PAYLOAD FLIGHT HAZARD REPORT				a. NO:	AMS-02-F13
b. PAYLOAD	Alpha Magnetic Spectrometer-02 (AMS-02)			c. PHASE:	II
d. SUBSYSTEM:	UPS	e. HAZARD GROUP:	Contamination, Explosion, Fire	f. DATE:	May 22, 2006
g. HAZARD TITLE:	Battery Failure (Leakage/Rupture)			i. HAZARD CATEGORY:	CATASTROPHIC **X** CRITICAL
h. APPLICABLE SAFETY REQUIREMENTS:	NSTS 1700.7B and ISS Add. 200.4a, 201.3 209.1 213.2				
j. DESCRIPTION OF HAZARD:	Rupture of Battery, release of electrolyte, accumulation of evolved gases can result in explosion, contamination and fire. Each of the UPS batteries is composed of eight Yardney Lithion NCP25-3 cells wired in series.				
k. CAUSES *(list)*	1. Shorting, Internal & External 2. Overcharging/Overvoltage Of Cells 3. Cell Reversal/Overdischarge 4. Excessive Internal Pressure 5. Thermal Extremes 6. Accumulation Of Hazardous Gases 7. Release/Leakage Of Electrolyte				

o. APPROVAL	PAYLOAD ORGANIZATION	SSP/ISS
PHASE I		
PHASE II		

PAYLOAD FLIGHT HAZARD REPORT			a. NO: AMS-02-F13
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)			c. PHASE: II
PHASE III			

l. HAZARD CONTROL (CONTROL), m. SAFETY VERIFICATION METHODS (SVM), n. STATUS OF VERIFICATIONS (STATUS)	OPS CONTROL
1. CAUSE: Shorting, Internal & External	
1.1 CONTROL: The Lithion NCP25-3 cells are designed to minimize the potential for internal shorting between the layers of electrodes that comprise the cell. 1.1.1 SVM: Qualification and Flight Screening of Li-ion Cells for the AMS (4.8 Vibration Testing) (5.2 Vibration Screening) 1.1.2 SVM: Qualification and Flight Screening of Li-ion Batteries for the AMS (4.6 Vibration Testing) (5.2 Vibration Testing) 1.1.1 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005. 1.1.2 STATUS: Open	
NOTE: Parenthetical references within the SVM are to specific paragraphs in the Statement of Work for the Alpha Magnetic Spectrometer –01 (AMS-02) Uninterruptible Power Source (UPS) Appendices: Appendix A, Qualification and Flight Screening of Li-ion Cells for the AMS, Appendix B, Qualification and Flight Screening of Li-ion Batteries for the AMS	
1.2 CONTROL: The Lithion NCP25-3 cells are designed to sustain external shorts without inducing thermal runaway or other hazardous effects. 1.2.1 SVM: Qualification and Flight Screening Of Li-ion Cells for the AMS (4.5 External Short Circuit Testing) 1.2.2 SVM: Qualification and Flight Screening Of Li-ion Batteries for the AMS	

PAYLOAD FLIGHT HAZARD REPORT		a. NO: AMS-02-F13
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)		c. PHASE: II
(4.4.2 External Short Circuit Testing) 1.2.1 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005. 1.2.2 STATUS: Open		
1.3 CONTROL: The BMS is designed to provide two levels of protection against external shorts by measuring current output of the battery. One of these is located in the BMS firmware control and the other is a discrete hardware circuit, independent of the firmware. In the event of a detected overcurrent (such as short) the BMS will isolate the battery removing it from the circuit. 1.3.1 SVM: Functional testing of the BMS protection circuitry. 1.3.1 STATUS: Closed. REFERENCE TBD		
1.4 CONTROL: Interconnecting wires to the Lithion NCP25-3, wiring the batteries in series and connecting the cells to the battery management system (BMS) are soldered in place or screwed in place with terminal lugs and potted to insulate and further secure the connections in place. 1.4.1 SVM: Review of Design 1.4.2 SVM: Inspection of as built hardware 1.4.1 STATUS: Open 1.4.2 STATUS: Open		
1.5 CONTROL: The interior surfaces of the battery box are treated to have a non-conductive coating to preclude any potential shorts to the case. Conductive surfaces that are alodined to provide grounding and bonding surfaces are inaccessible once assembly is complete. 1.5.1 SVM: Review of Design 1.5.2 SVM: Inspection of as built hardware 1.5.1 STATUS: Open 1.5.2 STATUS: Open		
2. CAUSE: Overcharging/Overvoltage Of Cells		

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F13
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

2.1 CONTROL: The Lithion NCP25-3 cells are designed to tolerate limited overcharging without inducing thermal runaway or other hazardous effects.

2.1.1 SVM: Qualification Of Li-ion Cells for the AMS

(4.3.1 Over Voltage Testing)

(4.3.2 Fast Charge)

(4.3.3 Over Voltage Testing)

2.1.1 STATUS: Closed. Reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005. Test 4.3.1 Over Voltage Testing, demonstrated the threshold limit for over-voltage.

2.2 CONTROL: The battery management system (BMS) will monitor each cell during battery charging. The BMS is designed to provide two levels of protection against overvoltage by measuring voltage state of the battery. One of these is located in the BMS firmware control and the other is a discrete hardware circuit, independent of the firmware. If an over voltage condition occurs a voltage comparator will detect and engage a shunt that will bypass the charging current and partially discharge the cell.

2.2.1 SVM: Review of Design

2.2.2 SVM: Qualification Of Li-ion Batteries for the AMS

(4.3 Over Voltage Testing)

2.2.3 SVM: Functional Testing of cell overcharge/overvoltage circuitry.

2.2.1 STATUS: Open

2.2.2 STATUS: Open

2.2.2 STATUS: Closed. REFERENCE TBD

2.3 CONTROL: The battery management system provides a circuit to control the charging cycle that will shut down charging operations if a overvoltage condition persists or a thermal sensor measures an over temperature condition for a cell.

2.3.1 SVM: Review of Design

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F13
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

2.3.2 SVM: Functional testing of battery overcharge circuitry.

2.3.1 STATUS: Open

2.3.2 STATUS: Closed. Reference Lithion document LiTP-6238, Rev. A, Dated January 2006.

3. CAUSE: Cell Reversal/Overdischarge

3.1 CONTROL: The Lithion NCP25-3 cells are designed to accommodate cell reversal to 150% of original charge capacity without rupture, thermal runaway or other hazardous effect.

3.1.1 SVM: Qualification Of Li-ion Cells for the AMS

(4.4.2 Fast Discharge)

(4.4.3 Discharge Series Combination)

3.1.2 SVM: Qualification Of Li-ion Batteries for the AMS

(4.4.1 Discharge into Reversal)

3.1.1 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005.

3.1.2 STATUS: Open

3.2 CONTROL: The BMS is designed to provide two levels of protection against overdischarge by measuring voltage state of the battery. One of these is located in the BMS firmware control and the other is a discrete hardware circuit, independent of the firmware.

3.2.1 SVM: Review of Design

3.2.2 SVM: Functional Testing of BMS Protection Circuitry

3.2.1 STATUS: Open

3.2.2 STATUS: Closed. REFERENCE TBD.

3.3 CONTROL: The BMS monitors cell operations using thermal sensors and charge/discharge rate to operate a MOSFET to inhibit BMS output.

3.2.1 SVM: Review of Design

3.2.2 SVM: Functional Testing of BMS Protection Circuitry

3.2.1 STATUS: Open

3.2.2 STATUS: Closed. REFERENCE TBD

4. CAUSE: Excessive Internal Pressure

4.1 CONTROL: The Lithion NCP25-3 cells are constructed with the inclusion of a burst disk that will relieve internal pressures at 350 ± 50 psid according to the manufacturer's certification. Lithion installation of the burst disks has been shown to lower the actual burst value consistently to 200 ± 50 psid. Testing of the cell cases without burst disks establish a burst pressure in excess of 1000 psid. Any vented products will be vented to the interior of the UPS box which is vented to exterior environments.

4.1.1 SVM: Qualification Of Li-ion Cells for the AMS

(4.7 Heat to Vent test)

(4.9 Vent Burst Pressure Test)

4.1.2 SVM: Cell Manufacturer testing of bursting pressure of cell enclosure and burst disks.

4.1.3 SVM: Inspection of battery cells for installation of burst disks

4.1.4 SVM: Inspection of battery box for venting paths

4.1.1 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005.

4.1.2 STATUS: Closed. REFERENCE TBD

4.1.3 STATUS: Open

4.1.4 STATUS: Open

5. CAUSE: Thermal Extremes

5.1 CONTROL: The worst case thermal environment for the AMS-02 UPS has been assessed to be -50 °C to 50 °C (operational maximum and non-operational minimum). Minimum operational temperature is -25 °C. Manufacturer data has indicated cell survival at temperatures as low as -65 °C and safe operation at 120 °C. Qualification testing will demonstrate cell performance and safety to –25°C to 40°C. UPS Battery Testing will demonstrate battery performance and safety -25º to 50º C. The AMS-02 UPS does not utilize any heaters to maintain thermal conditioning.

5.1.1 SVM: Qualification Of Li-ion Cells For the AMS

(4.2 Thermal Environment Test)

(4.10 Thermal Cycle (–35°C to 40°C))

5.1.2 SVM: Qualification and Flight Screening Of Li-ion Batteries For the AMS

(4.2 Thermal Environment Test)

(4.11 Thermal Vacuum Testing)

(5.5 Thermal Vacuum Testing)

5.1.3 SVM: Manufacturer Testing to -65 °C (Non-operational testing)

5.1.1 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005.

5.1.2 STATUS: Open

5.1.3 STATUS: Closed. Manufacturer communication of test results by email on June 30, 2005 indicating that worst case effect is “salting out” of electrolyte, which is a reversible non-hazardous phenomenon.

6. CAUSE: Accumulation Of Hazardous Gases

6.1 CONTROL: The chemistry of the Lithion NCP25-3 Li-ion cells does not evolve hazardous (explosive) gases as a consequence of nominal operations and charging. Evolution of pressurized gasses sufficient to rupture the burst disk are possible by vaporizing the electrolyte by raising the cell temperature beyond predicted thermal extremes and failure cases. As noted in previous controls, multiple faults are required to create this condition. In off nominal conditions the Lithion NCP25-3 may evolve small quantities of Carbon Monoxide, Carbon Dioxide, Water, Methane, Ethane and other primary hydrocarbons. The non-resettable burst disk will vent these gases when they exceed the disk burst pressure of 200 ± 50 psid. Nominal internal pressure is 1 atm absolute.

6.1.1 SVM: Review of Battery Design

6.1.2 SVM: Qualification Program for cells

6.1.1 STATUS: Open

6.1.2 STATUS: Open

7. CAUSE: Release/Leakage Of Electrolyte

7.1 CONTROL: The Lithion NCP25-3 cell design does not utilize free electrolyte. The cell enclosure is designed as a pressurized container and will contain the contents to a pressure of 350 ± 50 psid. Nominal internal pressure is 1 atm absolute.

7.1.1 SVM: Review of cell design

7.1.2 SVM: Qualification and Flight Screening Of Li-ion Cells for the AMS

(3.2 Electrochemical Characteristics)
(3.3 Charge Discharge Cycle)
(3.4 Vacuum Leak Test)
(4.9 Vent and Burst Pressure Test)
(4.10 Thermal Cycle Test)
(5.2 Vibration Test)

7.1.3 SVM: Qualification and Flight Screening Of Li-ion Batteries for the AMS

(3.2 Electrochemical Characteristics)
(3.3 Charge Discharge Cycle)
(3.4 Vacuum Leak Test)
(4.7 Thermal Vacuum Test)
(5.2 Vibration Test)
(5.5 Thermal Vacuum Test)

7.1.1 STATUS: Open

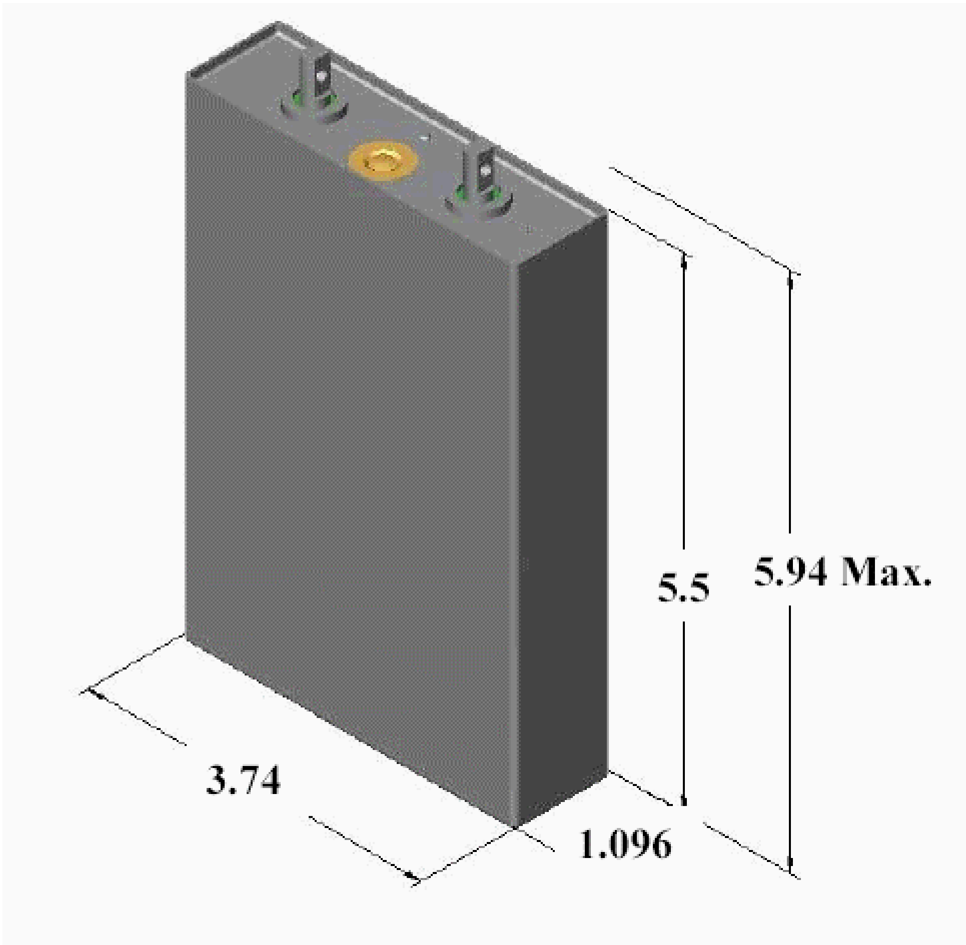
7.1.2 STATUS: Closed. For Qualification, reference Lithion document L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005.

7.1.3 STATUS: Open

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F13
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

NOTES:

ACRONYMS	
°C – Degrees Centigrade (Celsius)	MOSFET – Metal Oxide Semiconductor Field Effect Transistor
AMS-02 – Alpha Magnetic Spectrometer - 02	Ni – Nickel
atm – atmosphere	O – Oxygen
BMS – Battery Management System	P – Phosphorous
Co – Cobalt	psi – Pounds per Square Inch
F – Fluorine	psid – Pounds per Square Inch Differential
Li – Lithium	PVDF - Polyvinylidene fluoride
M – Molar	UPS – Uninterruptible Power Supply
mil – thousandth's of an inch	



AMS NCP25-3 Cell (8 cells in AMS-02 UPS)

Cathode

- 0.001” thick Al Foil Substrate
- $LiNi_{1-x}Co_xO_2$ Active Material
- Carbon Diluents
- PVDF Binder

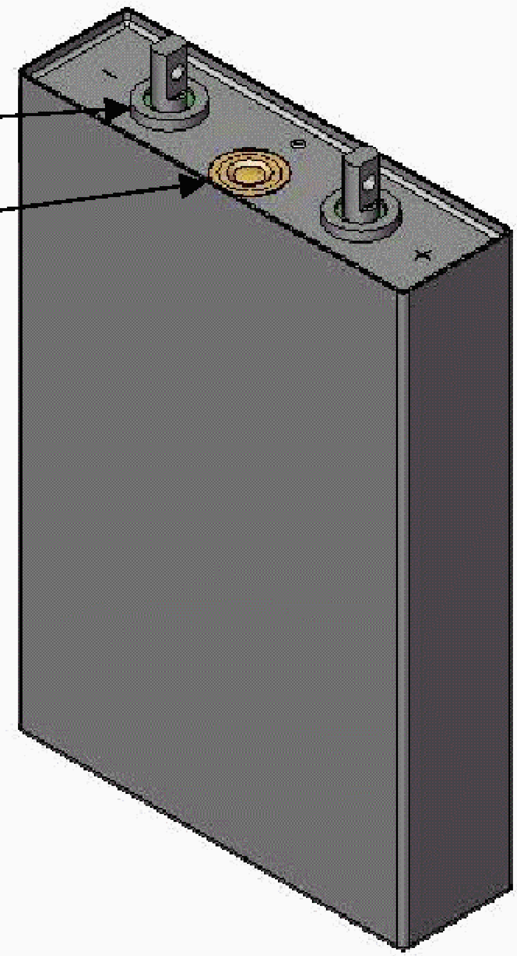
Anode

- 0.0005” thick Cu Foil Substrate
- MCMB 6-28 Active Material
- Carbon Diluent
- PVDF Binder
- Adhesion Promoter

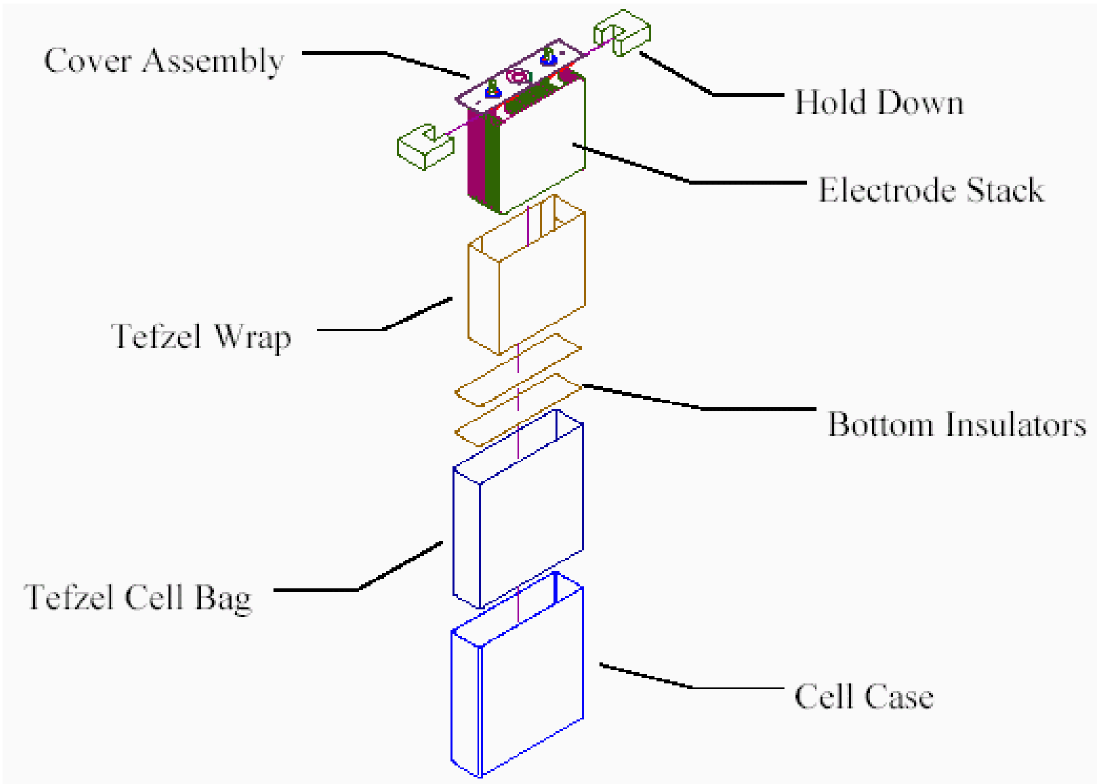
Electrolyte
1M $LiPF_6$ in 1:1:1:2 EC/DMC/DEC/EMC

SETELA (Tonen) E20 Polyethylene Separator

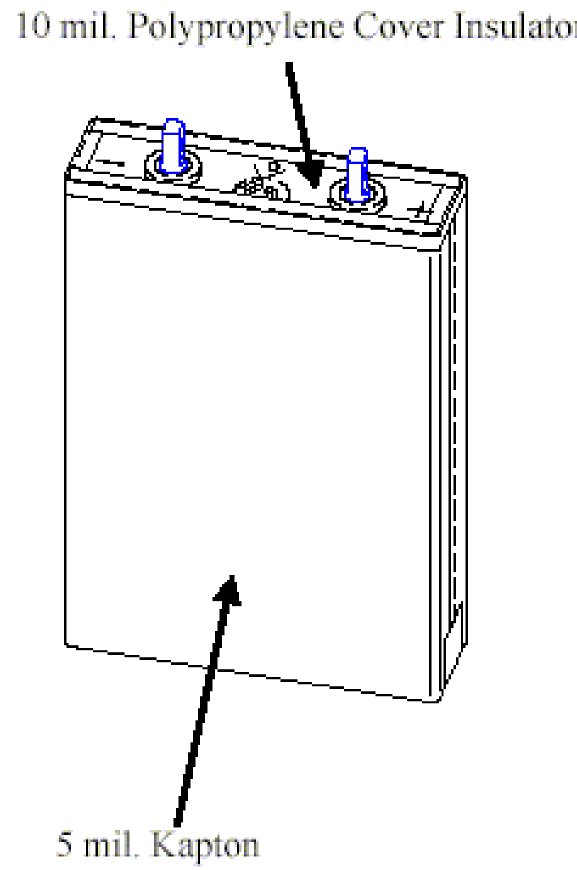
- *304L Stainless Steel components*
  - Laser welded construction
- *Glass to Metal Seals*
- *350 ±50 psi. Rupture Disk.*
- *Fill Tube*
- *Internal Stress Loops*
  - Improves Shock and Vibe
- *Internal Hold Downs*
  - Vibe and extra Insulation
- *Tefzel Wrap and Cell Bag*
  - Case Neutrality



AMS NCP25-3 Cell Construction (Note: Pressure value for burst disk modified by installation to 200 psid)

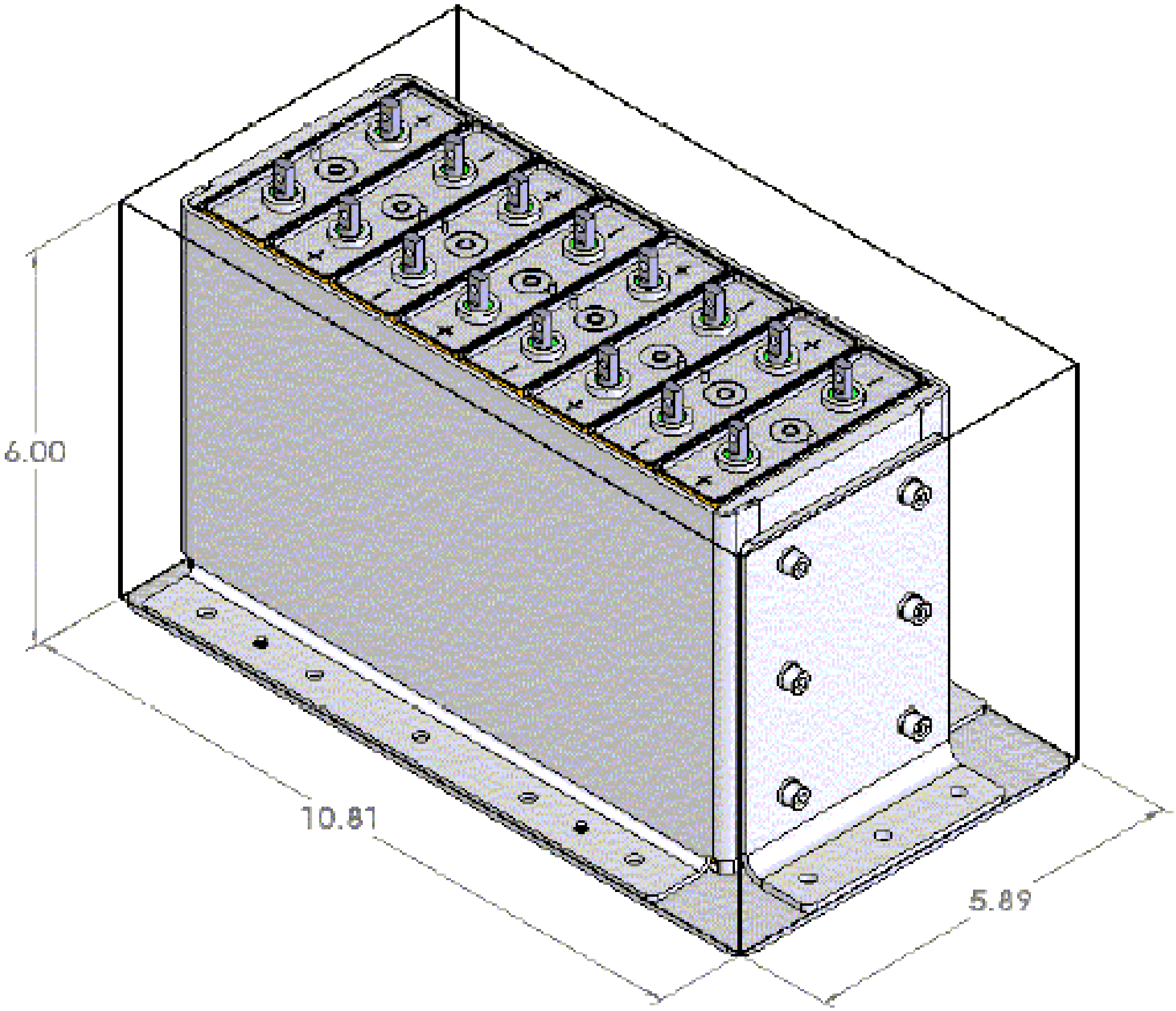


INTERNAL CONSTRUCTION



EXTERIOR INSULATION

Lithion AMS NCP25-3 Cell Construction



UPS Lithion Cell Support Structure

Material Safety Data Sheet **MSDS-001**
May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY (As Used on Label and List)
LITHIUM - ION CELLS

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name Yardney Technical Products, Inc.	*Emergeny Telephone Number* (800) 255-3924
Address (Number, Street, City, State, and Zip Code) 82 Mechanic Street	*Telephone Number for Information* 860-599-1100
Pawcatuck, CT 06379	*Date Prepared* 3/12/02
	Signature of Preparer (optional)

Section II - Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% (optional)
Contains one or more of the following:				
Carbonic Acid, Ethyl Methyl Ester		RTECS#	NA	
Diethyl Carbonate		RTECS#	FF9800000	
Dimethyl Carbonate		RTECS#	FG0450000	
Carbonic Acid, Cyclic Ethylene Ester		RTECS#	FF9550000	
Phosphate (1-), Hexafluoro-, Lithium; $LiPF_6$		RTECS#	NA	
Lithium Tetrafluoroborate; $LiBF_4$				
Lithiated Nickel Oxide Based Components (Suspected Carcinogens)				

Section III - Physical/Chemical Characteristics

Boiling Point	N/A	*Specific Gravity (H2O = 1)*	N/A
Vapor Pressure (mm Hg.)	N/A	*Melting Point*	N/A
Vapor Density (AIR = 1)	N/A	*Evaporation Rate (Butyl Acetate = 1)*	N/A

Solubility in Water
N/A

Appearance and Odor
Hermetically sealed prismatic cell. No odor

Section IV - Fire and Explosion Hazard Data

Flash Point (Method Used)	*Flammable Limits*	*LEL*	*UEL*
N/A	N/A	N/A	N/A

Extinguishing Media
Dry chemical, CO2, water spray or alcohol resistant foam.

Special Fire Fighting Procedures
Use self-contained breathing apparatus.

Unusual Fire and Explosion Hazards
When product is burned, it will emit flouride fumes.
Explosion could result in cases of extreme overcharge.

(Reproduce locally) OSHA 174, Sept. 1985

Section V - Reactivity Data

Stability			*Conditions to Avoid*
	Unstable		DO NOT PUNCTURE OR SHORT CIRCUIT, DO NOT MECHANICALLY
	Stable	X	ABUSE; DO NOT OVERCHARGE OR OVERDISCHARGE

Incompatibility (Materials to Avoid)
NONE

Hazardous Decomposition or Byproducts
NONE IN NORMAL CONDITIONS OF USE & SERVICE

Hazardous Polymerization			*Conditions to Avoid*
	May Occur		DO NOT OVERHEAT. DO NOT EXCEED 50°C.
	Will Not Occur	X	

Section VI - Health Hazard Data

Route(s) of Entry:	*Inhalation?*	*Skin?*	*Ingestion?*
	N/A	N/A	N/A

Health Hazards (Acute and Chronic)
NONE IN NORMAL CONDITIONS OF USE & SERVICE
Electrolyte is corrosive. Causes chemical burns on contact with skin. Inhalation of fine mist or vapors are irritating to the respiratory system.

Carcinogenicity:	*NTP?*	*IARC Monographs?*	*OSHA Regulated?*
	"N/A	N/A	NO

Signs and Symptoms of Exposure
NONE IN NORMAL OPERATING CONDITIONS

Medical Conditions Generally Aggraved by Exposure
N/A

Emergency and First Aid Procedures
INHALATION: REMOVE TO FRESH AIR, SEEK MEDICAL ATTENTION
EYES: FLUSH WITH COPIOUS AMOUNTS OF WATER, SEEK MEDICAL ATTENTION
SKIN: FLUSH WITH COPIOUS AMOUNTS OF WATER, SEEK MEDICAL ATTENTION
INGESTION: SEEK MEDICAL ATTENTION. DO NOT INDUCE VOMITING.

Section VII - Precautions for Safe Handling and Use

Steps to Be Taken in Case Material is Released or Spilled
ANY SPILLED LIQUID SHOULD BE ABSORBED WITH AN INERT DRY MATERIAL AND PLACED IN AN APPROPRIATE WASTE DISPOSAL CONTAINER.
KEEP AWAY FROM HEAT AND SOURCES OF IGNITION.

Waste Disposal Method
DO NOT DISPOSE OF IN FIRE. FOLLOW ALL STATE AND LOCAL REGULATIONS FOR SOLID WASTE

Precautions to Be Taken in Handling and Storage
DO NOT PUNCTURE, DO NOT SHORT CIRCUIT, DO NOT OVERCHARGE, DO NOT OVERDISCHARGE
DO NOT MECHANICALLY ABUSE, DO NOT OVERHEAT

Other Precautions
DO NOT EXCEED 50°C **TRANSPORTATION: Li BATTERIES PER UN3090 PG II**

Section VIII - Control Measures

Respiratory Protection (Specific Type)
NONE REQUIRED UNDER NORMAL CONDITIONS

Ventilation		
	Local Exhaust N/A	*Special* N/A
	Mechanical (General) N/A	*Other* N/A

Protective Gloves	*Eye Protection*
NONE REQUIRED UNDER NORMAL CONDITIONS	NONE REQUIRED UNDER NORMAL CONDITIONS

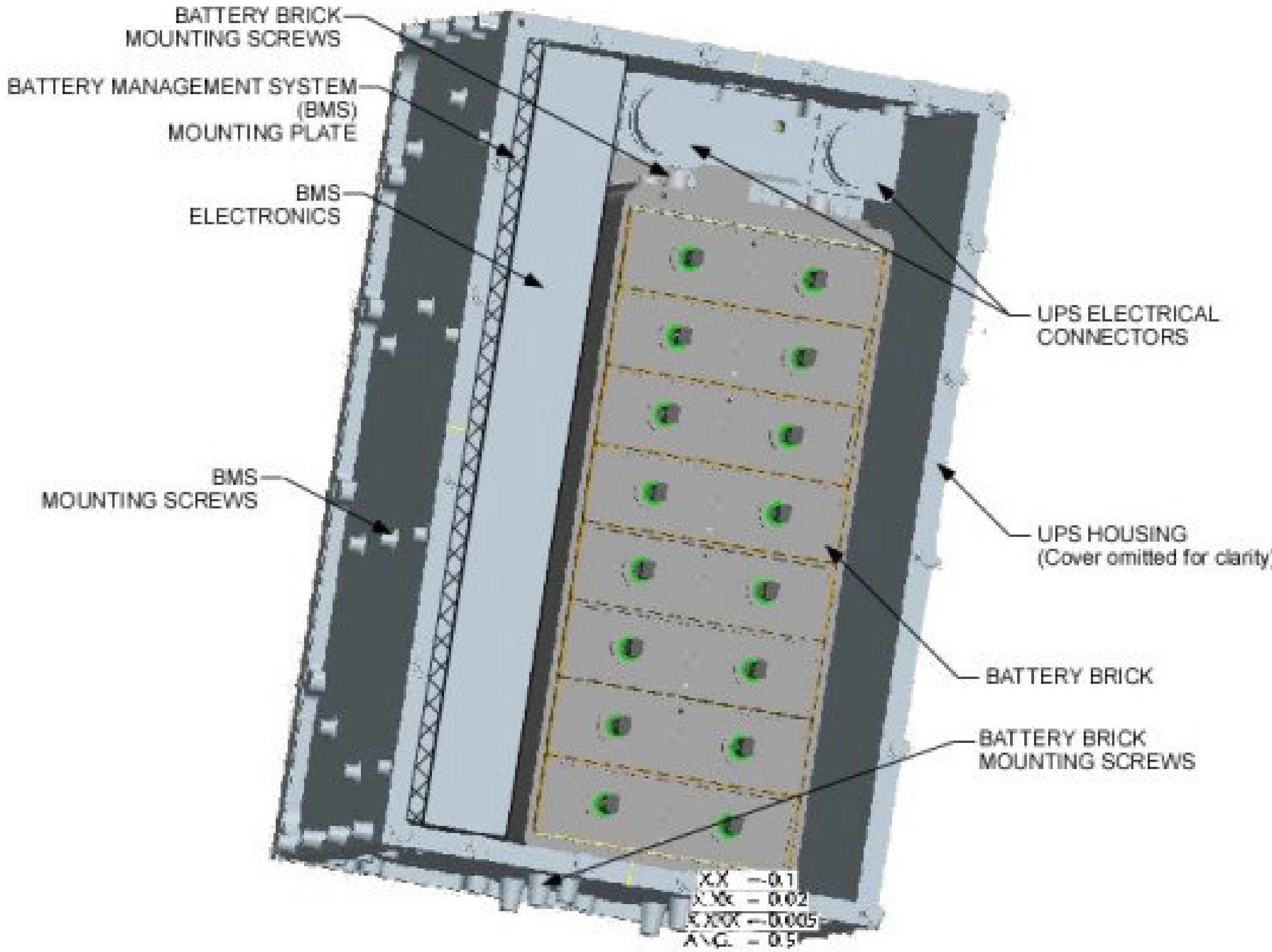
Other Protective Clothing or Equipment
NONE

Work Hygienic Practices
WASH THOROUGHLY AFTER USING THIS OR ANY BATTERY

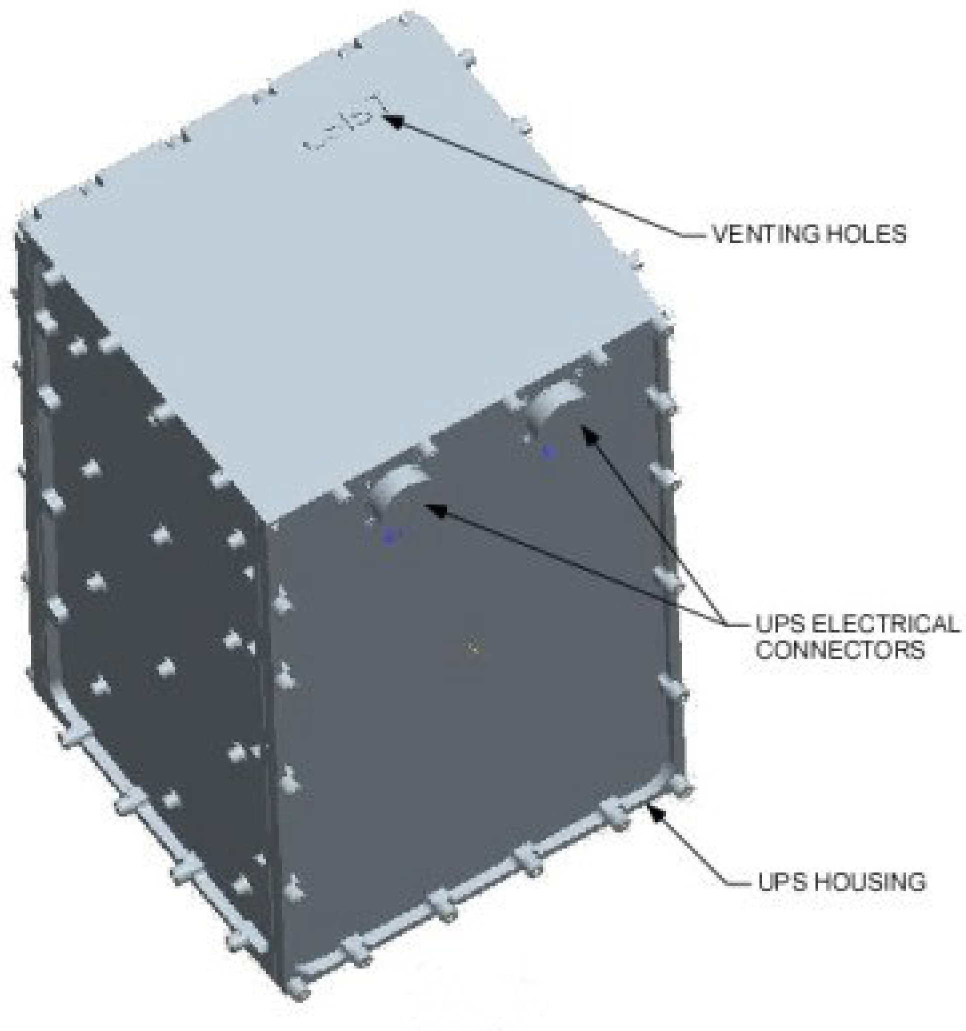
Page 2 U.S.G.P.O. 1986-491-529/45775

Lithion Cell MSDS

Note that the 50°C limit is a performance limit, not safety failure value.



UPS Battery Box Construction Interior View



UPS Battery Box Exterior View

EP5 BATTERY DESIGN EVALUATION FORM	Page 1 of 18

Section 1 to be completed by EP/Division Secretary:	
1a. EP Tracking Number:	**1b. Assigned EP5 Reviewer:**
Section 2 to be completed by the Hardware Point-of-Contact:	
2a. Hardware Point-of-Contact: (Name/Phone/Company/Mail Code) Timothy Urban / 281-461-5702 / ESCG (Barrios Technology) / B2SC	**2b. Hardware Name:** Alpha Magnetic Spectrometer-02, Uninterruptible Power Supply **Hardware Part Number:** 24-AMS-BB **Hardware Acronym:** AMS-02, UPS
2c. Hardware Managing Group, Company, or Agency: AMS-02 Project Management Office, JSC EA-2 and ESCG	
2d. Hardware Flight Information (i.e. flight application, target flight number and/or date, number of flights anticipated, etc.): Two UPS boxes, containing an eight-cell battery each, are to be integrated with the rest of the AMS-02 payload. The payload is scheduled as launch-on-demand and has no official flight manifested. The mission is planned to have one Shuttle flight up to ISS, where it will transferred via SRMS and SSRMS to the ISS S3 Upper inboard payload attach site. The payload will remain at this site for the remainder of the ISS mission life.	

2e. Hardware environmental Requirements:

Thermal (max, min, operational and non-operational ranges):

- **Storage:** To minimize aging effects on the battery, the battery should be stored at a 50% SOC within a 0 to 10 ° C temperature range.
- **Operating (and Acceptance Testing):** –25 °C and +50 °C
- **Qualification Testing:** –30 °C and +55 °C
- **Non-operating:** Manufacturer battery design and history data has indicated cell survival at temperatures as low as -65 °C and safe operation at 120 °C.

Pressure (EVA, IVA): External truss mounted payload

Life (calendar/shelf, cycle):

UPS Operational Life Requirements

The UPS battery is required to support the following profile to initiate a controlled quench of the AMS-02 cryo-magnet.

Phase 1:

Storage for 2-years at the optimum temperature and SOC. To minimize aging effects on the battery, the battery should be stored at a 50% SOC within a 0 to 10 °C temperature range. Because the BMS draws power from the battery, a charger (CSIST provided) will be required to maintain the appropriate charge level.

Phase 2:

Ground use, one year at room temperature. Operational profile is:

100% SOC maintained with charger, with a discharge/charge cycle once per month using the following profile:

- 8-hours of 40W external load
- 1.5 hours of a 50W load
- recharge to 100% SOC

Phase 3:

On-orbit use, 3- years, assume 100% SOC with the attached temperature profile, and the following profile:

- Four discharge/charge cycles per year using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - recharge to 100% SOC
- And one end of mission (after 3-year on-orbit ops) discharge using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - followed by the pulse (45Amps for 150ms, with a minimum battery voltage of 21.2V.

Section 3 to be completed by Hardware Point-of-Contact:

3a. Battery Hardware Description:

The UPS box is the overall avionics box, as shown in Figure 1.

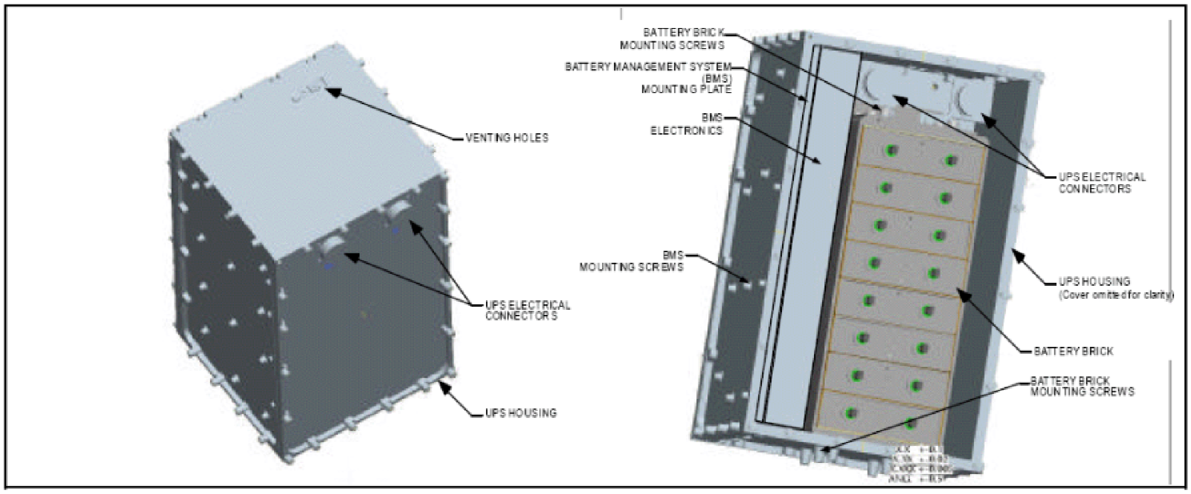


Figure 1 – UPS

The battery consists of eight cells in series, as shown in Figure 2 (cell interconnections are not shown in this picture). There is one such battery per UPS box. The UPS box also contains a set of BMS electronics, which is shown in Figure 3. These electronics monitor and control the battery charge and discharge operation cycles, as well as safety related factors such as over-voltage, over-charge, over-discharge, short-circuit and temperature. There are two such UPS boxes integrated on the AMS-02 payload.

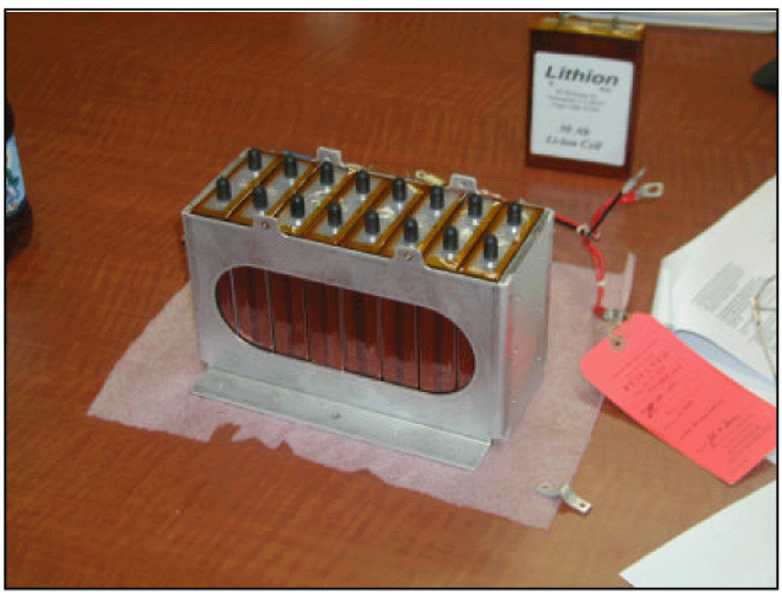


Figure 2 - Battery

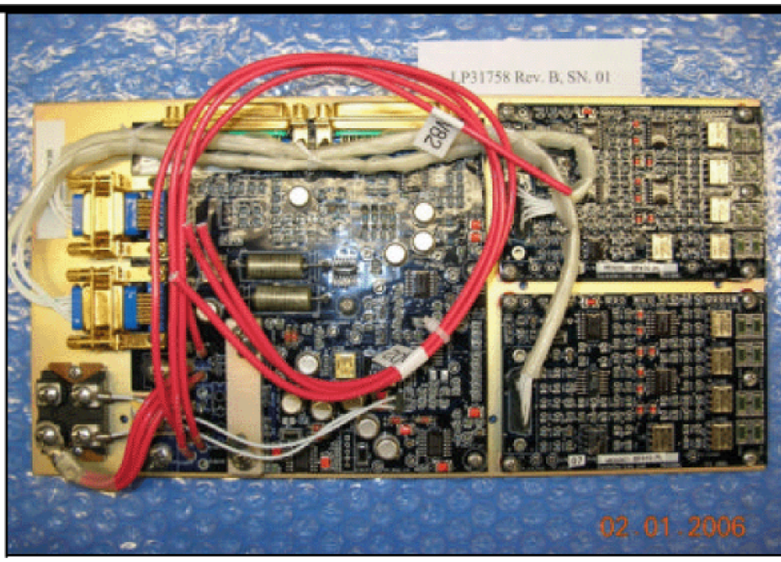


Figure 3 – Battery Management System Electronics

Are the cells/ the battery pack Commercial-off-the-shelf (COTS)?

No, the battery is based on a commercial design that is customized for the AMS-02 specifications and applications. This similar commercial design on which the battery is based has extensive NASA and military flight history.

Function/Operating mode (pulse? intermittent? clock backup? memory?):

The UPS battery is required to support the following profile to initiate a controlled quench of the AMS-02 cryo-magnet. This function is described in detail in Section 3b under circuit description.

Phase 1:

Storage for 2-years at the optimum temperature and SOC. To minimize aging effects on the battery, the battery should be stored at a 50% SOC within a 0 to 10 °C temperature range. Because the BMS draws power from the battery, a charger (CSIST provided) will be required to maintain the appropriate charge level.

Phase 2:

Ground use, one year at room temperature. Operational profile is:

100% SOC maintained with charger, with a discharge/charge cycle once per month using the following profile:

- 8-hours of 40W external load
- 1.5 hours of a 50W load
- recharge to 100% SOC

Phase 3:

On-orbit use, 3- years, assume 100% SOC with the attached temperature profile, and the following profile:

- Four discharge/charge cycles per year using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - recharge to 100% SOC
- And one end of mission (after 3-year on-orbit ops) discharge using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - followed by the pulse (45Amps for 150ms, with a minimum battery voltage of 21.2V.

Battery interfaces (connectors? equipment?): The battery is connected via terminals (terminal lugs fastened with screws) at the cells through a wire harness, internal to the UPS box, to the Battery Management System (BMS) electronics, which has PCB through hole soldered terminations. The BMS electronics are connected, through another wire harness, via PCB card edge connectors to the UPS housing mounted circular connectors (qty. 2). These UPS housing mounted circular connectors provide the electrical interface to the rest of the payload.

Stowage location (installation and use locations):
Two UPS avionics boxes are mounted to the AMS-02 structure, as shown in Figure 4. Also shown is the Cryomagnet Avionics Box (CAB), which provides the current for re-charging the batteries.

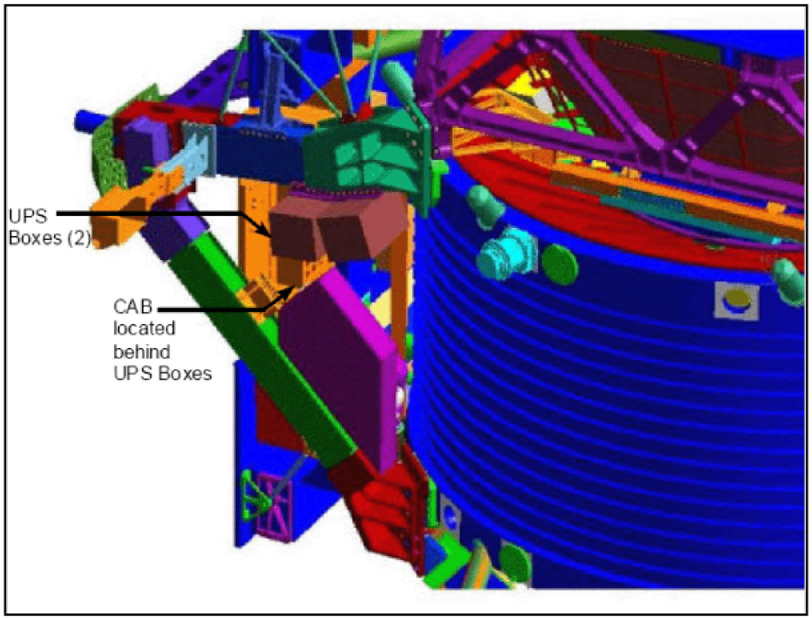


Figure 4 – UPS and CAB Locations

The AMS-02 Payload at its installed position in the Shuttle Payload Bay is shown in Figure 5.

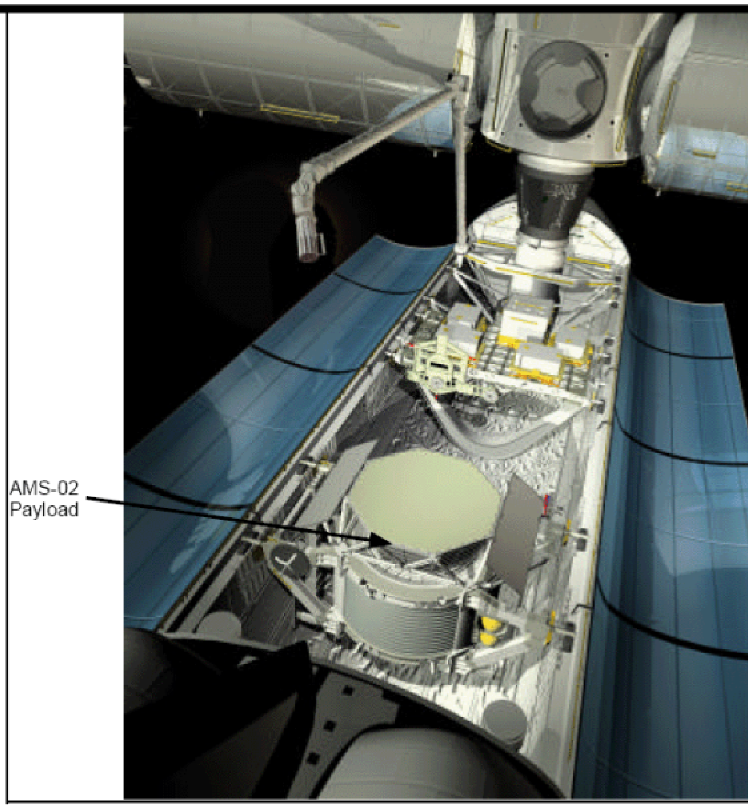


Figure 5 – AMS-02 Shuttle Location

The AMS-02 Payload at its installed position on the ISS S3 Upper Inboard truss is shown in Figure 6.

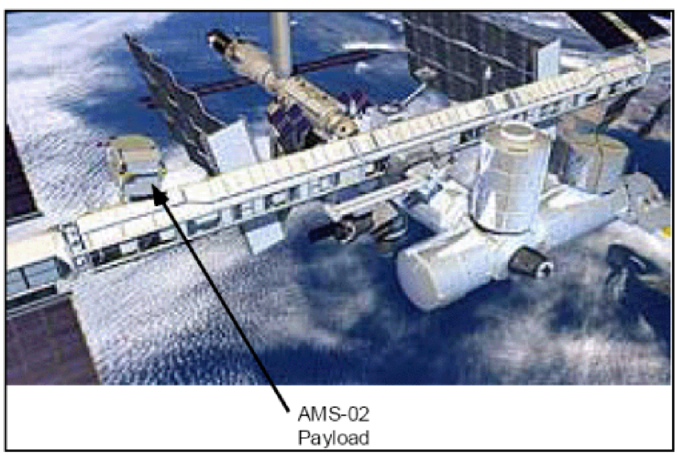


Figure 6 – AMS-02 ISS Location

Battery/cell access during flight: None required.

Short circuit/safe-touch temperature protection: Yes, performed by the BMS

Packaging (battery box material, coating, terminal protection): The UPS housing is manufactured from Aluminum

7075T7351. The outer surfaces are clear anodized, as are the inner surfaces, except joining surfaces, which are chem-film alodined. Once electrical connections have been made at the battery terminals, the connections will be potted with a vacuum-rated RTV.

Wicking material: None required.

Vent design and operating characteristics (opening pressure? redundancy scheme?):
The Lithion NCP25-3 cells are constructed with the inclusion of a burst disk that will relieve internal pressures at 350 ± 50 psid according to the manufacturer's certification. Lithion installation of the burst disks has been shown to lower the actual burst value consistently to 200 ± 50 psid. Testing of the cell cases without burst disks establish a burst pressure in excess of 1000 psid, for a working ratio of burst disk to cell case burst pressure that is better than 4:1. Any vented products will be vented to the interior of the UPS box which is vented to exterior environments, via machined through lettering in one face of the UPS box (see Figure 1.) Only gaseous products are expected during a venting event.

Test data for the cells, battery, or complete hardware package:

- Qualification and acceptance test data for the cells can be referenced in Lithion test report document *L1135-05, Qualification Test Report for the Alpha Magnetic Spectrometer-02 (AMS-02) Uninterruptible Power Source (UPS) NCP25-3 Lithium-ion Cells Per LiTP-6208 Test Dates 1~05 to 2/17/05, Rev. -, Dated 3/11/2005.*
- Qualification and acceptance test data for the BMS electronics can be referenced in Lithion test report document *LiTP-6328, Appendix pages 1-5 for each S/N 01 through 05, dated 1/24/06.*
- Qualification and acceptance test data for the integrated UPS avionics boxes will be performed by CSIST

3b. Chemical and Electrical Description: ***If more than one battery is contained in the hardware, provide information for all the batteries.***

Cell Description:

Chemistry: Lithion Ion, as detailed below:

- Lander Cathode: LiNi1-xCoxO2 Active Material
- Lander Anode: Graphitized MCMB 10-28 Active Material
- Lander Electrolyte: 1M LiPF6 in 1:1:1:2 EC/DMC/DEC/EMC

Size: Prismatic, 5.5 X 1.1 X 3.75 in (Figure 7) **Manufacturer:** Yardney Lithion **Model number:** NCP25-3

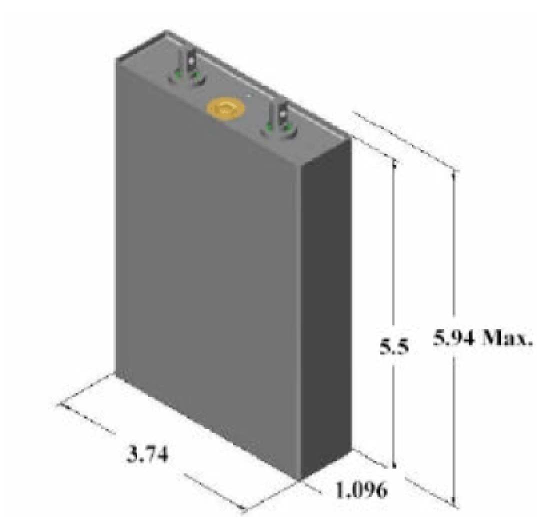
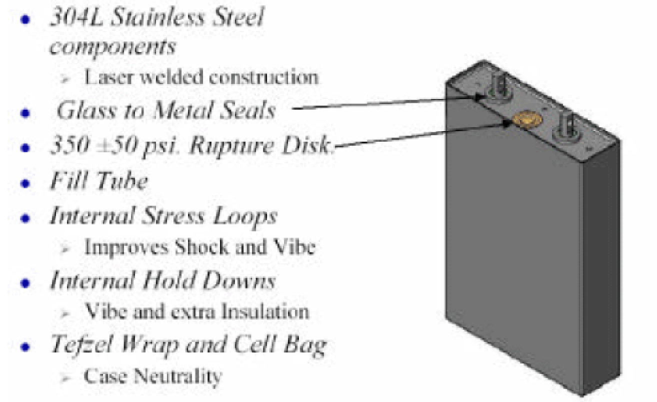


Figure 7 – NCP25-3 Cell Dimensions



NOTE: Post installed pressure value for rupture disk is 250 ± 50 psi.

Figure 8 – NCP25-3 Cell Features

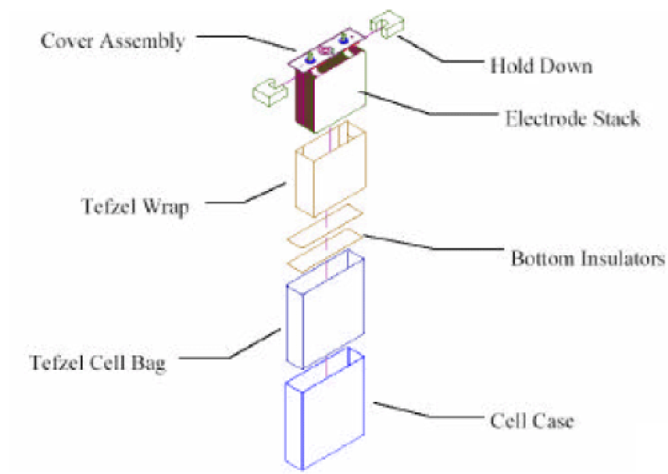


Figure 9 – NCP25-3 Internal Construction

Nominal open circuit voltage: 3.6 – 4.1 V **Expected load voltage:** 2.58 V **Rated capacity:** 28 Ah

Battery Description: (9 V COTS batteries shall be considered as single units)

Quantity of cells per battery: 8 **Connectivity of cells (serial? parallel?):** Series

Operating voltage range: 20.8 – 32.8V **Operating temperature range:** –25 °C and +50 °C

Average Load and duration: 2.1 A 9.5 Hr **Peak Load and duration:** 45A 150ms **Capacity Required:** 20 Ah

Circuit description and electrical schematic (attach electronically or indicate that a hard copy is provided):
The AMS-02 payload has a superconducting toroidal magnet that deflects high energy cosmic ray particles as they pass through the bore of the toroid. The AMS-02 science instruments then measure the trajectory, track and velocity of the particle.

Super-conducting magnets, such as the one utilized by AMS-02, may develop a condition where a portion of the coil begins to rise above super-conducting temperatures. When this condition occurs, the section of wire affected begins to develop resistance, and the current running through this resistance begins to heat the wire rapidly. This rapidly leads to dissipation of the magnet energy (in the form of heat) within the magnet, and is referred to as a magnet quench. This condition is highly undesirable from a mission success standpoint because resulting unbalanced magnetic forces in the different sections of the magnet may cause it to deform, making it unable to be recharged to the maximum field or even to return to a superconducting state, thus preventing the recharging of the magnet. This is a possible mission success critical failure, **not a safety issue**. Alterations in the magnetic field have already been accounted for in the safety assessment for nominal field strengths.

To protect the magnet from this condition, referred to as an unassisted quench, electronics have been designed that will detect the initiating condition and apply heat quench evenly throughout the magnet coils, causing the magnetic field to dissipate uniformly. This will prevent the heating from being isolated to a small section of the magnet, which could become damaged if the quench was uncontrolled. By performing an assisted quench, mission success criteria can be maintained.

The CSP contains quench detection electronics that monitor the status of the magnet coils to determine if a quench condition is starting to occur. To perform this function, redundant voltage measurements are taken across each coil. If a quench condition is imminent, a voltage will develop across the affected coil. When the CSP detects a change in voltage, the quench protection electronics issues a command to the Uninterruptible Power Source (UPS) to provide a pulse of at least 45A to quench heaters located throughout the magnet. The pulse, for a duration of 150 ms, is required to raise the entire magnet up to a non-superconducting state. This spreads the quench throughout the magnet and prevents isolated heating that could result in degraded performance.

The quench heater chains are redundant and supplied by two separate UPS systems, thus two UPS avionics boxes. The chains are routed to alternate coils throughout the magnet. Both heater chains are nominally used by the CSP to control a quench, however either chain independently is sufficient to protect the magnet coils from deformation.
It is important to note that the CSP system is required only for mission success. **Failure of the CSP does not constitute a safety hazard**. The magnet is designed to withstand the forces that would be generated by an unassisted quench.

The CSP provides additional functions to protect the magnet during off-nominal conditions. A "watch dog" timer, powered by the UPS, is continuously counting down. Periodically the timeout is reset via external command to about 8 hours. In the event of a power loss, or the loss of communication to the AMS-02 payload, the timeout is not reset and if power or communications are not restored to the AMS within the eight-hour period, the timer will trigger the CSP Control Electronics to initiate the nominal ramp down function, discharging the magnet. During the eight hour period and the ramp down, the UPS will continue to power the Quench Detection Electronics, and maintain the capability to perform an assisted quench (if necessary) until the magnet is completely discharged.

The AMS-02 CSP "circuit" schematic, of which the UPS is an integral part, is shown in Figure 10.

This description continues after the following graphics.

EP5 BATTERY DESIGN EVALUATION FORM **Page 9 of 18**

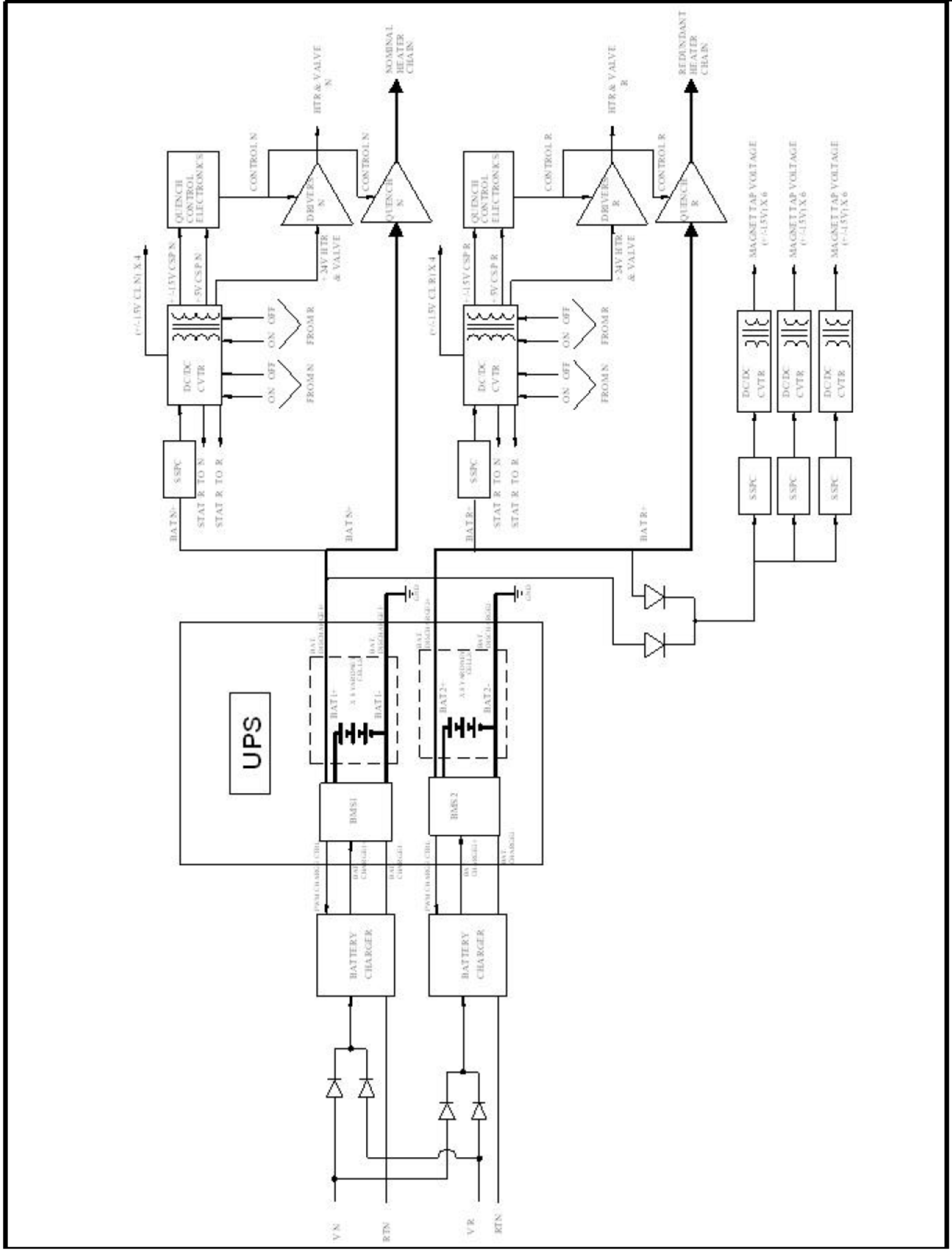


Figure 10 – AMS-02 UPS Circuit Schematic

As described earlier, each UPS contains a battery and a set of battery Management System (BMS) electronics, as shown in Figure 11.

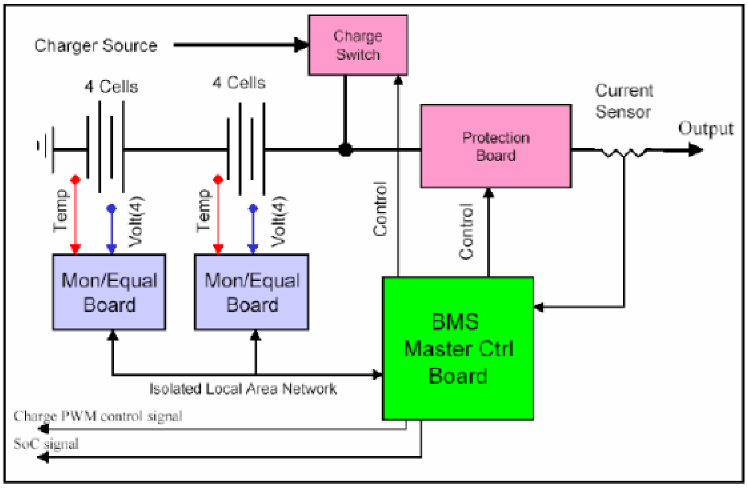


Figure 11 – Battery and Battery Management System Schematic

The BMS functions are as follows:

- Protect battery cells from over-voltage, under-voltage, high temperatures, short circuit
- Protection accomplished by isolating battery from charger and/or load using solid state switches
- Levels set in firmware, backed-up by hardware
- Provides control signal to charger located in the AMS-02 Cryomagnet Avionics Box (CAB)
- Provides telemetry to host system

Overview of BMS:

- Master Control Board (MCB)
  - Contains digital signal processor, signal conditioning circuits, battery over-voltage and over-current circuits
  - Provides feedback signals to CAB based charger
- Monitor/Equalizer Boards (MEQ), Two in System
  - Board No. 1 monitors cells 1-4, Board No. 2 Cells 5-8
  - Has equalization circuits for each cell
- Protection Board
  - Solid state switch disconnects battery during fault
  - 77 Amps @ 70°C
- Charger Switch (Figure 12)
  - Opens charger connection during fault or charger off
  - 10 Amps @ 70°C

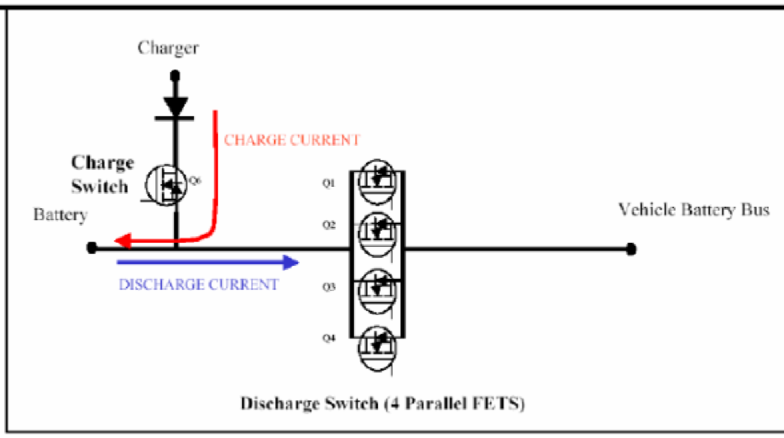


Figure 12 – Solid Stste Charge and Discharge Switches Schematic

The BMS consists of four independent circuit boards and is designed to have the primary responsibility for battery condition (along with good design). The four boards consist of: a master controller board, two monitor/equalizer boards, and a protection/regulator board.

The BMS master controller board communicates with the two monitor/equalizer boards to obtain cell voltage and temperature. The master controller board uses this information to calculate the battery state of charge (SOC) for use in the charge algorithm and to control the battery pack cell equalization. In case of a critical hardware failure, such as loss of communication to the monitor equalizer boards, the master controller board determines this condition and activates the protection board or charger switch.

The two monitor/equalizer boards monitor cell voltage and pack temperature. They perform cell equalization on each charge cycle by resistively bypassing any cell with a voltage in excess of a predetermined maximum. The bypass current is dissipated through a resistor array on the board. The master control board determines when the voltage condition is reached and activates the bypass. The master control board also determines when a cell voltage is exceeding allowable safety limits and activates the Protection and/or Charger switch as well.

The protection/regulator board is used to disconnect the pack from the load during fault conditions that include high cell temperature, low cell voltage and high current.

Additionally, a charger switch will disconnect the battery from the charger in cases of high cell temperature, high cell voltage or if the charger becomes uncontrollable. The switch will open in the case of a critical hardware failure, such as loss of communication to the monitor equalizer boards. The master controller board determines these conditions and sends the signal to the protection board or charger switch. The protection board employs multiple parallel metal-oxide-silicon field effect transistors (MOSFET) to carry the battery load current. Upon the occurrence of a short circuit the protection switch will open within 100 µsec to isolate the battery from the short circuit condition.

The BMS contains both hardware and software inhibits to control potential safety issues such as overcharge, over-discharge, over-temperature, and over-current. Regardless of failure of any of these items, a catastrophic failure of the battery is not credible. The safety settings are:

- Over Charge: If a cell charge exceeds 4.2 V for more than 2 to 3 seconds, software disconnects the battery from the charger. Exceeding 4.3 V on a given cell for 100 µsec causes a hardware inhibit to pull the battery off-line. Even if both of these inhibits malfunction, the battery charger is current limited to 3A and at this rate of charge the cells will vent before presenting any hazard.
- Over Discharge: If a cell voltage drops below 2.5 V for 3-4 seconds, software disconnects the battery from the discharge circuitry. A drop below 2.15 V for 200 µsec causes a hardware inhibit to disconnect the battery from the discharge circuitry.
- Over Temperature: Exceeding 80° C on a battery pack for 3-4 seconds causes software to disconnect the battery from the Charger.
- Over Current: A current draw of 80 A for more than 2-3 seconds causes a software inhibit to disconnect the battery from the discharge circuitry. A hardware inhibit initiates if 170 A is seen for 100 µsec.

Circuit protection (i.e. fuses, diodes, MOSFETs, resistors, source isolation, etc.):

Both the BMS and the CSP utilize MOSFETs. Further protection is provided as follows.

Figure 13 shows the protection circuitry for the CAB CSP providing isolation between the UPS and PDS. The CAB BCE design includes the following protection electronics:

- Two double diodes in a cross-strapping configuration of the nominal and redundant 28Vdc primary power busses coming from PDS unit.
- SSPC (Solid State Power Conditioner), implemented by means of an Latching Current Limiter (LCL), which opens in case of failure.
- The HV power transformer barrier, which provides galvanic isolation between the electronics on primary side and the electronics on secondary side.
- The control electronics to provide the fit current to the battery, and also includes a power transformer with galvanic isolation.
- The blocking diode included in the BMS Battery Management System Electronics, which only permits the current way in only one direction.

All the above-mentioned protections included in the CAB BCE guarantee no propagation of failure to the ISS or any other unit, such as the PDS, which provides the 28Vdc primary power busses.

On the other hand, the CSP electronics design includes the following protection electronics between UPS and the loads (quench heaters, magnet valves):

- Two switches in series to power the quench heaters. These switches are only closed during 150ms of time required for the quenching sequence.
- SSPC (Solid State Power Conditioner), implemented by means of an LCL Latching Current Limiter, which opens in case of failure.
- The power transformer barrier, which provides galvanic isolation between the electronics on secondary side and the electronics on the load side.
- Two switches in series to open or close the valves.

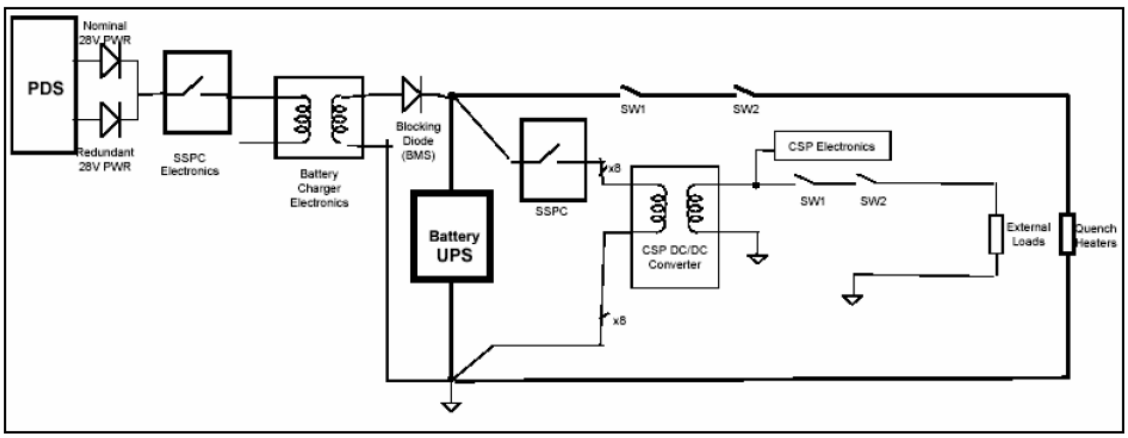


Figure 13 – PDS to UPS Interface Diagram

3c. Is the battery to be charged on-orbit? Yes ☒ No ☐ ***If yes, describe charging scenario, hardware, and protective device. Attach charger schematics.***

The voltage of each cell is monitored. If the OCV of a cell falls below 3.6 V, a charge enable signal tells the CAB CSP charge circuitry to provide charge current, and the BMS charge switch is closed. Since the cells are individually monitored, a cell may be bypassed once its OCV has reached 4.1V and while the other cells are charging. See preceding sections. Top level charger circuit schematic is shown in Figure 14, and detailed schematics are attached.

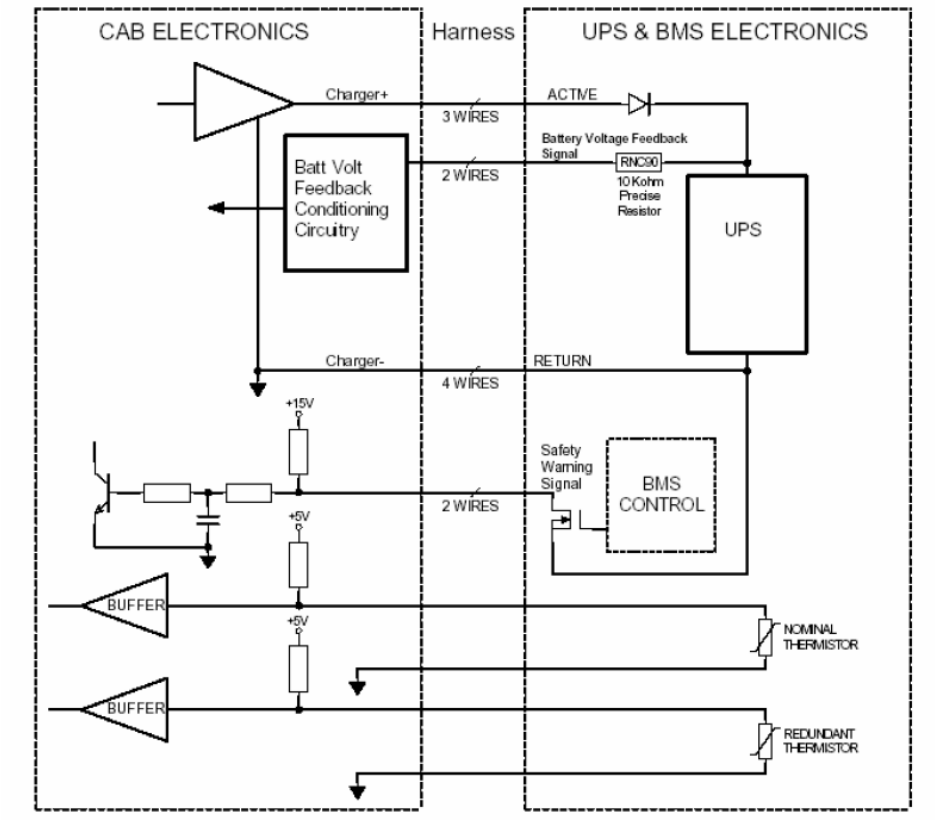


Figure 14 – Top Level CAB / UPS Charger Circuit Diagram

3d. Summarize the pre-flight processing plan for the hardware. (See Section 4.2 of EA-CWI-033 for an overview of the processes to be considered for battery pre-flight processing.) If the preflight processing plan is documented elsewhere, indicate where it is documented and provide a copy of the documentation.

The cells/batteries and BMS electronics are designed, manufactured and qualification and acceptance tested (independently at the cell and electronics level) at Yardney Lithion (or subcontractor) in Connecticut. These components are then shipped overseas to the Chung Shan Institute of Science and Technology (CSIST) in Taiwan, where they are integrated into the UPS box. The UPS boxes then undergo qualification and acceptance testing, at the integrated battery and electronics level.

Storage for 2-years at the optimum temperature and SOC. To minimize aging effects on the battery, the battery should be stored at a 50% SOC within a 0 to 10 °C temperature range. Because the BMS draws power from the battery, a charger (CSIST provided) will be required to maintain the appropriate charge level.

3e. Summarize the on-orbit processes and operational constraints for the hardware. (See Section 4.3 of EA-CWI-033 for an overview of the processes to be considered for on-orbit battery usage.) If the on-orbit processes and operational constraints are documented elsewhere, indicate where they are documented and provide a copy of the documentation.

The AMS-02 UPS boxes, containing the batteries, and integrated on the AMS-02 external payload. There is no crew interface for monitoring, re-charging, replacing or otherwise processing the batteries.

On-orbit use, 3- years, assume 100% SOC with the attached temperature profile, and the following profile:

- Four discharge/charge cycles per year using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - recharge to 100% SOC
- And one end of mission (after 3-year on-orbit ops) discharge using:
  - 8-hours of 40W external load
  - 1.5 hours of a 50W load
  - followed by the pulse (45Amps for 150ms, with a minimum battery voltage of 21.2V.

3f. Summarize the post-flight processing plan for the hardware. (See Section 4.4 of EA-CWI-033 for an overview of the steps to be completed as part of post-flight processing.) If the post-flight processing plan is documented elsewhere, indicate where it is documented and provide a copy of the documentation.

Not Applicable

Section 4 to be completed by EP5 Reviewer:

4. Evaluation Assessment:

4a. Does the design address:

Two-fault tolerance to catastrophic failure?	Yes ☐	No ☐	N/A ☐
Cell/battery gas generation mitigation or containment?	Yes ☐	No ☐	N/A ☐
Cell/battery electrolyte leakage mitigation or containment?	Yes ☐	No ☐	N/A ☐
Electrolyte toxicity memo obtained?	Yes ☐	No ☐	N/A ☐
Cell/battery electrical circuit protection?	Yes ☐	No ☐	N/A ☐
Cell/battery high temperature protection?	Yes ☐	No ☐	N/A ☐
Cell/battery materials compatibility and offgassing?	Yes ☐	No ☐	N/A ☐
Materials certification memo obtained?	Yes ☐	No ☐	N/A ☐

Are the battery requirements and hazard controls adequately addressed per JSC-20793 guidelines?
Yes ☐ No ☐ Date of review:
If no, describe additional hazard controls required for adequate control. If N/A, provide rationale.

4b. Is the cell screening or battery pack screening adequate per JSC-20793 guidelines?
Yes ☐ No ☐ Date of review:
If no, describe additional screening required for cells or packs.

4c. Does the pre-flight processing plan address: N/A ☐

Flight cell/battery pack qualification/certification testing?	Yes ☐	No ☐
Flight cell/ battery pack verification acceptance testing?	Yes ☐	No ☐
Installation of fresh, flight-acceptance tested cells/battery packs?	Yes ☐	No ☐
Maintaining storage conditions?	Yes ☐	No ☐

Is the pre-flight processing plan adequate per JSC-20793 guidelines and per Section 4.2 of EA-CWI-033?
Yes ☐ No ☐ Date of review:
If no, describe additional items to be added to the pre-flight processing plan.

4d. Do the on-orbit processing plan and operational constraints address: N/A ☐

Crew procedures to inspect and checkout hardware prior to usage?	Yes ☐	No ☐
Crew procedures for removing, discarding, and replacing non-rechargeable, depleted cells or batteries?	Yes ☐	No ☐
Crew procedure for removing, recharging, and storing rechargeable cells or batteries?	Yes ☐	No ☐
Crew procedures for stowage of equipment?	Yes ☐	No ☐
Crew procedures for documentation of anomalies?	Yes ☐	No ☐

Are the plans for on-orbit processing and operational constraints adequate per Section 4.3 of EA-CWI-033?
Yes ☐ No ☐ Date of review:
If no, describe additional items to be added to the on-orbit processing plan and operational constraints.

4e. Does the post-flight processing plan address: N/A ☐

Post-flight performance evaluation of hardware?	Yes ☐	No ☐	
Removal of cells and battery packs?	Yes ☐	No ☐	N/A ☐
Discarding or downgrading removed cells for non-flight use?	Yes ☐	No ☐	
Inspection of battery compartment and contacts?	Yes ☐	No ☐	
Hardware storage (minus cells and battery packs)?	Yes ☐	No ☐	

Is the post-flight processing plan adequate per Section 4.4 of EA-CWI-033?
Yes ☐ No ☐ Date of review:

If no, describe additional items to be added to the post-flight processing plan.

4f. Subsequent battery review held to verify:

4.f.1 Adequate hazard controls implemented? N/A ☐ Yes ☐ **Date of review:**
Comments from additional review:

4.f.2 Cell-screening or battery pack screening plan adequate? N/A ☐ Yes ☐ **Date of review:**
Comments from additional review:

4.f.3 Pre-flight processing plan adequate? N/A ☐ Yes ☐ **Date of review:**
Comments from additional review:

4.f.4 On-orbit processing plan and operational constraints adequate? N/A ☐ Yes ☐ **Date of review:**
Comments from additional review:

4.f.4 Post-flight processing plan adequate? N/A ☐ Yes ☐ **Date of review:**
Comments from additional review:

Section 5 to be completed by EP5 Reviewer:
5a. Evaluation Results: The results of the battery evaluation conducted for the hardware outlined in Section 2 are as follows: ☐ Battery design for use in the stated application is approved for the following purposes: ☐ Ground Testing ☐ Shuttle ☐ Space Station ☐ Russian Vehicles (specify) ☐ Other (specify) ☐ Battery design is not approved for the following reason(s): ☐ Evaluation request withdrawn by Hardware Point-of-Contact ☐ Hardware Point-of-Contact states requested modifications will not be incorporated ☐ Requested modifications could not be incorporated; new request for alternate hardware will be initiated by Hardware Point-of-Contact ☐ Other (specify)
5b. Approval of EP5 Battery Reviewer: ***Typed Name*** ***Signature*** ***Date***
Section 6 to be completed by Hardware Point-of-Contact:
6. Concurrence of Hardware Point-of-Contact: I concur with the results of the battery evaluation conducted for the hardware outlined in Section 2. Timothy J. Urban ***Typed Name*** ***Signature*** ***Date***