SPACE SCIENCE LABORATORY UNIVERSITY OF CALIFORNIA, BERKELEY	**THEMIS MINT PLANS**	
TITLE : **THEMIS PLAN for BATTERY MAINTENANCE and OPERATIONS**		DOC #: THM-MINT-PROC-054 Rev: D

REVISION DATE: May 24, 2006 APPROVALS ENG : ________________________ DATE __________ QA : ________________________ DATE __________ MSE : ________________________ DATE __________ PM : ________________________ DATE __________	REVISIONS:
1.0 INTRODUCTION, 2.0 BATTERY HANDLING DURING INTEGRATION AND TEST, 3.0 SHIPMENT, 4.0 STORAGE, 5.0 POWER SYSTEM EGSE, 6.0 EGSE/PROBE CONFIGURATION, 7.0 FINAL CHECKOUT AND PREPARATION FOR LAUNCH. APPENDIX A: BATTERY CHARGING SCHEMATIC.	

1. Introduction.

This document describes the plan for operating and maintaining the Lithium-Ion batteries used on the THEMIS probes. The first Probe is delivered to UCB from Swales with an Engineering Model (EM) battery, which is swapped with a flight battery after environmental testing. The subsequent four Probes are all delivered to UCB with flight batteries integrated. This battery plan is based on information obtained from the following documents, as well as direct consultations with the battery manufacturer, AEA Technology.

2. Reference Documents.

- THEMIS Li-Ion Design Description (AEA Technology, THMIS-AEA-RP-0005)
- THEMIS Li-Ion Battery User Manual and Design Description (AEA Technology, THMIS-AEA-MA-0039)
- THEMIS Li-Ion Electrical Analysis Report (AEA Technology, THMIS-AEA-RP-0014)
- THEMIS Battery Interim Charge/Discharge Procedure (Swales Aerospace, SAI-PROC-1558)
- THEMIS Battery Handling Memo (Swales Aerospace, SAI-TM-2647)
- THEMIS Launch Site Battery Processing (Swales Aerospace, SAI-TM-2827)
- THEMIS Power-Up/Power-Down Procedure (Swales Aerospace, SAI-PROC-1557)
- THEMIS Battery Rack Users Guide (Swales Aerospace)
- Joint 45 SW/SE and 30 SW/SE Interim Policy Letter Regarding EWR 127-1 Requirements for Li-Ion Batteries

3. Objective.

The purpose of this plan is to ensure safe operation of the battery and to preserve battery capacity prior to launch. Worst-case conditions during storage, shipping, integration and test, and launch site processing have been used in the Battery Electrical Analysis Software Tool, BEAST, to determine a battery fade estimate. This fade estimate was used to validate the battery capability over the mission lifetime. Following this plan will ensure that the fade analysis assumptions remain valid for the ground operations phase. The fade estimate from THMIS-AEA-RP-0014 for Integration and Test and Ground Operations is shown in Figure 1-1 below, with assumptions provided in the corresponding table.

In addition, it should be noted that the existing capacity fade estimate of 7% is conservative and could be reduced by: controlling the battery storage and testing thermal environment; limiting long periods of storage (over 4 days) at high SoC; and minimizing the quantity and severity of test on the ground (i.e. minimize time at high State of Charge (SoC), minimize charge/discharge rates, and minimize Depth of Discharge (DoD)). Whenever possible the battery will be kept at 20ºC or lower.

Phase	1	2	3
Phase Type	Operational	Non-Operational	Non-Operational
Temperature	25	25	25
Duration (Days)	50	133	365
Number of Cycles	50	0	0
DoD (%)	100	0	0
SoC (%)	50	100	10
	Test Cycles	Test non operational	Storage
	6 months		1 Year

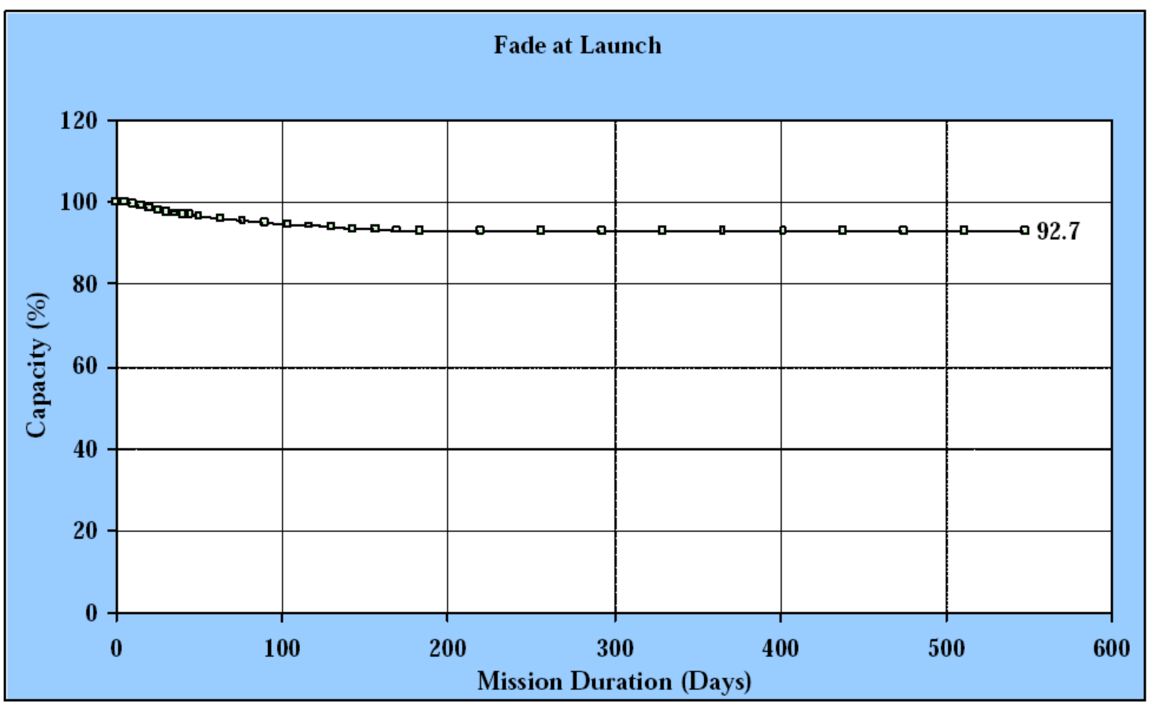

Figure 1-1: AEA Technology Fade Estimate for Ground Operations

2. Battery Handling During Integration and Test

2.1 Charging Safeguards and Procedure

2.1.1 Charging and Discharging

Charging/discharging the battery is done routinely during I&T when the Probe is set to Battery/SAS (Solar Array Simulator), or Battery/DPC (umbilical) operation. See normal operations section below. The typical probe load with all instruments on is 0.9A, close to the C/10, 1.2A desired. The maximum probe load with transponder on is approximately 1.7A. Additional current draw from the heaters is possible only during Thermal Vacuum testing.

During all Probe-level I&T activities, the linear shunt circuit is automatically activated whenever the battery voltage reaches the target voltage of 33.6V, sinking current not used by the loads away from the bus. Safe spacecraft operating voltage of approximately 25V, not the battery limit, sets the lower battery voltage used during I&T.

Note: AEA Technology recommends

- Charge/discharge rate of C/10 (1.2A), although up to 1C (12A) is acceptable; and
- Charge/discharge should be limited to between 33.6V and 20.0V.

2.1.2 State of Charge

During I&T activities, the battery will typically be between 50-70% SoC (31V to 32V, see Figure 3-1 below) as described in the normal operations section below. For transportation, the battery shall be discharged to <50% SoC. The AEA fade calculation assumes a non-op 100% SoC and 50 cycles to a 50% SoC. Battery SoC is constantly monitored via the ITOS system and a file log is maintained throughout all activities.

Note: AEA Technology recommends:

- Battery should not remain at high SoC for more than 6 days; and
- Batteries should be stored with <5% SoC

Prior to integration of the Probe with the Instruments, the batteries are stored at <5% SoC at Swales. The AEA fade calculation assumes storage at 10% SoC.

2.1.3 Protection Against Over-Voltage and Short Circuit Protection

100% SoC for the THEMIS battery is 33.6 Volts. The first line mechanism for not overcharging the battery is ensuring that the power systems shunts are always installed whenever the probe is powered by following the guidelines for Power/EGSE configuration above. Specifically, when a side solar panel is not installed, the C3038 Octopus harness must be connected.

In addition, the battery has built-in over voltage protection. Each cell contains a disconnect mechanism if that disconnects a cell should it charge beyond 4.8V, and the cells are matched to inhibit voltage imbalance between cells or overcharging of one cell.

Over-discharging is not a hazardous operation for this battery, contrary to other battery chemistries. Over-discharge tests show that this form of abuse may increase the internal resistance of the cells but does not result in a hazardous event.

The first line mechanism against short-circuiting the battery is installation of a Battery Fuse Plug, which is used at UCB during preliminary Instrument Integration. The Fuse Plug is removed during final close-out, after the Instruments have been integrated and prior to environmental test.

In addition, the battery has built-in short circuit protection. Each cell has a Positive Temperature Coefficient (PTC) polymer current limit device fitted to the top cap. This protects against over-current by temporarily increasing the in-line resistance as it expands thermally.

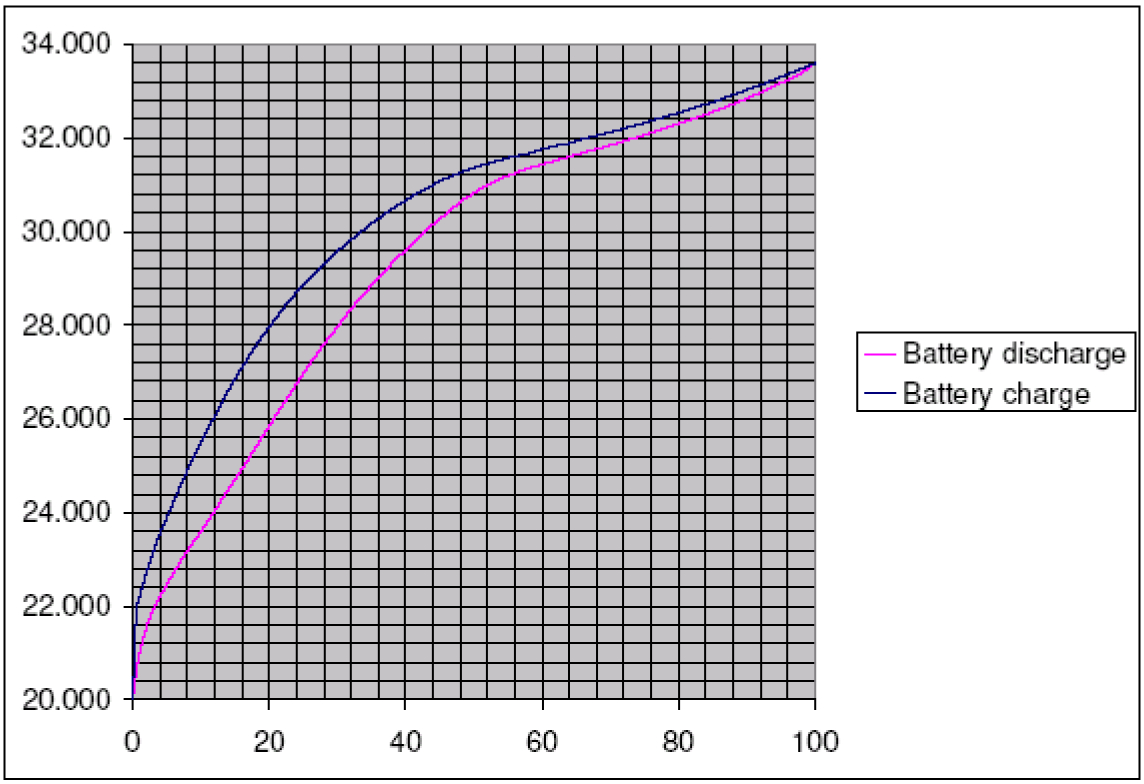

Figure 3-1: Battery Voltage versus SoC (%).

2.2 Operations During Integration

THM-MINT-PROC-010 Probe Power On/ Off Procedure provides the normal power on procedure for the THEMIS Probe. Unless otherwise noted for a specific test, the Probe shall always be run in the SAS/Battery or DPC/Battery configuration as opposed to being run off of the DPC without the battery connected. An ITOS script (**baupoweron.proc**) has been created to bring the Probe up in a safe power configuration. The script steps through the following sequence:

1. Brings up the system on DPC with the battery disconnected. Operator input for initial conditions of the DPC should be Battery Voltage plus approximately 4V and 1750mA.
2. Runs script (**dpcadjust.proc**) to match the DPC voltage and measured battery voltage.

3. Closes battery relay once voltages are matched and current is not flowing through the battery relay.

If running in SAS/Battery configuration, each of the four SAS power supplies (representing the four Solar Array strings) shall be set to 0.33A in constant current mode when the battery is below 70% SoC (<32V). This simulates the current expected to be provided by the Solar Arrays on-orbit. When the battery is above 32V, the SAS current shall be set lower than 0.33A or operations should be switched to use the battery only. If running in DPC/Battery configuration, the DPC shall be set to 32V plus the voltage drop determined (approx. 4V typ.) when bringing up the system.

The goal is to keep the battery at approximately 31-32V throughout the Integration and Test Phase. This will keep the battery SoC at 50-70%, keep the shunts off, minimize time at high SoC, minimize high charge/discharge rates, and minimize high DoD. Finally, it is similar to expected flight bus voltage, which is predicted to be at the full charge voltage of 33.6V most of the time.

For most I&T activities, the SAS/Battery configuration is desired as it most closely represents the on-orbit configuration.

2.3 Operations During Environmental Test

During all Environmental testing, batteries will be kept at a constant state of charge around 31-32V as stated above. During thermal vacuum testing, the battery temperature will stay within the vendor approved operating limits of -15C to +40C.

There are three thermistors on the battery for temperature monitoring. During all I&T activities, yellow temperature limits shall be set to -10°C and +30°C, and red temperature limits set to -15°C and +40°C in ITOS. Operators continually monitor the Probe whenever powered and will be alerted immediately if the battery goes outside of these limits. If conditions are such that the battery is run for an extended time (>15 minutes) above the yellow limits or if the red limits are reached, the test shall be stopped and the conditions changed. The AEA fade calculation assumes a typical operating temperature of 25°C. AEA has also stated that temporary (<48 hours) thermal excursions to +50°C are acceptable.

Note: AEA Technology recommends:
- Operating Battery temperature: -10°C and +30°C (preferred), -15°C and +40°C (acceptable)
- Storage Battery temperature: Refrigerator storage is recommended

2.4 Battery Charging Not Allowed

Due to safety concerns, no battery charging is allowed during RCS pressure testing and Probe fueling.

3.0 Shipment of Batteries.

The flight batteries shall be discharged to < 20% SoC for shipment durations longer than 10 days. The temperature of the environment will be monitored.

Following shipment, if the batteries are discharged, they shall recharged using the Battery Rack EGSE (See Swales Battery Rack Users Guide for charge rates and procedure).

4.0 Battery Storage.

Prior to integration of the Probe Bus with the Instruments, the battery shall be placed in controlled storage at Swales, for an estimated time period of 5 months. The batteries are stored in a refrigerator at approximately +4°C with monitored temperature. The AEA fade calculation assumes storage of up to a year at +25°C.

4.1 Charging Methods

Charging of the batteries may be accomplished via the DPC or the SAS in the EGSE rack, or via the battery rack.

4.2 Discharging Methods

The discharging of the batteries may be accomplished using the EGSE Rack only, and running the probe without charging it.

5.0 Probe Power System EGSE

The Power System EGSE consists of the following:

- 4 Solar Array Simulators: Agilent 6633B power supplies driven by labview programmed I-V curves. If setting the parameters manually, the nominal settings are 0.33A and 38V with the over-voltage protection set to 39V, and the current limit set to 0.500A.
- 1 Direct Power Supply (DPC): Agilent 6633B used for initial power of the probe, prior to commanding the battery enable relay closed. The current limit is generally set at 1.75A, and the over-voltage protection set to 39V.
- Solar Panel Set Simulator (SPSS): Allows SAS power routing to be switched between the Solar Panel connector interfaces and the umbilical interface. The SPSS also contains resistors to simulate the solar panel PRTs and linear shunt resistors.

6.0 EGSE/Probe Configuration

There are three possible power configurations used during various stages of Probe Integration and Test. Each requires a different EGSE configuration, which must be in place to power on the Probe without risk to the Battery.

- Probe with all solar array panels installed
- Probe with no side solar array panels installed
- Probe with some of side solar array panels installed

For a complete power system, the linear shunt resistor function must be included in the EGSE/Probe configuration. However, the probe may be powered using only the DPC with careful consideration for the shunt configuration, battery state of charge and power required.

Probe with all solar array panels installed: When the probe is completely assembled, the EGSE is not required to supply shunt resistors. In this configuration, the SAS power is routed to the probe via the umbilical harness, and the linear shunt resistors and PRTs are located on the solar array panels. The SAS Power Router Switch (SW 5) is set to PUD and all of the SAS switches (SW1, 2, 3, 4) are set to OFF.

Probe with no side solar array panels installed: Without the all of the side panels, the probe power system does not contain the linear shunt resistors required for battery charge regulation. In this configuration, the C3038 (Octopus) harness is connected to the probe solar array connectors, and the SAS power may be routed via the C3038 harness or the Umbilical. The SAS Power Router Switch (SW 5) is set to SPSS or PUD and all of the SAS switches (SW1, 2, 3, 4) are set to ON.

Probe with some side solar array panels installed: With some of the side panels installed, the probe can be powered through the umbilical, and the linear shunt function still preserved through the C3038 harness. In this configuration, the C3038 (Octopus) harness is connected to the uninstalled probe solar array connectors, and the SAS power routed via the Umbilical. The SAS Power Router Switch (SW 5) is set to PUD and all of the SAS switches (SW1, 2, 3, 4) are set to OFF.

When DPC only is used to power the probe (not typically recommended), power available for the bus will be limited. The over-voltage protection circuit is designed to turn all shunts on if the battery relay is disabled and power is applied to the probe. Therefore, the DPC will need to provide excess current above the expected bus current due to the linear shunt. The current provided is dependent upon the bus voltage.

7.0 Final Checkout and Preparation for Launch Configuration

The Flight batteries will receive final preparations for launch at Astrotech's Hazardous Operations Building just prior to shipment of the full payload (including Delta 3rd Stage). This final launch preparation will consist of charging the batteries to full SofC while monitoring using the umbilical rack (not the battery charging rack).

Transportation to the Pad and Pad Activities
Except for launch pad charging, no battery processing of any type will occur during transportation to or when the Payload is on the pad.

APPENDIX A: Schematic of Charging Circuit in Battery Rack