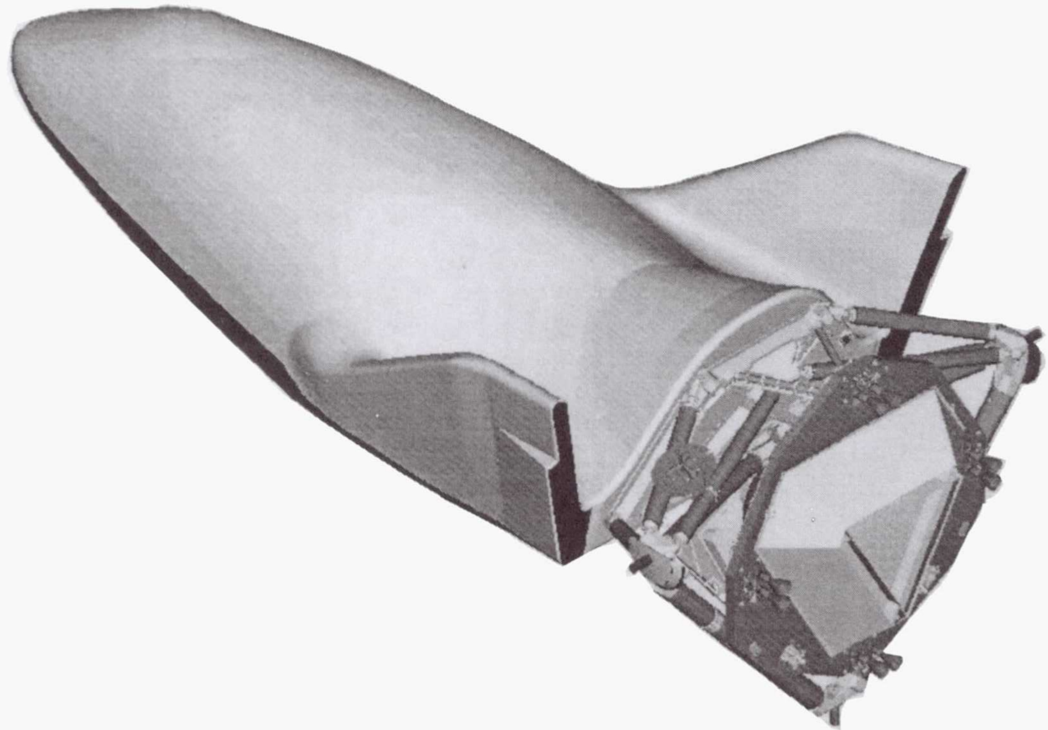


Calorimetric Measurements on a 32 Ah Li/MnO_2 Cell for the X-38 Crew Return Vehicle

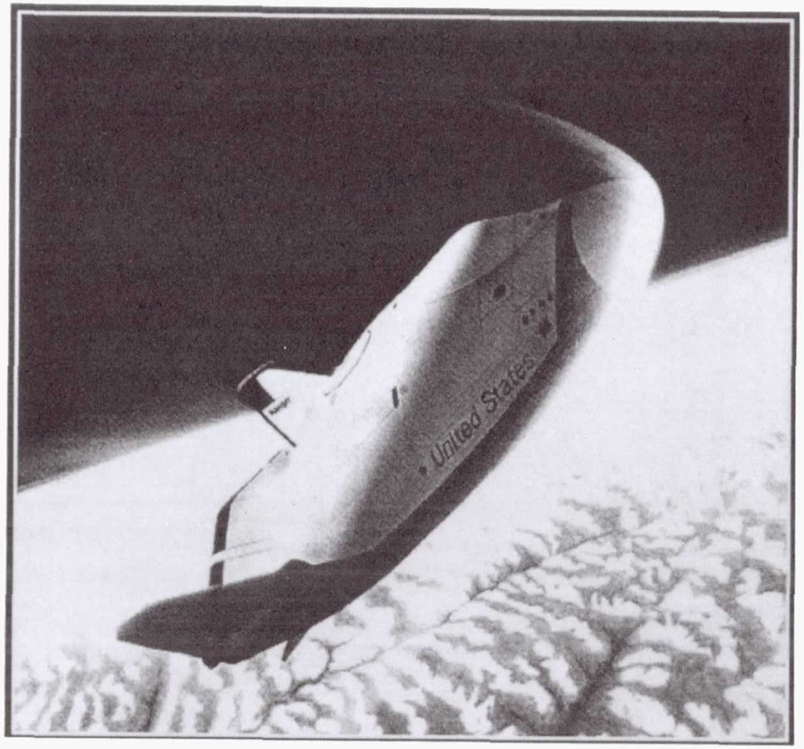
by
Eric Darcy/NASA-JSC and Chris Johnson/Boeing-Seattle

Presented at the
1999 NASA Aerospace Battery Workshop

Agenda

- Introduction
- Battery and Cell Description
- Thermal Vacuum Performance
- Comparison of Dewar vs Heat Conduction Calorimetry
  - Theory
  - Experiments
  - Results
- Preliminary Findings
- Future Work

Introduction

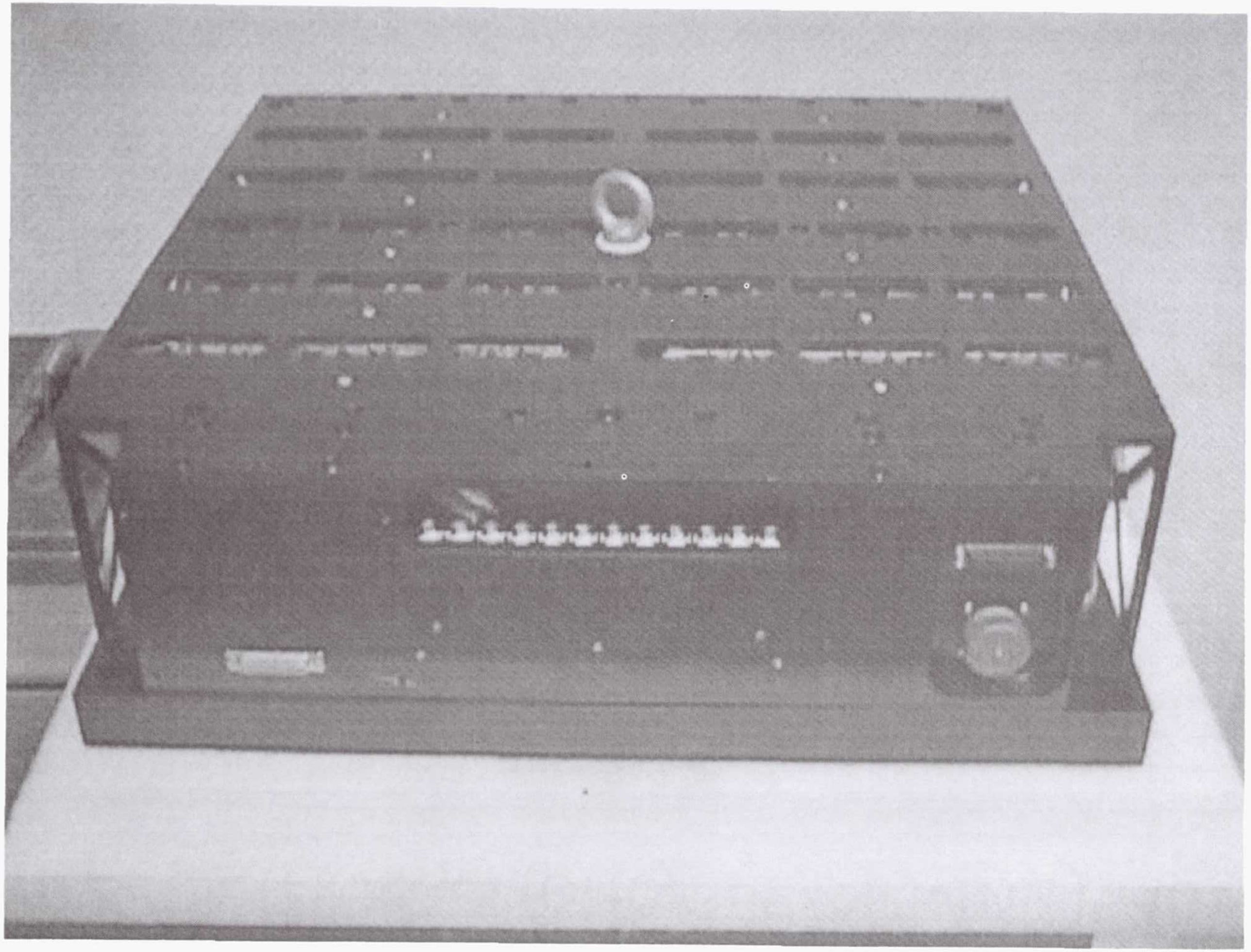


- Crew Return Vehicle Objectives
  - return ill or injured crew
  - evacuate crew from ISS
  - return crew if Shuttle is grounded
- X-38 Objective
  - Demonstrate the design in a unmanned spaceflight test (Feb 2002)
- X-38 Vehicle has 3 battery systems
  - Spacecraft
    - 28V In-Cabin NiMH (400 Ah total)
    - 270V high power (27 Ah total)
  - Deorbit Propulsion Stage (DPS)
    - 32V Li/MnO_2 (1400 Ah)

32V DPS Lithium Primary Battery

- Design Features
  - Li/MnO_2 32Ah cell (P/N M62) from Friemann & Wolf, Germany
  - Battery Module consists of 144 cells in a 12P-12S configuration
  - 4 Battery Modules per DPS
  - 350 Ah per Battery Module at 50A to 25V starting at 0 degC
  - 7 hour discharge rate
  - Refurbished by replacing cell strings
  - Battery Module Size
    - 620 mm wide, 620 mm deep, 206 mm tall
    - 79 kg

350Ah Li/MnO_2 Battery Module for X-38



Friemann & Wolf Part No. 49815-000.000

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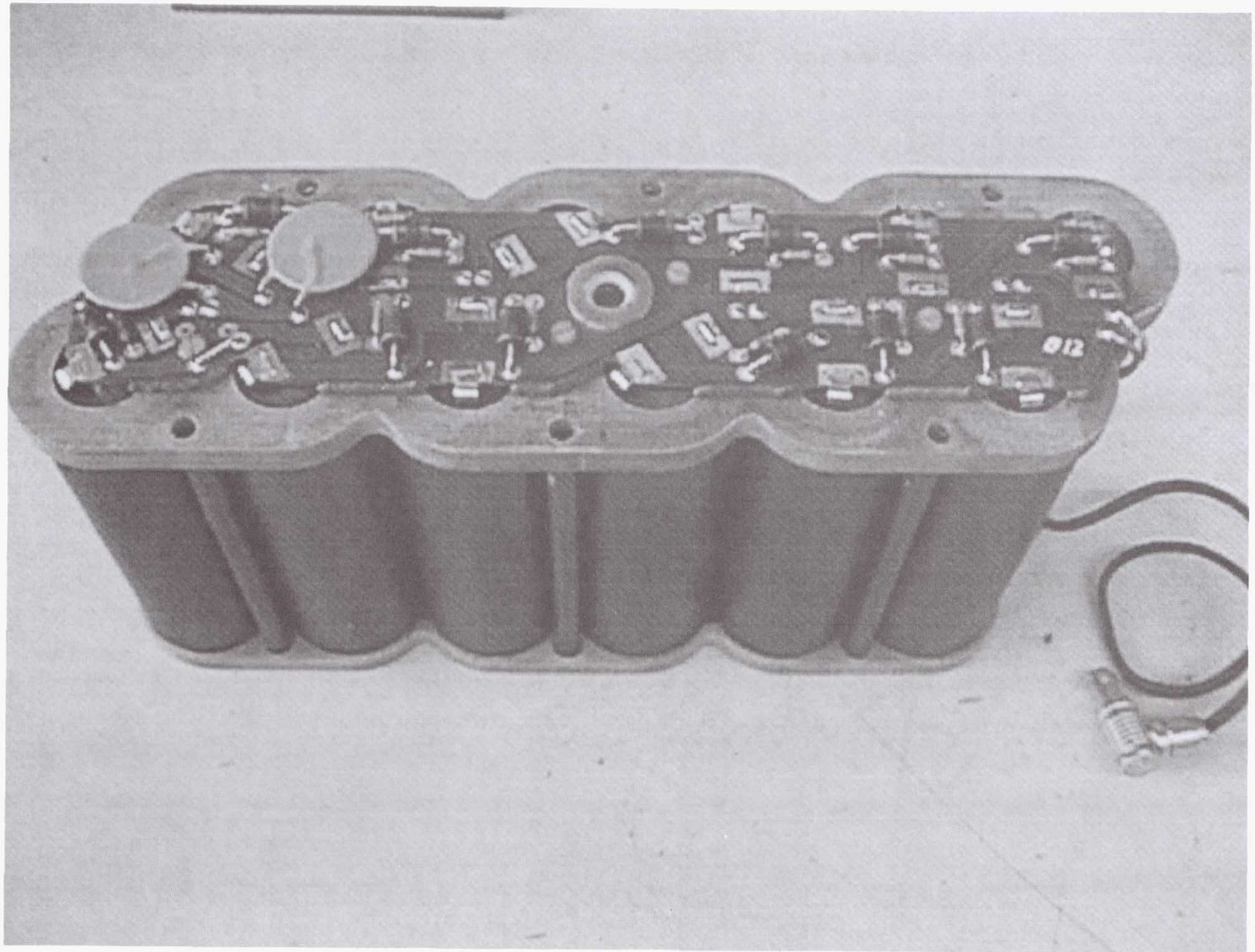
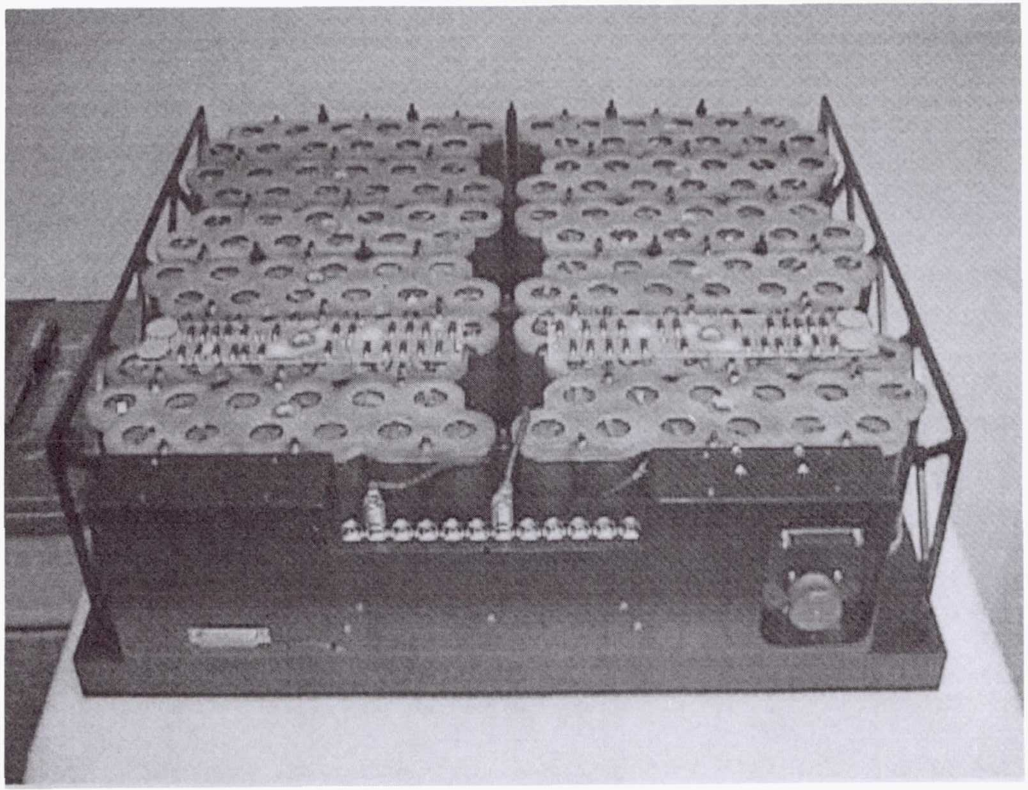
Li/MnO_2 Cell Description (P/N M62)

- Similar to commercial M25 cell
- Capacity = 32 Ah
- Mass = 354 g
- Diameter = 42 mm
- Height = 133 mm
- Spirally wound
- Hermetically sealed
- Vent = opens at 10-17 atms

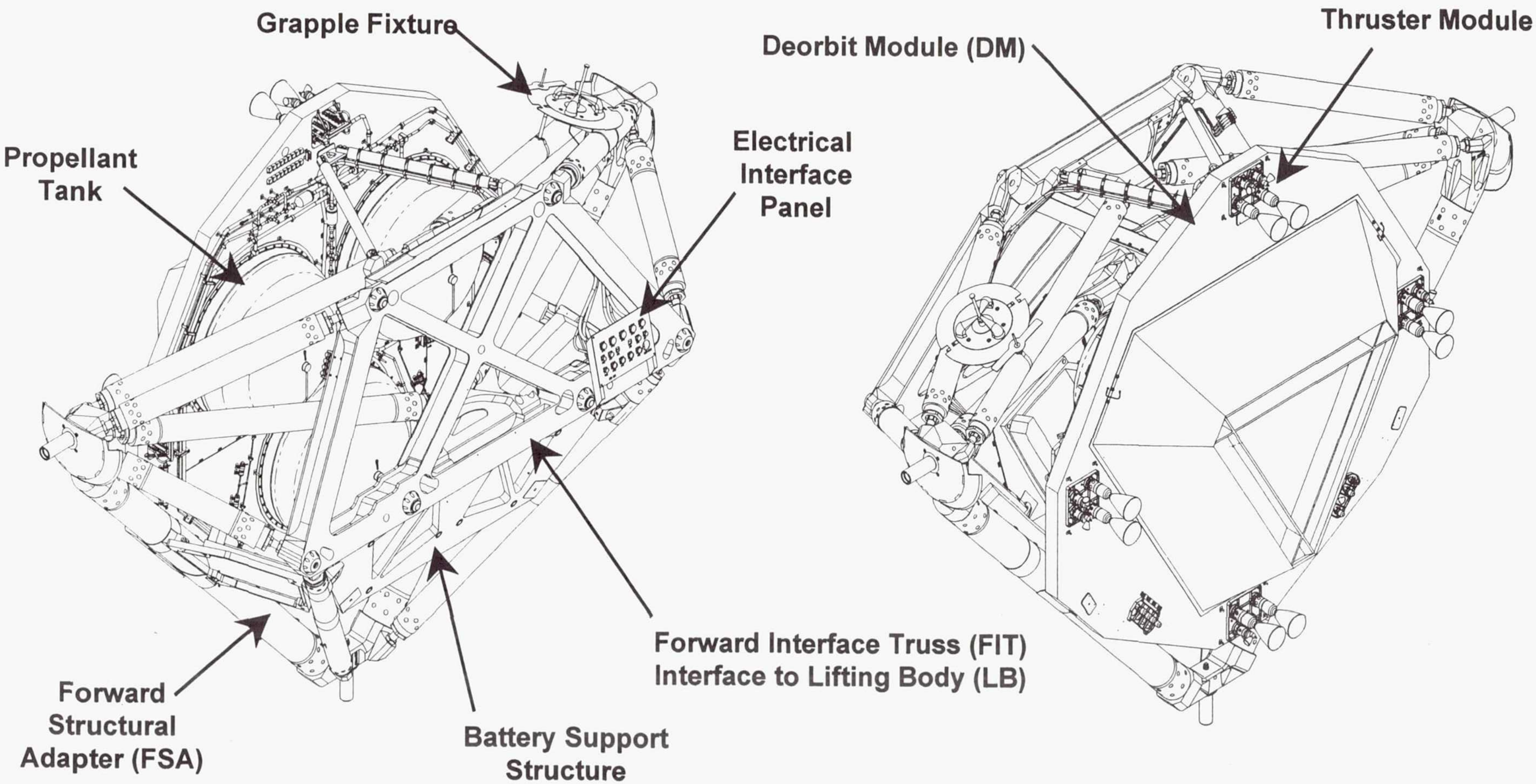
Battery String of 12 cells

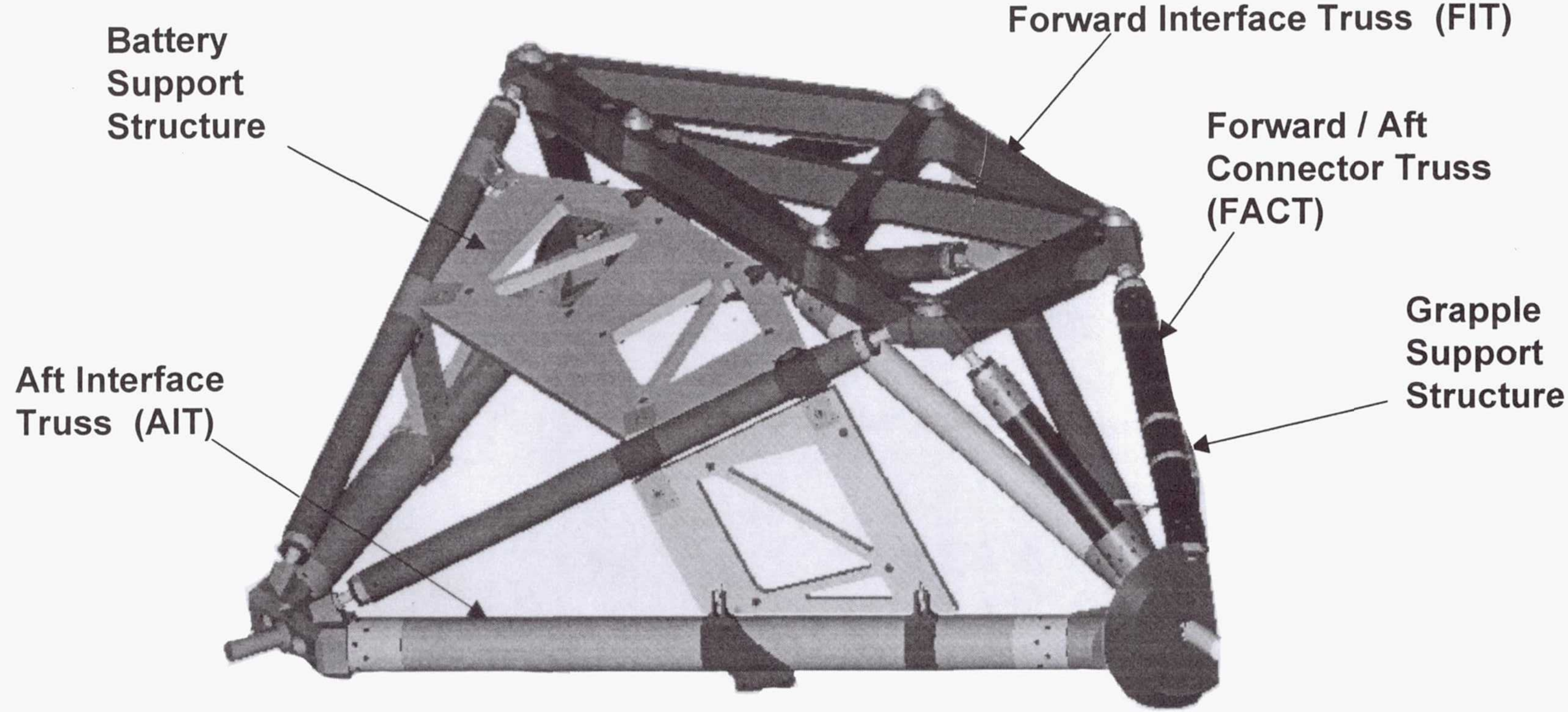


Battery Module Without Top Cover



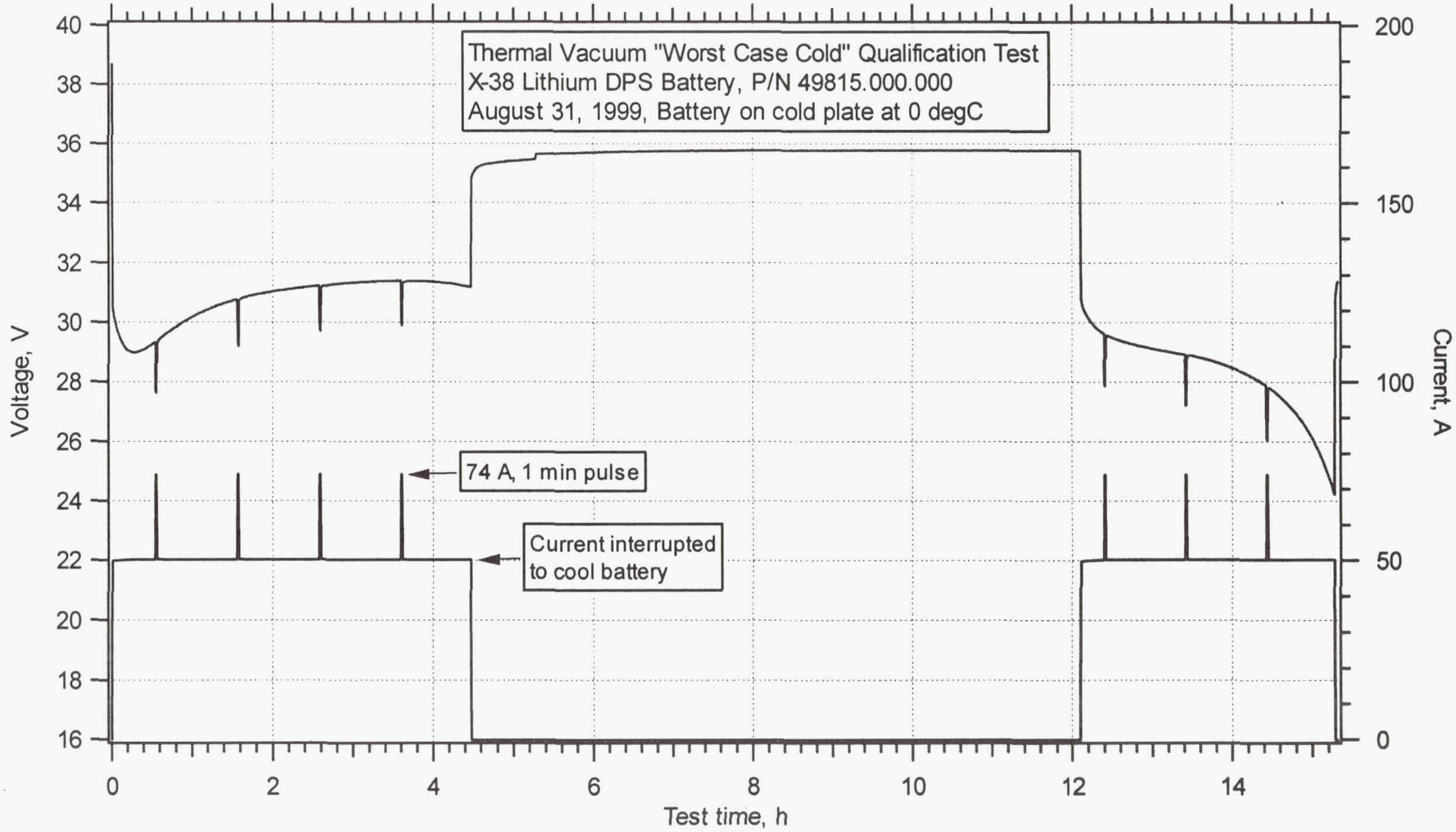
2 Views of the DPS



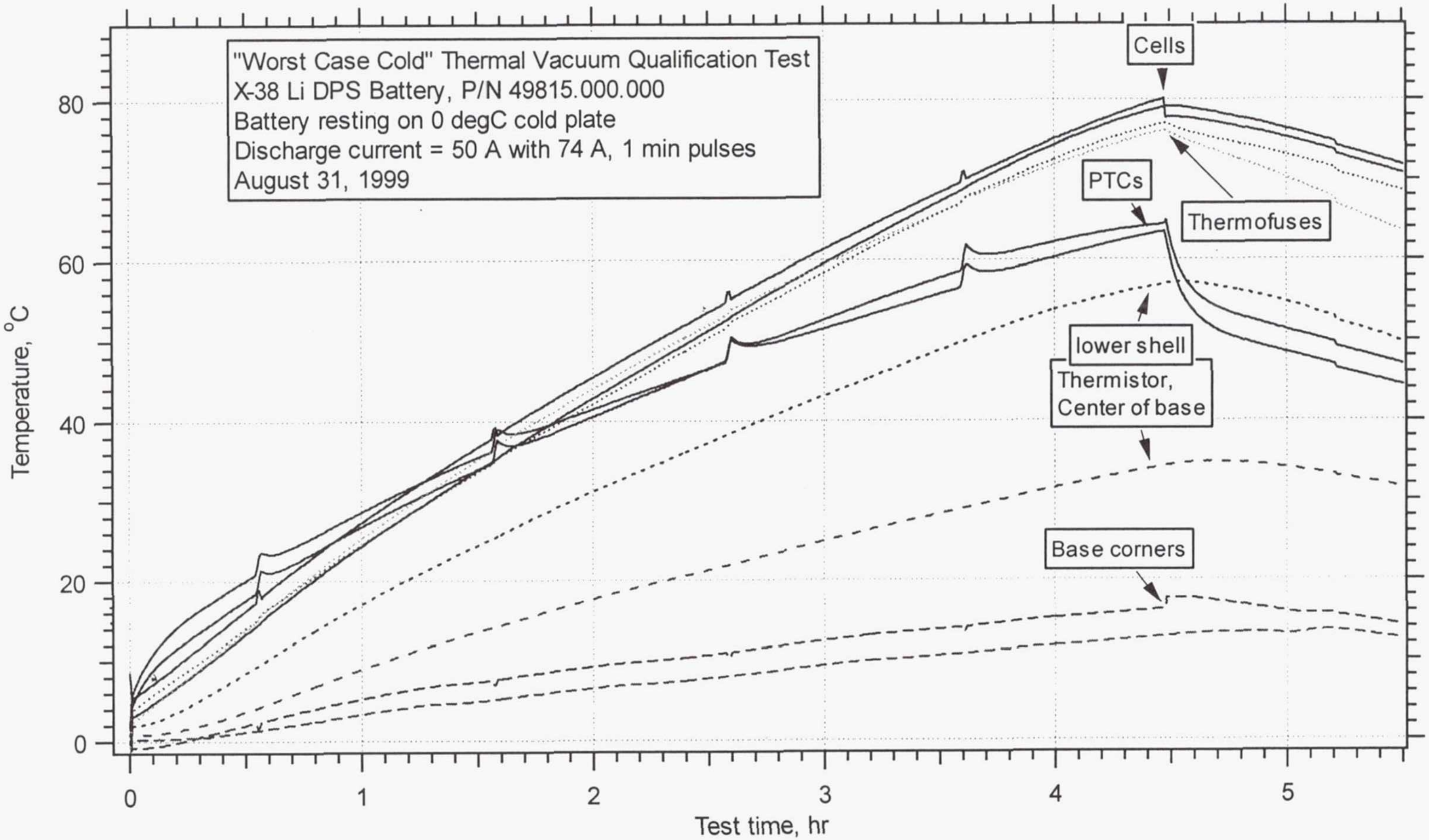


Forward Structural Adapter

1st Thermal Vacuum Test Results



Thermal Vacuum Test Results

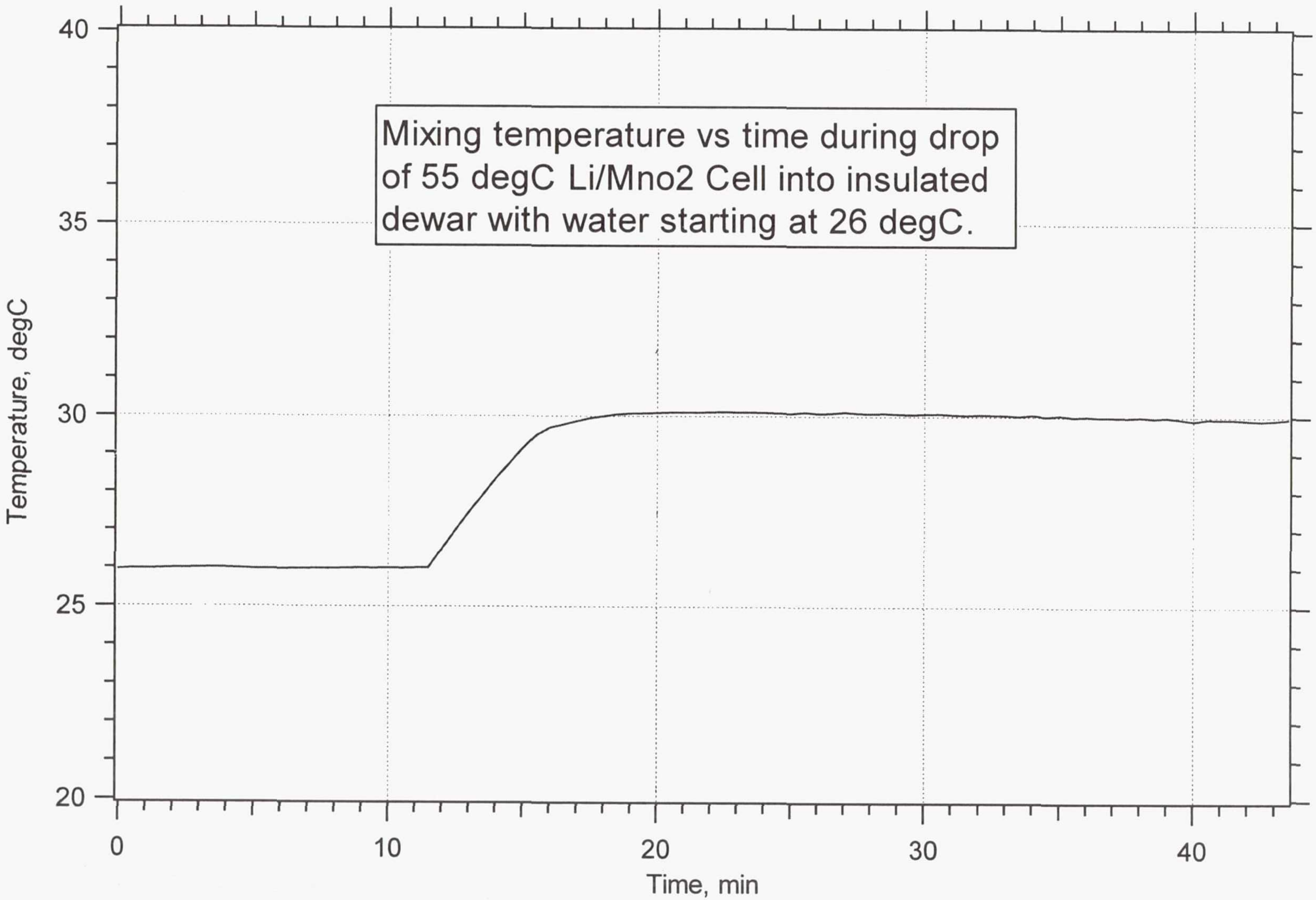


What is needed to improve battery thermal design?

- Cell thermal properties must be known accurately
  - Cell heat capacity, C_p, (cal/g/C)
    - No values found in the literature for Li/MnO_2 cells
    - Drop calorimetry
  - Cell heat generation, Q, (W)
    - No values found in the literature for Li/MnO_2 cells
    - Heat conduction calorimetry
- Battery heat conduction bottlenecks must be improved
  - From cell to the structure of the battery
- Battery must take full advantage of heat dissipation modes
  - Conduction to the DPS/battery structure
  - Radiation to the DPS propellant tanks

Two Drop Calorimetric Methods to get Cell C_p

- Adiabatic dewar method
  - Water in a dewar at 26 C
    - known mass of water
    - dewar assumed adiabatic
  - Cell at 55 C dropped into water
    - cell mass at 354 g
  - Cell C_p calculated from rise in temp of water/cell mixture
    - water C_p is known
  - Simple, inexpensive
- Theory
  - Heat inside dewar at start
    - $Q_{init} = (mC_p\Delta T)_{cell} + (mC_p\Delta T)_{water}$
  - Heat inside dewar at end
    - $Q_{final} = ((mC_p)_{cell} + (mC_p)_{water})T_{final}$
  - $Q_{init} = Q_{final}$, solve for cell C_p
- Heat conduction method
  - Oil bath maintained at 20 C inside water bath maintained at lower temp (16 C)
  - Cell at 33.8 C dropped into oil
  - Oil heating drops as cell heat is dissipated in the oil
  - (-1) * heater counts ~ to cell W
  - Custom instrument, expensive
- Theory
  - $E = \int Q\,dt = \int mC_p\,dT$
  - $C_p = E / m(T_2 - T_1)$
  - where $E = k^* E_{exp}$
  - where
    - E_{exp} = area under thermogram
    - k = cal/integrated counts



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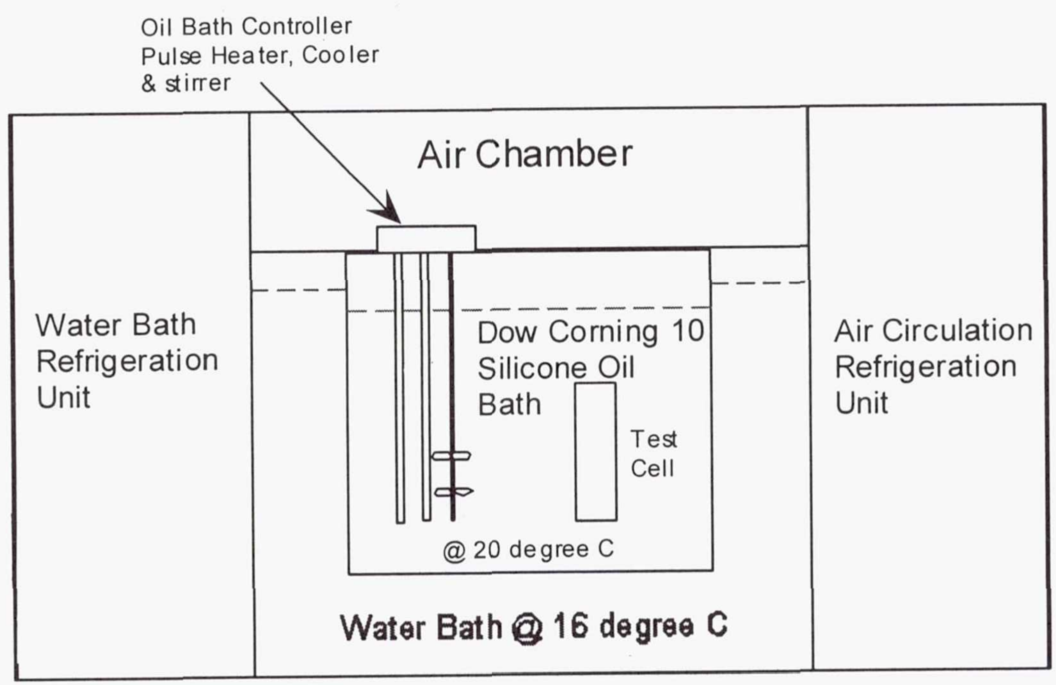
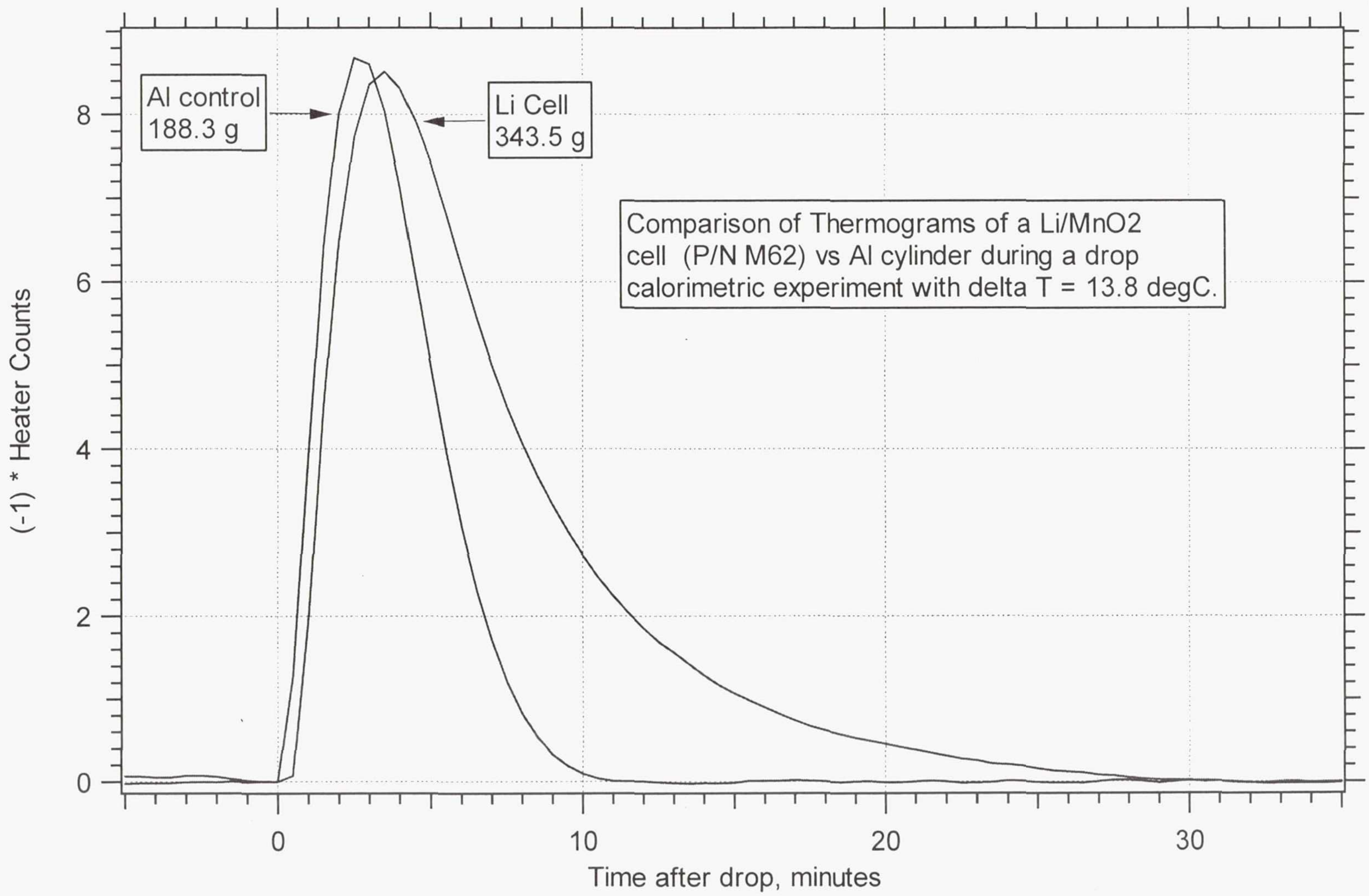
Heat Conduction Calorimeter

Boeing Calorimeter




Al control
188.3 g
Li Cell
343.5 g
Comparison of Thermograms of a Li/MnO2 cell (P/N M62) vs Al cylinder during a drop calorimetric experiment with delta T = 13.8 degC.
(-1) * Heater Counts
8
6
4
2
0
0
10
20
30
Time after drop, minutes

Results

- Adiabatic Dewar Method
  - Control = Al cylinder, 226g
    - Cp obtained = 0.249 cal/g/C
    - True Cp = 0.215 cal/g/C
    - 16% overestimation of true value
  - Cell data from 3 drops
    - complete cell, 354 g
    - Cp = 0.254 cal/g/C
    - s.d. = 0.0154 cal/g/C or 6%
    - 90% conf. Int.= +/- 17%
- Heat Conduction Method
  - Control = Al cylinder, 188.3 g
    - Cp obtained = 0.214 cal/g/C
      - based on 1W = 1000 heater counts
      - calibrated by energy balance with known power input into a resistor
      - <0.5% difference with true value
    - establish k factor = [integrated heater counts/cal]
  - Cell data from X drops
    - cell stripped of shrink wrap, 343 g
    - Cp = 0.203 cal/g/C
    - s.d. = TBD
    - 90% conf. Int. = +/- TBD

Preliminary Findings

- Difference between methods is significant
  - Cp difference is 20%
    - can not be explained by 11 g shrink wrap
- Possible source of errors with each method
  - Dewar method
    - small mixing temp rise (~ 4 degC) requires very accurate and precise temperature measurements
    - small errors in delta T measurement can propagate errors significantly
    - heat losses through top of dewar could be significant
  - Heat conduction method
    - small errors in delta T measurement
    - heat losses through top of oil bath are minimized by surrounding water and air bath
- Heat conduction appears to be more accurate and precise

Future Work

- Determine cell heat generation during 4.2 A discharge
  - Compare both methods
  - Calibrate both with a known power input through a resistor
  - Obtain effective thermoneutral potential, E_{tn} vs SOC
    - $Q = (E_{tn} - L.V.)\ I$
    - calculate heat generation at different discharge rates
- Improve battery heat conduction bottlenecks
  - From cell to the structure of the battery
- Take full advantage of heat dissipation modes
  - Conduction to the DPS/battery structure
  - Radiation to the DPS propellant tanks