STATEMENT OF WORK (SOW)

FOR THE

ALPHA MAGNETIC SPECTROMETER – 02 (AMS-02)

UNINTERRUPTIBLE POWER SOURCE (UPS)

REV. Baseline

DATE:
5 March, 2003

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CONTENTS

Appendices

CHANGE LOG

Listed below is the current change level for this document. Upon receipt of a revision to the document from the TBD buyer or subcontract administrator, the subcontractor shall proceed with performance of the work, as changed.

REVISION LEVEL	DESCRIPTION	REVISION DATE
Basic	Original Issue	5 Mar., 2003

1.0 INTRODUCTION

1.1 SCOPE

The Alpha Magnetic Spectrometer-02 (AMS-02) program has a requirement for a subcontractor to be responsible for the fabrication and performance, qualification and acceptance testing (as described in Sec.4.2), and delivery of certain space-qualified battery assemblies including a Battery Management System (BMS) for use in conjunction with the Cryomagnet Self Protection (CSP) system. These battery assemblies and associated BMS are to provide the power to the AMS CSP during periods of AMS primary power outages. The battery assemblies and associated BMS hereinafter will be referred to as the Uninterruptible Power Source (UPS).

This Statement of Work (SOW) sets forth the minimum requirements for the UPS.

The subcontractor is responsible for the UPS conforming to and meeting all sections outlined in this SOW and delivering the types and quantities specified in section 7.0.

The required operational life of the UPS is one and a half years ground operation and three years in space onboard the International Space Station (ISS) as part of an external attached payload (additionally, up to 2 years of cold storage is foreseen). Detailed operational life requirements are specified in Appendix D: UPS Operational Life Requirements. The UPS shall withstand five launches and five landings.

1.2 BACKGROUND

This specification establishes the performance, design, manufacturing, and verification requirements for the Uninterruptible Power Source (UPS), hereinafter referred to as the UPS, to be used in the Alpha Magnetic Spectrometer-02 (AMS-02) program. The AMS-02 is a particle physics experiment scheduled for launch on the Space Shuttle Utilization Flight 4.1 (UF-4.1) and installation on the International Space Station (ISS).

The UPS requirements are specified herein by defining total UPS capabilities in terms of its performance and external interfaces.

1.3 PURPOSE

The UPS is a subsystem for the Cryomagnet Self Protection (CSP) system. The CSP includes all the functions that must continue to be active in the event of loss of the power feed to the Cryomagnet Avionics Box (CAB).

The purpose of the UPS is to supply power to these critical cryomagnet monitoring systems, and to quench detection and initiation electronics in the event of a power loss or loss of communications with the ISS. The UPS is designed to operate for a minimum of eight hours during an ISS power outage, and to supply the power to initiate a normal ramp down of the magnet if power or communications with the ISS are not restored by that time. Throughout this operational period the UPS must retain the capability to deliver a current pulse of 45 Amps minimum for a minimum duration of 150msec to the quench heaters for the initiation of a controlled magnet quench, in order to prevent damage to the magnet. Li-Ion cells have been selected for this application.

1.4 OPERATION

The UPS subsystem shall include two identical UPSs (nominal and redundant) consisting of the following three major subsystems:

a. Eight-cell battery pack

b. Battery Management System (BMS)

c. Battery Charger Assembly

The BMS performs all of the control functions to assure the proper operation, safety and reliability of the Li-ion battery pack during charging and discharging. The BMS monitors the individual cell voltages, the battery pack current and the battery pack temperature. The BMS utilizes this information to establish the State of Charge (SOC) to control the battery charging and also to initiate a safety shutdown in the event that a cell is operating outside of predetermined safety limits. The BMS assumes the ultimate responsibility for the health and safety of the battery pack.

The CSP Block Diagram is included in Figure 1.

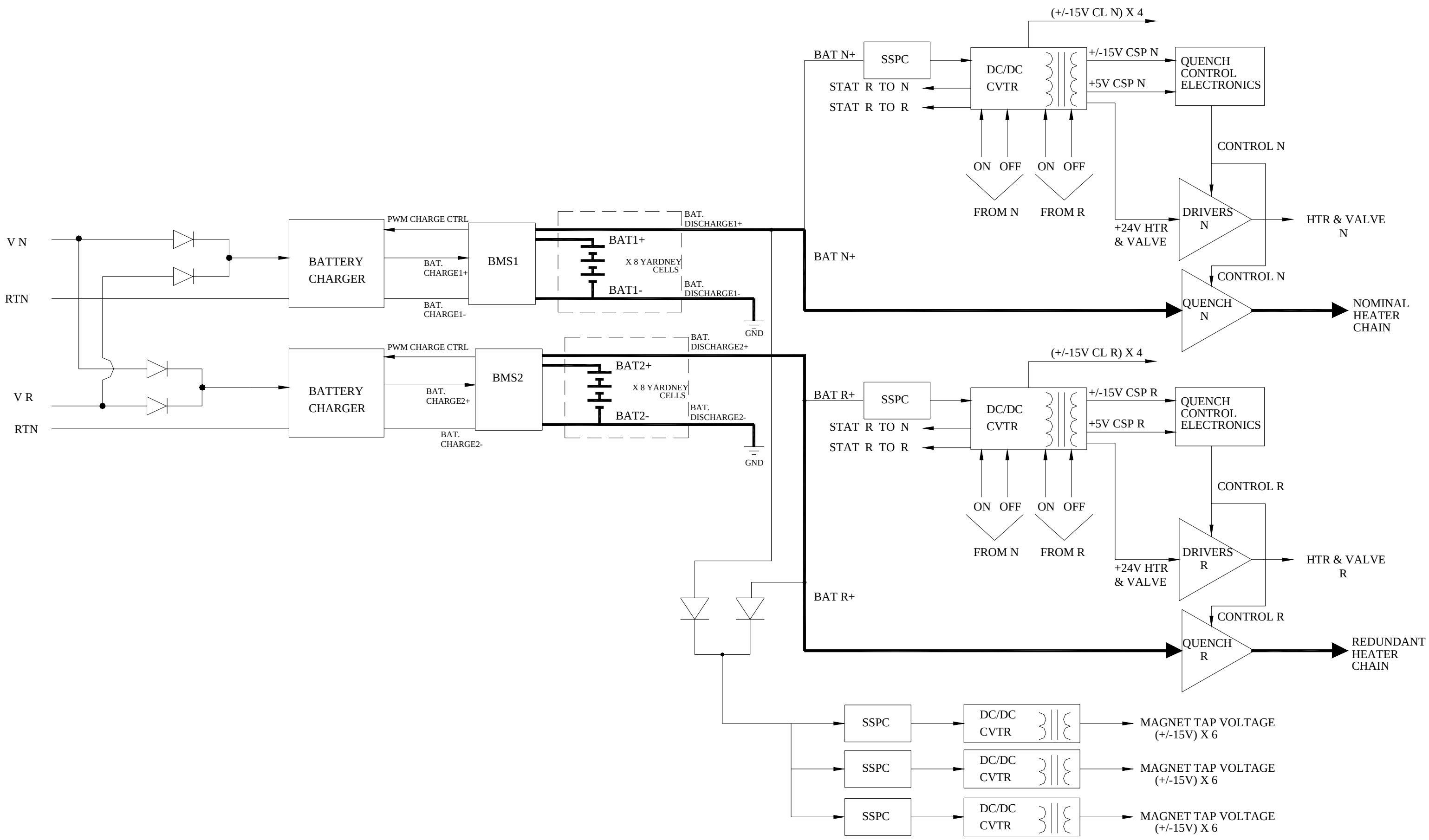

Figure 1: CSP Circuitry Block Diagram

2.0 ACRONYMS

A	Ampere
AMS	Alpha Magnetic Spectrometer
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BMS	Battery Management System
C	Centigrade
CAB	Cryomagnet Avionics Box
COTS	Commercial Off The Shelf
CRISA	Computadoras, Redes e Ingeniería, S.A. Madrid ,Spain
CSIST	Chung Shan Institute of Science & Technology, Taiwan
CSP	Cryomagnet Self Protection
DC	Direct Current
Deg	Degree
EBB	Electronic Breadboard
EDU	Engineering Development Unit
EEE	Electrical, Electronic, and Electromagnetic
FU	Flight Unit
ISS	International Space Station
JSC	Lyndon B. Johnson Space Center
KSC	Kennedy Space Centre
Lbs	Pounds
Li-ion	Lithium Ion
LMSO	Lockheed Martin Space Operations
m	milli
min	minute
MIL	Military
MIT	Massachusetts Institute of Technology
MIUL	Materials Identification and Usage List
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NSTS	National Space Transportation System
Psi	Pounds per Square Inch
PWM	Pulse Width Modulation
QU	Qualification Unit
SCA	Subcontract Administrator
SCL	Space Cryomagnetics Ltd., Oxfordshire, England
SEE	Single Event Effects
SOC	Stage of Charge
SOW	Statement of Work
SSP	Space Station Program
STD	Subcontractor Technical Directive
STM	Subcontractor Technical Monitor
STS	Space Transport System
TBD	To Be Determined
TBR	To Be Resolved
UPS	Uninterruptible Power Source

VDC	Volts Direct Current
W	Watt

3.0 APPLICABLE DOCUMENTS

The requirements of this SOW are derived in part from the following applicable documents. The applicable documents form a part of this specification to the extent specified herein. In cases of conflict between the SOW, the specifications, and these applicable documents, the SOW shall have first precedence and the specifications shall have second precedence over the applicable documents (latest revision).

JPG 5332.1	JSC Contamination Control Requirements Manual
NSTS 1700.7	Safety Policy and Requirements for Payloads Using the Space Transportation System
NSTS 1700.7	Safety Policy and Requirements for Payloads Using the International Space Station
SL-E-0002 (Book 3 Vol. 1)	Space Shuttle Specification Electromagnetic Interference Characteristics, Requirements for Equipment
SSP 30237	Space Station Electromagnetic Emission and Susceptibility Requirements
SSP 30245	Space Station Electrical Bonding Requirements
SSP 30423	Space Station Approved Electrical, Electronic and Electromechanical Parts List
SSP 30512	Space Station Ionizing Radiation Design Environment
NASA Letter #TA-92-038	Protection of Payload Electrical Power Circuits
JSC 28792	Alpha Magnetic Spectrometer-02 Structural Verification Plan for the Space Transportation System (STS) and the International Space Station (ISS)
MIL-STD-810	Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
JSC 20793	Manned Space Vehicle Battery Safety Handbook
ANSI/J-STD-001B	Requirements for Soldered Electrical and Electronic Assemblies
ASTM-E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
NSTS/ISS 13830 (Sec. 7.11)	Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle/International Space Station

ICD-2-19001	Shuttle Orbiter/Cargo Standard Interfaces
ANSI/ASQC Q9001	Quality Management Systems – Requirements

4.0 TASK DESCRIPTION

Yardney/Lithion Responsibilities: The subcontractor must manufacture a sufficient number of cells to satisfy the requirements of the deliverables plus test articles, perform the required screening and submit test data for review.

Upon concurrence, the subcontractor shall proceed with assembling five packages with eight matching cells each, including end-plates and brackets with the proper preload (1000 lbs) per Yardney/Lithion specifications (hereafter referred to as “bricks”).

In parallel with the cell manufacturing, testing and assembly, the subcontractor shall make any necessary design changes to the BMS design and proceed with the fabrication of five BMS units and spare modules as necessary to support this project.

Cell testing and screening requirements are delineated in Appendix A. BMS testing and screening requirements are delineated in Appendix C. The battery package supplier will be the Chung Shan Institute of Science & Technology, Taiwan (CSIST). Yardney personnel will be required for support of full battery testing at CSIST.

CSIST Responsibilities: The subcontractor shall design, fabricate, test, and deliver to the AMS program the space-qualified UPS, with exception of the chargers, capable of supplying the CSP power requirements during primary power outages that conforms to all sections of this SOW. The UPS shall be fabricated using Yardney INCP95/28/151 Li-ion cells. Table 1 summarizes the Yardney cell characteristics.

Cell Part Number	INCP95/28/151
Shape	Prismatic
Dimensions	95 mm (3.74") x 27.84 mm (1.096") x 139.7 mm (5.500")
Volume	.370 Liter (22.545 cu.in.)
Weight	900 g (1.982 lbs)
Cell Voltage	Nominal 3.6 V, Max 4.1V
Cell Capacity	28 A/h @ 25 ºC (Beginning of Life)
Energy Density	115 Wh/Kg (Beginning of Life)
Performance	Capable of meeting operational requirements defined in Appendix D.
Temperature Range: Charge and Discharge	–30 ºC to +50 ºC
Flight History	No, Mechanics Qualified for Expendable Launch Vehicle (ELV) flight Electrolyte qualified for aircraft application.
Random Vibration	Acceptance Level at 6.8 Grms, Qualification Acceptance Level at 10.7 Grms (Tests Meet JSC Requirements)

Table 1: Yardney Cell Characteristics

CSIST shall receive five bricks, along with the corresponding BMS systems. CSIST is to develop the battery packaging and all cabling and connectors required to connect to the CAB.

Emphasis must be placed on a reliable and efficient design/configuration without compromise to performance. All criteria must be ‘safety’ driven.

The various characteristics and specifications of the UPS are defined in subsequent parts of this section. The UPS functional block diagram is depicted in Figure 2.

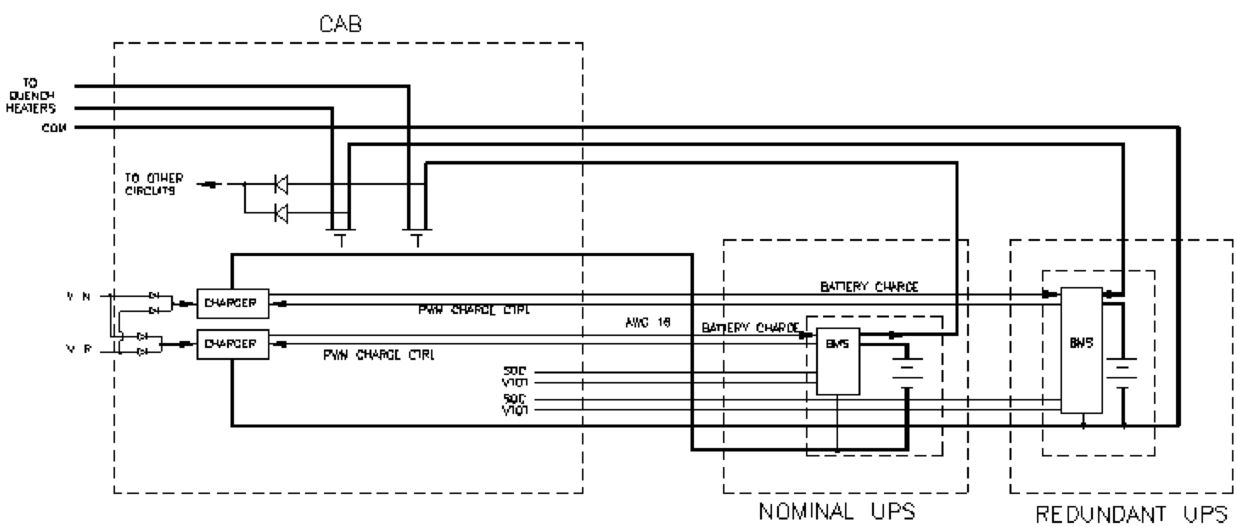

Figure 2: UPS Functional Block Diagram

Battery assembly testing and Screening requirements are delineated in Appendix B.

Computadoras, Redes e Ingeniería, S.A. Madrid ,Spain (CRISA, fabricators of the CAB) Responsibilities: CRISA shall be responsible for development of the charger within the CAB, and processing of the (2) telemetry signals , and the charger control signal, and will require complete definition of all interface signal characteristics to/from the BMS from Yardney/Lithion, Inc.

4.1 SPECIFICATIONS

4.1.1 ELECTRICAL

4.1.1.1 Voltage Requirements: The UPS batteries shall consist of 8 Yardney cells rated for a nominal 3.6 V and a maximum of 4.1 V at full charge. These cells shall be connected in series to supply an output voltage of 28.8 V nominal, and 32.8 V maximum. The batteries will be continuously connected to the charger via the BMS, so the battery charge shall be maintained at or near 100% SOC while power is available from the ISS.

Note: Yardney to determine best SOC to maintain batteries to ensure function throughout mission profile defined in Appendix D.

4.1.1.2 Power Requirements: The worst-case single event mission profile is defined as follows (worst case mission profile defined in Appendix D). Power is lost to the AMS experiment at time t. At this time, the battery must begin supplying the critical monitoring circuitry power and the watchdog timer power (estimated at 40W continuous by either UPS unit– TBR by CRISA). After 8 hours of this level of operation, the watchdog timer “times-out”, and the magnet begins a nominal ramp-down. During ramp-down, it is estimated that an additional 10W will be required from each UPS for one and one half hours (50W total). At anytime during this sequence, the UPS must have sufficient capacity to execute a quench, should a quench be detected and a commanded quench be initiated. The power profile for such an operation is illustrated in Figure 3.

Note: Requirements for battery operation beyond this point are TBD (Space Cryomagnetics Ltd., Oxfordshire, England (SCL)). The battery developer must work with SCL and CRISA to determine these requirements and determine the capabilities for battery operation, when a battery shut-down must occur to prevent over-discharge, and the proper magnet configuration at that time.

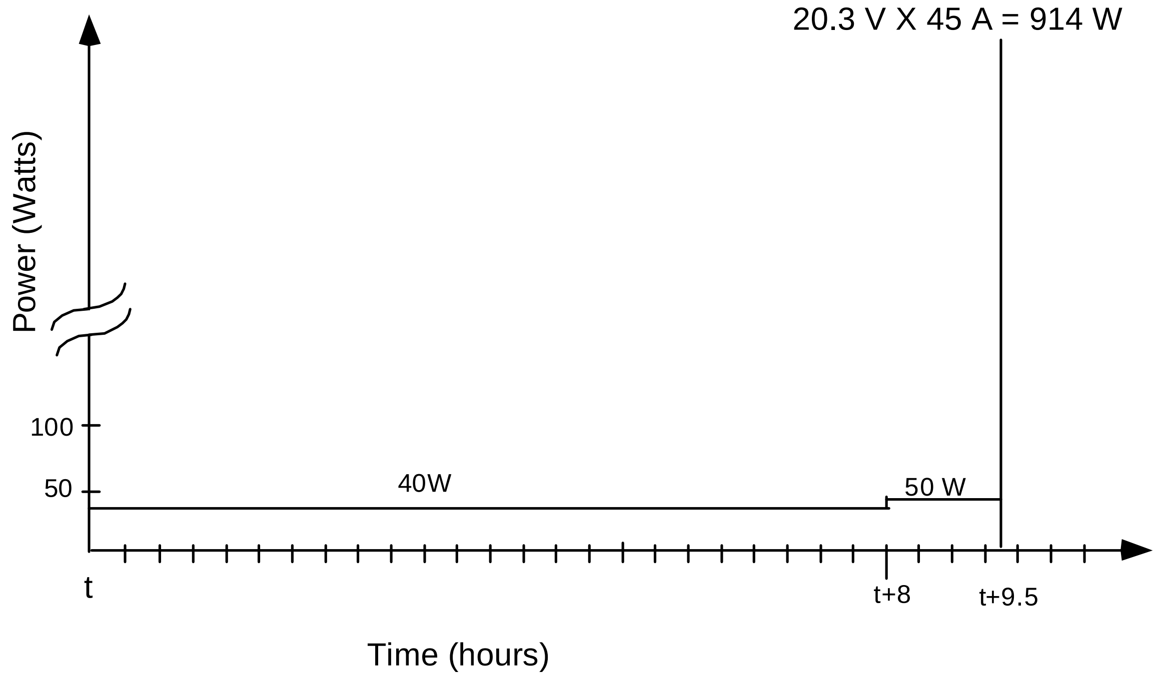

Figure 3: Power Profile (worst case)

4.1.1.3 Quench Requirements: To initiate a quench in the magnet, each bank of quench heaters must receive a minimum 45 A pulse at 12 V for 150 ms at the heaters inside the magnet case. This will cause the magnet to quench evenly, avoiding damage to the coils. To achieve this voltage at the quench heaters, the battery must maintain a substantially higher voltage due to losses from the internal resistance of the battery, the MOSFET switches which control the pulse, the wire resistance to the Vacuum Case, connector pin resistances and the wire resistance internal to the vacuum case.

Figure 4 illustrates the resistances that must be taken into account:

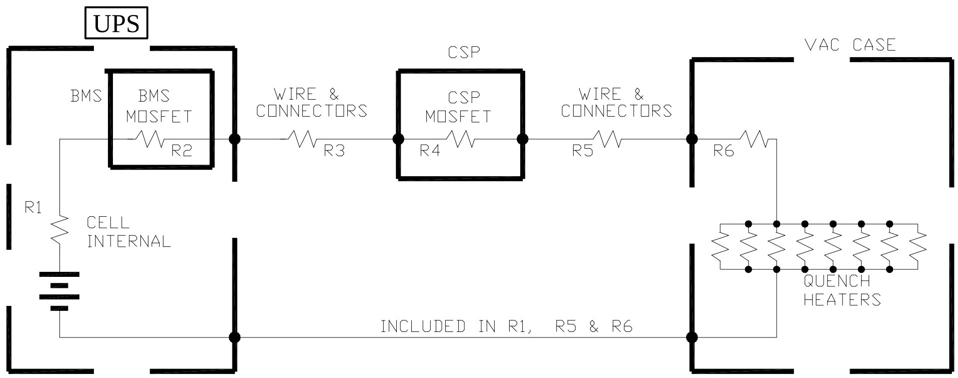

Figure 4: Circuit Resistance Diagram

R1 = 7.5mOhm x 8 =	60 mOhms	(accounted for in cell voltage)
R2 =	6 mOhms	
R3 =	21 mOhms	
R4 =	20 mOhm	
R5 =	46 mOhms	
R6 =	92 mOhms	
Total	245 mOhms	

The voltage drop due to resistances R2 through R6 at 45A is 8.3Volts (note: measurements of the cell voltage at terminals already takes cell internal resistance (R1) into account). Adding the 8.3Volts to the 12Volts required by the heaters yields 20.3V as the minimum battery voltage (at cell terminals) during the quench pulse. Yielding a minimum per cell voltage (measured at the terminals) of 2.54V (during 45A pulse). For conservatism a minimum cell voltage of 2.65V shall be used. The minimum UPS terminal voltage can be calculated by subtracting the voltage drop across the BMS (0.27V) from the combined cell voltage (8 X 2.65V), yielding 20.93V.

Note: The estimate for R_3 and R_5 is based on the use of two 16 awg wires in parallel to minimize line resistance and the associated connector pin resistance (consideration should be given to adding more parallel wires to decrease this line resistance), and add reliability, along with the parallel combination of MOSFET switches to minimize the resistances of R_2 and R_4. Every effort should be made to minimize this voltage drop as it can become the dominating feature. The CSP MOSFET switches are included in the CAB design.

4.1.1.4 Charger Requirements: The battery charger is to be supplied as part of the CAB design, and incorporated in the CAB.

The charger shall be connected to the battery/BMS/CSP continuously during operations. The charger shall consist of a current limited DC to DC converter with pulse width modulated (PWM) charger control input that shall be capable of an output voltage of at least 33.6 V (8 cells X 4.2 V) (TBR Yardney). The charger PWM control signal shall be provided by the BMS and will have a 500 ms period. The BMS shall control the charger 'on-off' time in accordance with battery assembly requirements. Details regarding the signal characteristics for this BMS output are to be supplied by Yardney/Lithion.

Note: The charger shall provide all the power to the CSP (30 to 40 W) continuously in addition to the power required to maintain battery charge (0 to 1.5 A). The BMS must sense the battery charge current only, and when no battery charge current is required, the charger must continue to output 28Vdc to the CSP.

The battery will include separate Charge and Discharge Cabling interfaces (see Figure 2).

4.1.1.5 Electrical Interfaces: Based on the information provided above, the following interfaces are required between the battery/BMS and the CAB.
Battery Charge Cabling
Battery Discharge Cabling (to monitor electronics and to Quench Heaters via the CAB)
Charger PWM Control Signal Wire
Battery Telemetry (To be processed by the CAB)

1) Battery Voltage (generated by the BMS Master Controller Board)
2) SOC (discrete signal that can be "set" to flag a predetermined SOC)

Note: Yardney/Lithion to work with CRISA to define signal characteristics for the Charger PWM Control Signal and the two telemetry parameters.

4.1.2 BMS SPECIFICATIONS:

4.1.2.1 BMS functional Block Diagram

The Battery Management System functional block diagram is shown in Figure 5.

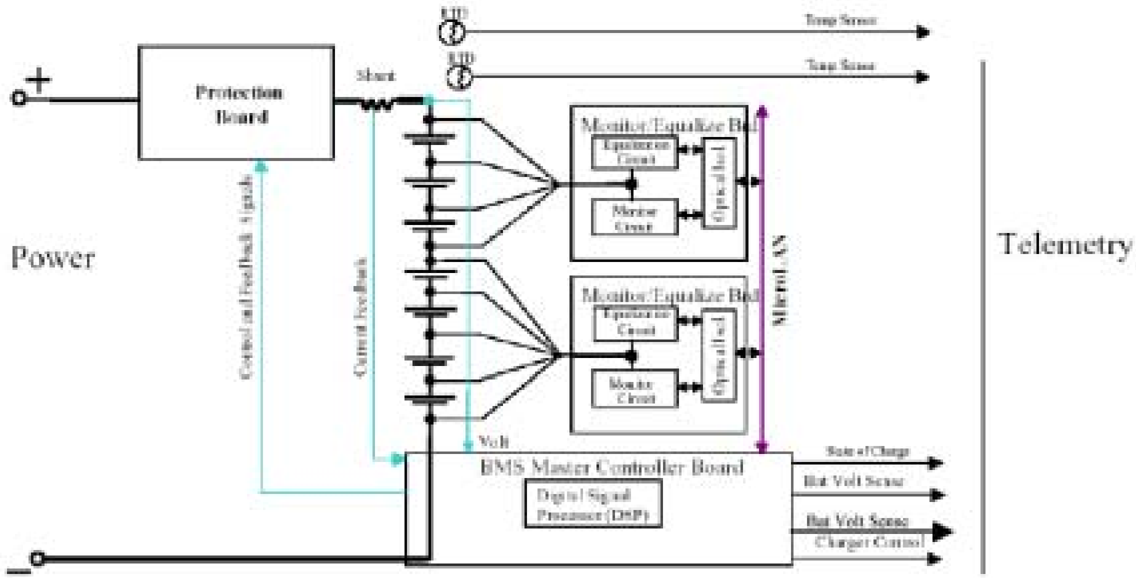

Figure 5: Battery Management System Functional Block Diagram

4.1.2.2 Master Controller 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 pack 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.

4.1.2.3 Monitor/Equalizer Board

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.

4.1.2.4 Protection/Regulator Board

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.

4.1.2.5 Charger Switch

The 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 MOSFETS to carry the battery load current. Upon the occurrence of a short circuit the protection switch will open within 100μsec (TBR) to isolate the battery from the short circuit condition.

4.1.2.6 System Safety Settings

Over Charge: If a cell charge exceeds 4.2V for more than 2 to 3 seconds, software shall disconnect the battery from the charger. Exceeding 4.3 V on a given cell for 100μsec will cause a hardware inhibit to pull the battery off-line.

Over Discharge: If a cell voltage drops below 2.5V for 3-4 seconds software shall disconnect the battery from the discharge circuitry. A drop below 2.15V for 200μsec will cause a hardware inhibit to disconnect the battery from the discharge circuitry.

Over Temperature: Exceeding 80 degC on a battery pack for 3-4 seconds will cause software to disconnect the battery from the Charger.

Over Current: A current draw of 80A for more than 2-3 seconds will cause a software inhibit to disconnect the battery from the discharge circuitry. A hardware inhibit will initiate if 170A is seen for 100μsec.

These inhibits are illustrated in Table 2.

Table 2: BMS Safety Inhibit Settings

Parameter	**Software Limit**	**Software Delay**	**Hardware Limit**	**Hardware Delay**
Over Charge	4.2V/cell	2-3 seconds	4.3V/cell	100 μsec
Over Discharge	2.5V/cell	3-4 seconds	2.15V/cell	200 μsec
Over Temperature	80°C	3-4 seconds	None	None
Over Current	80A	2-3 seconds	170A	100 μsec

Exceeding these limits will cause the BMS to pull the battery offline; however, the battery will return on-line at selected intervals to determine that the over-limit condition has been removed. If the condition still remains, the battery will go off-line again.

In the event of a loss of communication between BMS Subsystems, the BMS shall isolate the battery. The BMS shall not interpret a loss of charger output power as a fault condition. The BMS shall continue to deliver power to the load and monitor the health and status of the battery.

4.1.3 ELECTRICAL DESIGN REQUIREMENTS

4.1.3.1 Radiated Emissions

The BMS shall meet the radiated emission requirements of SL-E-0002, Space Shuttle Specification Electromagnetic Interference Characteristics, Requirements for Equipment, Book 3 Volume 1, Section 5.11, and the radiated emission requirements of SSP 30237, Space Station Electromagnetic and Susceptibility Requirement, Section 3.2.3.

4.1.3.2 Cable and Wire Harness Design

Conductors and wire harnesses shall be derated to safely operate under the maximum current allowed by the supply protection devices. Derating shall be per NASA Letter #TA-92-038, Protection of Payload Electrical Power Circuits.

4.1.4 THERMAL (TBR)

Cooling: Limited to radiation and conduction.

The UPS pulse requirements can be met between –25 degC and +50 degC. This should be the bounding range for the thermal environment. Care should be taken in determining the location of the UPS to ensure that these limits are not exceeded. CSIST shall define the final location of the UPS in conjunction with the STM and ETH personnel.

These thermal constraints must be evaluated further, based on the nominal mission requirements and UPS pulse capabilities.

The BMS thermal interface will be through all external surfaces utilizing radiation and through the mechanical interfaces utilizing conduction. Yardney/Lithion shall identify all heat dissipating components/assemblies, and heat sinking requirements and provide them to CSIST for incorporation into the battery package mechanical design. All internal power dissipating components shall have a low resistance thermal path to the base/mounting plate.

4.1.5 MECHANICAL

The UPS shall consist of two battery assemblies, each consisting of eight Yardney INCP95/28/151 cells and associated Battery Management System. The preferred packaging configuration for the cells is a one by eight layout as illustrated in Figure 6. This one by eight configuration would comprise a volume of 3.73” X 5.5” X 8.8” for the cells alone. The cells are to be delivered in packages of eight, as “bricks”, with end-plates and brackets by the vendor and loaded to the vendor specified 1000 lb load. This packaging allows for minor cell swelling of the individual cells while still maintaining a fixed volume for the package.

Yardney/Lithion to provide mechanical characteristics and drawings for the BMS and “bricks” to the customer, MIT.

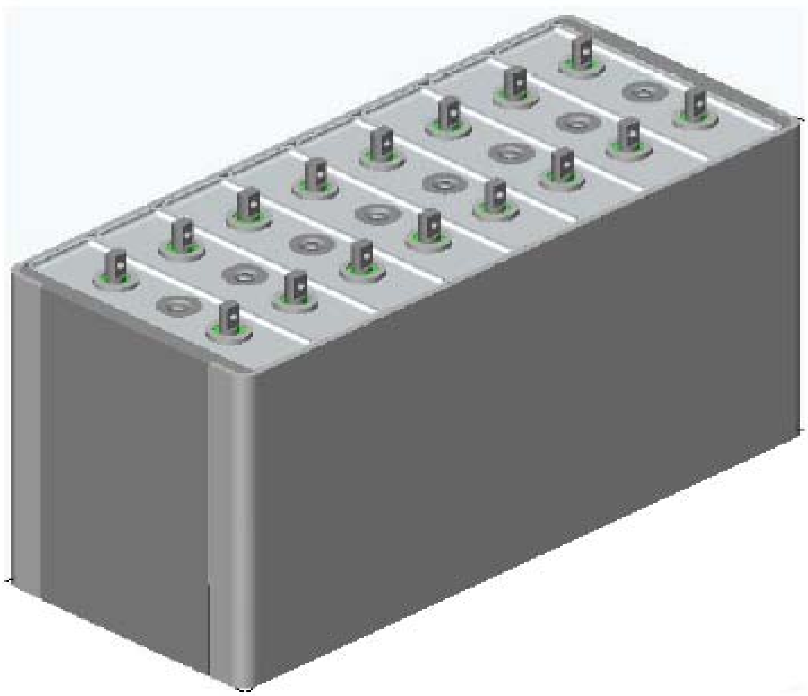

Figure 6: Proposed Battery Configuration

Additional volume will be required for the battery housing and the enclosed Battery Management System. For the purpose of identifying a potential location for the batteries, the following dimensions were used for each battery assembly: 7” by 10” by 7”. The proposed location based on these dimensions in illustrated in Figure 7.

Mechanical mating interfaces must meet the design requirements specified in JSC-28792 (Latest Rev), Alpha Magnetic Spectrometer-02 Structural Verification Plan for the Space Transportation System (STS) and the International Space Station (ISS).

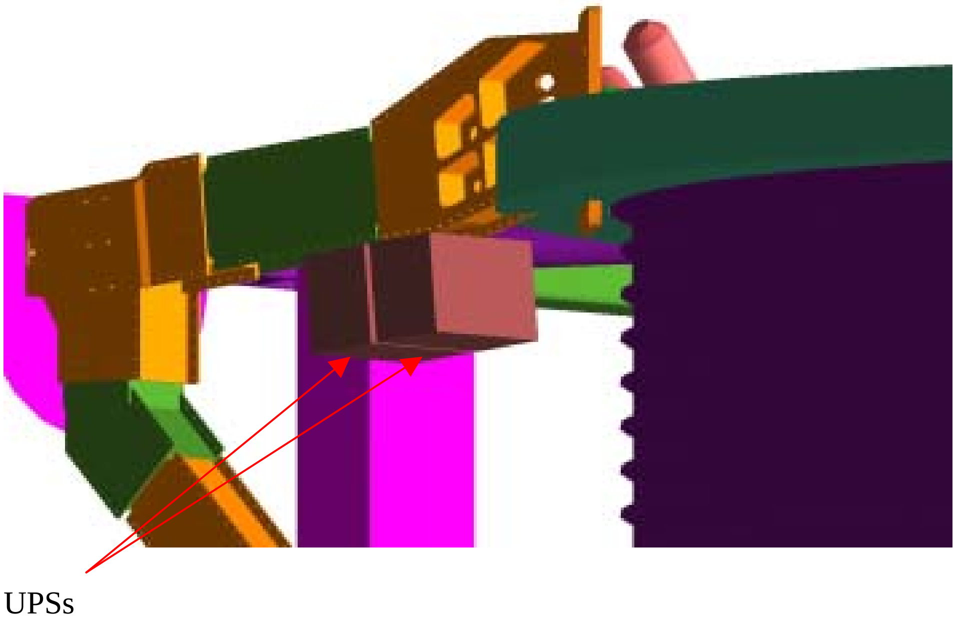

Figure 7: Proposed UPS Location

4.1.6 ENVIRONMENTAL

4.1.6.1 Long Term Storage

To minimize aging effects on the battery, the battery should be stored at a 50% SOC within a 0 to 10 degC temperature range. Because the BMS draws power from the battery, a charger (CSIST provided) will be required to maintain the appropriate charge level.

4.1.6.2 Thermal

Refer to section 4.1.4.

4.1.6.3 Pressure

4.1.6.3.1 Prelaunch Pressure Environment

The UPS shall be capable of operation when exposed to ambient pressures varying from 13.5 to 15.2 psia.

4.1.6.3.2 Ascent/Entry Pressure Environment

The UPS shall be compatible with the pressurization/depressurization rates for Ascent and Entry as illustrated in ICD-2-19001, Shuttle Orbiter/Cargo Standard Interfaces (Section 10.6). The maximum depressurization rate on launch is 0.455 psi/sec; the maximum pressurization on entry is 0.184 psi/sec.

4.1.6.3.3 <u>On-orbit Pressure Environment</u>

The UPS shall be capable of operation when exposed to on-orbit minimum pressure environment of 5.5 x 10 -12 psia (2.7 x 10 -10 Torr).

4.1.6.4 Humidity

4.1.6.4.1 <u>Transportation and Storage Humidity Environment</u>

The UPS shall meet specified performance following exposure in its transportation and storage configuration to 100 percent relative humidity.

4.1.6.4.2 <u>Prelaunch Humidity Environment</u>

The UPS in its prelaunch configuration, shall meet specified performance when exposed to 75 percent relative humidity.

4.1.6.4.3 <u>On-orbit Humidity Environment</u>

The UPS shall meet specified performance when exposed to an on-orbit minimum of 0 percent relative humidity.

4.1.6.5 Ionizing radiation

The UPS shall meet specified performance when exposed to the radiation dose environment and the nominal Single Event Effects (SEE) defined in SSP 30512. A radiation dose design margin of 2.0 shall be applied.

4.1.6.6 Magnetic Field

Static Magnetic Field: No more than 855 gauss, any orientation.

Estimates of the stray static magnetic field show that this will vary over a significant range in the volume reserved for the UPS. Detailed orientation and magnitude information is available to allow the vendor to determine best location of field sensitive components within the allocated volume.

The stray magnetic field will change from zero to the maximum static field value as the cryomagnet is charged. The field orientation will remain fixed. The field will drop to zero in approximately 4 seconds if the quench heaters fire, field orientation may vary due to eddy currents in the structure. The field will decay linearly for one and one-half hours during normal ramp-down to zero as the magnet energy is dissipated in the flywheel diodes, field orientation will then remain fixed.

4.1.6.7 Vibration

The BMS shall meet specified performance after exposure to the component random vibration workmanship screening test levels defined in Appendix A and B.

4.1.7 MATERIALS, PARTS, AND PROCESSES

Materials and processes used in the design and fabrication of the BMS and associated support hardware shall comply with NSTS 1700.7 Safety Policy and Requirements for Payloads Using the Space Transportation System, and NSTS 1700.7 ISS Addendum.

4.1.7.1 Electrical, Electronic, and Electromechanical (EEE) Parts

The use of electrical, electronic, and electromagnetic (EEE) parts per requirements of SSP 30423 and derating critieia are recommended. Commercial Off The Shelf (COTS) parts must meet the requirements of NSTS 1700.7 ISS Addendum, paragraphs 208.3 and 209.

Electronic hardware shall be designed to meet Section 6.0 Reliability requirements in a space ionizing radiation environment specified herein. Single Event Effects (SEEs) and total incident dose effects shall be considered.

4.1.7.2 Non–metallic materials

Non–metallic materials shall have low outgassing characteristics as defined by a total mass loss of < 1.0 percent and a volatile condensable material of < 0.1 percent when tested per ASTM–E595.

4.1.7.3 Cleanliness

As a minimum, the equipment shall be processed to the generally clean level per JPG 5322, JSC Contamination Control Requirements Manual.

4.1.7.4 Workmanship

BMS workmanship shall be comply with ANSI/J-STD-001B "Requirements for Soldered Electrical and Electronic Assemblies".

4.1.7.5 Restriction on Cadmium Usage

Use of cadmium and cadmium plating on BMS hardware is prohibited.

4.1.8 SAFETY

The UPS shall be designed in accordance with NSTS 1700.7 and NSTS 1700.7 ISS Addendum, and JSC 20793, Manned Space Vehicle Battery Safety Handbook. Its sub-system and components shall be designed or selected for minimum hazard to preclude or control hazards. The UPS shall be designed to ensure inherent safety through the selection of appropriate design features as fail-operational/fail-safe combinations and appropriate safety factors. The subcontractor shall provide the battery technical data identified in Section 7.11 of NSTS/ISS 13830C, Payload Safety Review and Data

Submittal Requirements for Payloads Using the Space Shuttle/International Space Station.

Hazards should be eliminated by design where possible. Damage control, containment, and isolation of potential hazards should be included in design considerations.
The minimum requirements for design safety are:

a. Fault tolerance - No combination of two failures or two operator errors shall result in a catastrophic hazard. No single failure or operator error shall result in a critical hazard.

b. Design for minimum risk - Hazards controlled by compliance with the technical requirements of NSTS 1700.7 and NSTS 1700.7 ISS Addendum, other than failure tolerance, are called Design for Minimum Risk. Examples are material compatibility, etc.

4.1.9 VERIFICATION

The verification phase of the project includes those activities performed to demonstrate the acceptability of a product to satisfy the requirements identified in this Document. Formal verification of performance characteristics for the full range of performance requirements are verified during qualification. Formal verification of workmanship, nominal performance, and physical requirements are verified during acceptance.

4.1.9.1 Methods

Verification methods are defined as follows:

a. Inspection is a method that determines conformance to requirements by the review of drawings, data, or by visual examination of the item using standard quality control methods.

b. Analysis is a process used in lieu of, or in addition to, other methods to ensure compliance to specification requirements. The selected techniques may include, but not be limited to, engineering analysis, statistics and qualitative analysis, computer and hardware simulations, and analog modeling. Analysis may also include assessing the results of lower level qualification activity. Analysis may be used when it can be determined that:

    1. Rigorous and accurate analysis is possible.
    2. Test is not cost effective.
    3. Verification by inspection is not adequate.

c. Similarity is the process of analyzing the specification criteria for hardware configuration and application for an article to determine if it is similar or identical in design, manufacturing process, and quality control to an existing article that has previously been qualified to equivalent or more stringent specification criteria. Special effort will be made to avoid duplication of previous tests from this or similar programs. If the previous application is considered similar, but not equal to or greater in severity, additional methods should concentrate on the areas of new or increased requirements.

d. Demonstration consists of a qualitative determination of the properties of a test article. This qualitative determination is made through observation, with or without special test equipment or instrumentation, which verifies characteristics such as human engineering features, services, access features, and transportability.

e. Test is a method in which technical means, such as the use of special equipment, instrumentation, simulation techniques, and the application of established principles and procedures, are used for the evaluation of components, subsystems, and systems to determine compliance with requirements. Test should be selected as the primary method when analytical techniques do not produce adequate results; failure modes exist which could compromise personnel safety, adversely affect flight systems or payload operation, or result in a loss of mission objectives. The analysis of data derived from tests is an integral part of the test program, and should not be confused with analysis as defined above.

4.1.9.2 Responsibility for Verifications

The suppliers are responsible for the performance of all verification activities. Yardney for verification of cells, bricks, and BMS; and CSIST for verification of complete battery packages.

4.1.10 RELIABILITY

The vendor shall be responsible for undertaking a thorough analysis of the design and for refining this as often as necessary to arrive at a fault tolerant design that must eliminate single point failure. The resulting analysis shall be presented for review for concurrence to manufacture.

The UPS shall comply with the relevant performance requirements for pressure, vibration, acceleration, power line noise and interference, EMC and ionizing radiation both for the International Space Station and for the Space Shuttle.

4.1.11 DESIGN LIFE

The required operational life of the UPS is one and a half years ground operation and three years in space onboard the International Space Station (ISS) as part of an external attached payload (additionally, up to 2 years of cold storage is foreseen). The UPS shall withstand five launches and five landings.

Detailed design life requirements are specified in Appendix D: UPS Operational Life Requirements.

4.1.12 QUALITY

The contractor shall establish, implement, document and maintain a quality system that ensures conformance to contractual requirements and meets the requirements of ANSI/ASQC Q9001, or an equivalent quality system model.

4.2 QUALIFICATION AND ACCEPTANCE TESTING REQUIREMENTS

Qualification and Acceptance testing requirements are delineated in the following 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

Appendix C: Qualification and Flight Screening of the Battery Management System for the AMS

5.0 TRAVEL REQUIREMENTS

The subcontractor shall propose travel requirements to be included in the cost. The subcontractor may be required to travel to Johnson Space Center, Houston to support Safety Reviews.

6.0 DATA REPORTING

During UPS development, the CSIST is required to submit sketches/drawings of the UPS block diagram, schematics and mechanical drawings as they are developed, for review by the customer and LMSO. The customer may also require the following formal reviews and retains the option to delay detailed design, manufacture and delivery respectively pending approval of each review stage:

- Preliminary Design Review (prior to start of detailed design)
- Critical Design Review (prior to start of manufacture)
- Delivery Review Board (prior to delivery)

Yardney shall supply Safety, Functional, and Acceptance Testing and Analysis and Inspection results to the customer for review.

7.0 DELIVERABLES

The following documentation is required:

1. Schematics
2. Detail Parts and Assembly drawings
3. Equipment Usage Log
4. Materials List

5. Limited Life Component List
6. Electrical and Structural Stress Analysis Report
7. EDU Test Procedures and Results
8. Space Qualification Verification Plan
9. Space Qualification Verification Procedure
10. Space Qualification Verification Report
11. Functional Test Procedures and Results
12. Flight Unit Acceptance Test Procedures
13. Flight Unit Acceptance Test Report

Yardney/Lithion, Inc. Specific: The cell and BMS developer/fabricator, Yardney/Lithion Inc., will provide a total of 40 cells. The cells shall be delivered as five packaged assemblies of eight cells each, "bricks". Additionally, a Battery Management Systems (BMS) must be included with each of the five bricks. Qualification and screening test requirements for the Cells are included in Appendix A, and Qualification and screening test requirements for the BMS are included in Appendix C.

All Qualification, Functional, and Acceptance test procedures and data are required at delivery.

Requirements for "unique" test equipment and hardware verification shall be provided to the customer.

CSIST Specific: The battery developer, CSIST, shall deliver two UPS flight units (FU) and a UPS flight spare, to ETH Zurich for integration with the AMS Experiment. All test data and reports must be included with the unit.

A UPS Qualification unit shall be produced to undergo the qualification testing specified in Appendix B. All test data and reports must be included with the unit.

An Engineering Development Unit (EDU) is to be developed using flight cells and BMS but need not be Flight Grade packaging. This unit is to be used to demonstrate the operation of the battery throughout the mission profile prior to development of the qualification and flight units.

CRISA Specific: CRISA shall provide access to an EBB (elegant Breadboard) with battery charger to verify the integrated system, which shall be performed with the EDU. CRISA shall also deliver (and support) one Flight CAB with its associated battery chargers.

8.0 CUSTOMER FURNISHED EQUIPMENT

The customer will not be required to furnish equipment during the fabrication and testing of the UPS.

9.0 SUBCONTRACTOR TECHNICAL MONITOR

The subcontractor technical monitor (STM) is a customer employee assigned to interface with the subcontractor. The STM is authorized to provide technical direction within the scope of the contract.

The STM is Paul Nemeth, Ph. 281-335-6706
FAX 281-335-2750

Mailing address: Lockheed Martin Space Operations
2400 NASA Rd. 1
Houston, TX. 77058

Appendix A:

Qualification and Flight Screening of Li-ion Cells for the AMS

Judith Jeevarajan
Lockheed Martin/ NASA-JSC/EP5
10/16/2002

1.0 PURPOSE and SCOPE

This document defines the testing required for qualification of the 28 Ah Li-ion cells for use in the Alpha Magnetic Spectrometer (AMS) Battery. The document also specifies the lot testing and acceptance/screening tests required for 100% of the flight lithium-ion cells.

2.0 CELL PROCUREMENT

The user shall provide for the procurement of all cells required for qualification and flight.

2.1 Quality Coverage

The screening of Lithium-Ion cells shall be carried out with quality coverage/approval. The contractor shall establish, implement, document and maintain a quality system that ensures conformance to contractual requirements and meets the requirements of ANSI/ASQC Q9001, or an equivalent quality system model.

3.0 PHYSICAL AND ELECTROCHEMICAL CHARACTERISTICS

Characteristics testing shall be performed on all (100 %) of the lithium-ion cells constituting the lot that includes the qualification and flight cells.

3.1 Physical Characteristics:

All cells shall be numbered and labeled. Dimensions and weight of all cells shall be recorded. Statistical information (average values and standard deviation) on the physical characteristics shall be provided. Visual inspection of the cells shall be made and notes on deformations and cracks or electrolyte leaks shall be recorded.

3.2 Electrochemical Characteristics:

The Open Circuit Voltage (OCV) and Closed Circuit Voltage (CCV) of the cells shall be measured and recorded.

The OCV of the cell should have values between 3.6 to 4.1 V. If the OCV of the cell is less than 3.6 V, a charge shall be performed on the cell using the charge protocol given in 3.3. Repeat the OCV test. The OCV of a fully charged cell should be 4.2 V. If the value of the OCV falls outside the specified range of 3.6 to 4.1 V, the NASA-JSC battery office shall be notified in writing.

Closed Circuit Voltage tests shall be performed with a 1.5 C current (example: 45 A or 0.093 ohms for a 30 Ah /4.1 V cell) for 30 seconds. Values of CCV below 2.6 V should be noted and the cells set aside. In the event that a cell has a CCV below 2.6 V, charge cell using the charge protocol given in 3.3 and repeat the CCV test. If the CCV is once again below 2.6 V, the cell shall be removed from the lot and the customer shall be notified in writing. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified in writing.

3.3 Charge/Discharge Cycle:

All cells shall undergo two charge/discharge cycles before they are subjected to the lot sample or screening tests listed below. Charging shall be performed using a C/5 current to 4.1 V and holding at constant voltage until the current falls to 50 mA. Discharge shall be at C/5 to a cutoff voltage of 2.6 V. The capacities of the cells shall be recorded. If the capacity of any cell during the second cycle is not greater than 95% of manufacturers specifications, the lot shall be a rejected lot (to be negotiated with customer), and the cell shall be removed from the lot and the customer shall be notified in writing. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified in writing.

3.4 Vacuum Leak Test:

The fully charged cells shall be weighed and placed in a vacuum chamber that is capable of holding approximately 0 psia pressure. The pressure of the chamber shall be taken down to approximately 0 psia at the rate of 8 psi per minute. The cells shall be held under this condition for six hours. The chamber shall be repressurized to 14 psia at the rate of 9 psi per minute. The cells shall be removed from the chamber and checked for any visual changes like cracks and leaks or venting. The cells shall be placed outside the chamber at ambient temperature for two hours and then weighed again. The difference in the weight of the cell should not be greater than 2 %.

One discharge/charge/discharge cycle shall be carried out on the cells. The capacity obtained from the second discharge shall be within ± 5 % of the capacity obtained in the second discharge test of 3.3 for that particular cell.

4.0 QUALIFICATION TESTS

The following tests shall be carried out on the Li-ion cells to determine the performance and safety characteristics of the cells.

4.1 Performance Test: Mission profile including pulse requirement.

4.2 Thermal Environment Test: Cells shall undergo ten charge/discharge cycles at the following temperatures. The temperatures tested shall be –25 ºC, 0 ºC, 20 ºC and 40 ºC. A different cell shall be used for each temperature test. Apply 45 A/150 msec pulses at 100 %, 50 % and 25 % SOC during discharge. Charge and discharge shall be as in Section 3.3.

4.3 Over Charge:

4.3.1 Overvoltage: One cell shall be charged to 5.0 V at C/5 rate and held at 5.0 V for 6 hours. Test shall be stopped if there is an occurrence. The cell shall be discharged at C/5 rate to 2.6 V.

4.3.2 **Fast charge:** One cell shall be charged at 3C rate to 4.1 V and the voltage maintained with current taper to 50 mA. The cell shall be discharged to 2.6 V at a C/5 rate.

4.3.3 **Overvoltage:** Perform an overcharge test on a fully charged cell by charging it with C/5 current for 50 minutes with a 12 V limit. The cell shall be discharged to 2.6 V at a C/5 rate.

4.4 Over Discharge

4.4.1 **Discharge into Reversal:** Discharge a fully charged cell down to 0 V and take it into reversal until 150 % of the original capacity has been removed from the cell. Charge and discharge cell to determine if the cell is in workable condition.

4.4.2 **Fast Discharge:** Discharge a fully charged cell down to 2.6 V using a 3 C current. Charge and discharge cell to determine if the cell is in workable condition.

4.5 **External Short Circuit:** Two fully charged cells shall undergo a short circuit test with a load of 10 mohm. If there is no occurrence, determine weight of cell after the test and perform one cycle of discharge/charge/discharge on the cell.

4.6 **Internal Short:** One fully charged cell shall be crushed or penetrated with a nail to simulate an internal short. If there is no occurrence, determine weight of cell after the test and perform one cycle of discharge/charge/discharge on the cell.

4.7 **Heat-to-vent:** Two fully charged cells shall be subjected to this test. The temperature of the chamber shall be raised at the rate of 2 ºC /minute. The temperature at which the cell vents shall be noted. The maximum temperature tested shall be 250 ºC. If there is no occurrence, determine weight of cell after the test. Perform one cycle of discharge/charge/discharge on the cell.

4.8 **Vibration:** Two fully charged cells shall be vibrated using the following spectrum for 15 minutes in each of the x, y and z axes. The OCV of the cells shall be recorded before vibration.

Frequency	Level
20 Hz	0.01 g^2/Hz
20-80 Hz	+3 dB/Octave
80-500 Hz	0.04 g^2/Hz
500-2000 Hz	-3 dB/Octave
2000 Hz	0.01 g^2/Hz
Overall	6.8 Grms

The OCV of the cells shall be continuously monitored or measured after each axis of vibration. The cells shall undergo a discharge/charge/discharge cycle to determine the capacity of the cells. The capacity obtained from the second discharge shall be within ± 5 % of the capacity obtained in the second discharge test of 3.3 for that particular cell.

4.9 Vent and Burst Pressure:

The vent pressure of the cells shall be determined on empty cells wherever available or on fully assembled cells. The burst pressure of the cell cans (empty or fully assembled) shall also be determined.

4.10 Thermal Cycle: Two fully charged cell shall undergo ten thermal cycles using the following protocol. Place cell in a thermal chamber and raise the temperature of the chamber to 50 ºC in one hour. The temperature shall be maintained for one hour. The chamber shall be lowered in temperature to –25 ºC within one hour. Repeat for 4 more cycles then bring the chamber to ambient temperature. Remove cells and check for leakage or deformation and cracks. Perform one set of discharge/charge/discharge to record the capacities of the batteries after the thermal cycle

5.0 SCREENING OF FLIGHT CELLS

Screening shall be performed on all (100 %) flight lithium-ion cells. Section 3.0 including the vacuum leak check will be carried out on all flight lithium-ion cells before the following tests are performed.

5.1 Charge:

All cells shall be charged using the protocol in Section 3.3.

5.2 Vibration:

The fully charged cells shall be vibrated using the vibration spectrum below for three minutes in each of the x, y and z axes.

Frequency	Level
20-80 Hz	+3 dB/octave
80-350 Hz	0.067 g^2/Hz
350-2000 Hz	-3 dB/octave

5.3 Discharge/Charge Cycles:

After vibration, one discharge step shall be performed on the cells at a C/5 current to a cutoff voltage of 2.6 V. Then, two additional full charge/discharge cycles shall be performed. Charging shall be performed using the protocol given in 3.3. Pass/fail criteria: the difference in OCV of the cell before and after vibration shall be within ± 5 %; the capacity shall be within ± 5 % of capacity obtained in test 3.3 for that particular cell. Lack of performance on the charge/discharge cycles will result in notification of the customer and a rejection of the cell. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified.

5.4 Storage of Lithium-ion Cells:

The lithium-ion cells shall be charged to 50 % and stored at temperatures between 0 to 10 °C.

5.5 Thermal Cycle: The cells shall undergo one and a half thermal cycles using the following protocol. Place cells in a thermal chamber and raise the temperature of the chamber to 50 ºC in one hour. The temperature shall be maintained for one hour. The chamber shall be lowered in temperature to –25 ºC within one hour, and maintained for one hour. The chamber shall then be raised to 50 ºC within one hour, and maintained for one hour. Bring the chamber to ambient temperature. Remove cells and check for leakage or deformation and cracks. Perform one set of discharge/charge/discharge to record the capacities of the cells after the thermal cycle.

6.0 REPORT

Four copies of the reports of the Qualification, Lot Sample Tests and the Flight Screening of Li-ion Cells shall be submitted to the customer. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) also receives copies of the reports.

Appendix B:

Qualification and Flight Screening of Li-ion Batteries for the AMS

Judith Jeevarajan
Lockheed Martin/ NASA-JSC/EP5
10/17/2002

1.0 PURPOSE and SCOPE

This document defines the testing required for qualification of the 28 Ah Li-ion battery for use in the Alpha Magnetic Spectrometer (AMS). The document also specifies the lot testing and acceptance/screening tests required for 100% of the flight lithium-ion batteries.

2.0 BATTERY PROCUREMENT

The user shall provide for the procurement of all batteries required for qualification and flight.

2.1 Quality Coverage

The screening of flight batteries shall be carried out with quality coverage/approval. . The contractor shall establish, implement, document and maintain a quality system that ensures conformance to contractual requirements and meets the requirements of ANSI/ASQC Q9001, or an equivalent quality system model.

3.0 PHYSICAL AND ELECTROCHEMICAL CHARACTERISTICS

Characteristics testing shall be performed on all (100 %) of the lithium-ion batteries constituting the lot that includes the qualification and flight batteries.

3.1 Physical Characteristics:

All batteries shall be numbered and labeled. Dimensions and weight of all batteries shall be recorded. Statistical information (average values and standard deviation) on the physical characteristics shall be provided. Visual inspection of the batteries shall be made and notes on deformations and dents shall be recorded.

3.2 Electrochemical Characteristics:

The Open Circuit Voltage (OCV) and Closed Circuit Voltage (CCV) of the batteries shall be measured and recorded.

The OCV of the batteries should have values between 28.8 to 32.8 V. If the OCV of the battery is less than 28.8 V, a charge shall be performed on the battery using the charge protocol given in 3.3. Repeat the OCV test. The OCV of a fully charged battery should be 32.8 V. If the value of the OCV falls outside the specified range of 28.8 to 32.8 V, the customer shall be notified in writing. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified in writing.

Closed Circuit Voltage tests shall be performed with a 1.5 C current (example: 45 A or 0.73 ohms for a 30 Ah /32.8 V battery) for 30 seconds. Values of CCV below 20.8 V should be noted and the batteries set aside. In the event that a battery has a CCV below 20.8 V, charge battery using the charge protocol given in 3.3 and repeat the CCV test. If the CCV is once again below 20.8 V, the battery shall be removed from the lot and the customer shall be notified in writing. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified in writing.

3.3 Charge/Discharge Cycle:

All batteries shall undergo two charge/discharge cycles before they are subjected to the lot sample or screening tests listed below. Charging shall be performed using a C/5 current to 32.8 V and holding at constant voltage until the current falls to 50 mA. Discharge shall be at C/5 to a cutoff voltage of 24.0 V. The capacities of the batteries shall be recorded. If the capacity of any battery during the second cycle is not greater than 95% of manufacturers specifications, the lot shall be a rejected lot, and the customer shall be notified in writing. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified.

3.4 Vacuum Leak Test:

The fully charged batteries shall be weighed and placed in a vacuum chamber that is capable of holding approximately 0 psia pressure. The pressure of the chamber shall be taken down to approximately 0 psia at the rate of 8 psi per minute. The batteries shall be held under this condition for six hours. The chamber shall be repressurized to 14 psia at the rate of 9 psi per minute. The batteries shall be removed from the chamber and checked for any visual changes like cracks and leaks or venting. The batteries shall be placed outside the chamber at ambient temperature for two hours and then weighed again. The difference in the weight of the battery should not be greater than 2 %.

One discharge/charge/discharge cycle shall be carried out on the batteries. The capacity obtained from the second discharge shall be within $\pm$ 5 % of the capacity obtained in the second discharge test of 3.3 for that particular battery.

4.0 QUALIFICATION TESTS

The following tests shall be carried out on the Qualification Unit battery to determine the performance and safety characteristics.

4.1 Performance Test: Mission profile including pulse requirement at ambient temperature. Monitor leakage current drawn by circuitry to monitor battery voltage during non-operational periods.

4.2 Thermal Environment Test: Battery shall undergo ten charge/discharge cycles at the following temperatures. The temperatures tested shall be –25 ºC, 0 ºC, 20 ºC and 40 ºC. Apply 45 A/150 msec pulses at 100 %, 75 %, 50 % and 25 % SOC during discharge. Charge and discharge shall be as in Section 3.3.

4.3 Overcharge:

4.3.1 Overvoltage: The battery shall be charged to 40.0 V at C/10 rate and held at 40.0 V for 6 hours. Test shall be stopped if there is an occurrence. The battery shall be discharged at C/5 rate to 20.8 V. (The BMS should protect the battery from going into an overvoltage condition by the activation of the appropriate protective features). The test shall be considered successful when proper operation of the BMS inhibits is verified.

4.3.2 Fast charge: The battery shall be charged at 3C rate to 32.8 V and the voltage maintained with current taper to 50 mA. The battery shall be discharged to 20.8 V at a C/5 rate.

4.3.3 Overvoltage: Perform an overcharge test on a fully charged battery by charging it with C/10 current for 50 minutes with a 12 V limit. The battery shall be discharged to 20.8 V at a C/5 rate. (The BMS should protect the battery from going into an overvoltage condition by the activation of the appropriate protective features). The test shall be considered successful when proper operation of the BMS inhibits is verified.

4.4 Overdischarge

4.4.1 Discharge into Reversal: Discharge a fully charged battery down to 0 V and take it into reversal until 150 % of the original capacity has been removed from the battery. Charge and discharge battery to determine if the battery is in workable condition (The BMS should protect the battery from going into an undervoltage condition by the activation of the appropriate protective features). The test shall be considered successful when proper operation of the BMS inhibits is verified.

4.4.2 Fast Discharge: Discharge a fully charged battery down to 20.8 V using a 3 C current. Charge and discharge battery to determine if the battery is in workable condition.

4.5 External Short Circuit: The fully charged battery shall undergo a short circuit test with a load of 50 mohm. If there is no occurrence, determine weight of battery after the test and perform one cycle of discharge/charge/discharge on the battery. (The BMS should protect the battery from being externally shorted by the activation of the appropriate protective features). The test shall be considered successful when proper operation of the BMS inhibits is verified.

4.6 Thermal Cycle: The fully charged battery shall undergo twenty-four (24) thermal cycles using the following protocol. Place battery in a thermal chamber and raise the temperature of the chamber to 50 ºC in one hour. The temperature shall be maintained for one hour. The chamber shall be lowered in temperature to –25 ºC within one hour. Repeat for 23 more cycles then bring the chamber to ambient temperature. Remove batteries and check for leakage or deformation and cracks. Perform one set of discharge/charge/discharge to record the capacities of the batteries after the thermal cycle.

4.7 Vibration: Two fully charged batteries shall be vibrated using the following spectrum for 15 minutes in each of the x, y and z axes. The OCV of the batteries shall be recorded before vibration.

Frequency	Level
20 Hz	0.01 g^2/Hz
20-80 Hz	+3 dB/Octave
80-500 Hz	0.04 g^2/Hz
500-2000 Hz	-3 dB/Octave
2000 Hz	0.01 g^2/Hz
Overall	6.8 Grms

The OCV of the batteries shall be continuously monitored or measured after each axis of vibration. The batteries shall undergo a discharge/charge/discharge cycle to determine the capacity of the batteries. The capacity obtained from the second discharge shall be within $\pm$ 5 % of the capacity obtained in the second discharge test of 3.3 for the battery.

5.0 SCREENING OF FLIGHT BATTERIES

Screening shall be performed on all (100 %) flight lithium-ion batteries. Section 3.0 including the vacuum leak check will be carried out on all flight lithium-ion batteries before the following tests are performed.

5.1 Charge:

All batteries shall be charged using the protocol in Section 3.3.

5.2 Vibration:

The fully charged batteries shall be vibrated using the vibration spectrum below for <u>one minute</u> in each of the x, y and z axes.

Frequency	Level
20-80 Hz	+3 dB/octave
80-350 Hz	0.067 g^2/Hz
350-2000 Hz	-3 dB/octave

5.3 Discharge/Charge Cycles:

After vibration, one discharge step shall be performed on the batteries at a C/5 current to a cutoff voltage of 20.8 V. Then, two additional full charge/discharge cycles shall be performed. Charging shall be performed using the protocol given in 3.3. Pass/fail criteria: the difference in OCV of the battery before and after vibration shall be within ± 5 %; the capacity shall be within ± 5 % or greater than 95 % of capacity obtained in test 3.3 for that particular battery. Lack of performance on the charge/discharge cycles will result in notification of the customer and a rejection of the battery. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) is notified.

5.4 Storage of Lithium-ion Batteries:

The lithium-ion batteries shall be charged to 50 % and stored at temperatures between 0 to 10 °C.

5.5 Thermal Cycle:

The batteries shall undergo eight (8) thermal cycles using the following protocol. Place batteries in a thermal chamber and raise the temperature of the chamber to 50 ºC in one hour. The temperature shall be maintained for one hour. The chamber shall be lowered in temperature to –25 ºC within one hour. Repeat for 7 more cycles then bring the chamber to ambient temperature. Remove batteries and check for leakage or deformation and cracks. Perform one set of discharge/charge/discharge to record the capacities of the batteries after the thermal cycle.

6.0 REPORT

Four copies of the reports of the Qualification, Lot Sample Tests and the Flight Screening of Li-ion Batteries shall be submitted to the customer. The customer shall be responsible for ensuring that the NASA-JSC Battery Office (EP5) also receives copies of the reports.

Appendix C:

Qualification and Flight Screening of the Battery Management System for the AMS

The following tests shall be carried out on all the Battery Management Systems (BMSs) to determine the performance and safety characteristics prior to delivery.

1 **Performance Test:** All BMSs shall undergo a Mission profile test (at ambient temperature) including pulse requirement as specified in Section 4.1.1.2. Monitor leakage current drawn by circuitry to monitor battery voltage during non-operational periods

2 **Thermal Cycling Test**: All BMSs shall undergo one and a half thermal cycles using the following protocol. Place BMS in a thermal chamber, perform a functional test at ambient to verify all BMS system safety settings and inhibits as specified in Section 4.1.2. Raise the temperature of the chamber to 85ºC. Upon equipment stabilization, maintain the chamber temperature for one-hour minimum. Perform a function test to verify all BMS safety settings and inhibits. The chamber shall be lowered in temperature to –40 ºC. This temperature shall be maintained for one hour. Perform a functional test to verify all BMS safety settings and inhibits. Raise the temperature of the chamber again to 85ºC and maintain this temperature for 1 hour. Perform a function test to verify all BMS safety settings and inhibits. Bring the chamber to ambient temperature and allow the temperature to stabilize for one hour. Perform a function test to verify all BMS safety settings and inhibits.

Appendix D:

UPS Operational Life Requirements

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

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) using the worst case temperature from the Upper Trunnioun Bridge (USS.20200) profile, Figure 1.

The worst-case temperature profile at the battery mounting location is shown in Figure 1.

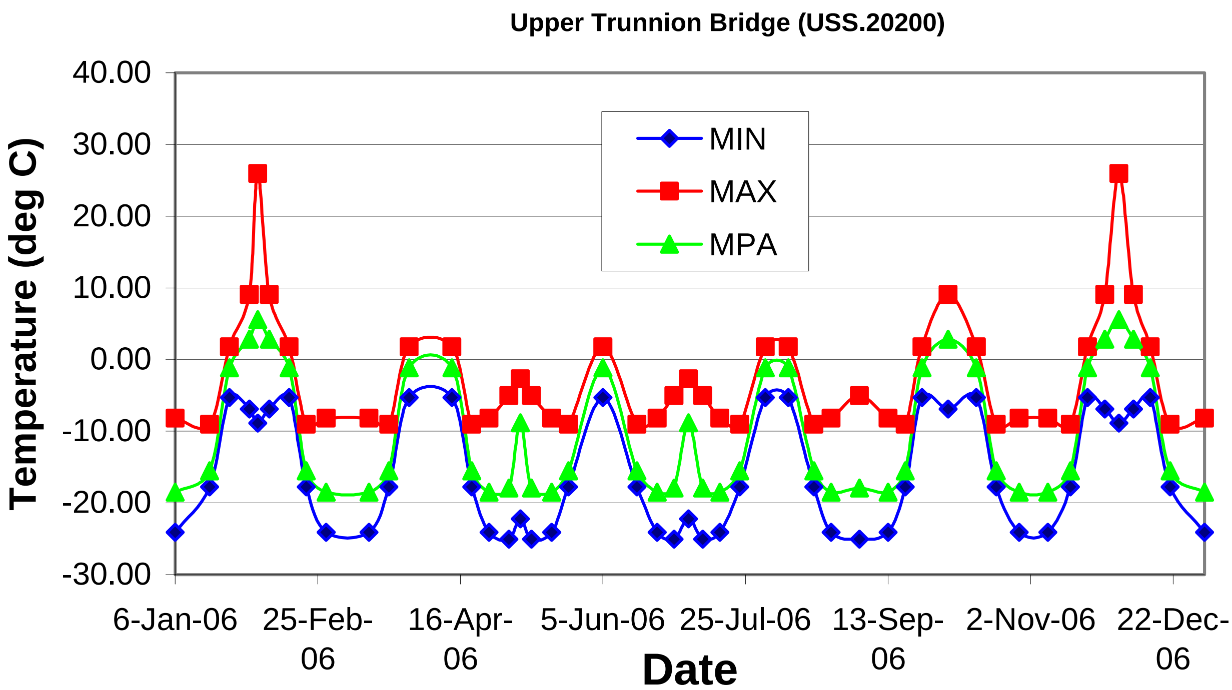

Figure 1: Predicted temperature profile for mounting location of battery

The battery must be capable of meeting these requirements with minimal aid from passive thermal design, heaters (if required), and good electrical design.