

# Ground Handling of Batteries at Test and Launch-site Facilities

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## Introduction

- Batteries are energetic devices and should be handled with safety in mind.
- Ground handling and testing are sometimes regarded as routine and safety is forgotten.
- For safety and maintaining battery integrity, documents are written to provide advice and requirements for ground handling.

# Ground Support Equipment Requirements

- Battery charging and discharging processes on-ground shall be continuously monitored by personnel if monitoring by personnel is stated to be a safety control per the hazard analysis. Personnel monitoring cannot be used as one of the first two levels of control.
- Battery EGSE shall be current-limited by design.
- Battery EGSE shall provide monitoring and protection for voltage, current, and temperature to prevent battery damage or failure.
- Charging and conditioning performed in hazardous locations shall comply with requirements specified for that particular location.

# Battery General Design Safety

- Battery designers or handlers shall use JSC 20793 Rev B as the requirements document if imposed before contract was placed (not imposed on CEV-CM battery).
- Orion battery design and operations shall be within the manufacturer's recommended design and safety limits.
- Orion battery design and operations, if not within the manufacturer's recommended design limits shall be certified to the required environments to confirm functionality and safety.
- For ground testing, all batteries shall be accessible for electrical disconnection or electrical isolation.
- Battery connectors shall be designed to prevent reverse polarity. Alternately, the polarity of EGSE battery terminals shall be marked.
- Inadvertent charge in primary (non-rechargeable) batteries shall be prevented. Diodes may be used to prevent inadvertent charge of primary batteries. The diodes may be placed either internal to the battery box or in the external circuitry

## Battery General Design Safety

- If a battery is not connected to the system, the battery terminals or connector plug shall be given positive protection against shorting.
- Sufficient ventilation shall be provided for EGSE non-sealed batteries to ensure concentrations of electrolyte vapors, combustible gases, or toxic gases do not reach 25 percent of the lower explosive limit (LEL).

# Flight Battery System Safety

- Flight batteries shall be safety certified for use in its designated application.
- Flight battery systems shall have two-fault tolerance to overcharge, overdischarge into reversal, external short circuits and high temperatures.
- Flight batteries shall be either tolerant to internal shorts or be screened for internal shorts.
- Lot testing shall be performed on every new flight lot procured to confirm that the above hazards and controls remain the same.
- Battery Assembly shall have vibration resistance and be safe, after exposure to transportation, Crew Exploration Vehicle (CEV), or other launch vehicle vibration environments (e.g. CxP 70036).
- Battery assembly shall have shock resistance and be safe after ground transportation, CEV or other launch vehicle flight and ground environments (e.g. MIL-STD-810E, Method 516.4, Procedure I).

## Flight Battery System Safety

- Cell and battery case materials shall be compatible and ensure that the material strength and function are maintained after exposure to electrolyte liquids and gases/vapors, painted or conformal coatings, potting materials and their solvents, cleaning solutions, cell case sealing materials and their solvents, or any other material to which the battery may be exposed.
- Battery cases that contain batteries with aqueous or flammable electrolytes shall be designed to release gases.
- Cell vents, if applicable, shall not be blocked or plugged with the application of potting materials or other obstructions.
- The battery case structure shall provide the strength to withstand or negate the stresses induced by cell swelling.
- Circuit interrupters, that are rated at 200 % of maximum required load on the battery or below the battery's short circuit current, shall be installed in the negative leg of the battery for a grounded battery or placed in either leg for a floating battery.

# Flight Battery System Safety

- The location of the circuit interrupters with respect to the terminal shall be designed to prevent any form of external short circuit.
- Voltage and current limitations of PTC devices shall be characterized if they are to be used as current limiters in cell or battery systems.
- The battery terminals on the outside of the battery case shall be protected from accidental bridging. Battery terminals which pass through metal battery cases shall be insulated from the case. Examples are an insulating collar, etc.
- Cell terminals shall be protected from contact with other conductive surfaces. Cells inside a battery shall be protected from accidental bridging with the battery case
- Wires inside the battery case shall be insulated, restrained from contact with cell terminals, protected against chafing, be stress free but physically constrained from movement due to vibration or bumping.
- Cells that do not have highly toxic electrolytes or pose a lethal hazard, shall have pressure relief devices. Cells with highly toxic electrolyte that pose a lethal hazard to the crew or battery handlers shall be hermetically sealed.



## Flight Battery System Safety

- Cell cases shall have a minimum burst to vent pressure ratio of 2.5:1. Additionally, if the cell's burst to vent ratio is lower than 2.5:1 but greater than 1.5:1 approval is contingent on the rigors of the fracture control process specified in JSC-25863.
- Transportation of flight cells and batteries shall follow Department of Transportation (DoT) requirements for transportation.
- Transportation containers for flight cells and batteries shall include temperature and shock sensors that record the maximum values of temperature and shock that the cells or batteries had been exposed to during transportation and handling.

# Battery and EGSE Operation and Test Safety

- All test equipment interfacing with flight batteries shall be calibrated periodically as required by the equipment manufacturer.
- Orion battery charge and discharge protocols shall be assessed by the SAO. Orion battery design and charging operations should be in accordance with the battery chemistry.
- Test equipment used to test or charge flight batteries shall have redundant controls in place to not impose any hazard to the flight batteries due to any form of malfunction. EGSE shall be verified to operate correctly prior to first operational use at the site, including all safety devices, prior to connecting a battery for charging.
- Test protocols programmed into the EGSE shall have tolerance ranges for all the parameters used for charging or operation. Test protocols programmed into the EGSE shall have design limits specified for the test parameters. The design limits will be based on those specified by the manufacturer or those that the battery has been certified to per the battery specification. Test protocols for EGSE shall have safety limits specified. Conversely, the EGSE should prevent the batteries from exceeding the safety limits. For example, such EGSE should prevent lithium-ion cells from exceeding 4.4 V or that recommended by the manufacturer or driving the cells to less than 0 V or that recommended by the manufacturer.
- The test equipment shall be designed with limits that prevent restart of equipment or a continuation of the test in the event of a power, test equipment or battery failures.
- EGSE shall have two independent controls for fault detection to an overcharge condition in the battery. These can be a combination of software and hardware controls.

## Battery and EGSE Operation and Test Safety

- The EGSE shall monitor and record battery measurements as required per the battery provider's handling plan as specified by Appendix J, during charging and discharging. For lithium-ion batteries, individual cell or parallel cell bank monitoring and recording is required during charging and discharging. As an exception, where small-cell lithium-ion battery designs are used, cell string monitoring capability shall demonstrate an equivalent level of safety to the SAO in the hazard analysis and verification testing program.
- Battery and cells shall be treated as always having a voltage potential; therefore, connection or disconnection of battery shall be considered an electrical personnel hazard and a "spark" potential.
- Safety devices and mandatory independent verification steps shall be incorporated into the EGSE designs and handling / operating procedures where two fault tolerance is not met by the battery system alone.
- Prior to connecting the battery, supporting equipment (ground or flight) shall be verified to operate safely prior to first operational use at the launch processing site including all fault tolerant devices.
- Sufficient ventilation shall be provided for batteries to ensure concentrations of combustible gases and vapors do not reach 25 percent of the Lower-explosive-limit (LEL).

# Battery and EGSE Operation and Test Safety

- Battery charging equipment shall be:
  - Monitored continuously by personnel when in operation if monitoring by personnel is stated to be a level of safety control per the hazard analysis..
    - Note: Personnel monitoring of the lithium Ion battery charging process is not allowed as one of the first two levels of safety control due to the rapidity of thermal runaway.
  - Designed and tested for recharging batteries of a specific chemistry and/or battery design. If multiple battery chemistries and designs are to be charged with the same EGSE charging equipment, the equipment's capability shall be verified and tested before testing any qualification or flight battery with a potential for creating a hazard during charging.
- The battery charging and conditioning laboratories or test areas shall have a designated eyewash station and shower (if shower is necessary based on operation) and devices for protecting charging equipment and batteries (i.e., bollards, guard rails, etc.).
- When handling vented batteries, the following safety actions shall be followed:
  - Appropriate PPE shall be worn.
  - An eye wash station shall be located nearby.
  - Ample water shall be available to flood spills of electrolyte.
  - No smoking, open flames or spark producing devices shall be allowed in the battery area.
  - Uninterrupted power supply (UPS) battery installation shall be reviewed by the SAO.
  - A Lith-X or Class ABC fire extinguisher, as required per the MSDSs of the batteries at the test site, shall be available in the test location.

# Summary

- Be Safe, Be Alert

## **Acknowledgment**

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CEV Safety Team at Lockheed Martin