Bipolar Nickel-Metal Hydride Battery Development Project

prepared by:

John H. Cole

presentation to:

NASA Aerospace Battery Workshop

Contract Agency:

NASA Lewis Research Center

October 27, 1998

Electro Energy Inc.
Shelter Rock Lane
Danbury, CT 06810
203-797-2699
1-800-BIPOLAR
203-797-2697 fax

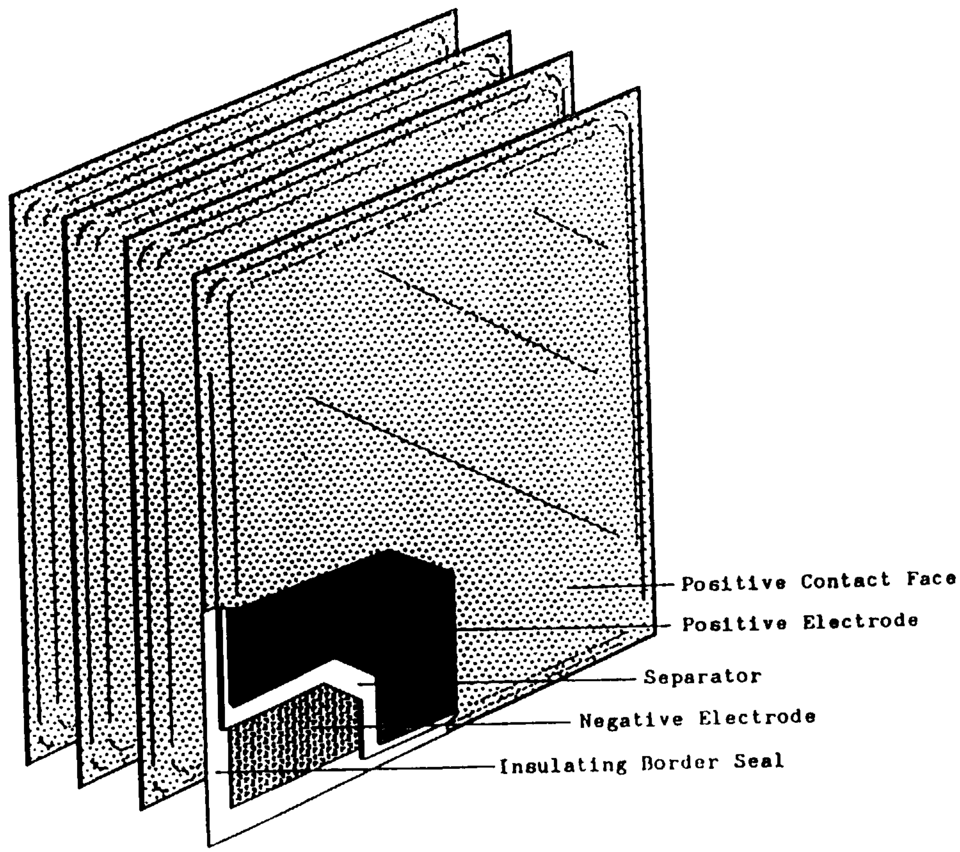
***PROJECT OBJECTIVE*: Design of 1 kW Bipolar Ni-MH Battery for LEO-Satellite**

Sponsor:	NASA Lewis Research Center	
Contractor:	Electro Energy Inc.	
Subcontractor:	Eagle-Picher Industries, Inc. Design Automation Associates Rhone-Poulenc, Inc. Rutgers College of Engineering	
Duration (Deliverable):	5 Year (Flight-weight Design Package)	
Option (Deliverable):	18 Month (3 Flight Quality Batteries)	
Technical Requirements:	a. 5-Year Operation in LEO Regime (C:55 min, D: 35 min) b. 40% DOD c. 28 V @ 1kW	
Energy Density:	Present SOA	Program Goals
	77 Wh/kg	100 Wh/kg
	175 Wh/l	250 Wh/l
		Challenging-Achievable

PROJECT SUMMARY

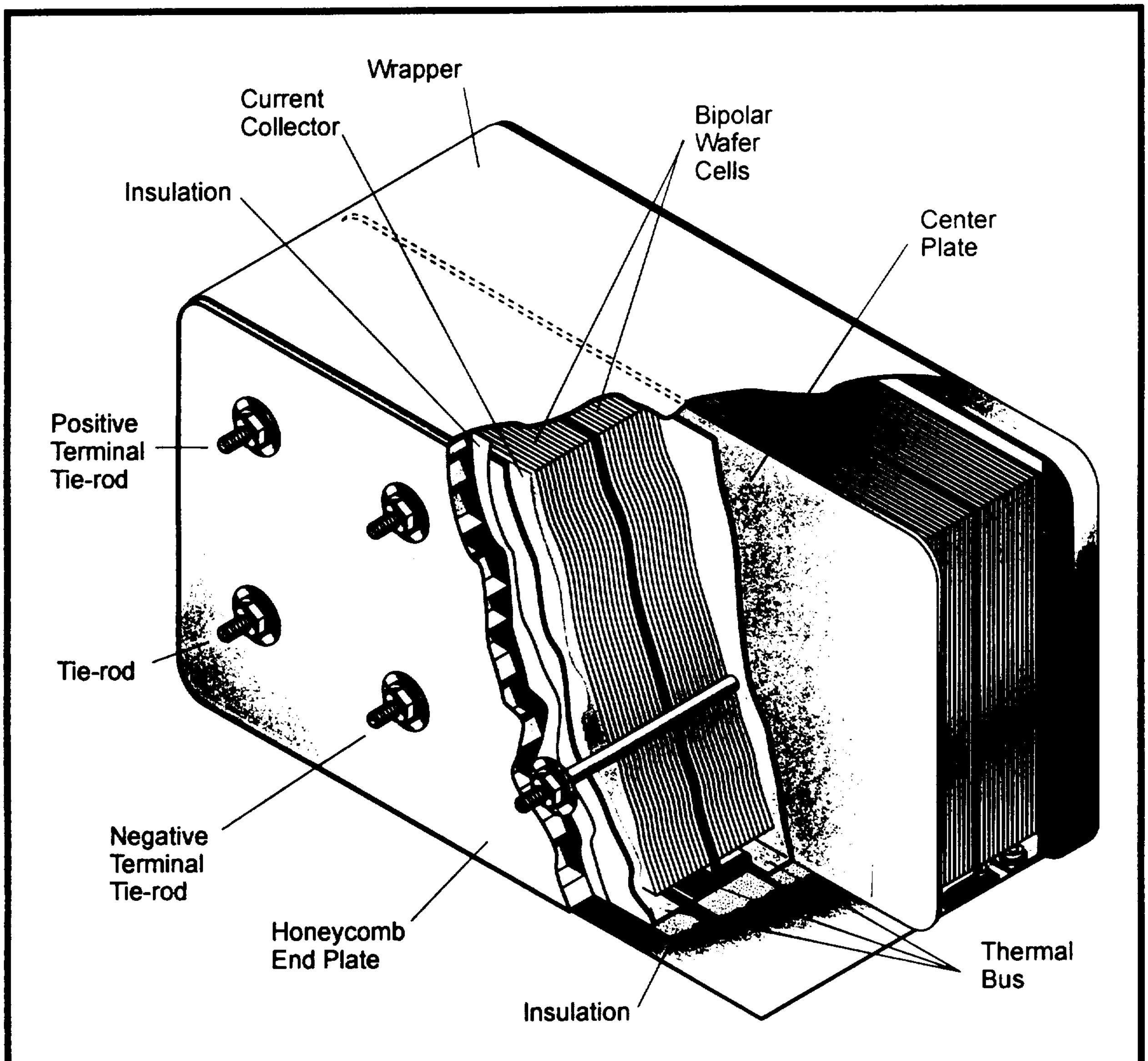
Tasks:	Status
Master Work Plan	Complete
Baseline Design	Complete
Component Development	80%
Trade Study	95%
Subscale Bipolar Batteries	66%
Preliminary Design Battery	Complete
Preliminary Boilerplate Hardware	50%
Improved Design Battery	Complete
Improved Design Prototypes	Starts 1998
Optimized Design Battery	Starts 1999
Optimized Design Prototypes	Starts 1999
Final Flight-weight Design	Starts 2000
Prototype Battery Option	Starts 2000

EEI's Stackable Wafer Cell Concept*



***U.S. Patent #5,393,617**
U.S. Patent #5,552,243

Electro Energy's Bipolar Nickel Metal Hydride Battery



Electro Energy, Inc.

Shelter Rock Lane
Danbury, CT 06810
(203) 797-2699

ADVANTAGES OF EEI WAFER BIPOLAR DESIGN

- Each cell individually sealed
- Allows repair or replacement of individual cells
- No external cell terminals
- No electrode current collectors
- Compatible with plastic bonded electrodes
- Adaptable to heat transfer fins placed in stack
- Scalable to large area, capacity, high voltage
- Automated flexible manufacturing
- Improved energy and power density
- Lower cost

COMPONENT DEVELOPMENT

Component Testing

- Three inch square bipolar wafer cell construction
- Test against baseline Ni or MH electrode with the baseline separator
- Vented, flooded cells
- Sealed starved electrolyte cells
- 50% DOD LEO cycles (55 min. Charge, 35 min. discharge)
- Charge Control:
    - Timed charge & discharge
    - 5% overcharge
- Build & test sample set cells in quadruplicate
- Build & test control cells in duplicate
- DPA Critical Experiments

COMPONENT DEVELOPMENT (cont'd)

Nickel Electrode Development

- Advanced EEI treated nickel compounds:

  Coating Thickness - Suppliers: Tanaka, Skerrit
  Alloying
  NiOH Particle Size
  Microstructure

- EEI plastic bonded nickel construction
- Sintered porous nickel
- Electrochemically impregnated fiber of foam plaque
- Pasted fiber of foam plaque

Resource Allocation

- EEI, EIP, RU

COMPONENT DEVELOPMENT (cont'd)

Metal Hydride Electrode Development

- Incremental Improvements of AB_5:
  - Refractor Metal Substitution Alloys
  - High Stoichiometric Ration Alloy with Mo and/or Si Additions
  - Modified RP40 Grade Alloy
- Radical Improvements of Rechargeable Battery Alloys
  - Mg_2Ni Alloys
  - Li_2Mg_{17} Alloys
- Plastic Bonded & Sintered AB_5 ($LaNi_5$) Construction
- Iron Titanium (FeTi) Doped Magnesium Compounds
- Protective Alloying or Coating

Resource Allocation

- EEI, EPI, Rh-P

COMPONENT DEVELOPMENT (cont'd)

Testing Summary

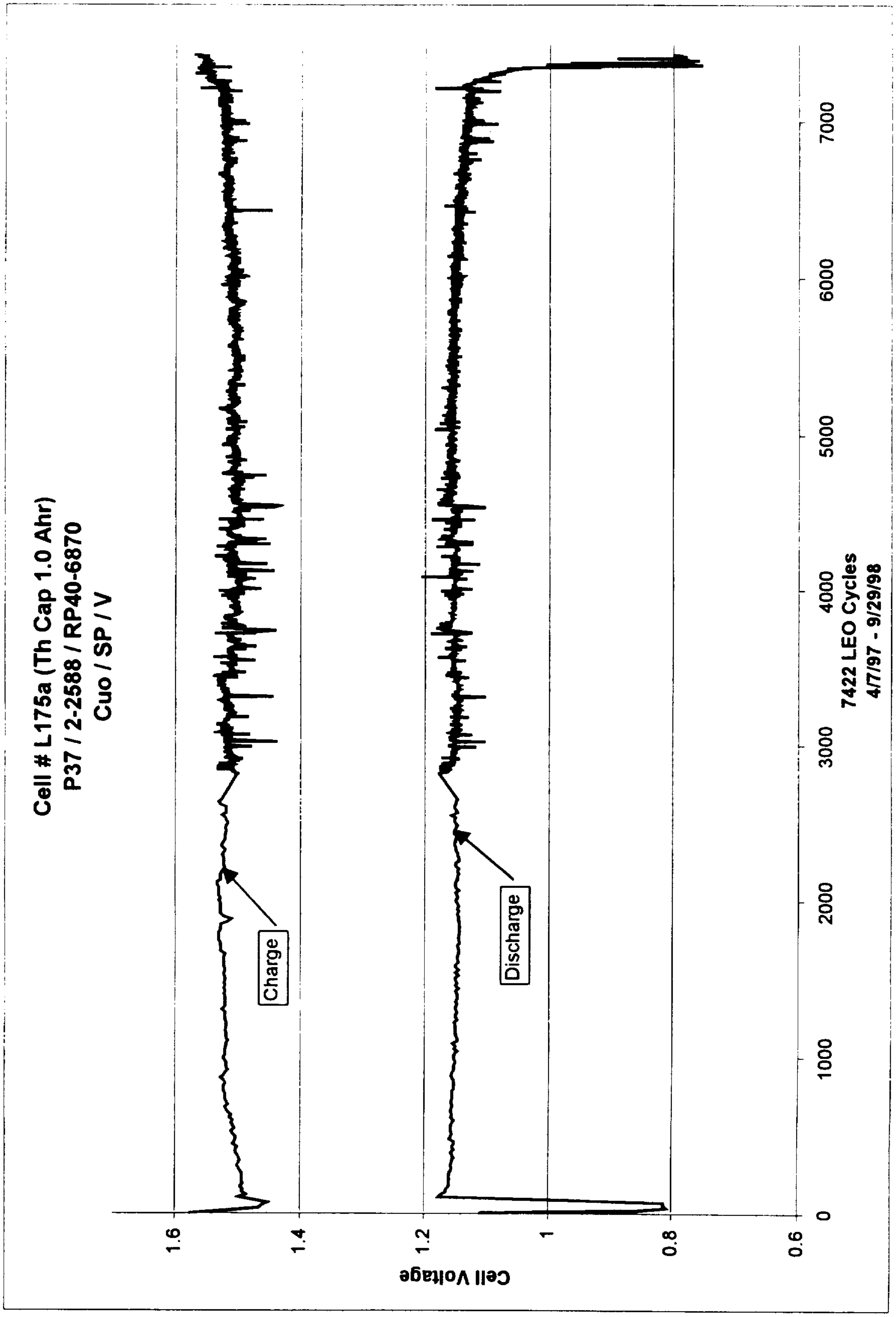
- **Up to 7000 LEO Cycles @ 50% DOD (Tripled Cycle-Life)**
- Up to 9200 LEO Cycles @ 25% DOD (1.18 volts @ EOD)
- 340 Sets of Cells Built and Tested - About **800** Cells
- Computer Controlled Automated Test Systems
- EEI and EPI Ni Electrodes
- EEI and EPI MH Electrodes

Replanned as a Four Year Task

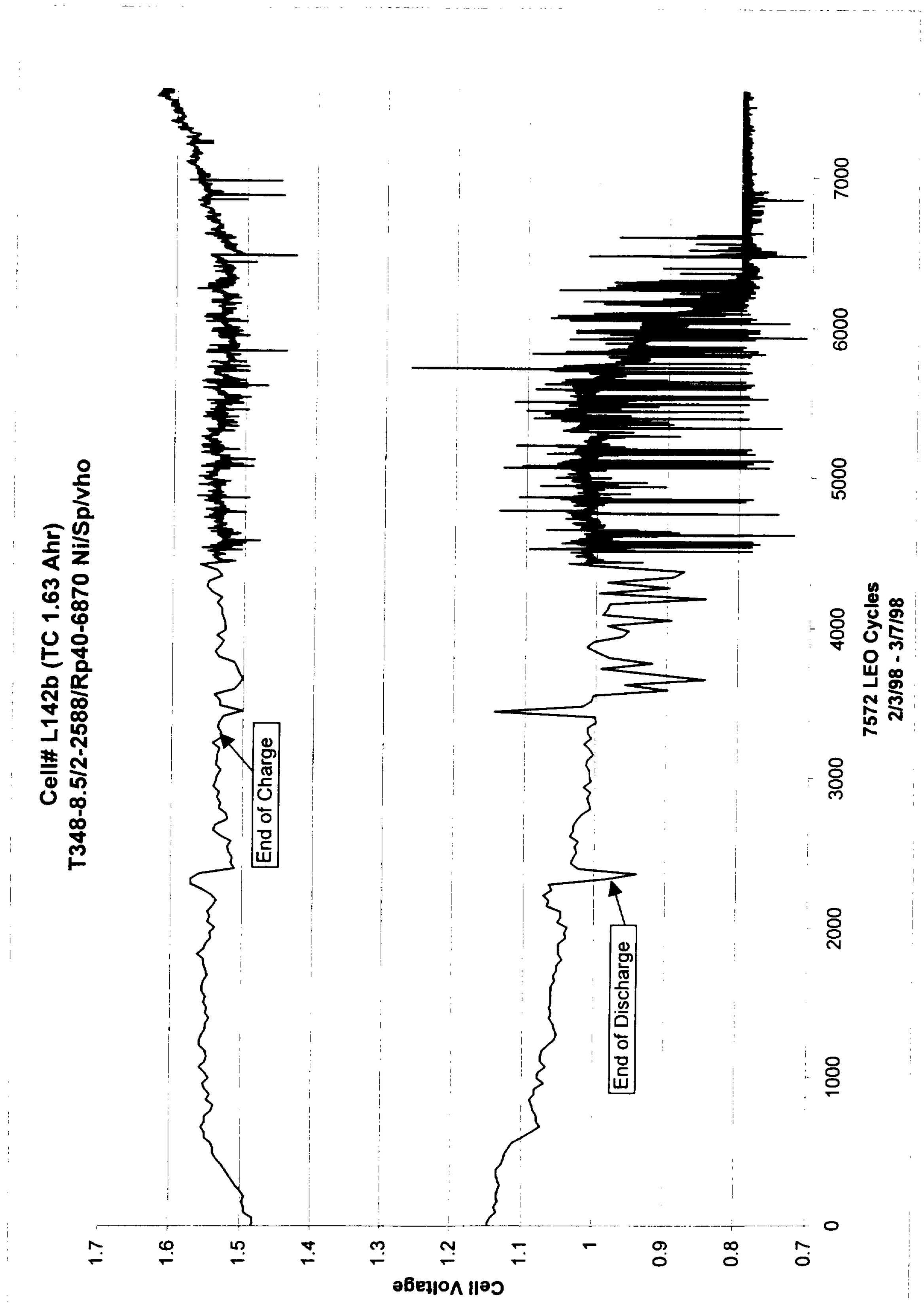
COMPONENT DEVELOPMENT (cont'd)

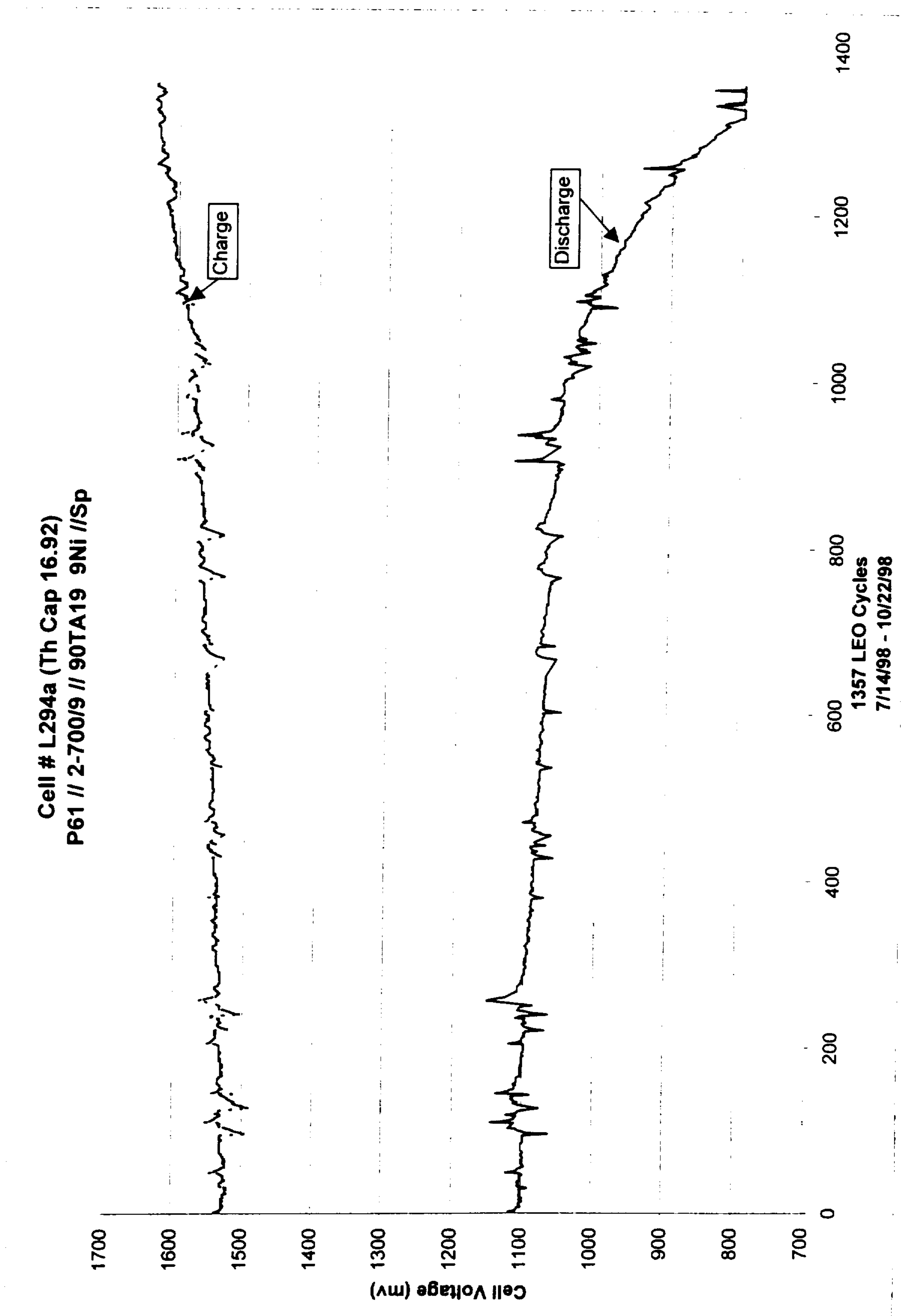
Foil Cell Design

- Developed a wafer cell using nickel foil instead of carbon plastic
- Advantages:
  - Lower contact resistance between cells
  - No permeation from sealed cells
  - Stronger wafer package
  - Higher lateral thermal conductivity
  - Long Life
- Disadvantages
  - Increases Cell Assembly Labor
  - Increases Weight (slightly)
- Vented Flooded
  - L175a - 7,400 LEO cycles
  - L142b - 7,000 LEO cycles
- Sealed
  - L225b - 2,600 LEO cycles
  - L229f - 2,120 LEO cycles

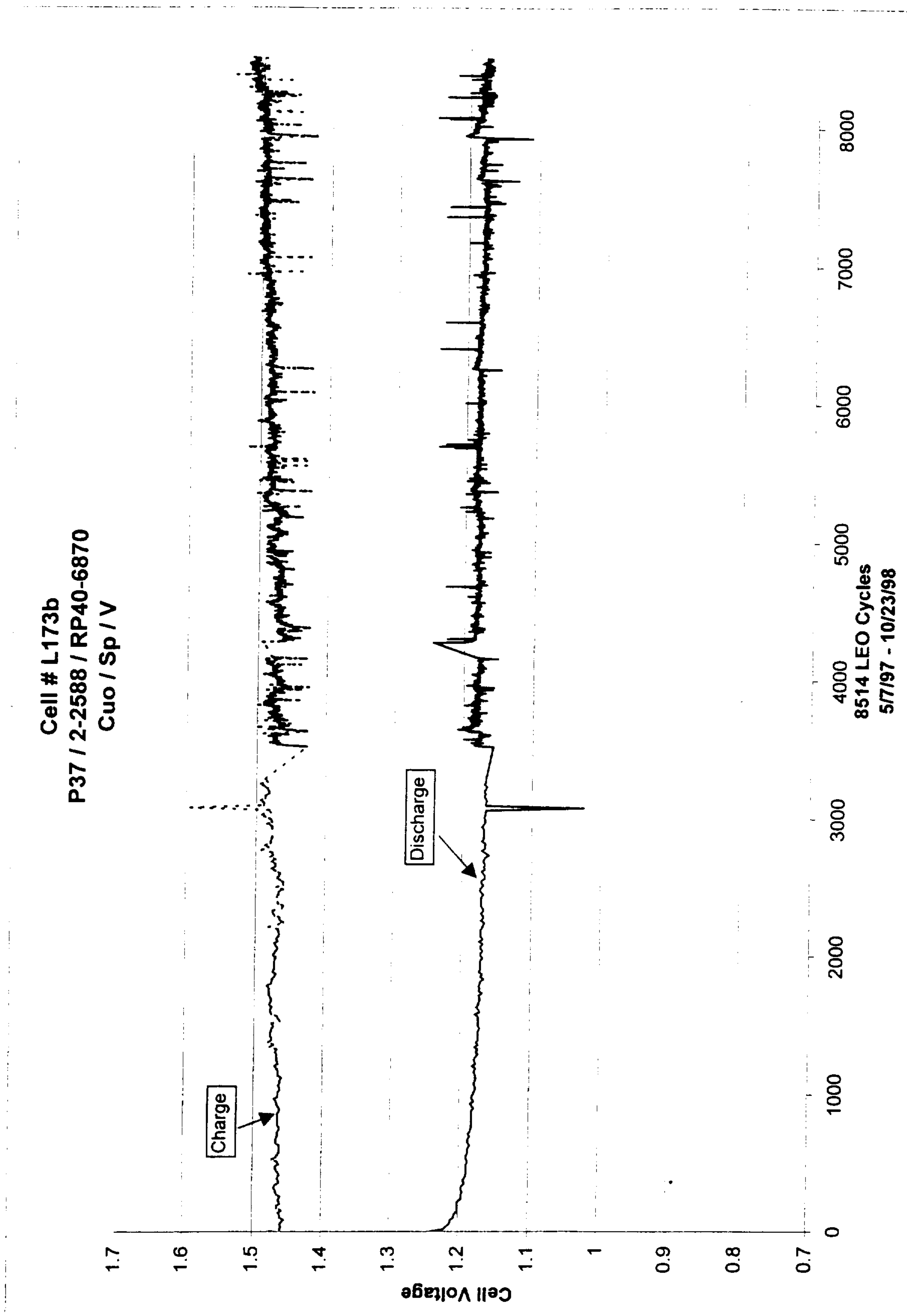


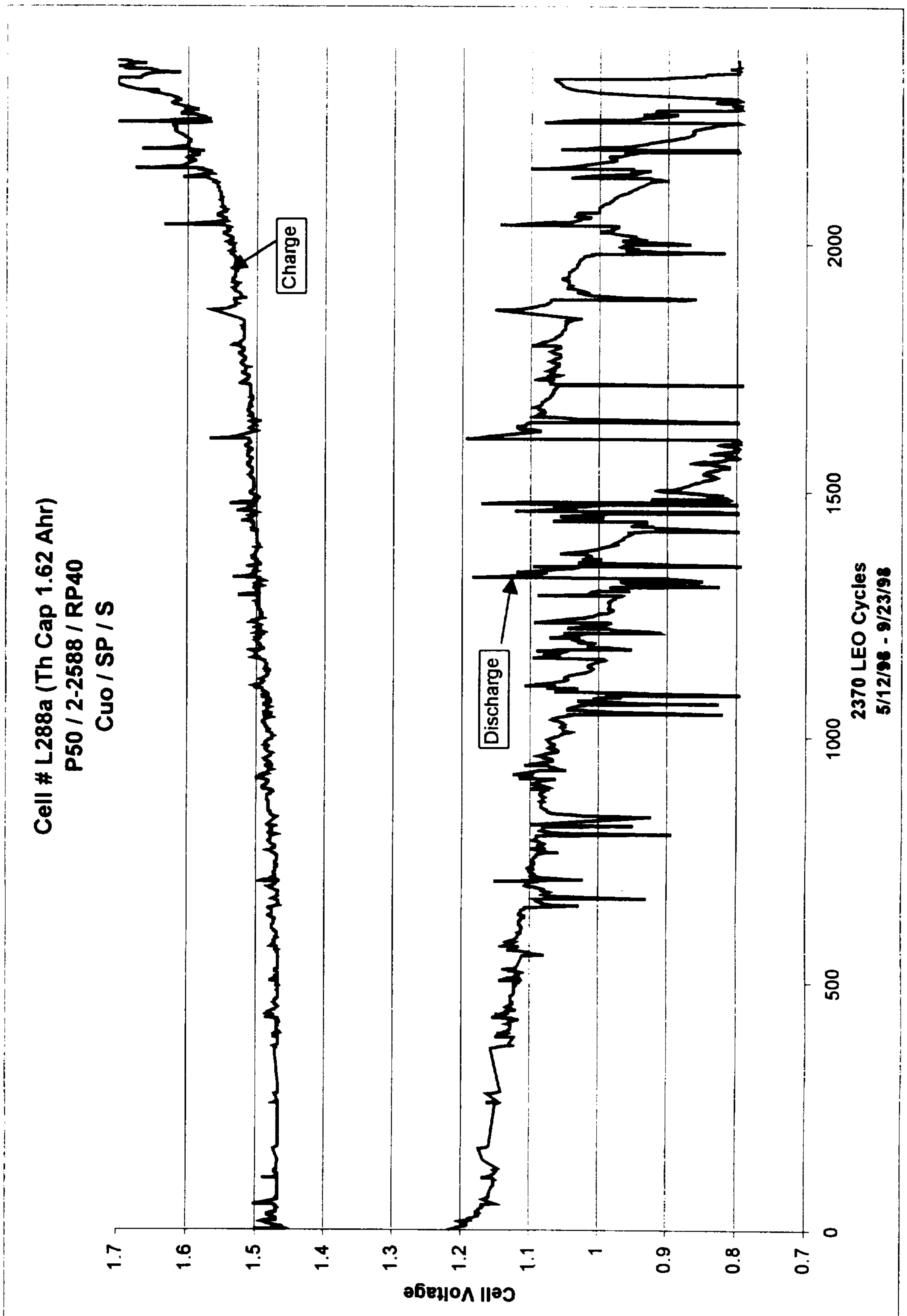
Cell # L175a (Th Cap 1.0 Ahr)
P37 / 2-2588 / RP40-6870
Cuo / SP / V
Charge
Discharge
Cell Voltage
1.6
1.4
1.2
1
0.8
0.6
0
1000
2000
3000
4000
5000
6000
7000
7422 LEO Cycles
4/7/97 - 9/29/98


Cell# L142b (TC 1.63 Ahr)
T348-8.5/2-2588/Rp40-6870 Ni/Sp/vho
Cell Voltage
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
1000
2000
3000
4000
5000
6000
7000
7572 LEO Cycles
2/3/98 - 3/7/98
End of Charge
End of Discharge



Cell # L294a (Th Cap 16.92)
P61 // 2-700/9 // 90TA19 9Ni //Sp
Charge
Discharge
Cell Voltage (mv)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
0
200
400
600
800
1000
1200
1400
1357 LEO Cycles
7/14/98 - 10/22/98


Cell # L173b
P37 / 2-2588 / RP40-6870
Cuo / Sp / V
Charge
Discharge
Cell Voltage
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
1000
2000
3000
4000
5000
6000
7000
8000
8514 LEO Cycles
5/7/97 - 10/23/98


Cell # L288a (Th Cap 1.62 Ahr)
P50 / 2-2588 / RP40
Cuo / SP / S
Cell Voltage
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
500
1000
1500
2000
2370 LEO Cycles
5/12/98 - 9/23/98
Charge
Discharge

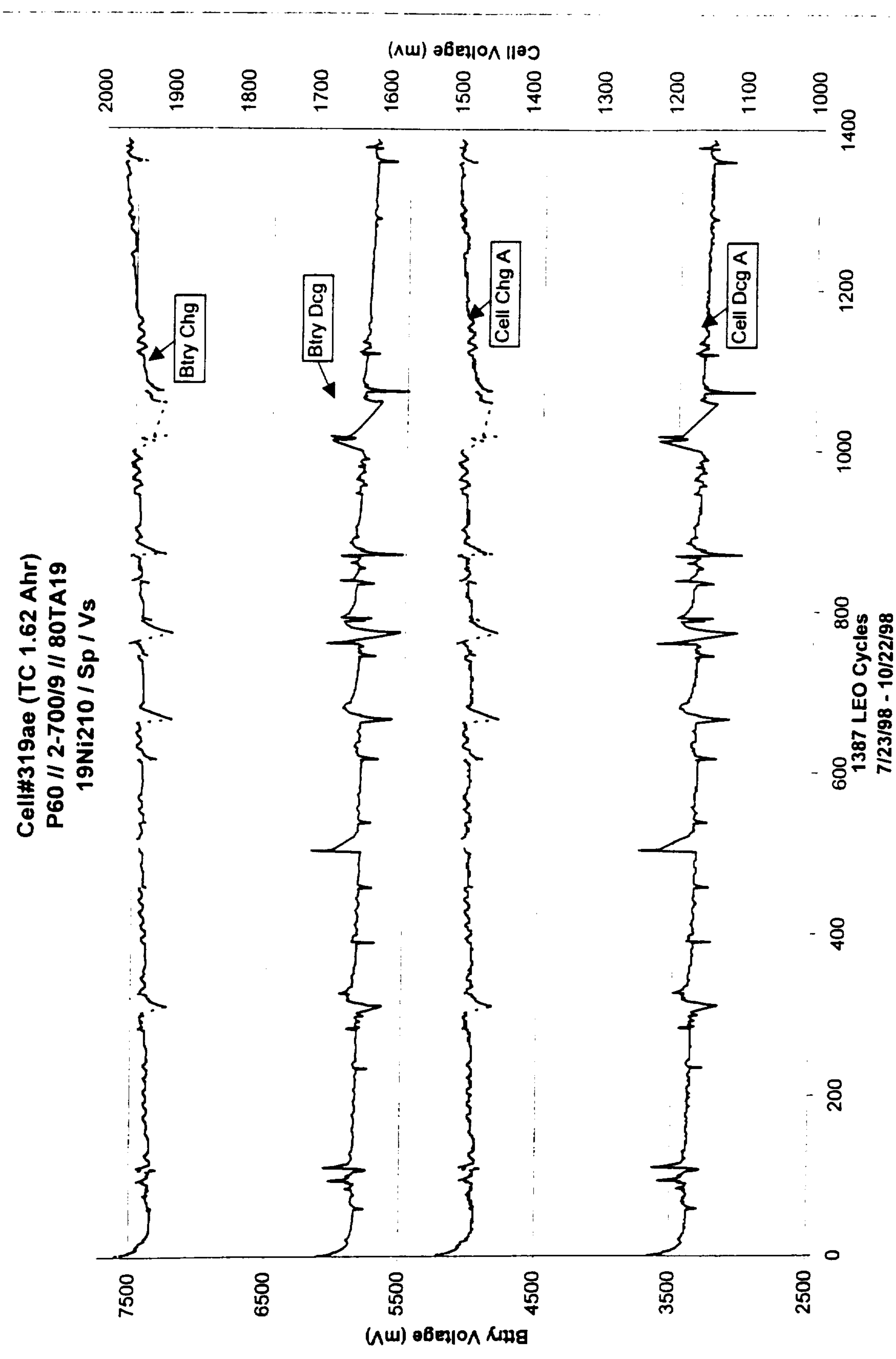
COMPONENT EVALUATION IN BIPOLAR CONFIGURATION

Subscale Bipolar Batteries

- Assemble 5-cell Stacks
- Construct Three Inch Square, Sealed, Starved Electrolyte Samples
- Test Three Top Ni Electrodes Against a Baseline MH
- Test Three Top MH Electrodes Against a Baseline NI
- Test for 500 to 1000 LEO Cycles at 50% DOD
- Perform DPA EEI & RU

Test Status:

- On-going: 1,100 LEO Cycles (to date) at 50% DOD; 1.15V @ EOD


Cell#319ae (TC 1.62 Ahr)
P60 // 2-700/9 // 80TA19
19Ni210 / Sp / Vs
Btry Chg
Btry Dcg
Cell Chg A
Cell Dcg A
Btry Voltage (mV)
7500
6500
5500
4500
3500
2500
Cell Voltage (mV)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
0
200
400
600
800
1000
1200
1400
1387 LEO Cycles
7/23/98 - 10/22/98

TRADE STUDY

Rules Based Technology

- Vary all electrode and cell components
- Prismatic vs Cylindrical Configurations
- Single vs Multiple Stack

Output Summary

- Coverpage - Bottom line results and 3D wireframe
- Input/Output Report - I/O by Category
- Weight Summaries - Battery, Cells and Hardware
- Layout - Front View, X-section and details
- Producibility Report
- Costed BOM
- Maintenance Guidelines

Automated Structural Analysis

- Cell Squeeze, Cyclic and Steady State Pressures
- Batch or Interactive
- 3-D wireframe model
- Area Summary
- Goodman Margins
- Contour Plot and Deformation Animation

TRADE STUDY (cont'd)

Automated Thermal Analysis

- Cold plate Location and Temperature, Power Profile
- Batch or Interactive
- 3-D wireframe model
- Area Summary
- Graphs of Max and Min Cell Temp
- Contour Plot of Cells

Trade Study Results		Battery Energy Density
♦ Baseline Flight-weight Design	-	66 Wh/kg 1995
♦ Preliminary Flight-weight Design	-	77 Wh/kg 1997
♦ Optimized Flight-weight Design	-	83 Wh/kg 1998

IMPROVED DESIGN FLIGHT-WEIGHT BATTERY SUMMARY

- Function:
  - The Improved Design Flight-weight Battery is a Flight-weight Battery Design for LEO Satellite applications.
- Description:
  - The battery is prismatic (rectangular) in shape.
  - The outer enclosure serves to contain cell stack pressure and is hermetically sealed.
  - Tie rods are used to maintain cell stack compression.
  - The battery has two (electrically parallel) 24-cell stacks (48 cells). Internal pressure is regulated by a preset relief valve.
  - There are four thermo-couples to monitor internal temperatures.

IMPROVED DESIGN FLIGHT-WEIGHT BATTERY SUMMARY (cont'd)

Design Requirements:

a.	Voltage:	28 V
b.	Current:	22.7 A Charge, 35.7 A Discharge
c.	Power:	1 Kilowatt
d.	Battery Capacity:	52 A-hr (20.8 A-hr at 40% DOD)
e.	Cell Weight (wet):	157 grams
f.	Cell Energy Density:	114 Wh/kg
g.	Cell Capacity:	26 Amp hours
h.	Current Density:	77 mA/cm^2
i.	Cycle Life:	30,000
j.	Operating Temperature:	-10° C to +25° C
k.	Overcharge:	5%
l.	Electrical Insulation Resistance:	> 1 megohm @ 100 VDC
m.	Cooling:	Conductive baseplate
n.	Maximum Temperature Change:	25° C above cold plate
o.	Thermal Generation:	128 Watts Average

IMPROVED DESIGN FLIGHT-WEIGHT BATTERY SUMMARY (cont'd)

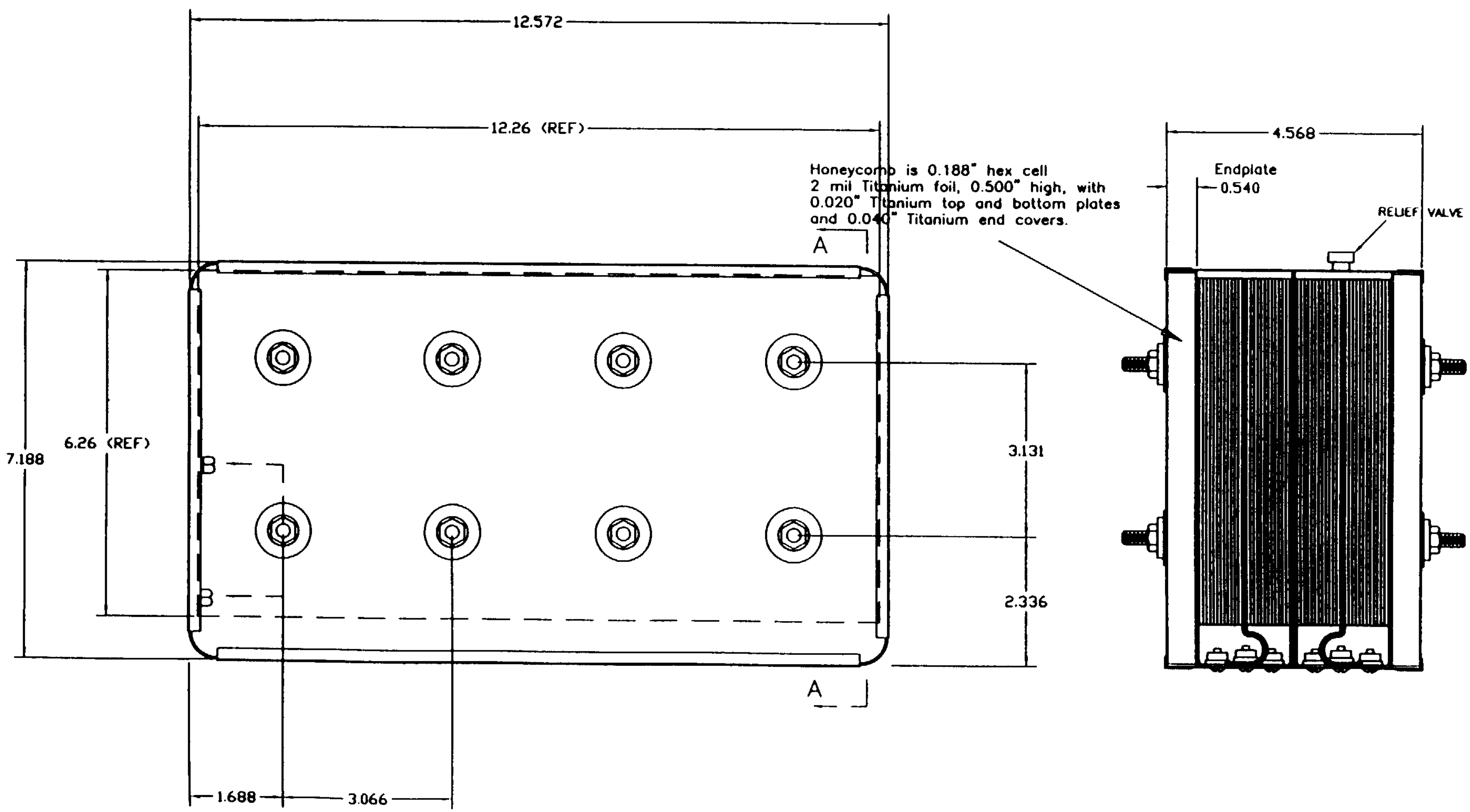
Size

- Overall dimensions of the battery case are approximately 12.6" wide by 7.2" high by 4.7" deep
- The Nickel-Metal Hydride cells (12) are approximately: 0.066" thick by 6.56" high by 12.56" wide

Materials

- Enclosure - Titanium
- Thermal Plates - Ni plated aluminum
- Cells:
  - The lightweight Nickel electrode is plastic bonded treated Nickel Hydroxide.
  - The separator consists of one layer of Pellon 2588.
  - The Metal Hydride electrode is EEI plastic bonded RP40.
  - The Electrolyte is 30% by weight Potassium Hydroxide solution with 1% Lithium Hydroxide.
  - Nickel Foil Cell Face.
  - Epoxy Insulating Frame.
- Tie Rods - Titanium
- Current Collectors - Nickel Foil

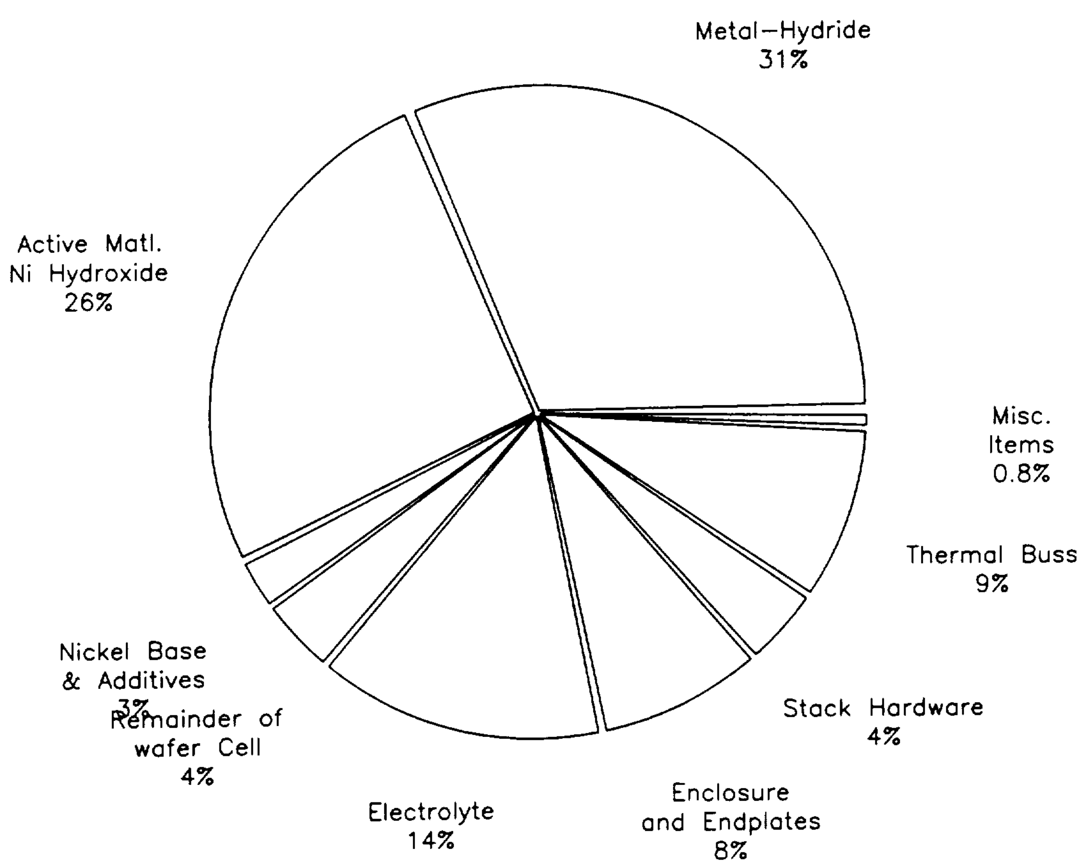
IMPROVED DESIGN FLIGHT-WEIGHT BATTERY SUMMARY (cont'd)



Battery Weight Summary

Battery Weight Table			
Item	Wt.(g)	Wt.(lbs)	Wt.%
Metal-Hydride	5500.0	12.1	31.3
M-H Electrode Additives	27.6	0.1	0.2
Nickel Base & Additives	442.6	1.0	2.5
Active Material Ni Hydroxide	4552.9	10.0	25.9
Electrolyte	2534.1	5.6	14.4
Remainder of Wafer Cell	679.9	1.5	3.9
Thermal Buss	1528.2	3.4	8.7
Stack Hardware	700.2	1.5	4.0
Enclosure and Endplates	1447.6	3.2	8.2
Miscellaneous Items	134.7	0.3	0.8
Total	17548.0	38.7	100

Battery Weight Distribution



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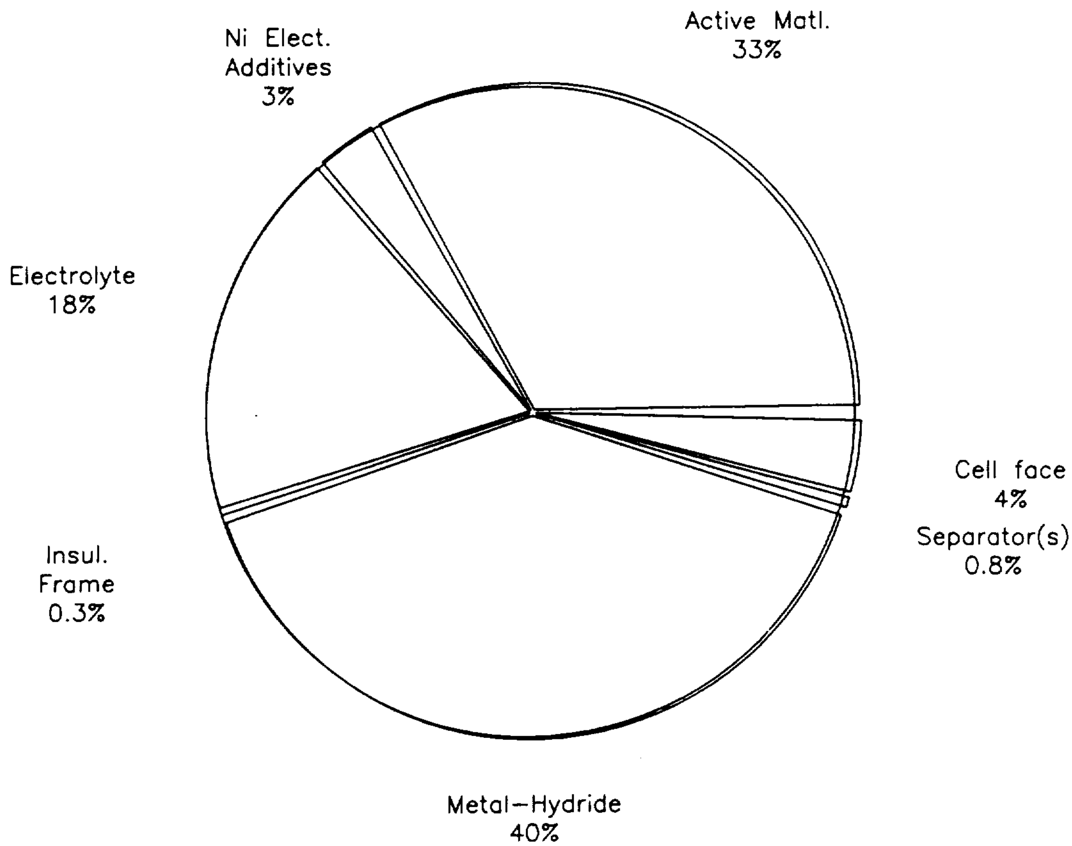
Wafer Cell Weight Summary

Wafer Cell Weight Table		
Item	Wt.(g)	Wt.%
Active Material	94.9	33.1
Ni Electrode Additives	9.2	3.2
Metal–Hydride	114.6	40.0
M–H Electrode Additives	0.6	0.2
Washer	0.4	0.1
Separator(s)	2.2	0.8
Electrolyte	52.8	18.4
Insulating Frame	0.8	0.3
Cell Face	10.8	3.8
Total	286.2	100

Wafer Cell Weight Distribution



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PRELIMINARY DESIGN BOILERPLATE BATTERY SUMMARY

- Function:
  - The Preliminary Design Boilerplate Battery is a prototype of the Flightweight Battery Design for Development Testing.
- Description:
  - The battery is prismatic (rectangular) in shape.
  - The outer enclosure serves to contain cell stack pressure and is sealed with o-rings and a gasket.
  - Tie rods are used to maintain cell stack compression.
  - The battery has one 12-cell stack. Internal pressure is regulated by a preset relief valve.
  - There are thermo-couples to monitor internal temperatures.

PRELIMINARY DESIGN BOILERPLATE BATTERY SUMMARY (cont'd)

Size

- Overall dimensions of the battery case are approximately 9.4" wide by 2.5" high by 13.6" long
- The Nickel-Metal Hydride cells (12) are approximately: 0.085" thick by 6.56" high by 12.56" long

Materials

- Enclosure - Ni plated aluminum
- Thermal Plates - Ni plated aluminum
- Cells:
    - The lightweight Nickel electrode is plastic bonded treated Nickel Hydroxide.
    - The separator consists of two layers of Pellon 2588.
    - The Metal Hydride electrode is EEI plastic bonded RP40.
    - The Electrolyte is 30% by weight Potassium Hydroxide solution with 1% Lithium Hydroxide.
    - Nickel Foil Cell Face.
    - Epoxy Insulating Frame.
- Tie Rods - Zinc plated steel
- Current Collectors - Nickel Foil
- Seals - Neoprene

PRELIMINARY DESIGN BOILERPLATE BATTERY SUMMARY (cont'd)

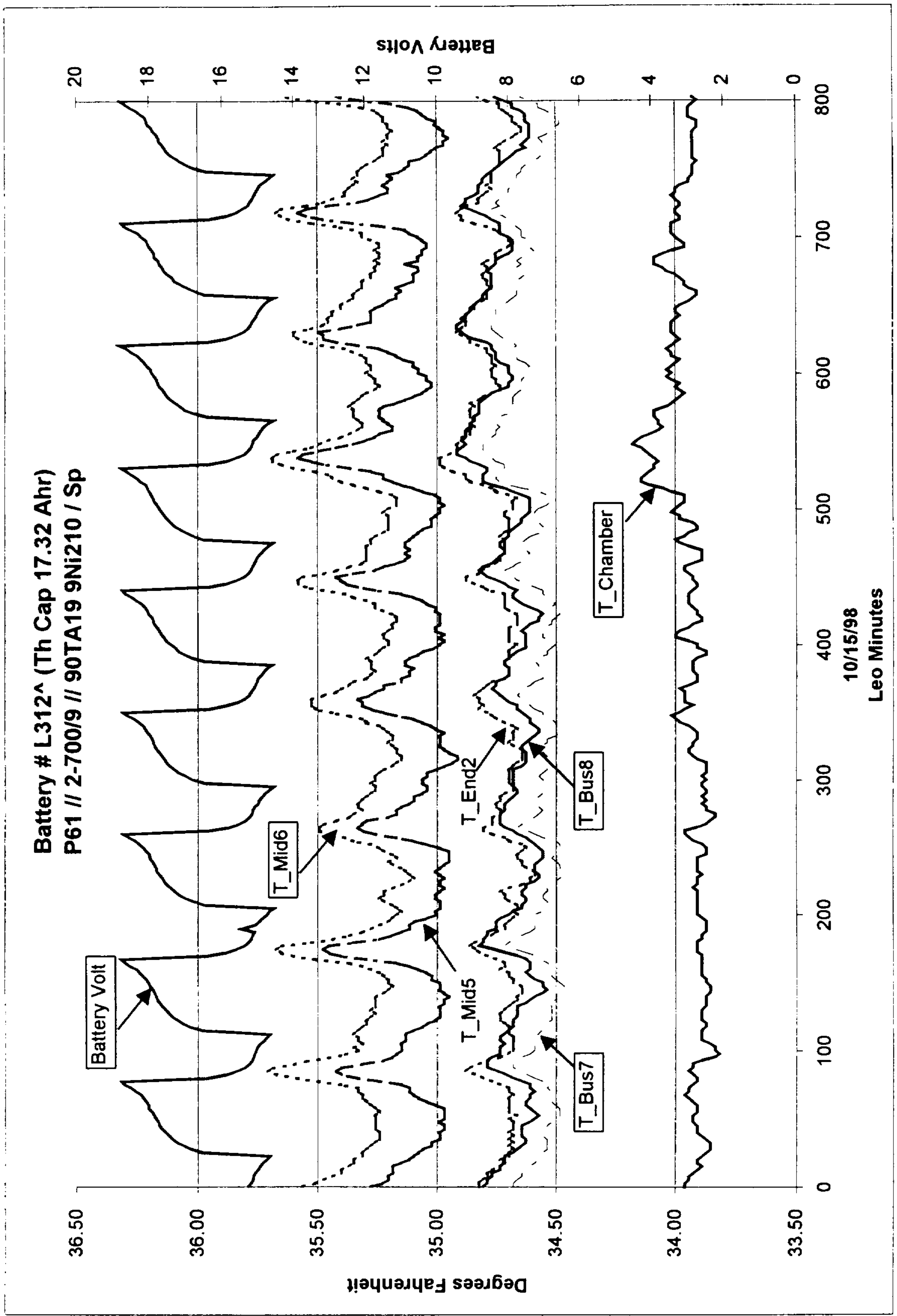
Design Requirements:

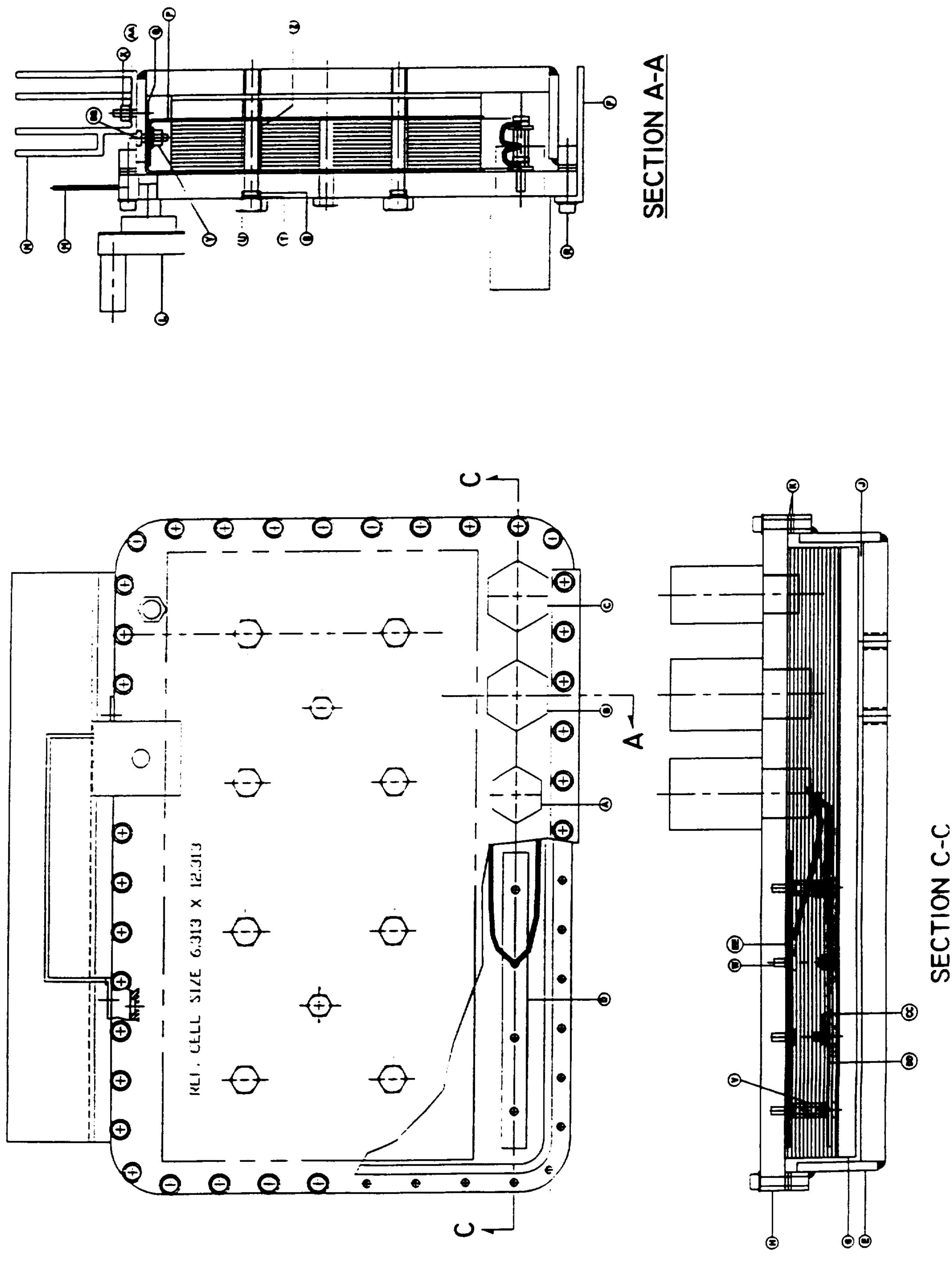
a.	Voltage:	14.4 V
b.	Current:	7.9 A Charge, 11.9 A Discharge
c.	Power:	.249 Kilowatt
d.	Battery Capacity:	17.3 A/hr (6.9 A/hr at 40% DOD)
e.	Cell Weight (wet):	313 grams
f.	Cell Energy Density:	63 Wh/kg
g.	Cell Capacity:	17.3 Amp hours
h.	Current Density:	26 mA/cm^2
i.	Cycle Life:	TBD
j.	Operating Temperature:	-10° C to +25° C
k.	Charge Retention:	TBD
l.	Overcharge:	5%
m.	Electrical Insulation Resistance:	> 1 megohm @ 100 VDC
n.	Cooling:	Conductive baseplate
o.	Maximum Temperature Change:	25° C above cold plate
p.	Thermal Generation:	32 Watts Average

PRELIMINARY DESIGN BOILERPLATE BATTERY TASK

- Test Results:
    - Theoretical Capacity: 17.3 A-hrs
    - Formation Capacity: 13.0 A-hrs
    - LEO Test (40% DOD, 5% OC): On-going

- Future Work:
    - Build a second PDBB (Nov. 98)
    - DPA first PDBB (1999)

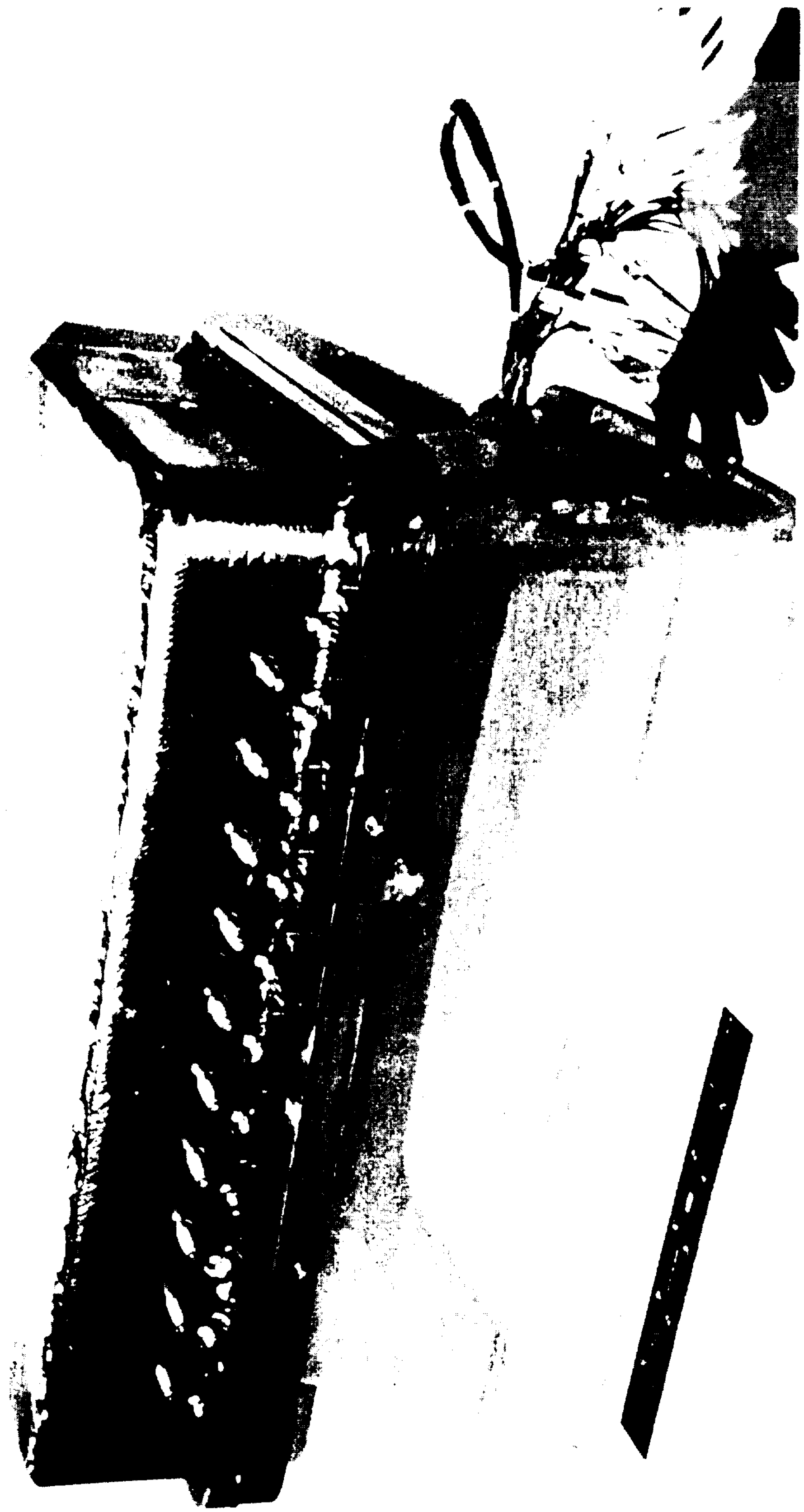

Battery # L312^ (Th Cap 17.32 Ahr)
P61 // 2-700/9 // 90TA19 9Ni210 / Sp
Battery Volt
T_Mid6
T_Mid5
T_End2
T_Bus8
T_Bus7
T_Chamber
Degrees Fahrenheit
Battery Volts
10/15/98
Leo Minutes


SECTION A-A
SECTION C-C
REF. CELL SIZE 6.313 X 12.313
A
C

PART LIST

ITEM	DESCRIPTION	DWG. OR PART NUMBER	QTY.
A	1/2" SEALED ELECTRICAL FEED	MHCA-040-8	1
B	3/4" SEALED ELECTRICAL FEED	PL-12-2	1
C	3/4" SEALED ELECTRICAL FEED	MHC5-032-16	1
D	BUS BAR	DA-018	1
E	HOUSING WELDMENT	DA-004	1
F	STAND	DA-016	1
G	FLOATING PLAT	DA-011	1
H	COVER	DA-005	1
J	FOAM RUBBER FILL GAP		1
K	GASKETS	DA-019	2
L	OMEGA INDUSTRIAL PRESSURE TRANSDUCER		1
M	HANDLE	MCMASTER CARR P#169A11	1
N	COOLING FAN	DA-015	1
P	THERMAL BUS	DA-013	1
Q	THERMAL BUS, STUD DESIGN	DA-014	1
R	#10-32 SOCKET HEAD SCREW		44
S	O'RING		8
T	BACK UP O'RING		8
U	#1/4-20 BOLT		8
V	#8-32 NYLON STANDOOF 1/4" HEX X 1"		2
W	#8-32 X .375 SCREW		6
X	#8 NUT		11
Y	#6 SELF LOCKING NUT		11
Z	#1/4-20 TIE RODS		8
AA	#8 WASHER		10
BB	SELF SEALING SCREWS		11
CC	#8 N UT		2
DD	#8 WASHER		2
EE	12 GA WIRE LUG		2

Preliminary Design Bipolar Ni-MH Pouch Type Battery



100 W-HR/kg APPROACHES

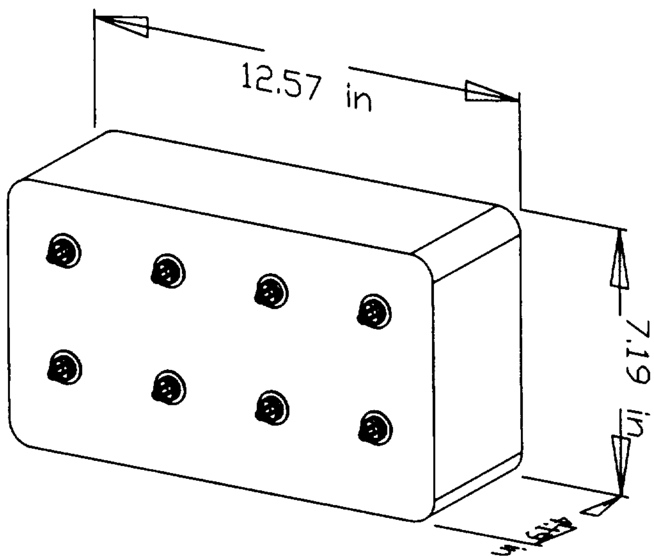
(1) Develop a MH Alloy that has 500 mA-hr/g and 5-year LEO Life

- On-going

(2) Develop a Ni Electrode that gives 1.25 electron transfers and a 365 mA-hr/g and 5-year LEO Life

Bipolar Nickel Metal Hydride Battery Design System

User:	MnStk+500 mAH/g MH
Power:	1.0 kW
Battery Capacity:	52.1 Ah



	Metric	SAE
Specific Energy:	99.3 Wh/kg	218.9 Wh/lb
Energy Density:	234.9 Wh/l	8.3 Wh/ft3
Overall Weight:	14.7 kgs	32.4 lbs
Cell Weight:	11.0 kgs	24.3 lbs

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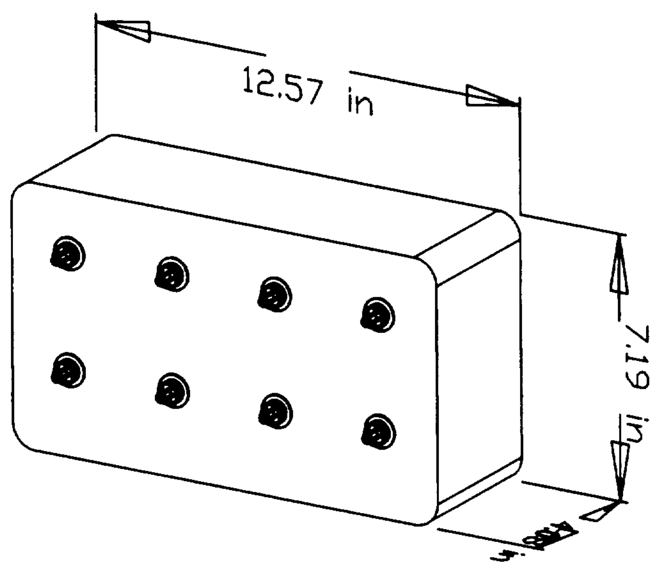
Bipolar Nickel Metal Hydride Battery Design System

User: Min Stk+125% Theo Ni+365MH

Power: 1.0 kW
Battery Capacity: 52.1 Ah



	Metric	SAE
Specific Energy:	100.2 Wh/kg	220.9 Wh/lb
Energy Density:	241.5 Wh/l	8.5 Wh/ft3
Overall Weight:	14.6 kgs	32.1 lbs
Cell Weight:	10.7 kgs	23.7 lbs

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Status of EEI's Bipolar Ni-MH Battery Project

The Bipolar Ni-MH Battery Project has:

- **Demonstrated the Wafer cell concept in multi-cell stacks on the LEO test regime**
- Demonstrated the advantages of the bipolar wafer cell concept in multi-cell stacks
  - Allows repair or replacement of individual cells
  - No external cell terminals
  - No electrode current collectors
  - Adaptable to heat transfer fins placed in stack
  - Scalable to large area and high capacity
  - Improved energy and power density
  - Lower cost plastic bonded electrodes
- **Tripled the LEO cycle-life of vented-flooded bipolar wafer cells**
  - Vented-flooded cells: 7400 LEO cycles @ 50% DOD
9200 LEO cycles @ 25% DOD (EODV=1.18 V)
- **Doubled the LEO cycle-life of sealed-starved bipolar wafer cells**
  - Sealed-starved cells: 2400 LEO cycles @ 50% DOD (EODV=1.0 V)
- Completed a very high energy density bipolar battery design
  - 83 Wh/kg (37.8 Wh/lb)
  - 211 Wh/liter (7.4 Wh/ft^3)

Status of EEI's Bipolar Ni-MH Battery Project (cont'd)

The Bipolar Ni-MH Battery Project will:

- Build two .5 kW, 24 cell prototype batteries with lightweight housings and 105 Wh/kg cells in 1999
  - 70 Wh/kg (31.6 Wh/lb)
  - 154 Wh/liter (5.5 Wh/ft^3)
- Build two 1.0 kW, 48 cell prototype batteries with lightweight housings and 114 Wh/kg cells in 2000
  - 82 Wh/kg (37.3 Wh/lb)
  - 204 Wh/liter (7.2 Wh/ft^3)
- Complete a high energy density Flight-weight Bipolar Battery Design and drawing package
  - 100 Wh/kg (45.5 Wh/lb)
  - 235 Wh/liter (8.3 Wh/ft^3)

Conclusions:

- Improved active Ni and/or MH materials a required to increase the battery energy density from 83 Wh/kg to 100 Wh/kg.

Acknowledgments

Thanks and recognition needs to be given to:

- **The NASA Lewis Research Center** for having the vision, and funding the project.
- **Michelle Manzo** and **Tom Miller** for their support, technical expertise, leadership and encouragement.
- **Rhodia** (formerly Rhone-Poulenc), **Rutgers University**, and **Design Automation Associates** for their significant cost sharing contributions.
- **Dr. Bao-Min Ma** (Rh), **Charles Grun** (RU), and **Sean Sullivan** (DAA) for their significant technical contributions and excellent customer support.
- **Eagle-Picher Industries** for their technical guidance and sharing of their extensive design-to-orbit experience.
- **James DeGruson** (EPI) for his project guidance and persistent grappling for EPI resources.