Energy Storage - Hazard Analysis TEMPLATE for

Watts on The Moon Level 3 Testing in VF-3

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| October 2023Revision: Final (Updated)    |

Hazard Analysis for Watts on The Moon

Level 3 Testing in VF-3

October 2023

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# DOCUMENT PURPOSE

This document contains an analysis of hazards associated with the energy storage subsystem for the Watts on the Moon (WOTM) Level 3 testing, which will be conducted in Vacuum Facility 3 (VF-3) at the NASA Glenn Research Center in Building 16 from May–July of 2024. Controls are defined to mitigate these hazards and an assessment is made of the remaining risk.

# SCOPE

This document covers the Watts on The Moon Level 3 testing that is to occur at the NASA Glenn Research Center between May–July 2024 by the four finalist teams. Each team will be responsible for filling in the template on pages 8-9 of this document and submitting a version specific to their energy storage hardware solutions. Teams will document the hazards identified with their hardware solutions and the steps that have been or will be taken to mitigate those hazards.

This document will then be reviewed by a NASA safety panel to approve shipment of the hardware to NASA and testing in VF-3. Teams that are not approved after the safety review will have up to 30 calendar days to correct deficiencies, document the revisions, and receive approval for hardware shipment and testing.

# SYSTEM PURPOSE

WOTM is a NASA Centennial Challenge, which incentivizes technology development through technical challenge and competition. WOTM is incentivizing the improvement of long-distance power transmission and energy storage in a challenging, simulated lunar environment.

1. **HAZARD ANALYSIS SUMMARY**

Hazards for the WOTM Level 3 testbed operation are listed below:

## ELECTRICAL POTENTIAL

A key objective of the WOTM challenge is to demonstrate long distance power transmission in a simulated lunar environment. Solutions could include the conversion to very high voltages for transmission, which would be a severe hazard to personnel during handling and integration. Teams will need to ensure that there is no possibility for high voltages to be present or exposed to personnel prior to the start of testing.

## OVER-PRESSURIZATION

Energy storage system failures can cause energetic venting of hot gasses. Energy storage systems are expected to be comprised of 10s to 100s of individual units, and these units cannot fail simultaneously. In a worst-case failure, the failure would start with one unit, and then slowly propagate to neighboring units, with a high probability of propagation accelerating until all units are consumed. This process would take minutes, so the VF-3 oil diffusion pumps (ODPs) would be evacuating gas as it is being generated.

The total internal volume of the VF-3 facility is roughly 8,325 liters. Teams will need to provide an estimate of the volume of gasses that may be generated during a catastrophic failure of their energy storage systems to ensure that the internal VF-3 chamber pressure will not exceed atmospheric pressure.

## SMOKE OR FIRE

Energy storage system failures can result in a total release of stored energy in the form of hot, vented gasses and flame. Because of the lack of oxygen, failures in a vacuum tank are expected to be less severe than failures at ambient conditions where oxygen is readily available. Even single unit failures can cause propagating failures in neighboring units and eventually through the entire energy storage system. The most likely failures would occur during the Level 3 vacuum testing, and therefore personnel would not be exposed to the smoke or fire.

However, the resulting release of all stored energy will at a minimum ‘foul’ the VF-3 tank, pumps, and internal cold wall, and may cause thermal damage as well. As such, NASA will be heavily focused on steps and mitigations that must be taken be the teams to ensure that a thermal runaway cell failure is driven to as low a probability as possible.

Teams must also ensure that if they rely on some type of energy storage management controller to mitigate hazards, they must also have an over-arching mitigation for a failure of that controller during testing. Note: teams will be allowed to monitor the state of the controller through a digital communication channel during testing using an external computer/monitor and can rely on human-in-the-loop or automated detection of the potential controller failure.

## HIGH TEMPERATURES

During operation, load banks will dissipate up to 650W of power. The load banks are standard rack mounted devices with fan cooling, and hot surfaces are shielded from touch.

Energy storage system failures can create very hot gasses, but these gasses will be contained within the VF-3 facility, will quickly cool, and will be vented outside per the VF-3 facility configuration.

## MATERIAL LEAKAGE

Teams will need to prove that their energy storage systems will not leak hazardous materials during the Level 3 test that could foul the test facility or create a personnel hazard during hardware de-integration. Teams can demonstrate this by exposing their energy storage system components to the anticipated vacuum and thermal conditions and conducting a few charge/discharge cycles to prove vacuum compatibility prior to shipping to NASA.

In addition, the energy storage system will be inspected for leakage or physical damage before handling and integration into VF-3 by the team member(s) on site for Level 3 testing and NASA personnel.

## TOXIC ATMOSPHERE

An energy storage failure could create a temporary toxic atmosphere within VF-3 and near the vacuum pump vents. Should a failure occur during testing, NASA will ensure that the toxic atmosphere has been mitigated prior to opening VF-3 to the lab environment.

## SHARP POINTS OR EDGES

Equipment should not contain sharp edges that could harm personnel while handling.

 **RISK ASSESSMENT CODES (RACs)**

**Hazard Categories**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Category** | **Personal Illness/Injury** | **Equipment Loss ($K)** | **Downtime** | **Data Integrity** | **Environmental Effect** |
| 1 - Catastrophic | Death | >$1,000 | >4 months | Data never recoverable or primary program objectives lost | Long-term (>5 years) environmental damage or requiring >$1M to correct and/or in penalties |
| 2 - Critical | Severe injury or occupational illness | $1,000 to $250 | 4 months to 2 weeks | Repeat test program | Medium-term (1-5 years) environmental damage or requiring $250K-$1M to correct and/or in penalties |
| 3 - Marginal | Minor injury or occupational illness | $250 to $25 | 2 weeks to 1 day | Repeat test period | Short-term (<1 year) environmental damage or requiring $25K-$250K to correct and/or in penalties |
| 4 - Negligible | No injury or illness | $25 to $1 | <1 day | Repeat data point or data requires minor manipulation or computer rerun | Minor environmental damage, readily repaired and/or requiring $1K-$25K to correct and/or in penalties |

**Likelihood Estimate**

|  |  |  |  |
| --- | --- | --- | --- |
| **Level** | **Descriptive Word** | **Qualitative Definition** | **Quantitative Definition** |
| A | Frequent | Likely to occur repeatedly in system/component life cycle | X > 10-1 |
| B | Probable | Likely to occur several times in system/component life cycle | 10-1 ≥ X > 10-2 |
| C | Occasional | Likely to occur at some time in system/component life cycle | 10-2 ≥ X > 10-3 |
| D | Remote | Not likely to occur in system/component life cycle, but is possible | 10-3 ≥ X > 10-6 |
| E | Improbable | So unlikely that it can be assumed occurrence may not be experienced | 10-6≥ X |
| F | Impossible | Occurrence is physically impossible |  |

**RAC Matrix**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **RAC** | **A Frequent** | **B Probable** | **C Occasional** | **D Remote** | **E Improbable** |
| **1 Catastrophic** | **1** | **1** | **2** | **3** | **4** |
| **2 Critical** | **1** | **2** | **3** | **4** | **5** |
| **3 Marginal** | **2** | **3** | **4** | **5** | **6** |
| **4** **Negligible** | **3** | **4** | **5** | **6** | **7** |

| ***If the RAC is…*** | ***Then the risk is…*** |
| --- | --- |
| **1&2** | **Unacceptable** – All operations shall cease immediately until the hazard is corrected, or until temporary controls are in place and permanent controls are in work.A safety or health professional shall stay at the scene at least until temporary controls are in place. RAC 1 hazards have the highest priority for hazard controls.Center Director is authorized to accept the risk with adequate justification in rare cases where critical tests must be done, and the risk cannot be reduced. |
| **3** | **Undesirable** – All operations shall cease immediately until the hazard is corrected or until temporary controls are in place and permanent controls are in work.Program Manager (directorate level), Organizational Director, or equivalent management is authorized to accept the risk with adequate justification. |
|  |  |
| **4–7** | **Acceptable with Committee Review**. |

| HAZARD | CAUSE | EFFECT | Severity/ ProbabilityRAC | CONTROLS | VERIFICATION | DISPOSITIONSeverity/ Probability RAC |
| --- | --- | --- | --- | --- | --- | --- |
| Electrical shock  | 1. Energization of Metal Surfaces accessible to casual contact of the research hardware | Personnel injury | 1 B 1 |  |  |  |
| 2. Inadvertent Contact with Energized Circuits while conducting maintenance/assembly/disassembly of research hardware | Personnel injury | 1 B 1 |  |  |  |
| Smoke/Fire Hazards | 1. Energy storage system is physically damaged leading to release of all stored energy | Damage to equipment and facility | 3 B 3 |  |  |  |
| 2. Energy storage system is overcharged leading to release of all stored energy | Damage to equipment and facility | 3 B 3 |  |  |  |
| 3. Energy storage system gets too hot during charge or discharge, leading to release of all stored energy.  | Damage to equipment and facility | 3 D 5 |  |  |  |
| 4. Energy storage system charged after abusive over-discharge, leading to failure and release of all stored energy. | Damage to equipment and facility | 3 B 3 |  |  |  |
| 5. Energy storage system charged at low temperatures (less than 0°C), leading to potential failure and release of all stored energy.  | Damage to equipment and facility | 3 B 3 |  |  |  |
| 6. Manufacturing defect causes internal short circuit, leading to release of all stored energy.  | Damage to equipment and facility | 3 D 5 |  |  |  |
| High Temperature Environment or Surfaces | 1. Energy storage system overheats due to failure. | Personnel Injury | 2 C 3 |  |  |  |
| Material leakage | 1. Chemical energy storage system seals compromised | Damage to Facility and Personnel Injury | 2 C 3 |  |  |  |