SLS EM-1 Secondary Payload Phase X Safety Review for **Payload Name**

Date Here (month & year)
Safety Review Agenda- Phase X

• 10:00 A.M.-10:10 A.M., Introduction
  ▪ Introduction and Opening Remarks by Panel Chairperson

• 10:10 A.M.- 11:00 P.M., Payload Name Overview
  ▪ Mission Overview
  ▪ Spacecraft Design Overview (includes Battery Concepts)

• 11:00 P.M.- 12:00 P.M., Payload Name Safety
  ▪ Payload Safety Engineer Preliminary Safety Assessment
  ▪ Compliance with SLS Safety Requirements
  ▪ Anticipated Hazards

• 12:00 P.M.- 12:30 P.M., Closing
  ▪ Actions/Discussion
  ▪ Closing

Note: Times can be adjusted based on payload time zone. This example reflects a PDT payload.

*All times noted in Central Time.
Payload Name
Presenter(s): Presenter Name(s)

Note: The following is a set of suggestions (outlines) to aid in describing the payload. More charts can be added to express the payload design and any potential hazards.
Payload Name

Objectives

- Recent robotic mission data (Mini-RF, LRO) strongly suggest the presence of ice deposits in permanently shadowed locations.
- Water measures the various reflectivity in LOLA and temperatures also.

SKG Addressed: Understand the quantity and distribution of water and other volatiles in lunar cold traps.

Look for surface ice deposits and identify favorable locations for in-situ utilization.

Example Rear. Assessment - Design Dependent

Sunlight is specularly reflected off the sail. Light diffusely reflected off the lunar surface in a 3 deg beam. Light diffusely reflected off the lunar surface enters the spectrometer to distinguish water/ices from regolith.
Payload Name
Concept of Operations

Separation from SLS

- De-tumble, panel deployment
- ~8 m/s Δv to target first lunar fly-by

Sail deployment

- ~8m/s Δv to target first lunar fly-by
- Target second lunar fly-by

De-tumble, panel deployment

- De-tumble, panel deployment
- ~8 m/s Δv to target first lunar fly-by

Sail deployment

- ~8m/s Δv to target first lunar fly-by
- Target second lunar fly-by

• ~1.35 million km max Earth distance

Cruise

- ~1 year spiraling phase around the moon

Sail Characterization

- Instrument Calibration (Jupiter)

Lunar Capture

- 78 passes total

Spiraling down

- ~1 year spiraling phase around the moon

Science
# Payload Name Flight System Overview

## Payload
- NEA Scout: Malin Space Science Systems ECAM-M50 imager w/ NFOV optics w/ Static color filters (400-900 nm)
- Lunar Flashlight: Custom spectrometer

## Mechanical & Structure
- “6U” CubeSat form factor (~10x20x30 cm)
- <12 kg total launch mass
- Modular flight system concept

## Propulsion
- ~85 m² aluminized Kapton solar sail (based on NanoSail-D2)

## Avionics
- Radiation tolerant LEON3-FT architecture

## Electrical Power System
- Simple deployable solar arrays with UTJ GaAs cells (~35 W at 1 AU solar distance)
- 6.8 Ah Battery (3s2p 18650 Lithium Cells)
- 10.5-12.3 V unregulated, 5 V/3.5 V regulated

## Telecom
- JPL Iris 2.0 X-Band Transponder; 2 W (NEA Scout) and 1 W (Lunar Flashlight) RF supports doppler, ranging, and D-DOR
- 2 pairs of INSPIRE-heritage LGAs (RX/TX)
- Lunar Flashlight: ~500 bps to 34m DSN at all times
- NEA Scout: 8x8 element microstrip array HGA (TX); ~500 bps to 34m DSN at 0.8 AU

## Attitude Control System
- 15 mNm-s (x3) & 100 mNm-s RWAs
- Zero-momentum slow spin during cruise
- VACCO R-236fa (refrigerant gas) RCS system
- Nano StarTracker, Coarse Sun Sensors & MEMS IMU for attitude determination

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**Example Reqr. Assessment – Design Dependent**
## Schedule

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### Example Rqr. Assessment – Design Dependent
Launch Related Activities

**Ops Prior to Handover at KSC**

♦ Cubesats will be turned over to the Launch Services Program dispenser integration contractor with batteries at approximately 50% state of charge and propellant loaded.

♦ Upon completion of cubesat-to-dispenser integration and required acceptance testing, dispenser will be transported to KSC for integration to the vehicle.

♦ Upon arrival at KSC, cubesats will do a final abbreviated functional test within the deployer (post-ship aliveness check).

**Ops After Handover at KSC**

♦ Integrated system transferred to SLS/GSDO through a DD149 for integration to the SLS MPCV Stage Adapter.

♦ Cubesats will be powered off during all remaining launch activities, with the exception of battery charging.

♦ Charge batteries to >95% SOC after integrated.
Spacecraft (SC) Operational Sequence

♦ SC is unpowered through ascent
♦ Once signal is sent to dispenser from sequencer, cubesat will separate.
♦ SC initiates autonomous power up sequence once the SC senses separation (through 2 mechanical separation switches):
  • Power on
  • Boot up of flight software (roughly 2 minutes)
  • Close switch to allow RF transmissions
  • Reaction wheels and thrusters used to de-tumble spacecraft due to separation
  • Solar arrays deployed
  • Enter transmitter beacon mode
♦ <10 m/s Trajectory Correction Maneuver before L+24 hours
♦ Solar sail deployed at L+4 days (after first lunar flyby, depending on lunar transit time)
Two mechanical switches provide two independent inhibits to RF transmissions, solar array/sail deployment, thruster firing, etc.

Currently planning to put separations switches on the sides of the spacecraft.
Propellant Safety

♦ Propellant is R-236fa
  • 1,1,1,3,3,3-Hexafluoropropane
  • Link to Safety Data Sheet
  • Link to Safe Handling Instructions
  • SDS# 001163

♦ Toxicity
  • No known significant acute effects or chronic hazards
  • LC50 inhalation dose of 914,000 ppm for 1 hour
  • AIHA WEEL exposure limit of 1000 ppm for 8 hours

♦ Hazards
  • Can cause frostbite under rapid depressurization
  • ~270 g on BioSentinel limits quantity required for coolant
  • May displace oxygen
  • May cause cardiac sensitization at 20000 – 150000 ppm

♦ Propellant passed an ISS Safety Panel
• **Battery and hardware description**
  - **Battery System description**
    - Three series two parallel battery packs (6 cells total)
    - Full state of charge voltage of 12.3V
    - Max capacity of 6.8Ah
    - Battery pack has thermostatically controlled survival heater set at -10°C
    - Battery voltage is measured across the full stack of both battery packs
    - No individual cell voltage monitoring
    - Provides access to battery and temperatures monitoring in the dispenser at the VAB
  - **Battery packaging**
    - Clam shell package design with integrated survival heater
    - Can be mounted to standard 96mm x 90mm PWB but may be used without the PWB by fastening the clamshell to the inside wall of the cubesat
**Battery and hardware description**

- **Battery cell description**
  - Panasonic 18650 NCR B cells
  - Full charge voltage of 4.1V
  - Max capacity of 3.4Ah
  - Graphite/LiNiCoAlO2 (NCA) Chemistry
  - Temperature range from -10°C to +30°C

- **Safety features**
  - Positive temperature coefficient (PTC) device
  - Current interrupt device (CID)
  - Exhaust gas hole built into each cell
  - Panasonic employs heat resistance layer (HRT) technology
    - Insulating metal oxide layer on the surface of the electrodes
    - Battery will not overheat even under short circuit conditions

**Strongly considering use of Orbtronics cells (adds Seiko protection IC to Panasonic cells) which adds the following safety features:**

- Over-voltage/over-charge
- Over-discharge/under-voltage
- Over-current protection
- Over-heating protection
- Dual Short Circuit
Battery System Diagram

Safety Features

System level features are not available during payload charging operations
• EPS card is powered off
• Only GSE protection and cell level protection is active

Cell Level (current):
• Over-current protection
• Over-temperature protection
• Cell short circuit protection

Cell level (if Orbtronics is selected):
• Over-voltage/over-charge
• Over-discharge/under-voltage
• Over-current protection
• Over-heating protection
• Dual Short Circuit protection
#1 The payload battery needing a charge, while mounted in the vehicle, shall contain a diode on the positive leg of the charging circuit to the battery.  
**Status:**  Comply

#2 The payload battery needing a charge, while mounted in the vehicle, shall contain a 10K thermistor within the battery pack with the leads made available to an external connector.  
**Status:**  Comply. Working on packaging to allow measurement with a single thermistor.

#3 The payload battery needing a charge, while mounted in the vehicle, shall use a separation connector pin-out as shown in Figure x.xx.x-x.  
**Status:**  Comply.

#4 The payload battery needing a charge, while mounted in the vehicle, shall have the charging circuit separate from the payload system’s circuit.  
**Status:**  Comply.

#5 The payload battery needing a charge, while mounted in the vehicle, shall use Li-ion 18650 rechargeable batteries with built in protection listed below:
- Overcharge
- Overdischarge
- Overcurrent
- Overheating, and dual short circuit protection  
**Status:**  Partially comply. Cells do not have over discharge and over charge protection without EPS card powered. If Orbtronics cells are utilized, then NEAS/LF will comply fully.
Grounding/Bonding

♦ Internal electrical system is grounded to the cubesat structure/chassis
♦ Cubesat is grounded to the dispenser through an electrical connector and mounting
♦ Dispenser is grounded to the SLS-provided bracket.
♦ Utilize class-S Bond per the SLS IDRD
♦ If vibration isolation is used between dispenser and SLS bracket, a grounding strap will be used to ground the dispenser to the bracket.
RF System Overview

♦ JPL IRIS 2.0 X-band Transponder and Low-Profile X-band patches as low gain antenna for receive and transmit.

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<thead>
<tr>
<th></th>
<th>Uplink Frequency</th>
<th>Downlink Frequency</th>
<th>Transmit Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEA Scout</td>
<td>7.1 GHz</td>
<td>8.4 GHz</td>
<td>2 W</td>
</tr>
<tr>
<td>Lunar Flashlight</td>
<td>7.1 GHz</td>
<td>8.4 GHz</td>
<td>1 W</td>
</tr>
</tbody>
</table>

Example Req. Assessment – Design Dependent
*Note: RF PA’s can be biased to 1W or 2W. Baseline uses 1W power amplifiers.
Name, Payload Safety Engineer
Performs on the preliminary design and hazards identified

- Standardized Hazard Control Report (short form) used as a checklist
  - Short form will be prepared for each payload
- Long Form will be used to document unique hazards.
  - Pressure System (Attitude Control System)
    - Rupture
    - Leakage
  - Batteries
    - Rupture
    - Leakage
    - Fire (ground)
• 1. Payload Deployment
  • Meet deployment system requirements

• 2. Structural Failure
  • Primary Structure – FoS of 1.4
  • Mounted in approved dispenser

• 3. Rotating Equipment
  • Powered off
  • Contained

• 4. Structural Failure – Sealed Containers
  • No Sealed Containers?

• 5. Structural Failure – Vented Containers
  • Vent analysis/sizing

• 7. Materials - Biological
  • Not applicable

• 8. Materials - Flammability
  • MAPTIS material evaluation
  • Cert MUA issued by M&P

• 9. Materials - Offgassing/Outgassing
  • MAPTIS material evaluation
  • Cert MUA issued by M&P

• 10. Deployment Actuators
  • NEAs (no pyrotechnics)
  • Inadvertent operation assessment

• 11. Ionizing Radiation
  • Not applicable

• 12. Electromagnetic Radiation – (Non-ionizing)
  • General
    • Powered off
    • EMI analysis/test
    • Class S bond

• 13. Lasers
  • Not applicable

• 14. Electrical Power – Causing damage to electrical equipment
  • Powered off
  • Circuit protection/wire sizing
  • Bonding and grounding

• 15. Ignition of Flammable Atmospheres
  • Powered off
  • Class S bond
Payload Name Safety Assessment
Unique Hazards

- **Pressure System/Attitude Control System**
  - *Warm* Gas system (no combustion, no hypergolics)
  - MDP analysis/controls (rupture)
  - Leakage

- **Batteries**
  - System level safety features
  - Cell level safety features
  - Charging during ground processing
Payload Name Safety
## Approach to Meeting IDRD Safety Requirements

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<th>Req ID: [SDDS.P L.####]</th>
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<tbody>
<tr>
<td></td>
<td>TECHNICAL INTERFACE REQUIREMENTS</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>9 Powered Off</td>
<td>X</td>
<td></td>
<td>Battery charging only. Off at all other times.</td>
</tr>
<tr>
<td>6.3.2</td>
<td>10 Radio Frequency Output Less Than 1.5 W</td>
<td>X</td>
<td></td>
<td>LF will have &gt;2 inhibits to inadvertent transmissions during ground processing and ascent. Upon deployment, LF will have at least 1 inhibit (time required to boot up the flight software) through the 15 sec requirement.</td>
</tr>
<tr>
<td></td>
<td>11 Radio Frequency Output Greater Than 1.5 W</td>
<td>X</td>
<td></td>
<td>NEAS will have &gt;2 inhibits to inadvertent transmissions during ground processing and ascent. Upon deployment, NEAS will have at least 2 inhibits (time required to boot up the flight software and a switch to turn on the transmitter) through the 15 sec requirement.</td>
</tr>
<tr>
<td></td>
<td>20 Payload Activation</td>
<td>X</td>
<td></td>
<td>The only deployable that meets the 3x launch envelope criteria is the solar sail. The flight software boot up time will require minutes, which will serve as an inhibit. Also a command from the ground is required to deploy the sail. This is nominally planned 4 days after deployment. A retention mechanism (e.g., burn wire) will be in place to prevent inadvertent deployment.</td>
</tr>
<tr>
<td></td>
<td>21 Payload Transmission</td>
<td>X</td>
<td></td>
<td>Once deployed the flight software will require on the order of minutes to boot up. Once the boot up sequence must be closed to allow transmissions.</td>
</tr>
<tr>
<td>6.3.1</td>
<td>22 Payload Deployments</td>
<td>X</td>
<td>X</td>
<td>LF and NEAS plan to deploy as early as allowed by SLS (anticipate prior to L+24 hours).</td>
</tr>
<tr>
<td>6.3.1</td>
<td>23 Payload Co-Deployments</td>
<td>NA</td>
<td>NA</td>
<td>N/A</td>
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</table>
## Approach to Meeting IDRD Safety Requirements

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<td>TECHNICAL INTERFACE REQUIREMENTS</td>
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<tr>
<td>6.3.3</td>
<td>Gas or Fluid Release</td>
<td>X</td>
<td></td>
<td>Levy requirements on design. Perform compatibility analysis of leakage (in a failure scenario).</td>
</tr>
<tr>
<td>6.5</td>
<td>Failure Propagation</td>
<td>X</td>
<td></td>
<td>Solar sail and solar array deployment will be contained by the dispenser.</td>
</tr>
<tr>
<td>6.7.1</td>
<td>Structural Design and Test</td>
<td>X</td>
<td>X</td>
<td>Propulsion analysis from IRD requirement 26.</td>
</tr>
<tr>
<td>6.7.1</td>
<td>Structural Design Factors of Safety</td>
<td>X</td>
<td>X</td>
<td>Inadvertent solar sail and solar array deployment would be contained by the dispenser.</td>
</tr>
<tr>
<td>6.7.1</td>
<td>Fracture Control</td>
<td>X</td>
<td>X</td>
<td>Primary structure will comply with NASA-STD-5001.</td>
</tr>
<tr>
<td>6.7.1</td>
<td>Fasteners</td>
<td>X</td>
<td>X</td>
<td>Will comply with NASA-STD-5019 for primary structure.</td>
</tr>
<tr>
<td>6.7.1</td>
<td></td>
<td></td>
<td></td>
<td>Will comply with NASA-STD-5020 for critical fasteners in primary structure.</td>
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## Approach to Meeting IDRD Safety Requirements

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<td>[SPDS. PL.###]</td>
<td>TECHNICAL INTERFACE REQUIREMENTS</td>
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<tr>
<td>6.7.1.1, #1</td>
<td>Safety Critical Fasteners</td>
<td>X</td>
<td>X</td>
<td>NEAS and LF will utilize NEAS and verifiable locking features. Loosening could create a catastrophic hazard.</td>
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<td>6.7.1.1, #1</td>
<td>Locking Devices</td>
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<td>Comply for any necessary locking devices.</td>
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<td>6.7.1.1, #2</td>
<td>Rotational Joints</td>
<td>X</td>
<td>X</td>
<td>Only rotation joints are the solar array articulation and the solar sail. They are prevented from rotating in the launch configuration. They require deployment in order to rotate. The dispenser would also contain the rotation.</td>
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<td>6.7.1.1, #3</td>
<td>Fastener Installation</td>
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<td>Plan to comply.</td>
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<td>Preload Torque</td>
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<td>Thread Locking Compounds</td>
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<td>Stress Corrosion</td>
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<td>Plan to comply.</td>
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<td>Alloy Material Usage</td>
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<td>6.7.4</td>
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<td>Maximum Design Pressure</td>
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<td>Pressure Control Tolerance</td>
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<td>Pressure Relief Capabilities</td>
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<td>Pressure Vessel Materials</td>
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<td>Composite Overwrapped Pressure Vessels</td>
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<td>Pressure Stabilized Vessels</td>
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<td>Pressurized Lines, Fittings and Components</td>
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<td>Secondary Volume Pressure Factors of Safety</td>
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<td>Secondary Volume Vent or Relief Provision</td>
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<td>Burst Disc with Reversing Membrane</td>
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<td>Sealed Containers</td>
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<td>Vented Containers</td>
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<td>Hazardous Material Containment</td>
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<td>6.7.5.1</td>
<td>Hazardous Fluid Systems</td>
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<td>6.7.5.1</td>
<td>Toxic or Hazardous Chemical Containment</td>
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<td>Req ID: [SPDS.P L.###]</td>
<td>Section / Requirement Title</td>
<td>Payload</td>
<td>Deployer</td>
<td>Approach</td>
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<td>6.7.5.4</td>
<td>Biological Materials Classification</td>
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<td>6.7.8</td>
<td>Material Outgassing</td>
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<td>Will perform MAPTIS material evaluation and have a certification MUA issues by M&amp;P.</td>
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<td>6.8</td>
<td>Pyrotechnic Devices</td>
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<td>Radioactive Material Licensing</td>
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<td>6.9.2</td>
<td>Emissions and Susceptibility</td>
<td>X</td>
<td>X</td>
<td>Perform analysis to demonstrate design is not susceptible.</td>
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## Approach to Meeting IDRD Safety Requirements

<table>
<thead>
<tr>
<th>SLS-RQMT-21 6, Safety Req.</th>
<th>Req ID: [SPDS PL.###]</th>
<th>Section / Requirement Title</th>
<th>Payload</th>
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<th>Approach</th>
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<tr>
<td>TECHNICAL INTERFACE REQUIREMENTS</td>
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<td>6.9.3</td>
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<td>Lasers</td>
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<td>Electrical Circuit Protection</td>
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<td>Electrical Design</td>
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<td>Battery Compliance</td>
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<td>Designing to JSC safety requirements.</td>
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<td>Circuit Upset from Lightning</td>
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<td>6.13</td>
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<td>Payload Commanding</td>
<td>X</td>
<td></td>
<td>NEAS and LF will not perform commanding prior to deployment from SLS.</td>
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<td>6.14</td>
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<td>Flammable Atmospheres</td>
<td>X</td>
<td>X</td>
<td>Powered off during ascent with 2 inhibits to inadvertent power-on. Class S bond to launch vehicle/dispenser.</td>
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<td>6.14</td>
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<td>Conductive Surfaces</td>
<td>X</td>
<td>X</td>
<td>Utilize Class S bonds.</td>
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<td>82</td>
<td>Ground Hazards</td>
<td>X</td>
<td>X</td>
<td>Battery charging activities will comply.</td>
<td></td>
</tr>
</tbody>
</table>
Anticipated Hazards

♦ Inadvertent RF transmissions
  • Anticipated controls: Two inhibits through separation switches for pre-launch and during ascent. Two inhibits in place after deployment from the dispenser.

♦ Pressure vessel over pressurization/leak
  • Anticipated controls: Design for minimum risk. Leak before burst design.

♦ Over charge of lithium ion batteries
  • Anticipated controls: Built-in battery controls, GSE, human in the loop monitoring.

♦ Pre-mature deployment of solar arrays/solar sail
  • Anticipated controls: Two inhibits through separation switches. Dispenser will contain solar arrays and sail if deployed prior to cubesat deployment. Post-cubesat deployment, flight software boot up time serves as inhibit.
Payload can list any design options/trades being planned which might affect a hazard

(example: propulsion – presented a cold gas system but you’re considering an Ion thruster or chemical engine)
PAYLOADS can ask the PSRP specific safety questions which might cause design changes or change planned operations.
BACKUP

Add any informational charts you feel could be relevant to the review in answering potential questions.
Payload and SPDS Battery Charging Requirements
#1 The payload battery needing a charge, while mounted in the vehicle, shall contain a diode on the positive leg of the charging circuit to the battery.

Verification by: Inspection

#2 The payload battery needing a charge, while mounted in the vehicle, shall contain a 10K thermistor within the battery pack with the leads made available to an external connector.

Verification by: Inspection & Test

#3 The payload battery needing a charge, while mounted in the vehicle, shall use a separation connector pin-out as shown in the figure.

Verification by: Inspection

#4 The payload battery needing a charge, while mounted in the vehicle, shall have the charging circuit separate from the payload system’s circuit.

Verification by: Inspection

#5 The payload battery needing a charge, while mounted in the vehicle, shall use Li-ion 18650 rechargeable batteries with built in protection listed below:

- Overcharge
- Overdischarge
- Overcurrent
- Overheating, and dual short circuit protection

Verification by: Inspection
Secondary Payloads Battery Charging Concept Update
Charging Concept for CubeSat Batteries:

- Secondary Payloads can be charged similar to the avionics system’s battery.
- Up to 12 batteries would be part of the secondary payload charging scheme on the SLS EM-1 MSA ring. 11 secondary payload batteries and 1 avionics system battery.
- Ground power will need to be provided by drag–on GSE (GSE tentatively provided by MSFC).
- Battery Cell health will no longer need to be monitored through an RS 422 connection.

Battery Cell health during charging will be monitored as follows:

- Proposed setup allows monitoring of all battery temperatures when the cables are connected & Agilent Benchlink Software is operating.
- 4 wires are required per battery for charging and monitoring the batteries.
- One battery voltage and current will be monitored at a time.
- Using the known line resistances from the power supply to the CubeSat charge ports the voltage at the input to the CubeSat can be calculated and displayed during charging.
- Voltage will be limited to the maximum battery charge voltage + .7V.
- The voltage will be displayed on the data monitoring screen along with the battery temperature

- Cubesat VAB charging
  - The charge path will need a diode on the positive leg & a 10K thermistor centrally located inside the cell stack.
Breakout box & cables will be fabricated / tested at MSFC prior to being delivered to KSC.
Safety Features

Secondary Payload GSE features are:

- The voltage limit on the power supply (PS) will be set to prevent battery from overcharging.
- The current limit on the PS will be set to the specified trickle charge limit.
- The negative leg of the PS will be fused at approx. 1.5X the charge current.
- The positive leg of the power supply will have a current monitoring shunt to verify current displayed on the front panel of the PS.
- The charger rack will be manned when batteries are charging.
- The data logger display screen will provide digital displays and strip chart plotting of the battery voltage, current, and temperature while undergoing charge.

Note: Not having battery voltage sense leads will prevent from having hot pins on MSA ring & on the CubeSat separation connector.