355,807 km. The timing and sequence for deployment of the secondary payloads is determined by the MSFC Secondary Payload Integration Office with input from the secondary payload developers. This process is represented graphically in Figure 2.2-1. One of the LunIR deployment objectives is to minimize the possibility of collisions or physical interference with other secondary payloads and with ICPS, thus reducing the chance of generating orbital debris.

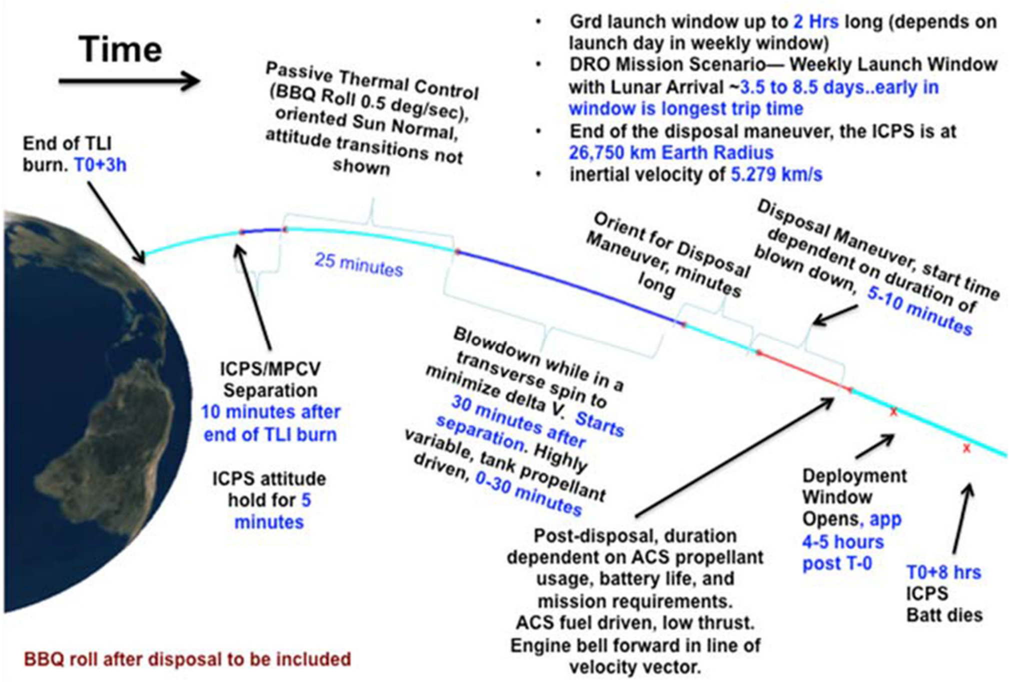

Figure 2.2-1: Deployment Overview for EM-1 Microsatellites

LunIR is scheduled to be deployed after clearing the Van Allen Belts at approximately T-0 plus 7 hrs. Upon deployment, LunIR will begin a power up sequence and a 15 second delay timer will be activated. After completion of the required 15 second delay, LunIR will initiate antenna and solar panel deployments. Then LunIR will null deployment rates and desaturate the reaction wheels as necessary using the attitude control only propulsion system. After stabilization, attitude knowledge, and control are achieved, LunIR will point its solar arrays at the sun to achieve a power positive condition and establish communications links. Initialization and checkout of the LunIR payload sensor components will follow. Then, using a proprietary mid-wave infrared (MWIR) sensor payload, LunIR will image the lunar surface while flying by the moon. Following the lunar flyby and MWIR data collection, LunIR will downlink imaging to Earth ground stations. Once downlinking has been achieved, and the mission is complete, LunIR will execute mission shutdown and eventual disposal onto a heliocentric disposal trajectory, as shown in Figure 2.2-6.

Being a non-propulsive spacecraft, the LunIR trajectory is determined largely by the trajectory of the SLS/ICPS at the moment of deployment.

Figure 2.2-2 shows LunIR distance from the Earth and Moon during the first 30 days of the mission. As is seen here, the Lunar flyby occurs approximately 5.5 days following deployment. Following the Lunar flyby, LunIR does dip briefly within the Lunar orbit before the distance to both Earth and Moon begin to increase steadily. At the end of the minimum duration of the LunIR mission, LunIR has reached a distance of approximately 1.7 million km from Earth.

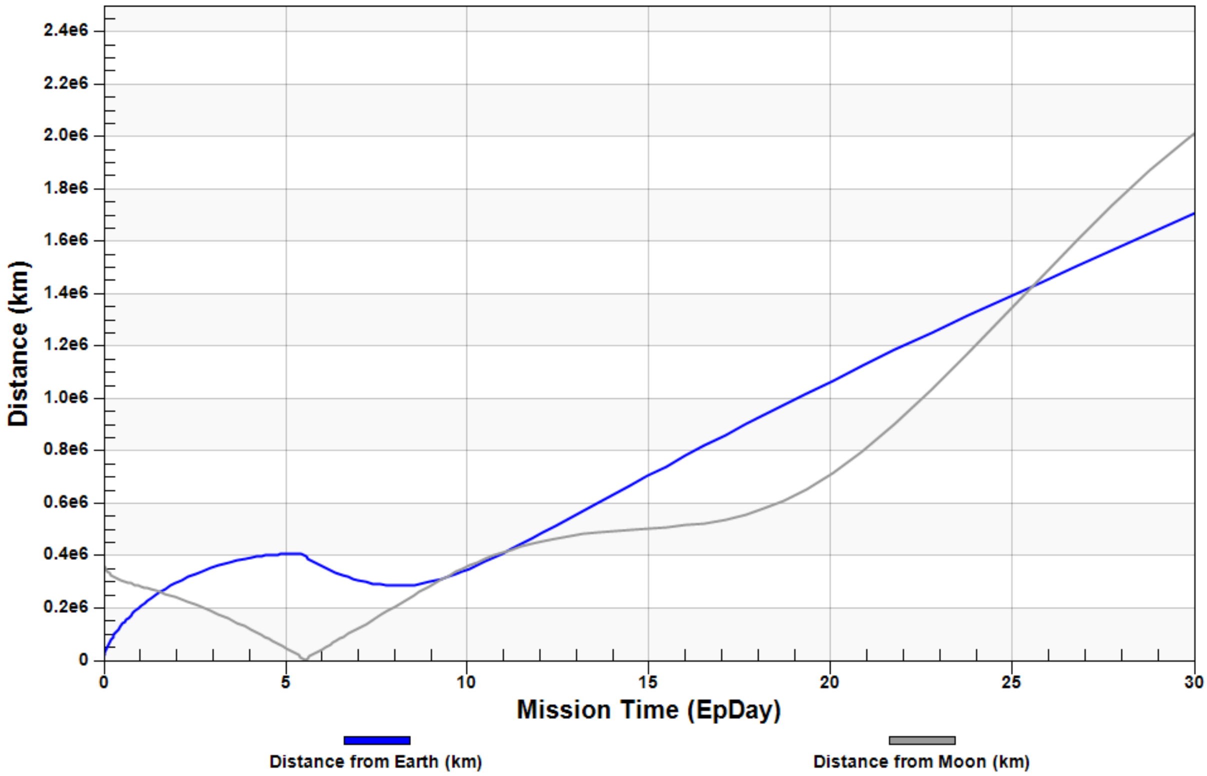

Figure 2.2-2: LunIR Distance to Earth and Moon in the first 30 days

At the end of the first six months, LunIR has reached a distance from Earth and Moon of approximately 0.25 AU, as shown in Figure 2.2-3. After one year, LunIR has reached a distance of approximately 0.55 AU (shown in Figure 2.2-4), and after 18 months, LunIR has reached a distance of slightly more than 0.7 AU (shown in Figure 2.2-5).

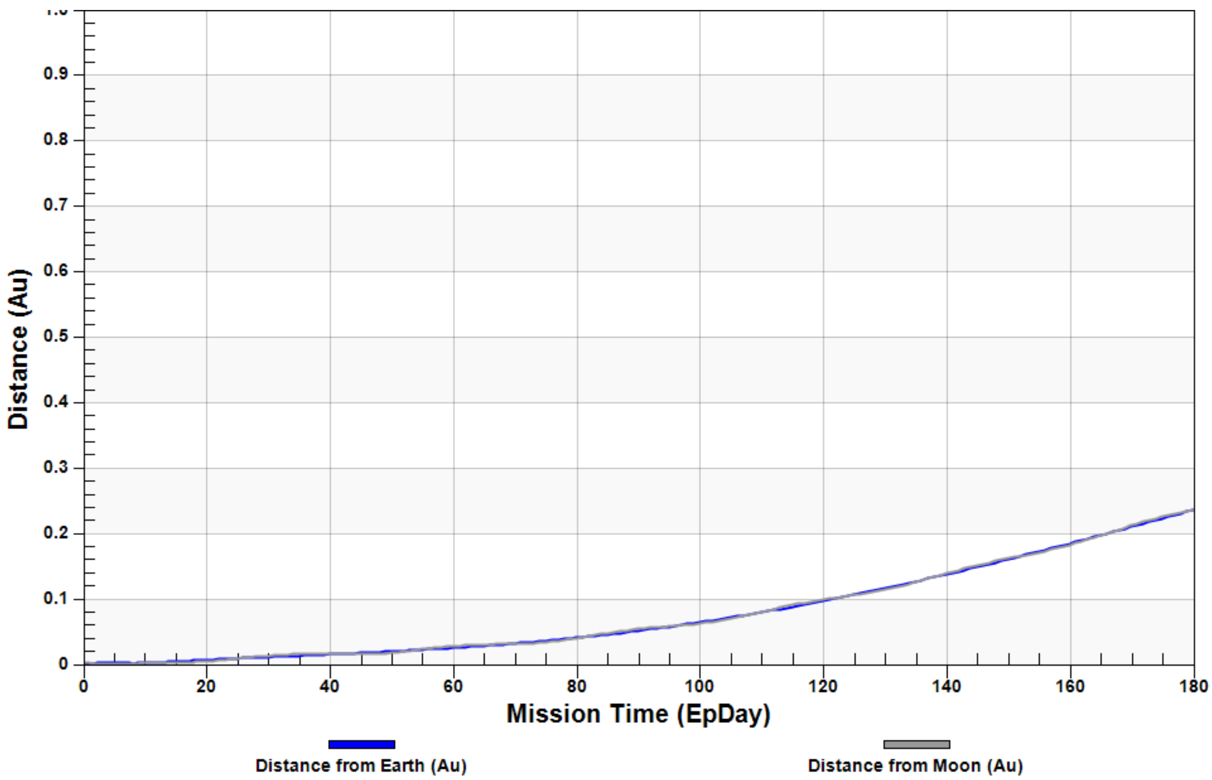

Figure 2.2-3: LunIR Distance to Earth and Moon in first 180 days

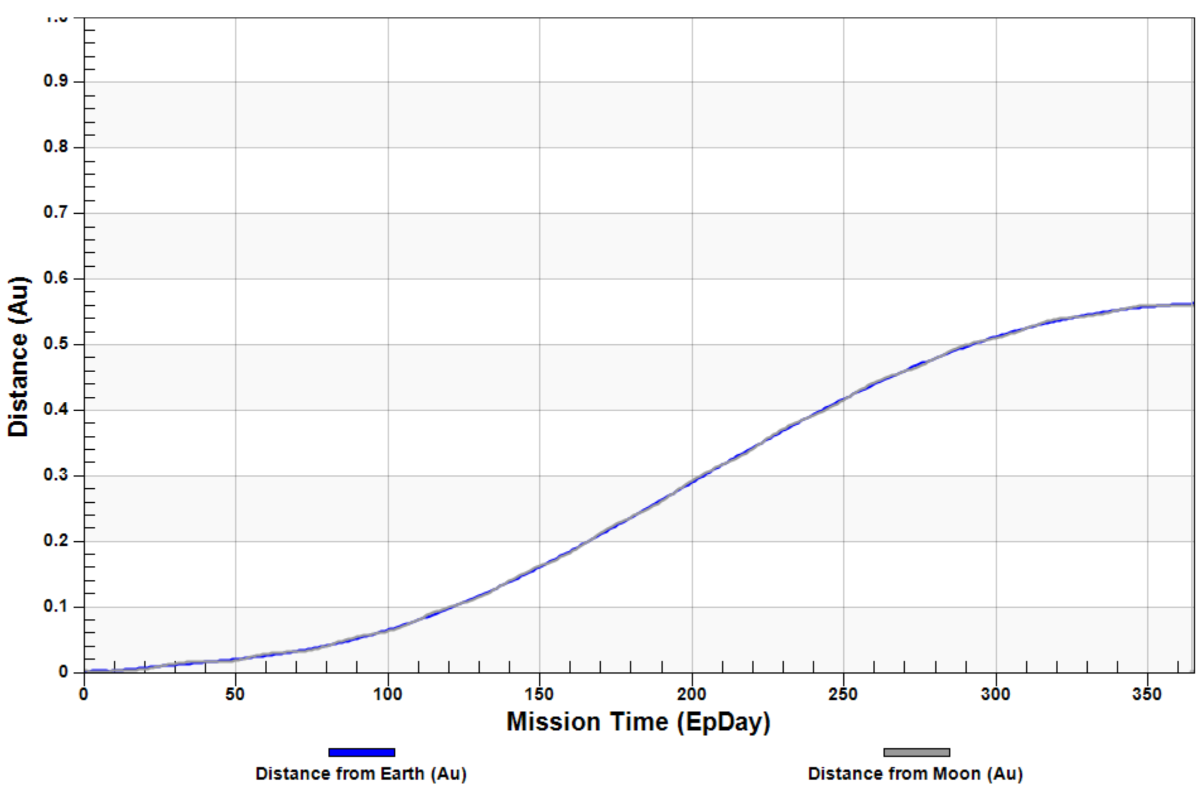

Figure 2.2-4: LunIR Distance to Earth and Moon in first year

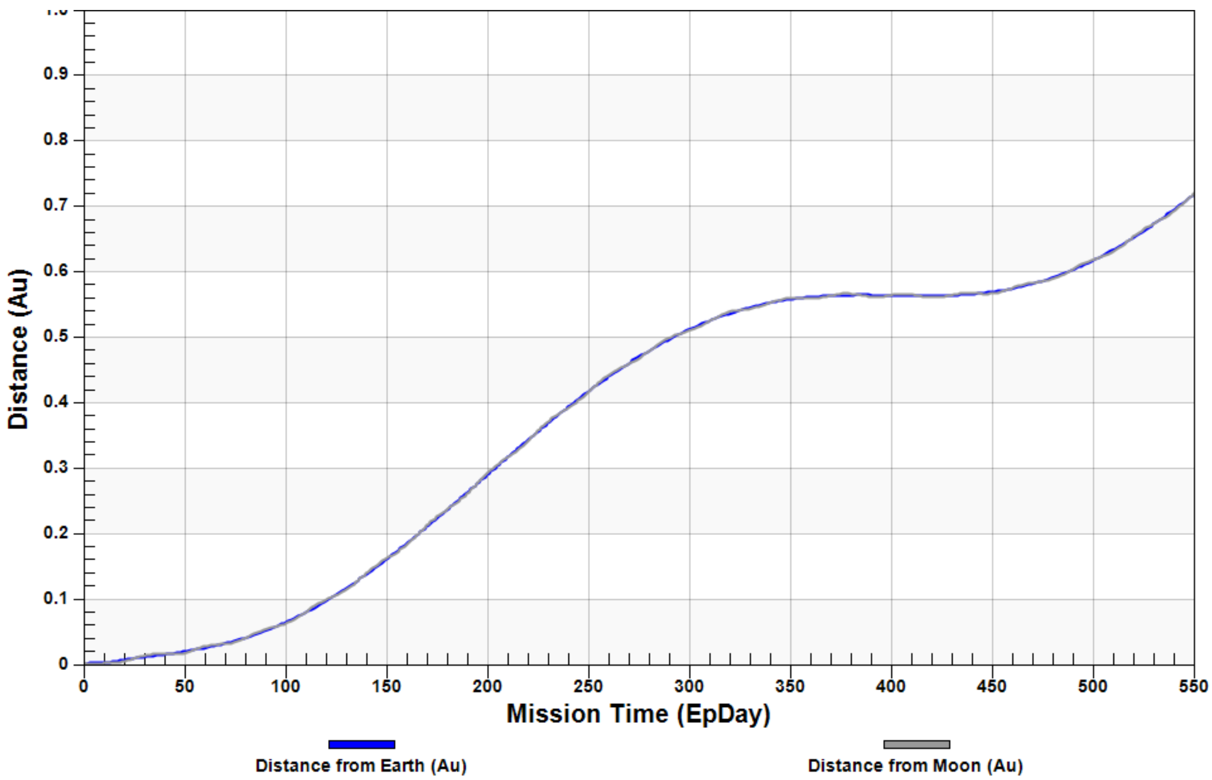

Figure 2.2-5: LunIR Distance to Earth and Moon in first 550 days (~18 months)

The LunIR heliocentric disposal orbit is shown in Figure 2.2-6, and Figure 2.2-7 is a plot of LunIR distance from Earth and Mars over a 30 year period following deployment.

The LunIR mission life baseline is approximately 30 days but could extend beyond 100 days if propellant and budget for extended operations are available. A breakdown of the LunIR Trajectory by mission phase is included in
Table 2.2-1, and each mission phase is described in the sections that follow.

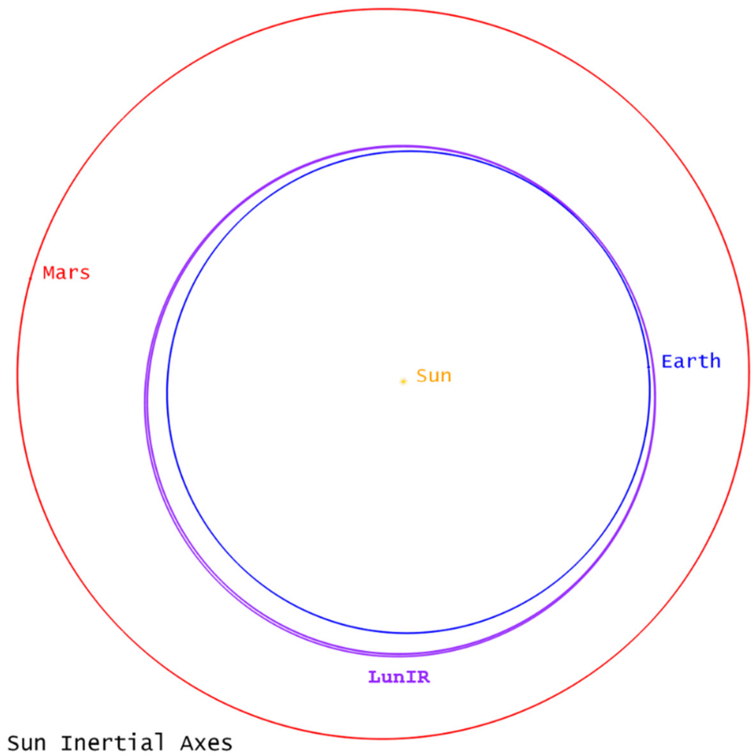

Figure 2.2-6: LunIR Heliocentric orbit in Sun Inertial Axes

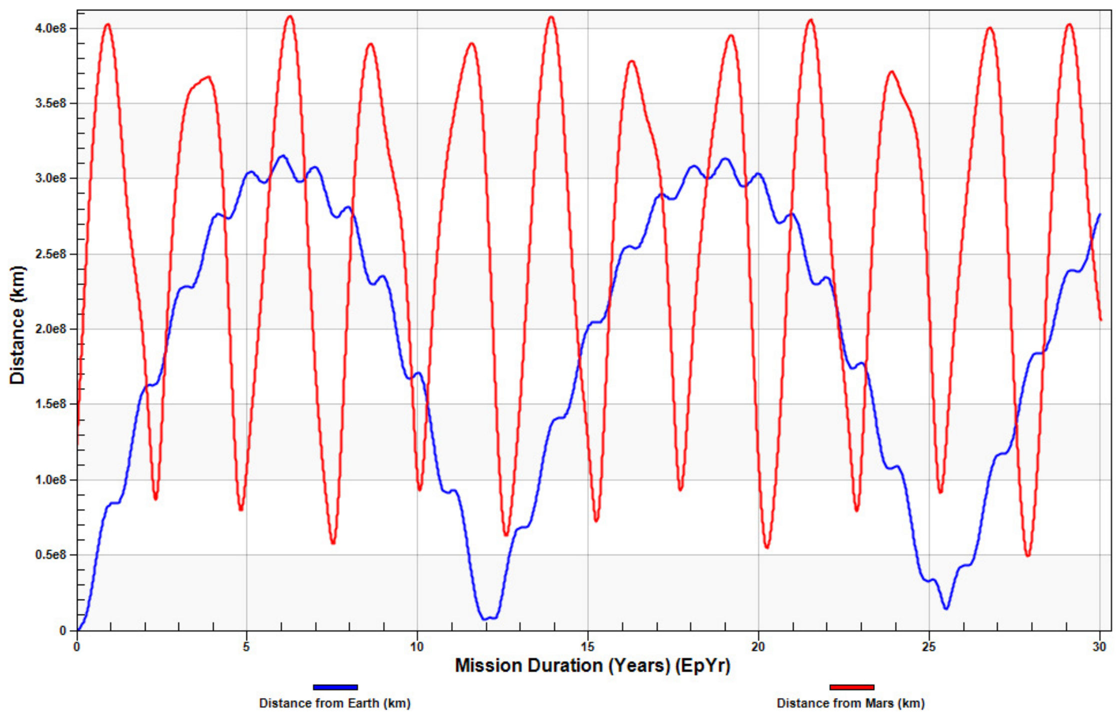

Figure 2.2-7:LunIR Distance to Earth and Moon over 30 Year Period

Mission Phase	Primary Body	Start Time (After Launch)	Duration
Launch to Checkout	Earth	4:43:00 h:m:s	~5 hours
Checkout to Lunar Flyby	Earth, Cis-Lunar coast, Lunar flyby	~ 5 hours	~5.5 days (Launch Window dependent)
Lunar Flyby	Moon	~5.5 days	~hours
Heliocentric Coast	Sun	8 days	30 days (minimum); 100 days (maximum)
End of mission	Sun	30 days	

Table 2.2-1: Description of Mission Phases

2.3 Launch to Checkout

The LunIR trajectory during this phase is based on the trajectory of the EM-1 mission. A trans-lunar injection (TLI) burn will be performed somewhere between 0 and 3 hours post-launch. The upper stage will then perform a divert maneuver, blow-down residual propellants, orient itself for disposal and perform a disposal maneuver. This maneuver results in a Lunar flyby with a perilune altitude between 100 – 1000 km. This flyby places the upper stage into a heliocentric graveyard orbit. As mentioned previously, LunIR is non-propulsive and therefore does not have the capability to perform any translational ΔV maneuvers. As such, the only velocity imparted to LunIR will be from the Secondary Payload dispenser supplied by Tyvak. This imparted velocity is negligible compared to the velocity of the ICPS at the time of deployment and is not reflected in the plots shown in the previous section.

2.4 Checkout to Lunar Flyby

LunIR will boot, power up relevant subsystems, acquire the sun, and deploy its solar arrays and antennas. During the first day after deployment Spacecraft Commissioning will be performed. The second day after deployment, Instrument Commissioning and calibration will be performed. LunIR will then alternate between sun pointing and imaging during the Cis-Lunar Coast phase in preparation for Lunar fly by.

2.5 Lunar Flyby

The mission objective for LunIR is to observe infrared Lunar radiance in space using mid-wave Infrared (MWIR). This will be accomplished during the Lunar flyby. The LunIR Instrument will first initiate a cool-down of the nBn Focal Plane Array in preparation for imaging. Then it will alternate between Instrument calibration and collecting images of the Moon. Following the collection of images, LunIR will enter sun-pointing mode. During the post-flyby phase the spacecraft will alternate between downlinking data and sun pointing, accomplishing the LunIR mission goals.

2.6 Heliocentric Coast

During the heliocentric coast following Lunar Flyby, additional time exists for downlinking of any additional images. This mission phase starts following the Lunar flyby and ends 30 days post-deployment.

2.7 Decommissioning/End of Life

The LunIR mission is complete when all of the images have been downlinked. After downlinking is complete, LunIR will be decommissioned by passivating LunIR subsystems. Any remaining propellant will be vented, the reaction wheels will be passivated, and the batteries will be fully discharged and disconnected from the solar arrays. LunIR will remain in a heliocentric disposal orbit with all subsystems disabled.

2.8 Other Programmatic Issues

There is currently no foreign government or space agency participation in the LunIR mission.

EM-1 will launch through the LEO environment. LunIR deployment is planned at an altitude around 25,000 km, in the Medium Earth Orbit (MEO) field. Therefore, LunIR will pass through the MEO and Geostationary Earth Orbit GEO fields. Only one transit of these fields is planned. Primary COLA analysis will be performed by the SLS program office with secondary analysis performed at the payload integration office at MSFC.

At the point of Lunar Flyby, LunIR may encounter other vehicles. Of primary concern is avoidance of recontact with Orion, ICPS, or any of the other secondary payloads. Orion recontact analysis has been completed for a launch date of October 9, 2018. Since this launch date continues to be revised, an updated analysis will be completed using the revised launch date when officially released. More information on the recontact analysis results is provided in Section 6.1. LunIR recontact with ICPS and other Secondary Payloads has not been assessed at this time.

Updated missions will be used in COLA analyses closer to the LunIR PSR and FRR and will be used to adjust the EM-1 trajectory and the final timing of the LunIR deployment.

3 SPACECRAFT DESCRIPTION

3.1 Physical Description of the Spacecraft

The LunIR spacecraft is a 6U rectangular prism microsatellite. Spacecraft size is approximately 24 by 36 by 11cm. Total satellite mass, including all subsystems, is approximately 14kg. The solar arrays are mounted to the body for launch and are deployed after LunIR's deployment from the EM-1 ICPS MSA. The volume is comprised of a 2U MWIR Instrument. The rest of the Spacecraft is comprised of the bus, including the Communications Subsystem, Electrical Power System (EPS), Command & Data Handling (C&DH), propulsion, Guidance, Navigation and Control (GN&C) and thermal control.

3.2 Propulsion System

The propulsion system is used to manage the reaction wheel momentum for wheel desaturation. The propulsion subsystem is a cold-gas system using non-hazardous R-236fa refrigerant.

The gas generator includes a tank with R236fa refrigerant and an integral plenum for vaporizing the propellant. The tank is loaded with 176 grams of R-236fa refrigerant; the R-236fa is contained within the tank in gas and liquid phase until after LunIR deployment. The gas generator is classified as a Non-Fracture Critical (NFC) Non-Hazardous Leak-Before-Burst (NHLBB) pressurized component, with a MDP of 54.5 psia prior to deployment and 97.5 psia for operations. The gas generator is proof pressure tested to 150 psi, and leak checked. The thrusters, lines, and fittings also have a MDP of 54.5 psia prior to deployment and 97.5 psia for operations and are classified as Non-Fracture Critical pressurized components. The propulsion system design is included in the LunIR Fracture Control Plan, which has been reviewed and approved by the MSFC/SLS Fracture Control Board.

3.3 Attitude Determine & Control System

LM LunIR uses a guidance, navigation, and control (GNC) system based on a set of two orthogonal star trackers, a moon camera, 1 coarse sensor, and a three-axis MEMS gyro. These sensors are paired with a set of three reaction wheels as primary attitude control actuators.

GNC computations are performed on a control processor on the Tyvak main flight computer board. The GN&C components are as follows:

1 Gyro
2 Star Trackers
1 Coarse Sensor
1 Moon Camera
3 Reaction Wheels
6 Cold Gas Thrusters

3.4 Electrical Power System

LunIR has a pair of Tyvak-designed solar panels mounted to the +Z and –Z faces of the satellite that are deployed by a burnwire device.

The LunIR bus uses three 60 W-hr battery modules. The battery module utilizes lithium-ion 18650 cells and includes battery protection circuits, thermal control heaters, mission end-of-life solar power disconnects, and two fault isolated strings. All battery cells are INR18650MJ1 procured by NASA. NASA tests the cell lot for compliance to JSC 20793.

3.5 Fluids and Pressure Vessels / Pressurized Components

The LunIR Instrument contains a single fluid. Helium is used as the coolant in the cryocooler for the MWIR sensor. The cyrocooler pressure shell has a Leak-Before-Burst failure mode. The total stored energy in the volume (<300 CC) is less than 1,500 Joules at MEOP. This volume corresponds to less than 16 standard liters of helium gas. The Cryocooler was granted an alternate Non-Fracture Critical classification by the MSFC Fracture Control Board due to its non-hazardous fluid, low fluid volume, small size, low stored energy, elevated proof test factor, multiple levels of containment within the cubesat structure, canisterized satellite dispenser, and MIL-STD-1522A leak-before-burst assessment. The LunIR flight cryocooler was also TVAC tested prior to cubesat integration.
In the unlikely event that helium were to leak from the cryocooler, it would not create a hazard.

The gas generator has a Leak-Before-Burst (LBB) design. It is loaded with 176 grams of the non-hazardous (NH) refrigerant R236fa, and is classified as a Non-Fracture Critical Nonhazardous Leak Before Burst (NHLBB) pressurized component. The gas generator is proof pressure tested to 150 psi, and leak checked. The propulsion system can operate safely at its maximum expected operating pressure for the LunIR mission of 97.5 psia. At the end of the mission, the propulsion system is vented by firing the thrusters until the propulsion system propellant is depleted.
In the unlikely event of leakage of the R236fa refrigerant/propellant, the small quantity of

176 grams would not pose a hazard. And depleting the propellant, passivates the propulsion system.

3.6 Hazardous Materials Assessment

LunIR doesn't have any radioactive or hazardous materials in it's construction. The LunIR MIUL has been approved through the SLS/SPIE Safety Review Process. And since LunIR does not re-enter the Earth's atmosphere no mitigations are required and no hazardous materials are produced.

3.7 Post-Deployment Conops

LunIR is powered off until a deployment signal is received from the cubesat dispenser. After deployment LunIR powers on, and beacons to establish a connection with the ground. After a stable connection with the vehicle has been established, the bus components are exercised to characterize their performance. Then the instrument is powered on, followed by checkout of the instrument electronics, and tests of the optics and associated image downlinks.

The flyby imaging sequence will occur after payload calibration imaging sequences. Post-flyby, the bus will recharge the batteries and downlink the science data collected by the payload. When all images have been downlinked, LunIR systems are passivated as described in Section 2.7. See Sections 2.2 – 2.6 for additional details following LunIR deployment.

4 DEBRIS RELEASED DURING NORMAL OPERATIONS

No debris is planned to be released into Earth orbit during launch, or payload deployment. LunIR is not planned to orbit in LEO or GEO orbits and does not plan to leave any debris in either orbit, so LunIR is inherently compliant with Requirements 4.3-1 and 4.3-2. LunIR does not plan to leave behind any debris during orbital operations, or during and after disposal in Heliocentric orbit.

LunIR also complies with NPR 8715.6B, Section 3.3.1, since no objects are planned to be left in lunar orbit.

5 INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

There are no plans for designed spacecraft breakups, explosions, or intentional collisions. The sources of stored energy on-board are the reaction wheels, the batteries, the Cryocooler, and the propulsion system. The cryocooler contains a small amount of helium with total stored energy of less than 1,500 joules. It has a leak-before-burst failure mode, and is proof pressure tested to 1.5x the maximum expected pressure. The propulsion system is a cold gas system that uses a small amount of R236fa refrigerant/propellant, as described in Section 3.2. Any R236fa refrigerant that wasn't used during the mission will be depleted to passivate the propulsion system at the end of the mission. The leak-before-burst design of the cryocooler and the propulsion system passivation make these systems low risk for explosion. The reaction wheel rotors have a very low mass and spin at around 6000 rpm. The rotational energy is therefore fairly low and unlikely to cause fracturing of the casing and structure in the event of failure. The most likely potential cause for explosion would be a battery overcharge-related explosion. This type of malfunction is very unlikely since the pack is protected against both temperature and pressure buildup. Overcharge of the battery is prevented by flight software, by the limits built into the charge circuit, as well as by pack level protection devices preventing over and under voltage protection, overcurrent discharge protection and low state-of-charge current limit. The batteries also have solar power short protection and isolation, and a mission end-of-life solar power disconnect.

5.1 Accidental Explosions

The current passivation plan is to inhibit solar array charging to the batteries, vent all unused propellant, and spin down the reaction wheels. Disconnecting the batteries will cause them to drain and prevent reactivation.

LunIR complies with requirement 4.4-1 for safety of other spacecraft since the mission is not in an area with orbiting satellites, and neither Earth nor Lunar orbits are planned. In addition, LunIR will be compliant with the SLS safety review requirements and processes, ensuring safety for the SLS/Orion MPCV and other EM-1 CubeSats.

LunIR complies with requirement 4.4-2 for design for passivation after completion of mission operations while in orbit about the Earth or the Moon, since the end of the mission is not in LEO or GEO orbits. Disposal of LunIR in a heliocentric orbit is planned.

Additionally, passivation of energy sources, venting of propellant, and leak-before-burst designs will reduce the risk of generating orbital debris from unintentional explosions.

5.2 Intentional Breakups

Requirements 4.4-3 and 4.4-4 are not applicable to LunIR since there are no planned breakups.

6 POTENTIAL FOR ON-ORBIT COLLISIONS

6.1 Assessment of collision with large objects during spacecraft operations

The satellite has a mean cross sectional area of ~0.1 m2, which is very small. In addition, the mission is going through heliocentric space, where there is practically no man-made debris present; so the risk of collision with a large object is extremely small.

The launch vehicle will pass through GEO very briefly, resulting in practically no exposure to orbital debris still in orbit. Prior to launch a Collision Avoidance (COLA) analysis of the launch trajectory will be performed by the SLS EM-1 mission to ensure that it does not intersect with existing satellites or debris objects tracked by the US Space Surveillance Network.

6.1.1 Assessment of Collision with Orion

The following information has been provided by the Space Launch System (SLS) Spacecraft/Payload Integration and Evolution Office (SPIE) to address the probability of recontact with Orion. This information will be re-assessed when a SLS/Orion launch date is selected.

> The Space Launch System (SLS) Spacecraft/Payload Integration and Evolution Office (SPIE)
> Exploration Mission 1 (EM-1) Orion/ICPS and Orion/Secondary Payload Re-contact Analysis results were documented in SLS-SPIE-RPT-066, Version 1, with release date June 14, 2018. This analysis, performed by JSC/FOD, used the Preliminary Mission Analysis (PMA) cycle trajectory data provided to examine the probability of intersection with the Orion Keep Out Sphere (KOS) in both mid-field and far-field resulting in a Probability of Collision (Pc) value. A launch date of October 9, 2018 was assumed. Since this launch date is no longer accurate, the analysis will be re-examined using a future launch date.
>
> The findings, in general, showed no Orion re-contact concerns for the nominal ICPS and secondary payload trajectories investigated for both mid-field and far-field. Although the mid-field Pc's were non-zero due to proximity at Orion/ICPS separation and secondary payload deployment times, the opening rates were sufficient to overcome dispersions resulting in no concerns for re-contact mid-field. Specifically, the payloads are not deployed until Orion is already 13.5 to 29.7 nm (25 to 55 km) from ICPS. The range and range rate plots indicated that there is a sufficient opening rate during this period to preclude re-contact. Given that the ICPS attitude at secondary payload deployment associated with the PMA trajectories directs the payloads generally in the velocity vector direction, towards

Orion, it can be stated that re-contact of payloads with Orion in the mid-field region of flight is unlikely to occur on any launch date.

In the far-field for the nominal trajectories, the ICPS and secondary payloads pass closest to Orion in the vicinity of the Moon. For the far-field Pc's, all were zero, even throughout the lunar flyby, except for LunIR. The Pc is 1.46E-06 which is only slightly above the one in a million threshold for which the PMA analysis was originally instituted to quantify. The conclusion for the PMA nominal trajectories in the far-field is that, there are no concerns for re-contact with Orion.

Since this study was completed, it has been decided that Orion will perform an Orbital Maneuvering System (OMS) Checkout (OCO) burn. This will, thus, put Orion in a different orbital plane from the secondary payloads and ICPS. This will further decrease any probability of collisions.

6.1.2 Assessment of Collision with ICPS and Other Cubesats

A near-field collision assessment has been performed by the Space Launch System (SLS) Spacecraft/Payload Integration and Evolution Office (SPIE) to address the probability of LunIR recontact with ICPS and other EM-1 cubesats. This near-field assessment showed there is not a concern for LunIR recontact with ICPS and other cubesats after LunIR's deployment from the ICPS. There is no mid-field or far-field analysis planned to address recontact between LunIR and ICPS or other cubesats.

6.2 Failures which could prevent disposal

Failure of the LunIR system to deploy from the upper stage of the SLS system will still result in entry to a heliocentric graveyard orbit. No credible failures of the LunIR system will prevent proper disposal.

6.3 Systems required to Accomplish Disposal

Since the LunIR heliocentric science orbit is the same as its disposal, no disposal-specific systems are required for LunIR.

6.4 Assessment of Collisions with Small Debris During Mission

As discussed in Section 2.8, the main concern for collisions is between LunIR and Orion, ICPS and the other secondary payloads co-manifested on EM-1. Preliminary trajectory analysis has been done to assess the Orion recontact risk and to take steps to ensure that the risk of recontact is minimized.

7 POST-MISSION DISPOSAL PLANS AND PROCEDURES

LunIR is deployed after the launch vehicle/ ICPS passes through LEO and GEO, so Requirements 4.6-1 through 4.6-5 do not apply to LunIR. LunIR performs a Lunar flyby to perform lunar imaging after deployment and continues on the same trajectory to a heliocentric disposal orbit. There will not be procedures or plans after the disposal of the LunIR mission.

8 ASSESSMENT OF REENTRY HAZARDS

There will not be procedures or plans after the disposal of the LunIR mission. Since the mission is not re-entering the Earth's atmosphere, the risk to human life is zero. Requirements in 4.7 do not apply.

9 ASSESSMENT OF HAZARDOUS MATERIALS Delete

10 ASSESSMENT FOR TETHER MISSIONS

This does not apply to LunIR. The mission does not employ any tethers in the design.

11 LAUNCH VEHICLE (SECTIONS 9-14)

Since LunIR is a secondary payload on the SLS launch vehicle, the NASA SLS will perform the primary orbital debris assessment for the EM-1 launch vehicle.