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N95- 26793

# Unique Features of a New Nickel-Hydrogen 2-Cell CPV

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Eagle Picher Ind., Joplin MO

Abstract

Two-cell nickel-hydrogen common pressure vessel (CPV) units with some unusual design features have been successfully built and tested. The features of interest are half-normal platinum loading for the negative electrodes, the use of rabbit-ear terminals for a CPV unit, and the incorporation of a wall wick. The units have a nominal capacity of 20 Ah and are 3.5 inches in diameter. Electrical performance data is provided. The data support the growing viability of the 2-cell CPV design concept.

## Cell Description

The unit described in the tests described here is a 3½ inch-diameter RNHC 20-5. It is a two-cell common-pressure-vessel design with a nominal capacity of 20 Ah. Its construction is identical to that of a 40 Ah tandem-stack ManTech cell, except that the two stack-halves are internally connected in series rather than parallel. One of the units is shown in figure 1. As can be seen, this unit has rabbit-ear terminals, which has the advantage of reducing battery height and cell-to-cell interconnection mass.

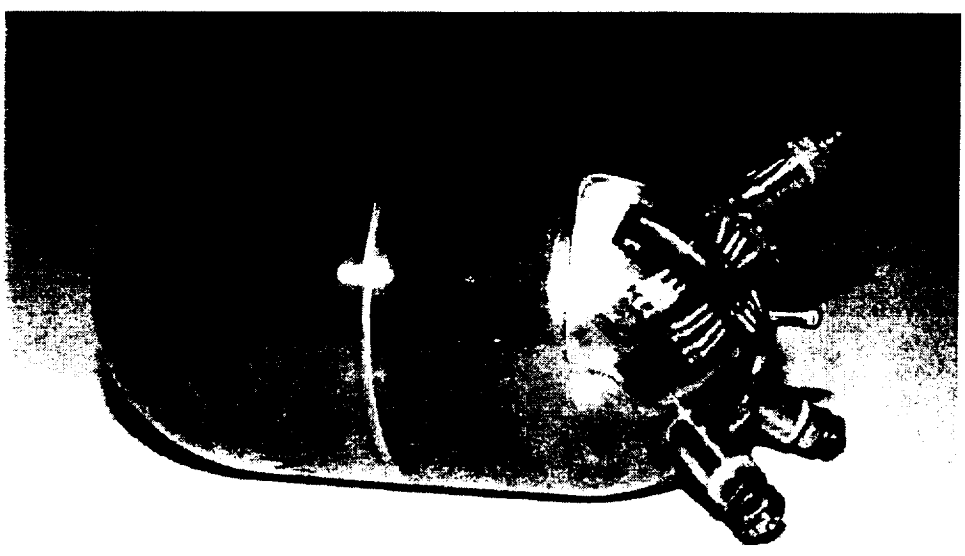

Figure 1.
RNHC 20-5

By "ManTech" is meant an Eagle Picher design which uses pineapple-slice-shaped electrodes and stack elements, a central polysulfone core, continuous nickel-foil leads on electrodes, and a wall-wick to ensure a recirculating path to return and equilibrate electrolyte throughout the cell stack. Also unlike an IPV, there is no separator/electrolyte bridge provided between the cell stacks. Although not present in these units, a hydrophobic Teflon strip adjacent to the weld ring on either side is planned for future units to discourage any possible long-term ionic migration through electrolyte film between the two internal cells.

Other features include a spring washer for uniform stack compression and separator/electrolyte contact with the cell wall to facilitate heat transfer. The positive electrode material is 80% slurry. The active material loading was a standard 1.65 g/ccv.

The separator material is two layers of zirconium-oxide cloth per positive electrode. Having two layers was desired because the intended functions were for operation in low earth orbit (LEO). The double separator design results in more weight for the unit, much of which is electrolyte.

Unusual Features

These units have some unusual features which distinguish them from normal production:

The use of a wall wick in a 2-cell CPV unit.

The negative electrodes were loaded to a platinum level of 4 g. per $cm^2$, which is half the normal loading.

This is the first 3.5 inch-diameter CPV unit with rabbit-ear terminals to be built by Eagle Picher. The third terminal on this unit is a special test terminal (center voltage tap) which is connected internally between the two cells. It is not necessary to the unit's function and would not be present in flight units.

The slurry plaque for the positive electrodes was manufactured in Eagle Picher's Range-Line plant in Joplin, Missouri. This is notable since all of EP's flight production thus far has come from its Colorado plant. The plaque design is otherwise identical however.

Performance

Seven units of this design were built and tested using conventional acceptance-type tests and a 2C (40 amp) pulse test. The pulse was applied for 20 seconds after 15 minutes of discharge at the normal rate of 10 amps (C/2). The performance of the units in testing was essentially what would be expected for individual-pressure-vessel cells, allowing for the double voltage of these units. The test results are shown in table 1, and the charge and discharge curves at 10°C and 0°C are shown in figures 2 through 5. It is noteworthy that the charge retention of these units, at 88% for a 72-hour open-circuit stand, is virtually the same as for an IPV with the same separator. The cells showed no ill effects of the 2C (40 amp) pulse. Average minimum voltage at the end of the pulse was 2.36 volts (IPV equivalent: 1.18 volts).

Table 1.
RNHC 20-5 CPV
AVERAGE PERFORMANCE

| Test | 2.0 Volts | 2.2 Volts | Max. Chg. Volts |
|---|---|---|---|
| 10°C Capacity (Ah) | 22.19 | 21.99 | 3.051 |
| 0°C Capacity (Ah) | 24.34 | 23.81 | 3.132 |
| 10°C High Rate (Ah) | 23.77 | 23.61 | 3.046 |
| 10°C 72-Hr. C.R.* | 20.91 | 20.77 | 3.045 |

* 88.0%

## Conclusions

The results of the tests support the viability of the 2-cell CPV design at a time when interest in this concept for nickel-hydrogen batteries is growing. With half as many interconnects in a 2-cell CPV battery and somewhat less pressure-vessel weight per cell, they represent a significant potential weight-savings at the battery level[1]. Fears of internal electrolyte bridging in two-cell unit have proven unfounded, and now the compatibility of the wall wick with the 2-cell CPV concept has also been demonstrated.

Two cell CPV's have already flown in the MISTI, TUBSAT and APEX programs[2], and common use in the future seems likely. The use of single rather than double layer separator would be appropriate for GEO applications and would make the weight of the battery more attractive. Had this unit been a single-layer design, its weight would have been 1146.6g., a savings of 106.3g (computer-design projection). The cost would be improved as well since the separator is an expensive component.

The successful manufacture and testing of the units documented here add to the growing literature for 2-cell CPV's, and in addition show that reduced platinum loading of negative electrodes can be combined with the CPV concept. The compatibility of the rabbit-ear terminal configuration is also affirmed with this work. The use of slurry plaque from a different source was shown to perform to the same standards as that from the more-usual one.

## Acknowledgments

David Cooke managed the assembly and testing of the RNHC 20-5. His contributions are gratefully acknowledged.

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[1] Otzinger, B. M., and Wheeler, J. R., "Common Pressure Vessel Nickel Hydrogen Battery Development", Vol. III, p. 1381, IECEC Proceedings, 1989.
[2] Coates, D. K., and Fox, C. L., "Current Status of Nickel-Hydrogen Battery Technology Development", Part 1, pp. 75-80, IECEC Proceedings, 1994

# Status Of Bipolar Nickel-Metal Hydride Development

*November 15, 1994*

**Martin Klein**

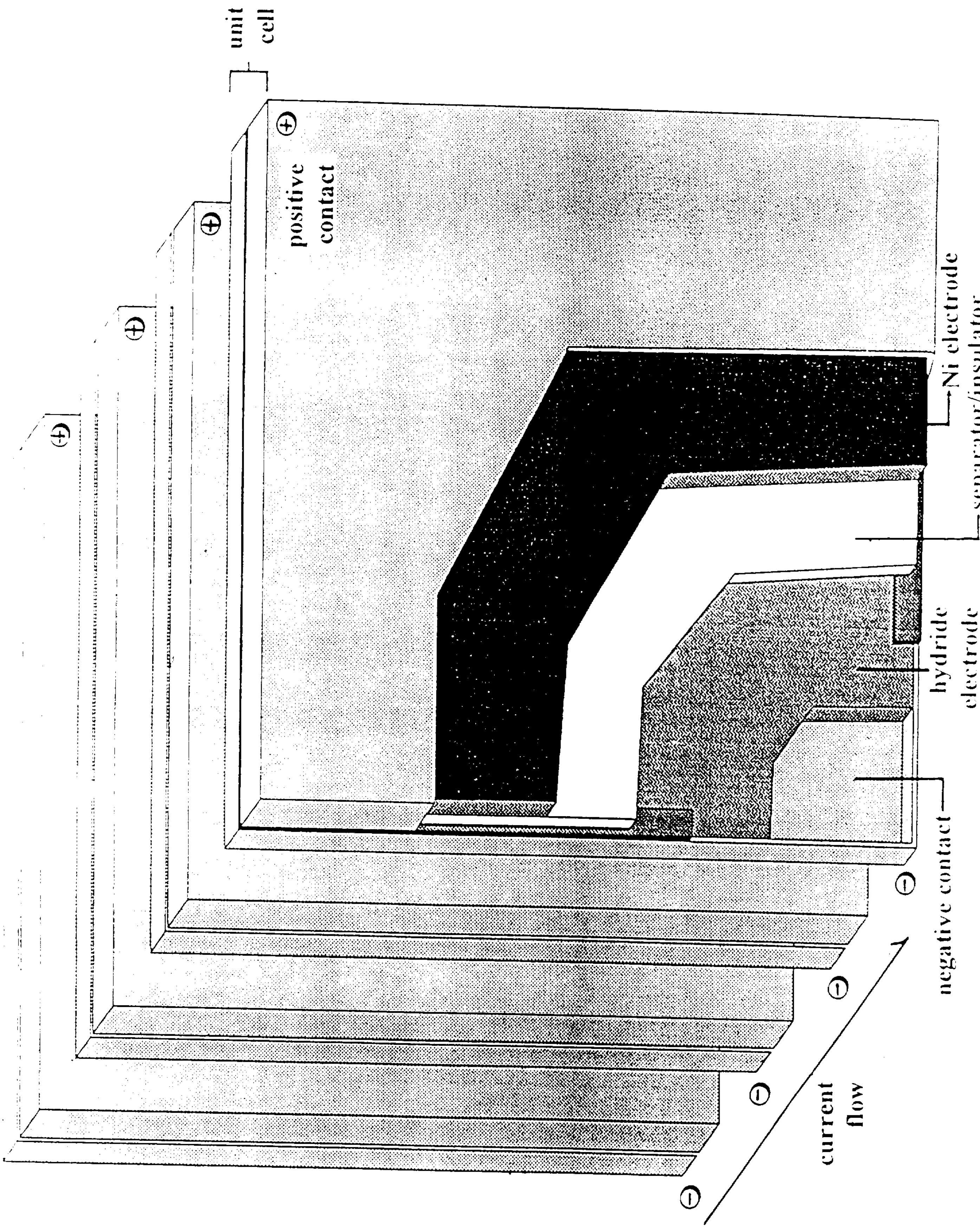
Electro Energy, Inc.
Shelter Rock Lane
Danbury, CT 06810
203-797-2699

$$Ni(OH)_2 + OH^- \text{ ------------ } NiOOH + H_2O + e^-$$

$$M + e^- \text{ ------------ } 1/2\ MH + OH^-$$

$$Ni(OH)_2 + M \text{ ------------ } NiOOH + 1/2\ MH$$

**Cell Reactions**



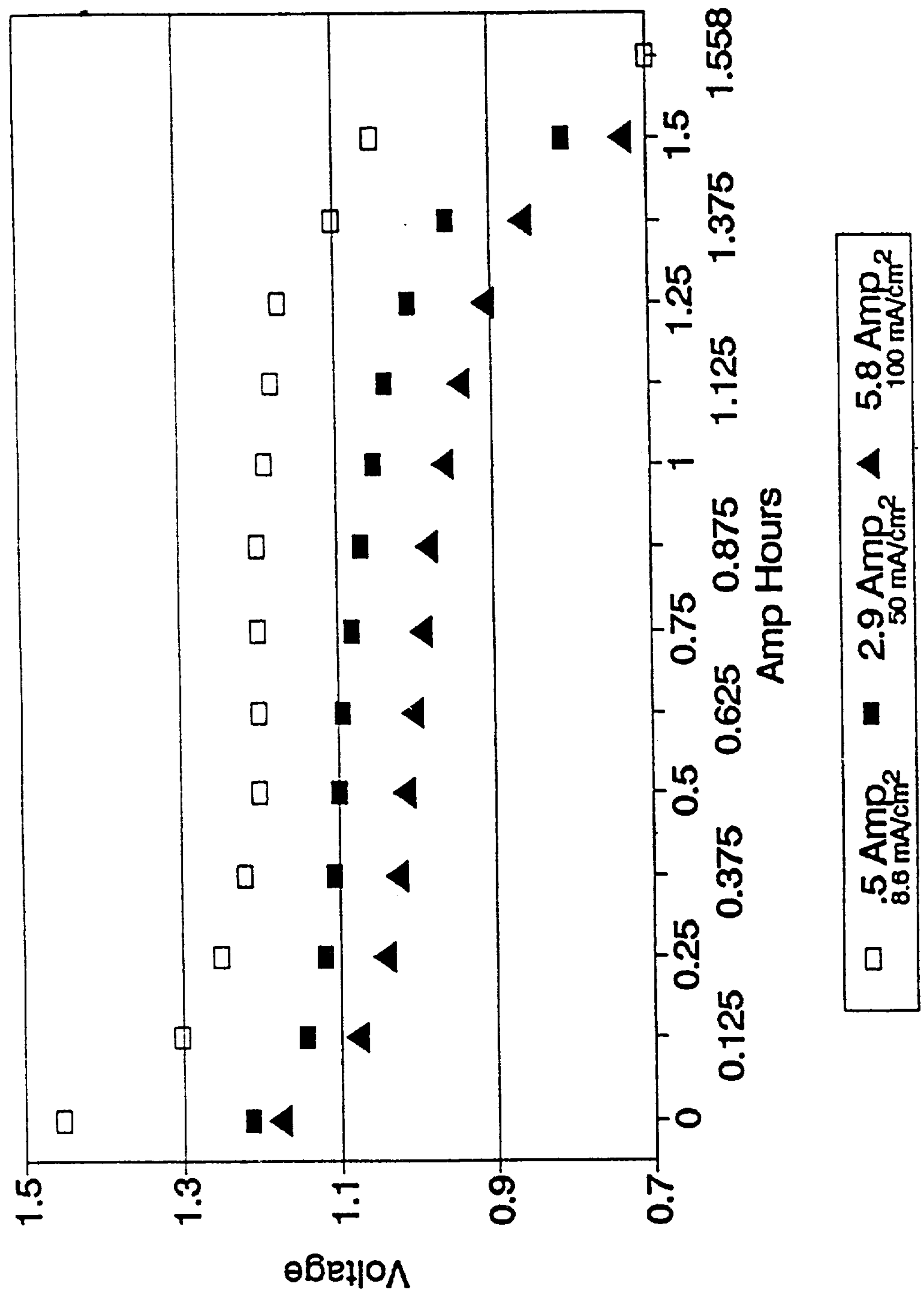

**Bipolar Wafer Cell Concept**

- Commercial sintered nickel electrodes
- Plastic-bonded nickel electrodes fabricated at EEI
- Pasted nickel foam electrodes fabricated at EEI
- Separator material consisting of non-woven nylon, polypropylene, or plastic-bonded inorganic compounds
- Hydride materials consisting of various rare earth $AB_5$ alloys similar to the International Common Samples.

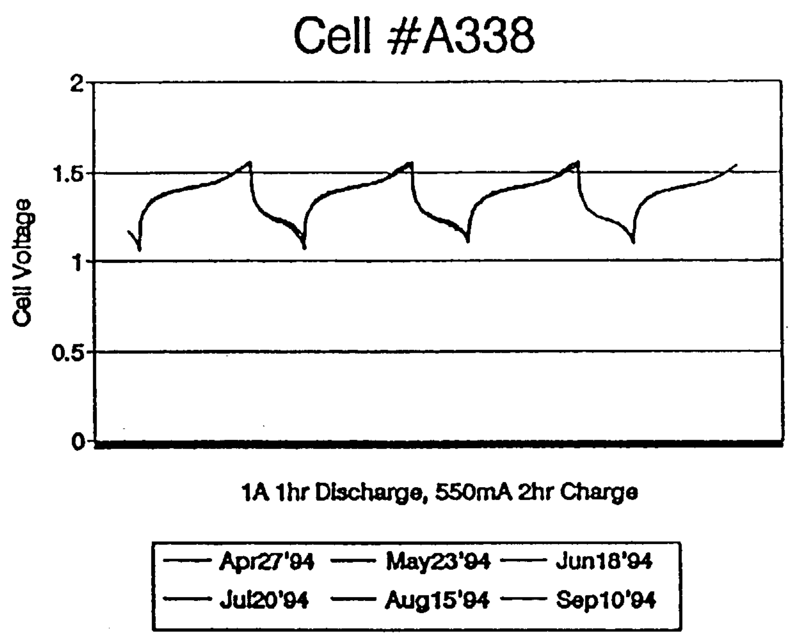
**Major Component Variables**

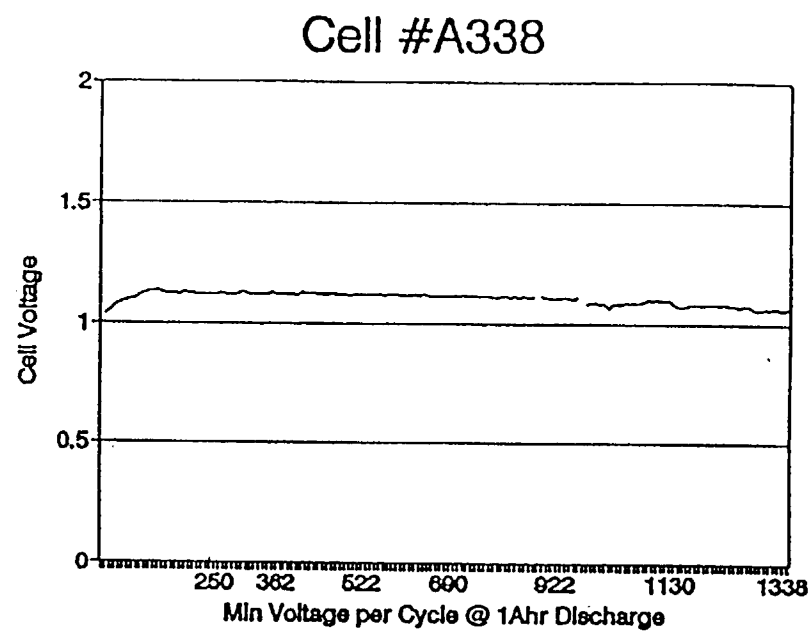
| | | |
|---|---|---|
| (1) | IBA MH No. 1 | $MmNi_{3.55}Co_{0.75}Mn_{0.4}Al_{0.3}$ |
| (2) | IBA MH No. 2 | $MmNi_{3.5}Co_{0.7}Al_{0.8}$ |
| (3) | IBA MH No. 3 | LmNi alloy |
| (4) | IBA MH No. 4 | $Ti_{1.6}V_{2.2}Zr_{1.6}Ni_{4.2}Cr_{0.7}$ |
| (5) | IBA MH No. 5 | $MmNi_{3.5}Co_{0.7}Al_{0.8}$ |
| (6) | IBA MH No. 6 | $MmNi_{3.5}Co_{0.8}Mn_{0.4}Al_{0.3}$ |

## International Common Samples of MH Alloys



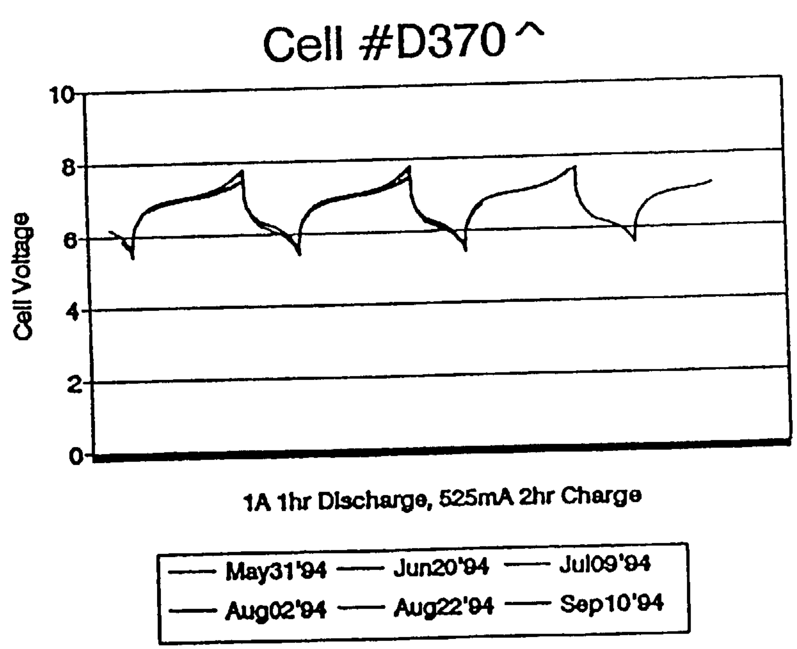

**Bipolar Cell Rate Tests**

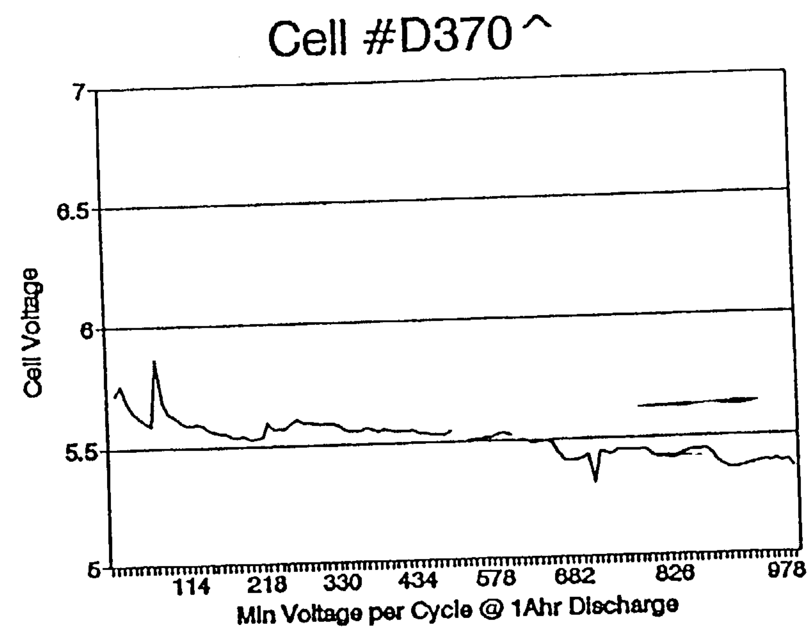


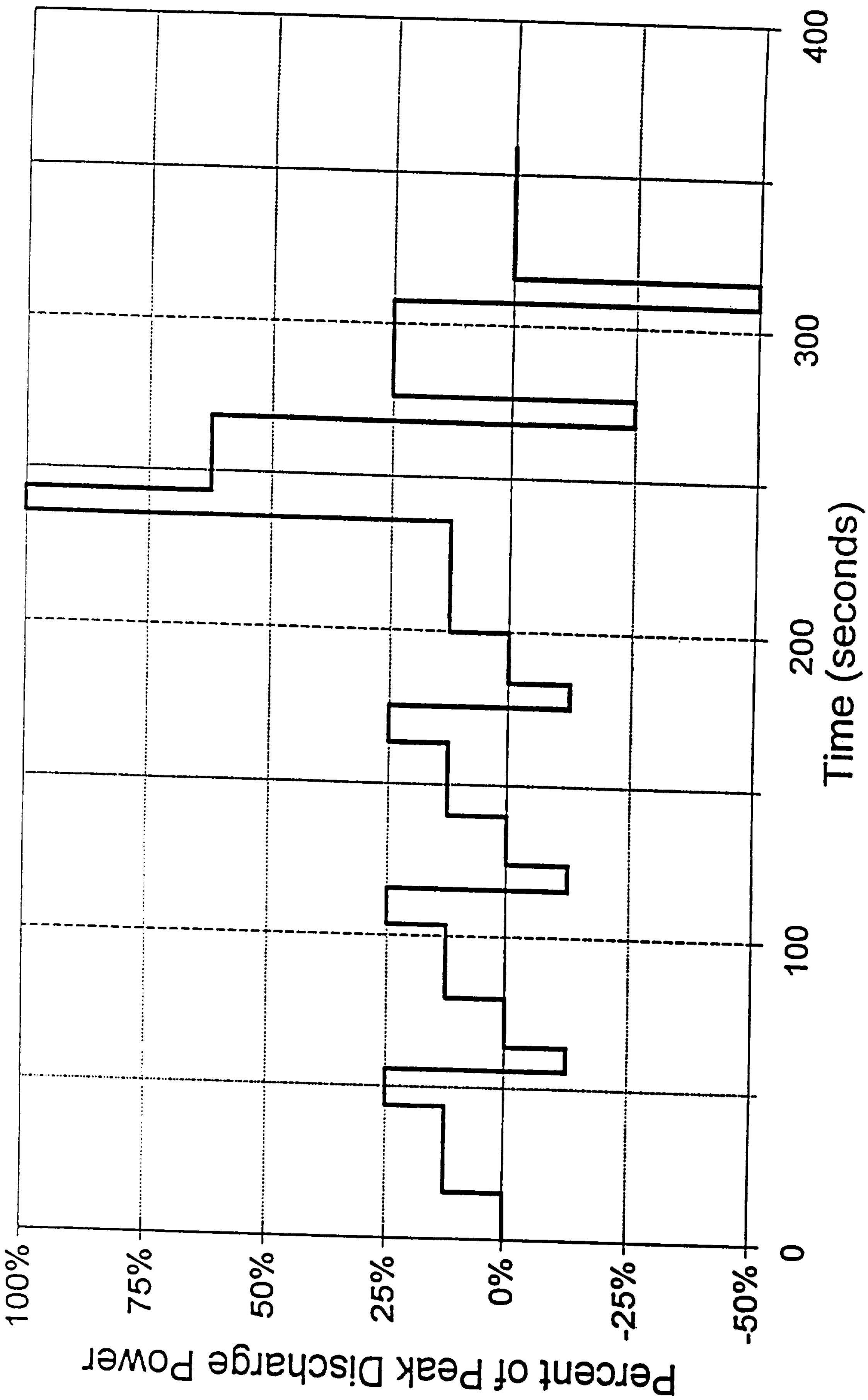

**Single Vented Wafer Cell 3" x 3" Electrodes**
**1.5 Ah Nominal Capacity**
**Cycle 66% DoD, 1 h Discharge/2 h Charge**

# Plastic Bonded, Nickel Electrode, Life Test

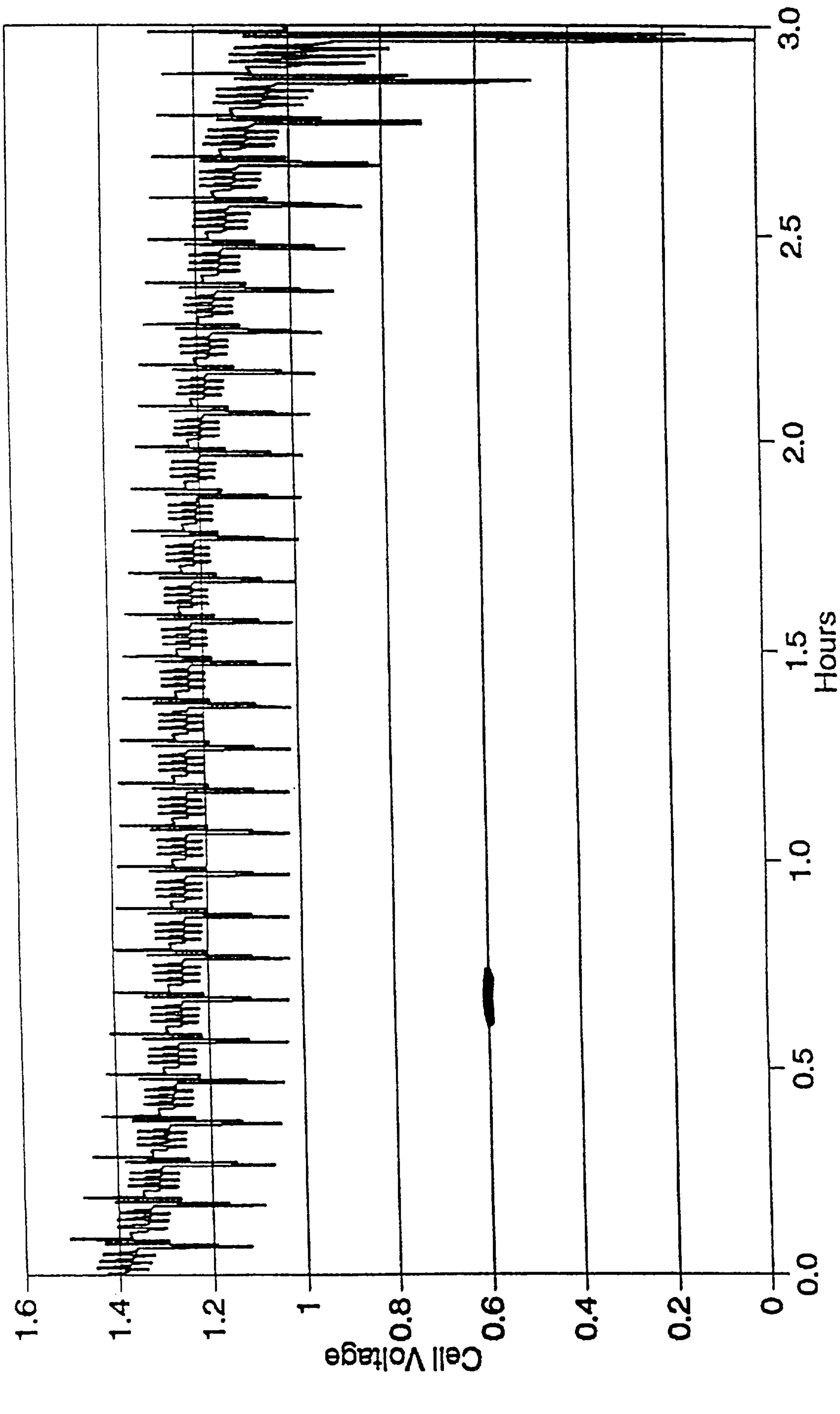


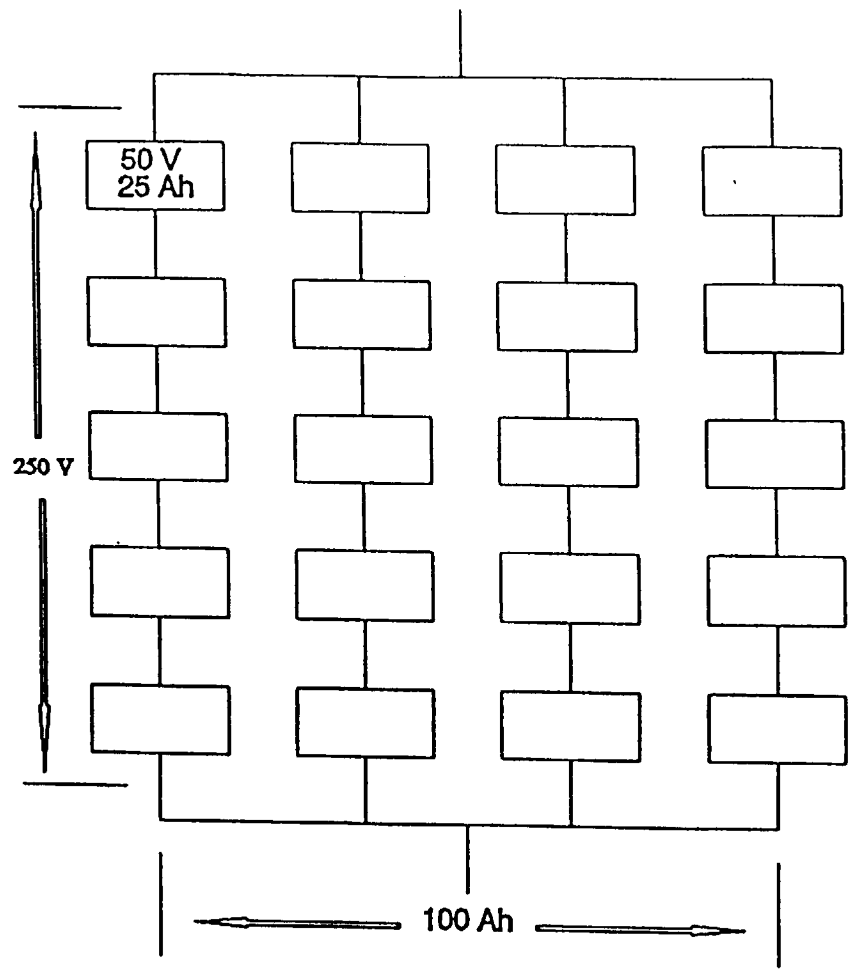

# Vented 5 Cell Pack, Life Test




**Dynamic Stress Test (DST) Cycle**




**DST Discharge Profile**

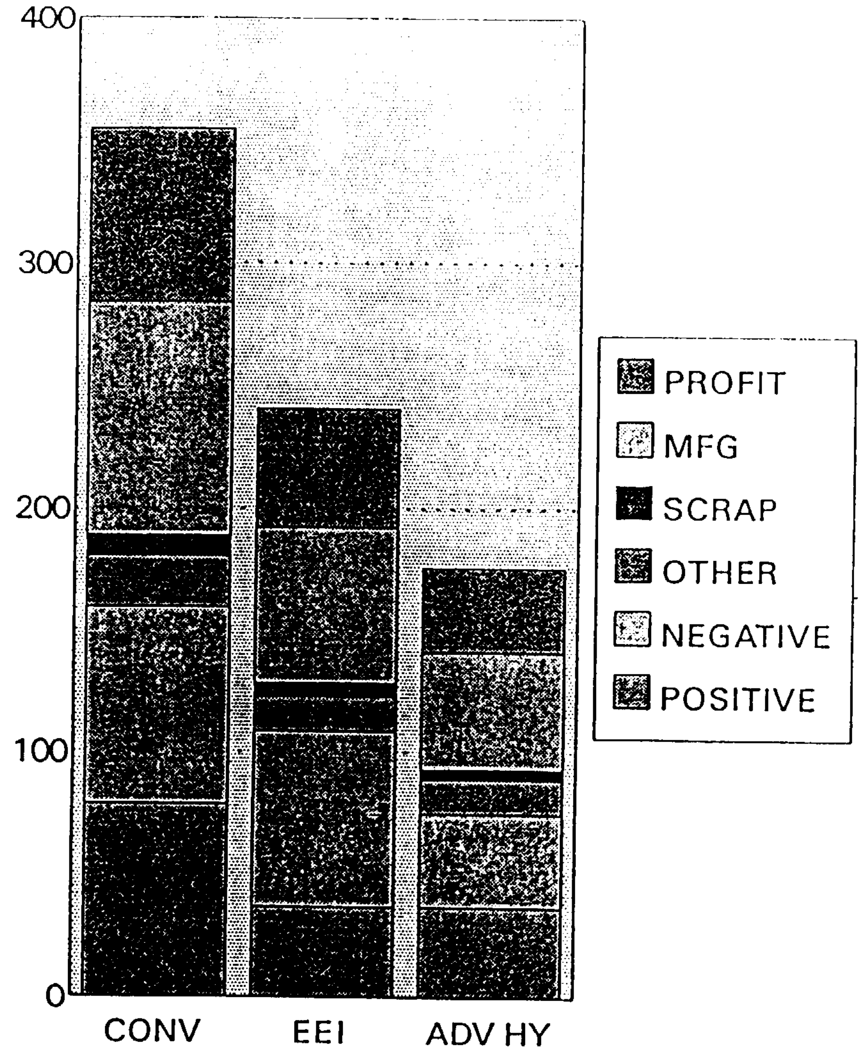



**Electric Vehicle Battery Arrangement**

## 100 Ah 250 V BATTERY PARAMETERS

| | |
|---|---|
| NO. PARALLEL MODULES | 4 |
| VOLTAGE, CAPACITY, | 250 V, 100 Ah |
| ENERGY | 25 kWh |
| DIMENSION (in.) | 10 x 40 x 23 (150 l) |
| WEIGHT (inc. hardware)(5%) | 420 kg |
| E.D. GRAVIMETRIC | 60 Wh/kg |
| E.D. VOLUMETRIC | 167 Wh/l |

100 Ah 250 V Battery Parameters




# Estimated Ni-MH Cost Analysis ($/kWh)

- Nickel-Metal Hydride Battery System a leading contender for EV Applications.
- Bipolar approach has cost and power advantages.
- Results of single and multi-cells demonstrate stabioity of materials of construction and power capability.
- Growth potential
  Improved Nickel and Hydride
  80 to 100 Wh/kg

## Summary

# RECHARGEABLE LITHIUM - STATUS OF SAFT ACTIVITIES

J.L. FIRMIN

SAFT

C. BASTIEN

SAFT

1994 NASA WORKSHOP
HUNTSVILLE, ALABAMA

## PRESENTATION CONTENT

- HISTORY
- LI - ION TECHNOLOGY
- SAFT STRATEGY
- SAFT SPACE PLAN
- ELECTRONICS
- PRODUCT PERFORMANCES AND CHARACTERISTICS

# HISTORY

**SINCE 1964, SAFT HAS BEEN ONE OF THE PIONEERS OF THE LITHIUM BATTERY CHEMISTRY.**

- **TODAY**, SAFT IS THE WORLD LEADER OF $LiSO_2$ AND $LiSOCL_2$ PRIMARY BATTERIES
- **OVER THE LAST TWO YEARS**, SAFT HAS DEVELOPPED $LiV_2O_5$ AND $LiNiO_2$ RECHARGEABLE CELLS FOR MILITARY APPLICATIONS.
- **MORE RECENTLY**, A NEW TYPE OF RECHARGEABLE LITHIUM HAS BEEN DEVELOPPED FOR LONGER LIFE AND IMPROVED SAFETY : **Li -ION**

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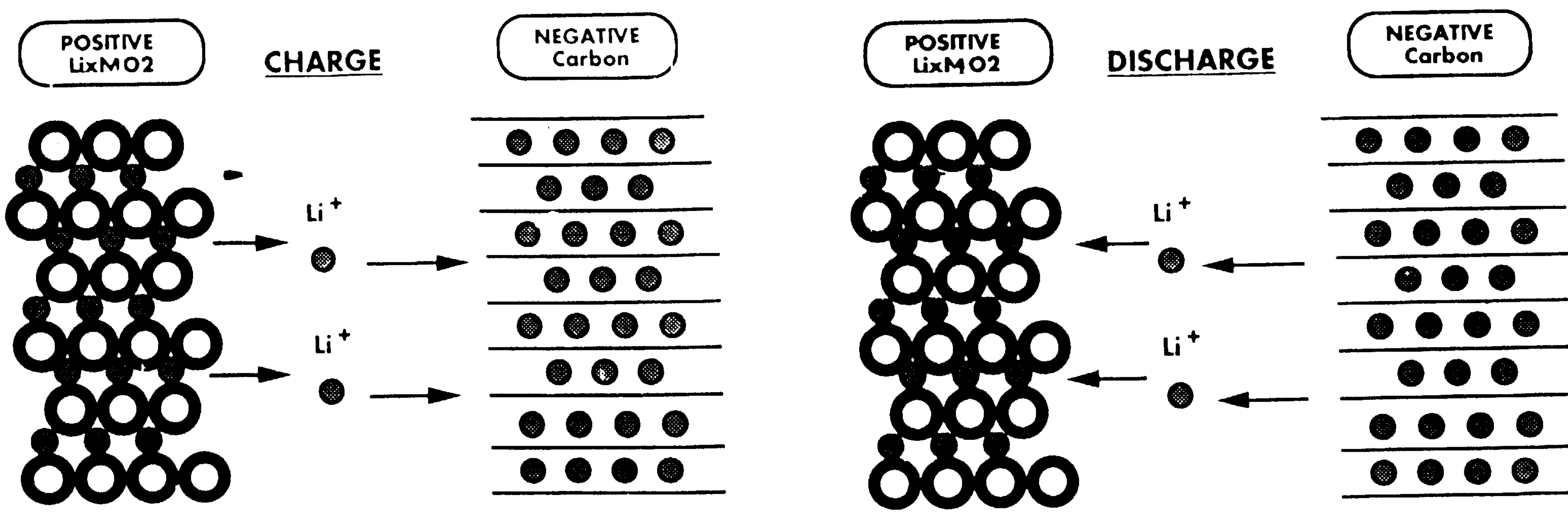
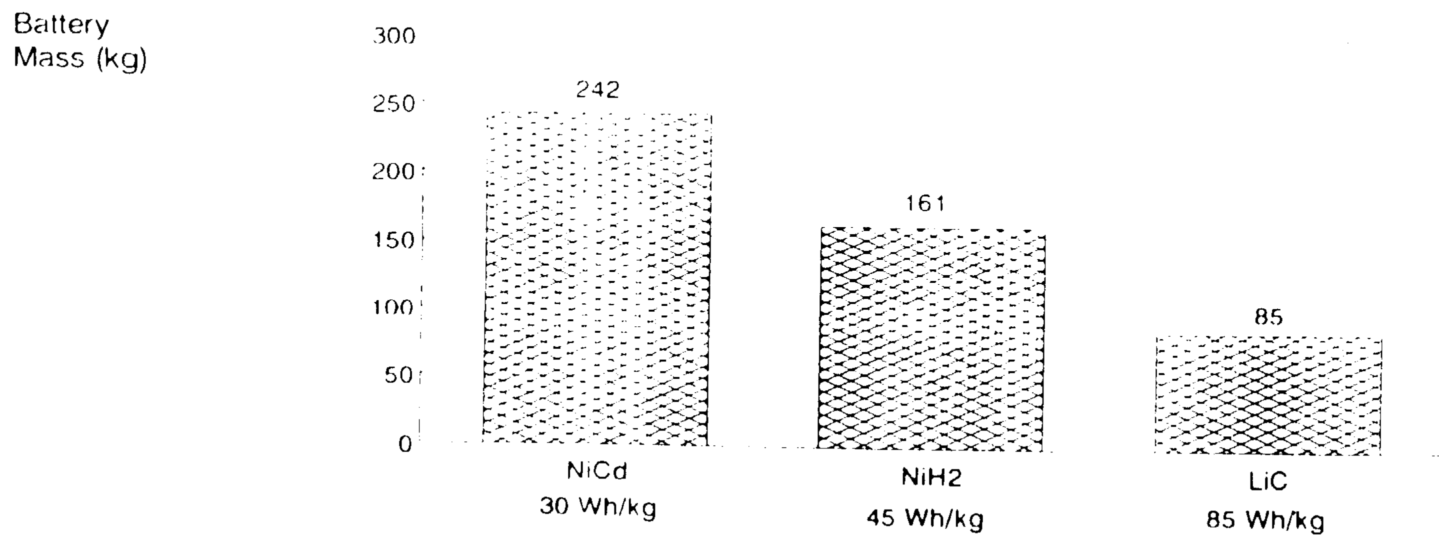
# Li - ION TECHNOLOGY

• Li -ION operating principles



# LI - ION TECHNOLOGY

- **A lighter energy : Estimation of a 4.5 kW geostationary satellite battery mass in function of the electrochemical couple.**




MASS GAIN BETWEEN A NiH2 AND LiC BATTERY : **76 kg** (for a 4.5 kW powerful satellite)

***FACTOR 2***

# LI - ION TECHNOLOGY

- **And more than that !**

| | | Alkaline family | | | Lithium | |
|---|---|---|---|---|---|---|
| | | Standard Ni-Cd | Enhanced Ni-cd | Ni-MH | Li-Ion | |
| 1 | Nominal capacity (mAh) | + | ++ | +++ | - | |
| 2 | Volumetric Energy (Wh/l) | - | + | ++ | +++ | ← |
| 3 | Weight Energy Density (Wh/Kg) | - | + | ++ | +++ | ← |
| 4 | Nominal Voltage | 1.2V | 1.2V | 1.2V | 3.6V | ← |
| 5 | Charge retention | + | ++ | + | +++ | ← |
| 6 | Cycle life | +++ | ++ | ++ | + | |
| 7 | High rate charge | +++ | ++ | ++ | + | |
| 8 | Memory effect | - | - | + | +++ | ← |
| 9 | Overcharge ability | +++ | ++ | + | - | |
| 10 | Overdischarge ability | +++ | ++ | ++ | - | |
| 11 | Internal resistance during cycling | +++ | ++ | + | + | |
| 12 | Cost per Wh (in same shape) + cost of the charger / electronics | ++ | ++ | + | - (today) | |

## A GENERAL PURPOSE TEÇHNOLOGY

# *LITHIUM RECHARGEABLE ...*

**... A NEW, GENERAL PURPOSE, ELECTROCHEMISTRY WHICH CAN HAVE AS BRIGHT A FUTURE AS NiCd HAS EXPERIENCED IN THE LAST 20 YEARS.**

## SAFT STRATEGY

# SAFT PERCEIVE RECHARGEABLE LITHIUM AS A GENERAL PURPOSE TECHNOLOGY

- ➔ 1 Electrochemistry
- ➔ 1 Electrode definition and process
- ➔ 1 Kind of equipment
- ➔ Several applications : PORTABLE, ELECTRIC VEHICLE, SPACE
- ➔ Several shapes : Cylindrical, Prismatic, Plastic battery
- ➔ Several sizes : Small, Medium, Large
- ➔ The R&D effort can be supported by a larger turn over

# GUIDELINES

❶ SAFT WILL HAVE ITS OWN PROPRIETARY TECHNOLOGY ( $LiNiO_2$ / Graphite )

❷ THINK DIFFERENTLY

➔ Rechargeable lithium has unique features :
- Voltage
- Thin, flexible electrodes
- Electronics control
- Cost advantages

➔ New concepts : format, plastic can, battery design, association cell / electronics ...

❸ CLOSE COOPERATION WITH CUSTOMERS

# ORGANISATION

| | | |
|---|---|---|
| ***RESEARCH*** | ALCATEL ALSTHOM CORPORATE | |
| | RESEARCH CENTER - MARCOUSSIS (France) | |
| ***MARKETING*** | MARKETING STRATEGIC COMMITTEE | |
| | SAFT WORLDWIDE SALES & SUBSIDIARIES NETWORK | |
| ***DEVELOPMENT ENGINEERING*** | CYLINDRICAL CELLS | Valdese North Carólina (USA) |
| | PLASTIC BATTERY | |
| | MEDIUM PRISMATIC | |
| | ELECTRIC VEHICLE | Poitiers (France) |
| | SPACE | |
| ***GENERAL MANAGEMENT OF THE PROGRAM*** | SAFT ADVANCED BATTERIES GROUP | |

# SAFT SPACE PLAN

**2 APPLICATIONS** : GEOSTATIONARY SATELLITES

Low earth orbit (LEO) 2 years missions, LAUNCHERS, PROBES

**1 STRATEGY** :

- USE MULTI-APPLICATION TECHNOLOGY ( PORTABLE, ELECTRIC VEHICLE, SPACE )
- INCLUDE FLIGHT VALIDATIONS IN DEVELOPMENT PLANS
- HAVE A GROUND BATTERY QUALIFICATION IN 1998

SAFT ADVANCED BATTERIES

# CELL OFFER

| GEOSTATIONARY SATELLITES | LEO 2 years missions, LAUNCHERS, PROBES |
| --- | --- |
| 40 Ah - 200 Ah | 5 Ah |
| Based on Electric Vehicle experience | Same cell as for military and commercial applications |
| Same basic materials and electrodes process | |
| Specific space cell development | - No specific space cell development |
| Space Battery and Electronics development | Space Battery and Electronics development |

***Technical Objectives*** :

| GEOSTATIONARY SATELLITES | LEO 2 years missions, LAUNCHERS, PROBES |
| --- | --- |
| **Battery** : 100 Wh/kg, 150 Wh/l — **Cell** : 140 Wh/kg, 260 Wh/l | **Battery** : 70 Wh/kg, 120 Wh/l — **Cell** : 100 Wh/kg, 240 Wh/l |
| **Cycle life** : 1500 cycles - 80% DOD - 15 years + Ionic propulsion (TBD) | **Cycle life** : 10 000 cycles - 20% DOD |

## RECHARGEABLE LITHIUM - Status of SAFT Activities

**RESEARCH :**

- Increase cycle life ( storage and fading )
- Increase gravimetric energy
- Limit corrosion
- Study charge & discharge control parameters and their aging

**CELL DEVELOPMENT :**

- Electric & Mechanical connection with thin electrodes supports
- Stack blocking
- Formation mode ( no plates formation available )
- Charge mode

**BATTERY & ELECTRONICS:**

- Electronics management design
- Promote new concepts

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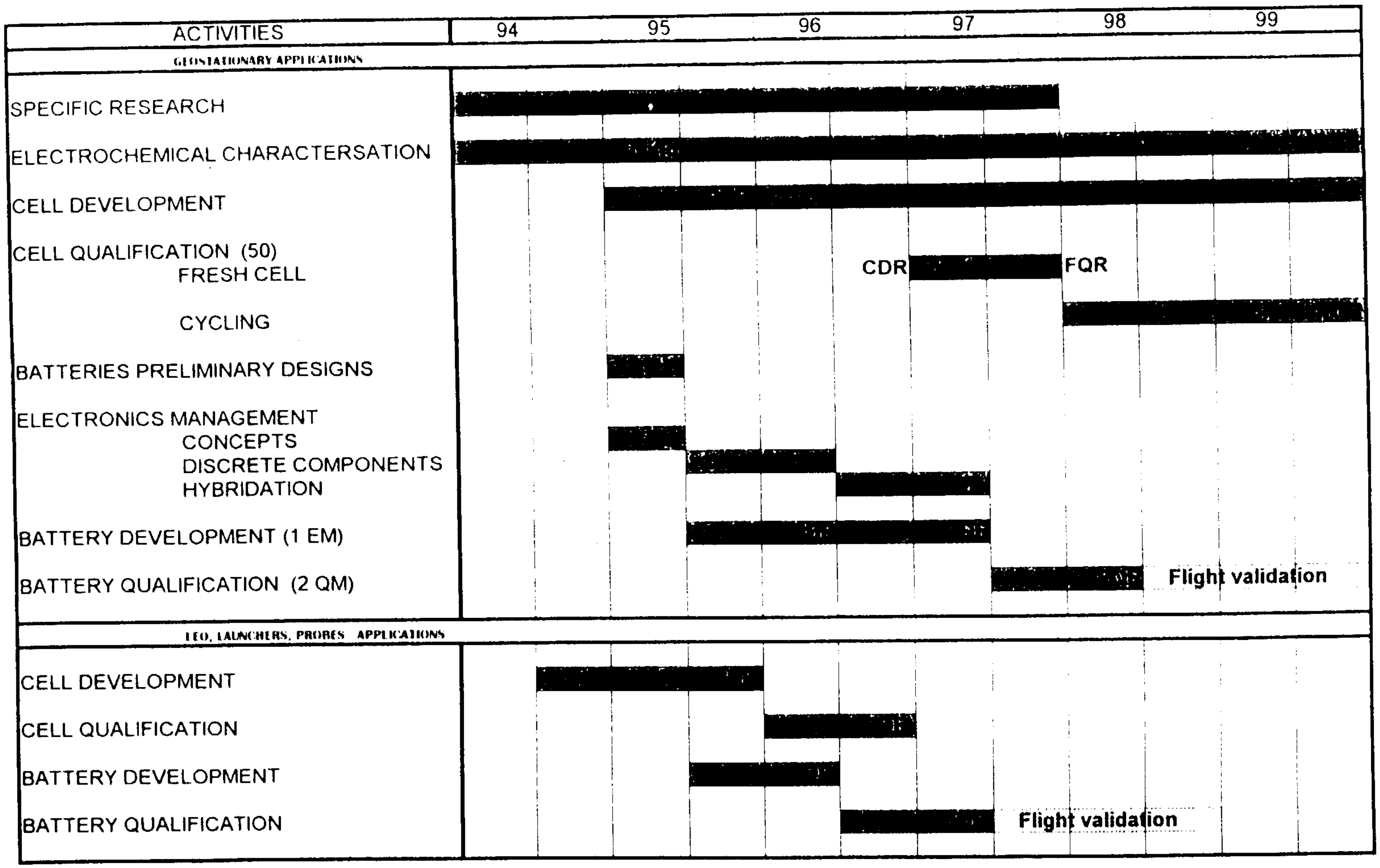
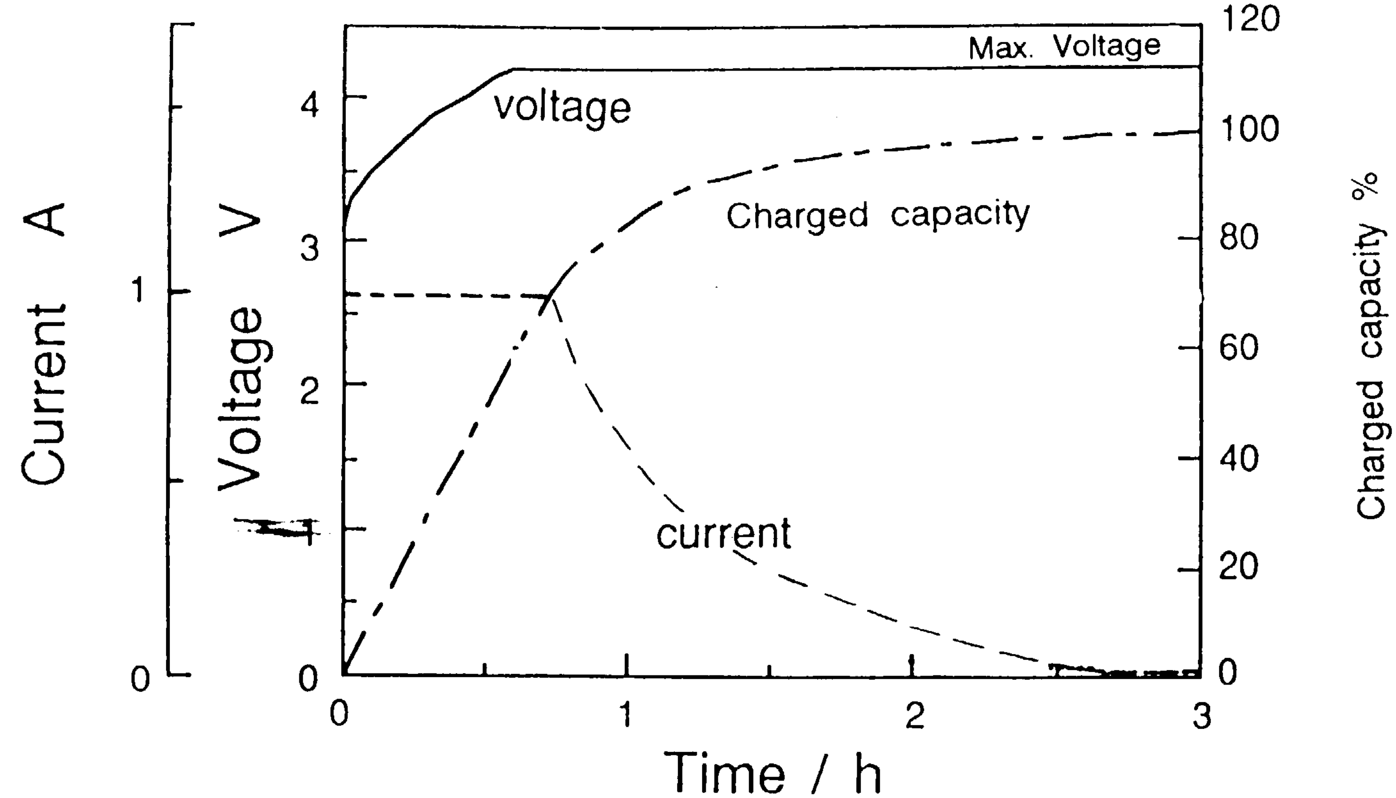
## RECHARGEABLE LITHIUM - Status of SAFT Activities

# SCHEDULE



# Li - ION CHARGE MODE



# ELECTRONICS

**ELECTRONICS CONCEPTS :**

**The difficulty comes from the voltage management mode for cells in series**

**2 families of concepts :**

➔ ***BATTERY CHARGE MODE WITHOUT CELL BY-PASS* :**
**Management by the cell with highest voltage**

- **Constant current**
- **Constant current by steps**
- **Constant current and battery constant voltage**

👍 **Easy to manage ( same as NiCd & $NiH_2$ )**

👎 **Limit cell capacity performances**

# ELECTRONICS

→ *BATTERY CHARGE MODE WITH CELL BY-PASS* :
Management of each cell

- Constant current and constant voltage ensured on each cell by electronic control

👍 Guaranteed to use the maximum cell capacity
Compensate cells dispersion

👎 New Electronic concept to study
Cost (to be evaluated at system level)

**SAFT's AIM IS TO DELIVER A COMPLETE BATTERY SYSTEM**

SAFT ADVANCED BATTERIES

# PRODUCT PERFORMANCES AND CHARACTERISTICS

## MAIN REQUIREMENTS COMPARISON

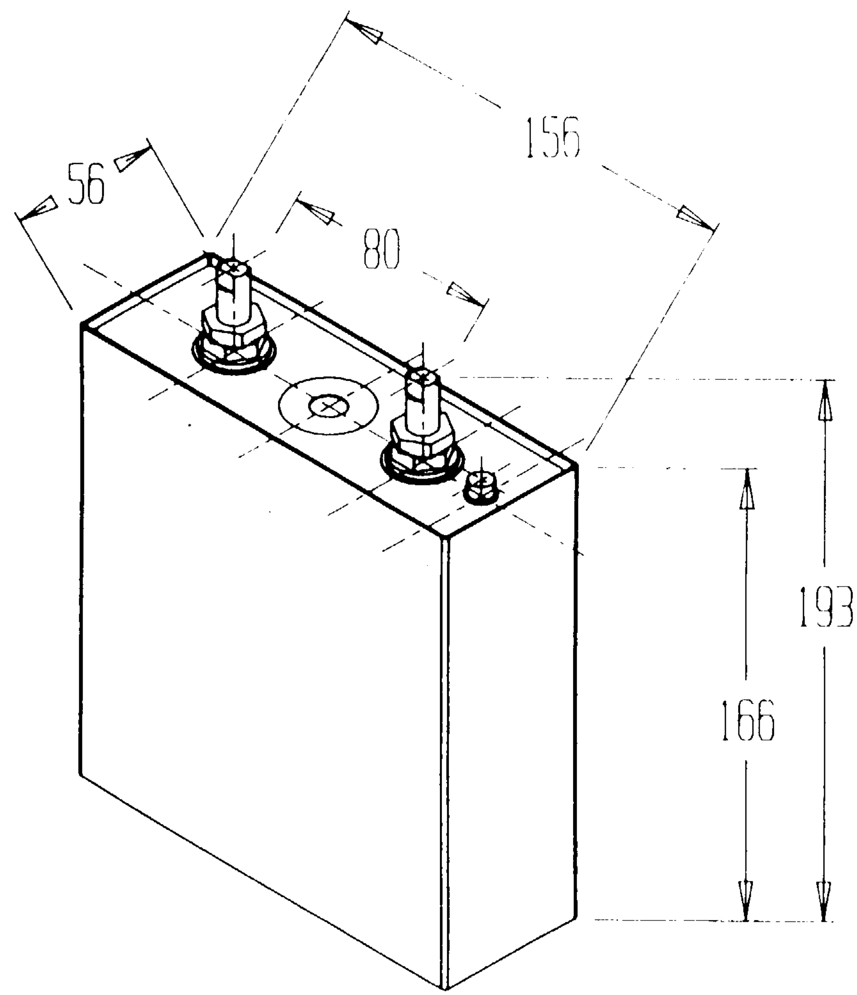
| *Requirements* | PORTABLE | ELECTRIC VEHICLE | SPACE |
|---|---|---|---|
| Charge rate | C/20 to C | C/10 to C | C/20 to C/1.5 |
| Discharge rate | C/8 to C | C/5 to 2C | C/1.5 |
| Peak discharge | Up to 3C | up to 3C | Up to C |
| Charge Temperature range | 0°C to 50°C | - 20°C to + 50°C | tbd |
| Discharge Temperature range | -20°C to +60°C | id. | tbd |
| Storage Temperature range | -40°C to +85°C | id. | tbd |
| Gravimetric Energy | > 120 Wh/kg (Beg.of life) Cell | 140 Wh/kg (Beg. of life) Battery | 100 Wh/kg (End of life) Battery |
| Life time | >1000 cycles 100%DOD with >70% Nominal Capacity 4 years | >1000 cycles 100%DOD with >80% Nominal Capacity 10 years | 1500 cycles 80 % DOD + ionic propulsion 15 years |
| Charge retention | < 10 % after 1 month 20°C < 10 % after 8 days 45°C | | < 25 % after 72 h 20°C |

**Specific Space requirement:**

- **. 135 days rest period in between 45 days use**
- **. Launchers vibrations & shocks**
- **. 15 years life time and more than 10 000 cycles**

# Li - ION 100 Ah CELL SCHEMATIC

Dimensions in mm



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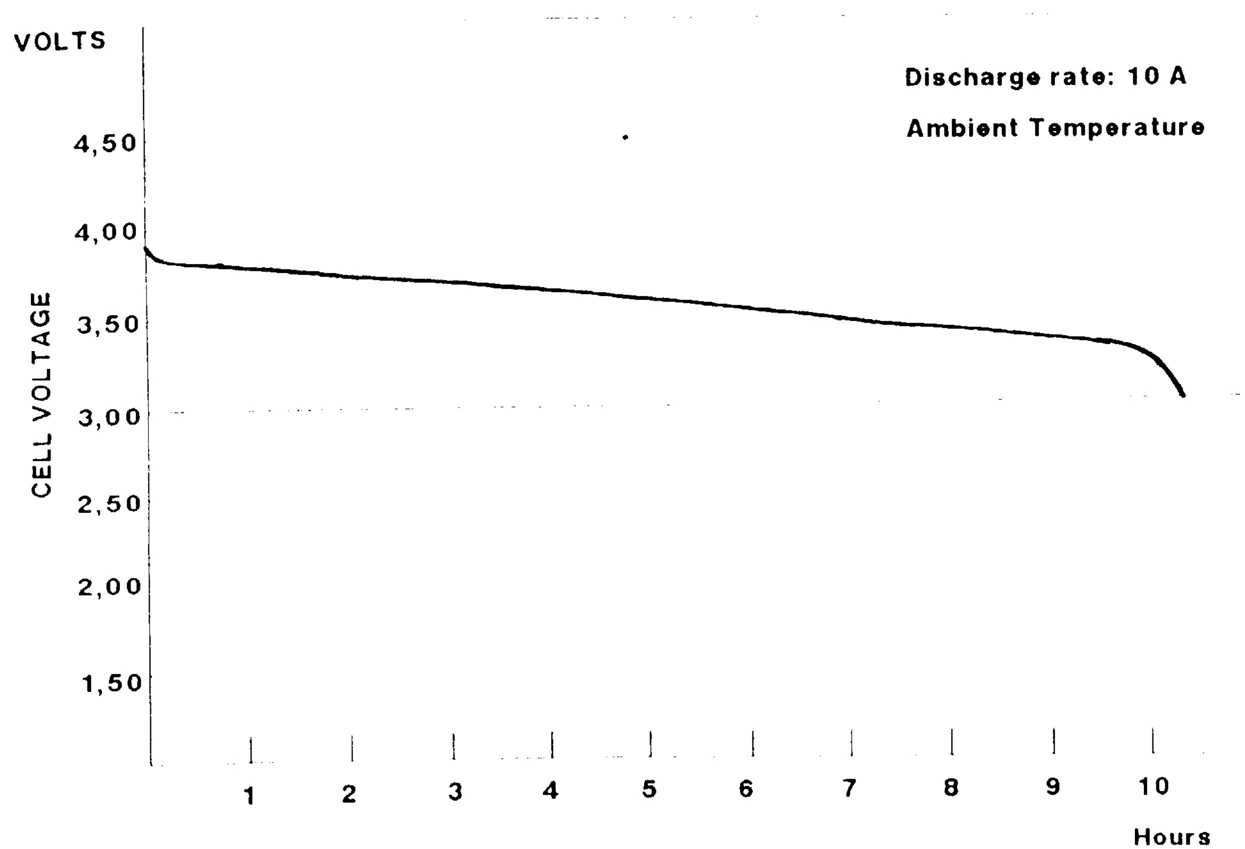
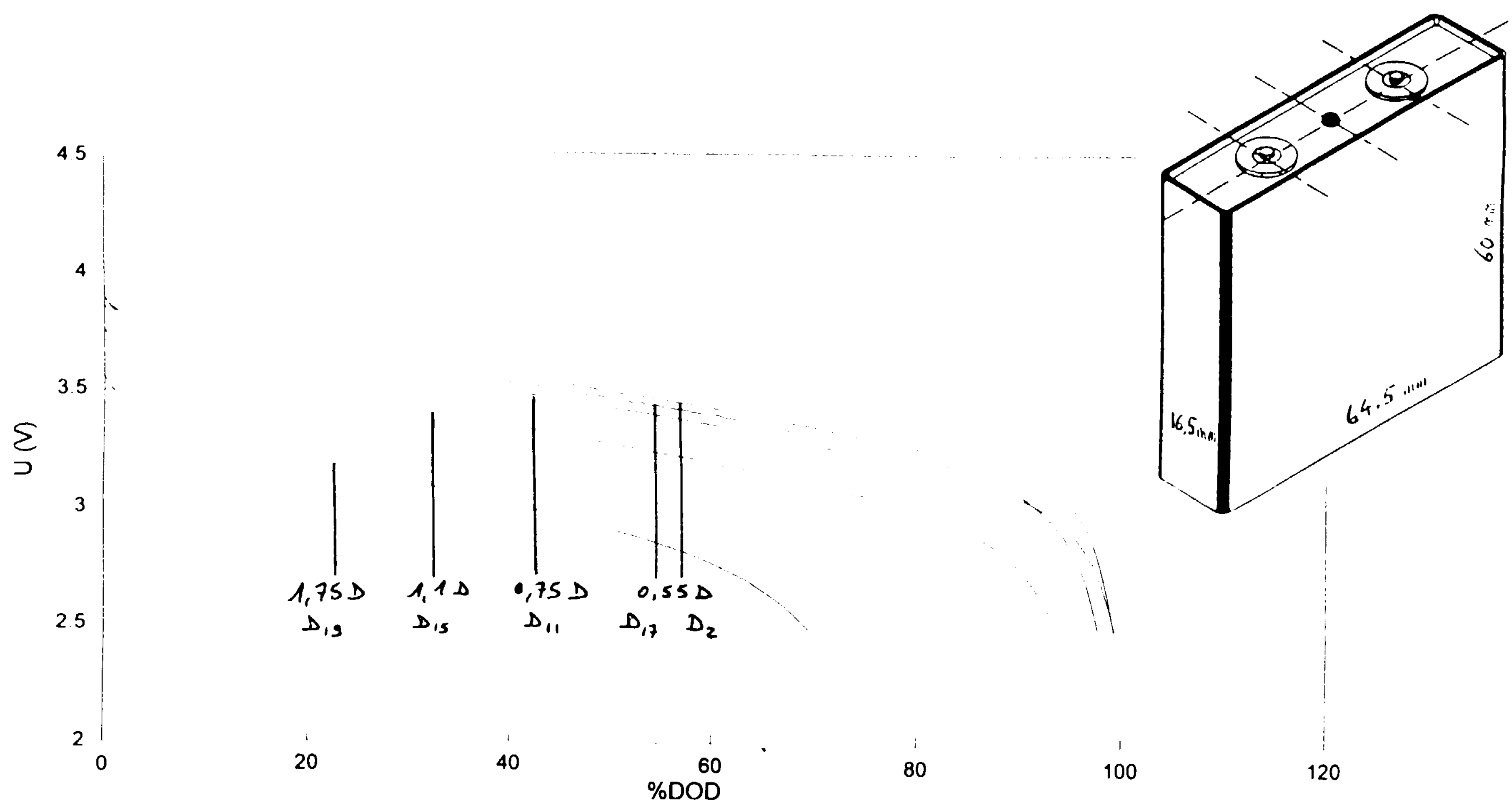
# 100 AH DISCHARGE CURVE




DISCHARGE PROFILE OF A 100 AH LiNiO2/GRAPHITE PRISMATIC CELL (CYCLE 5)

# 5 AH CELL DISCHARGE CURVE



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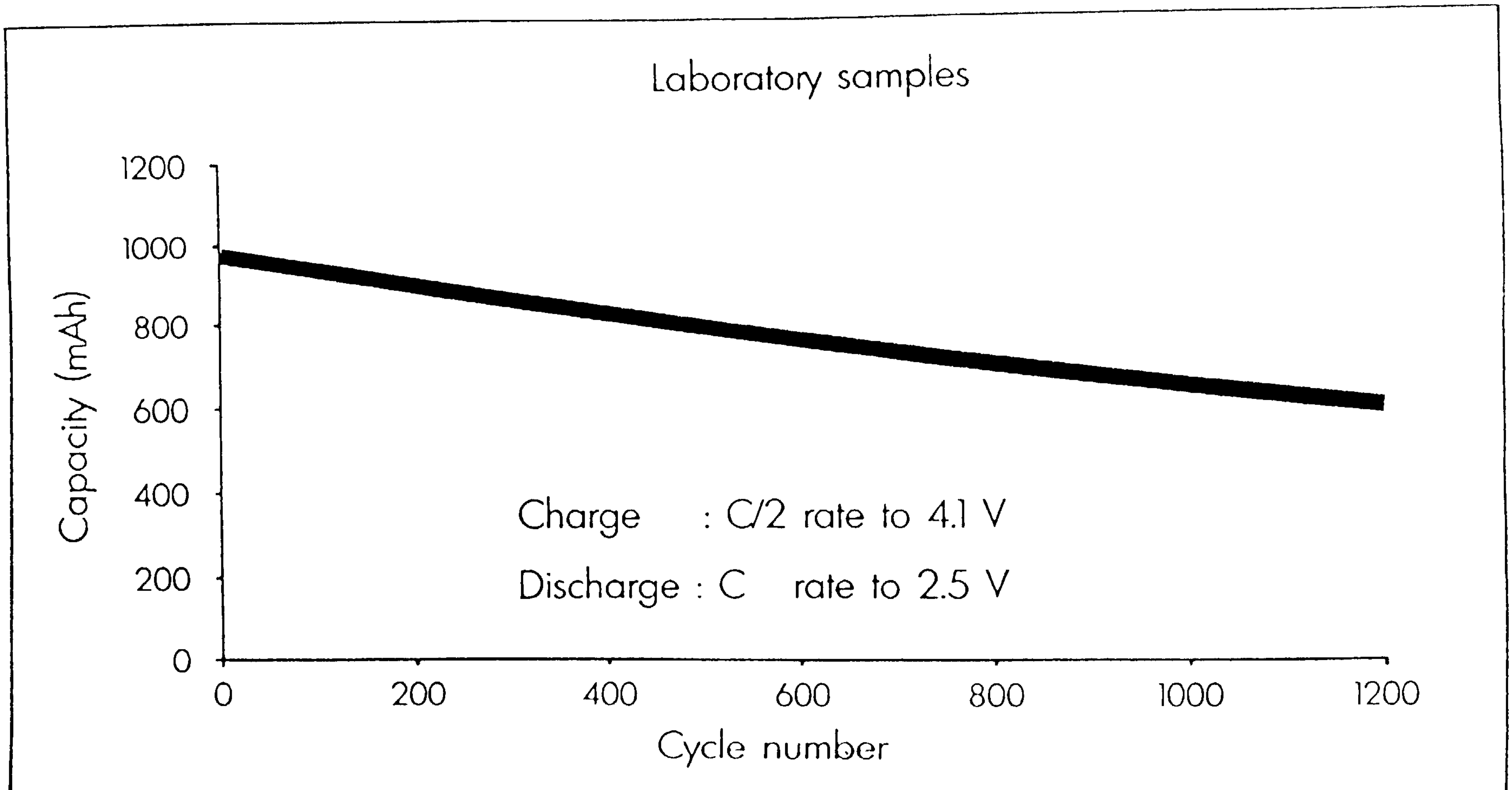
# CYCLE LIFE ON LABORATORY SAMPLES



# AA CELL PERFORMANCES COMPARISON

| | Standard NiCd | Top of the range NiCd | Nickel metal hydride | Li-Ion |
|---|---|---|---|---|
| Nominal capacity (mAh) | 600 - 700 | 900 | 1200 | 400 to 550 |
| Nominal voltage (volts) | 1.2 | 1.2 | 1.2 | 3.6 |
| Weight energy density (Wh/kg) | 35 - 40 | 50 | 60 | 80 - 110 |
| Volumetric energy density (Wh/l) | 100 - 110 | 140 | 180 | 190 to 260 |
| Cycle life (number of cycles) | 1000 | 1000 | 500 - 1000 | 500 - 1000 |

# CYCLE LIFE PERFORMANCE EVALUATION OF Li-ION CELLS

Rao Surampudi, Dave Perrone, Ron Nauman, Chen-Kuo Huang
Ratnakumar Bugga, Gerald Halpert

NASA Battery Workshop
Huntsville Alabama
November 15-17, 1994

# Outline

- Objective
- Cell Description
- Test Plans
- Charge/Discharge Characteristics
- Cycle Life Performance

  100% DOD

  40% DOD

- Summary

# Objective

**Determine Cycle Life Performance of Lithium Ion Cells at 100% DOD and 40% DOD (NASA stress test)**

# Cycling Parameters 100% DOD Test

## Charging

- Constant Current @ 100mA
- EOC Voltage to 4.2 volts cutoff

## Discharging

- Constant Current @ 200mA
- EOD Voltage to 3.0 volts cutoff

## Open Circuit Period

- End of Charge: 30 minutes
- End of Discharge: 30 minutes

# Cell Description

**Type I**

Anode: Carbon (Coke)

Cathode: $LiCoO_2$

Electrolyte: EC-Based Electrolyte

Rated Capacity: 1 ampere-hour

OCV: 3.8 volts

**Dimensions**

Length= 64.1 mm

Diameter = 18.2 mm

Weight = 40 grams

Manufactured by Sony

Specific Energy: 70.0 Watt-Hours/Kg

# Cell Description

**Type II**

Anode: Carbon (Coke)

Cathode: $LiCoO_2$

Electrolyte: EC-Based Electrolyte

Rated Capacity: 1 ampere-hour

OCV: 3.8 volts

**Dimensions**

Length= 51 mm

Diameter = 21 mm

Weight = 40 grams

Manufactured by Sony

Specific Energy: 80.5 Watt-Hours/Kg

# Test Plan Overview

Measure and Record Physical Characteristics of Cells

↓

Conditioning Cycles (3)

↓

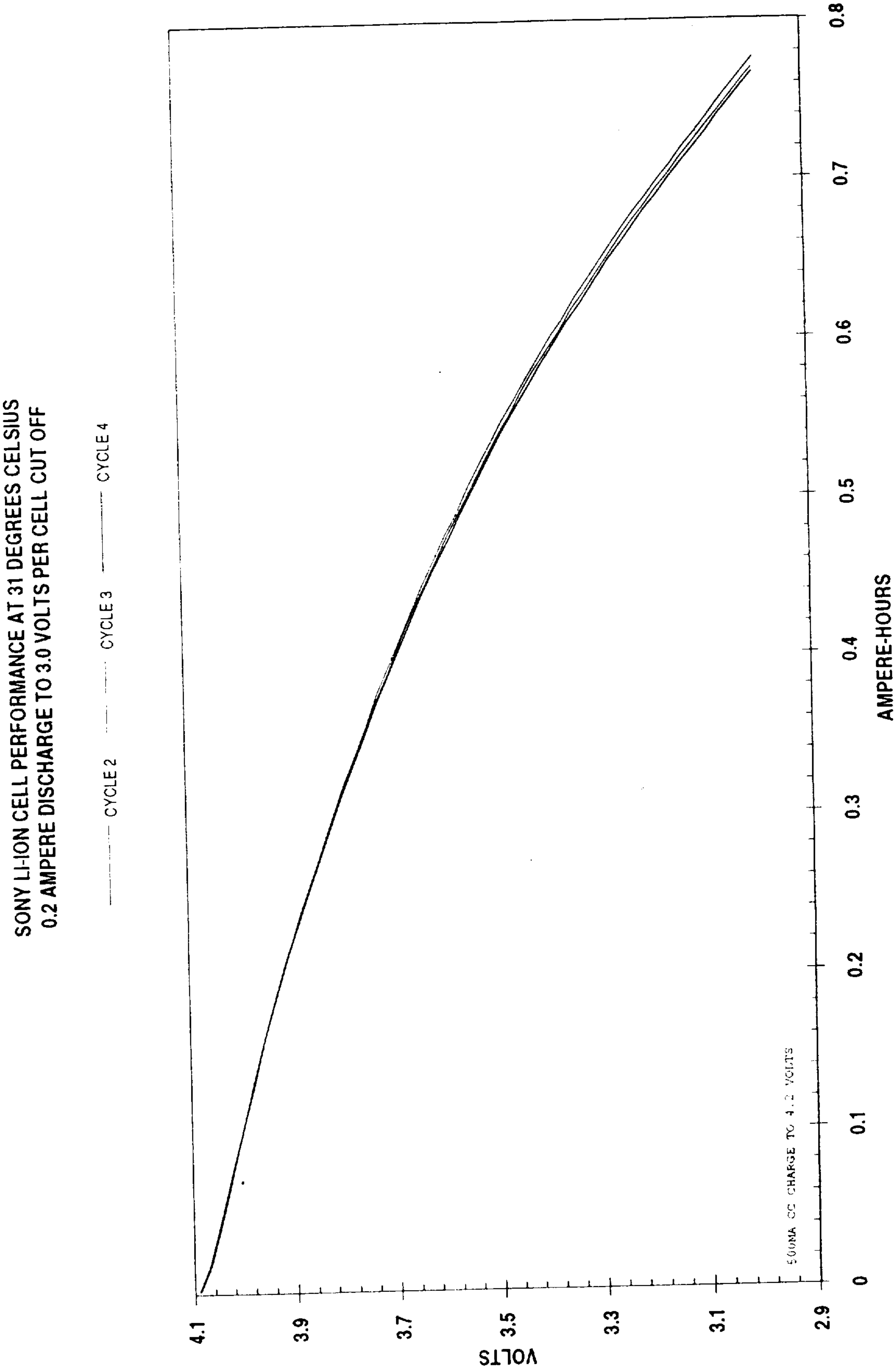
Discharge Rate Characterization

↓

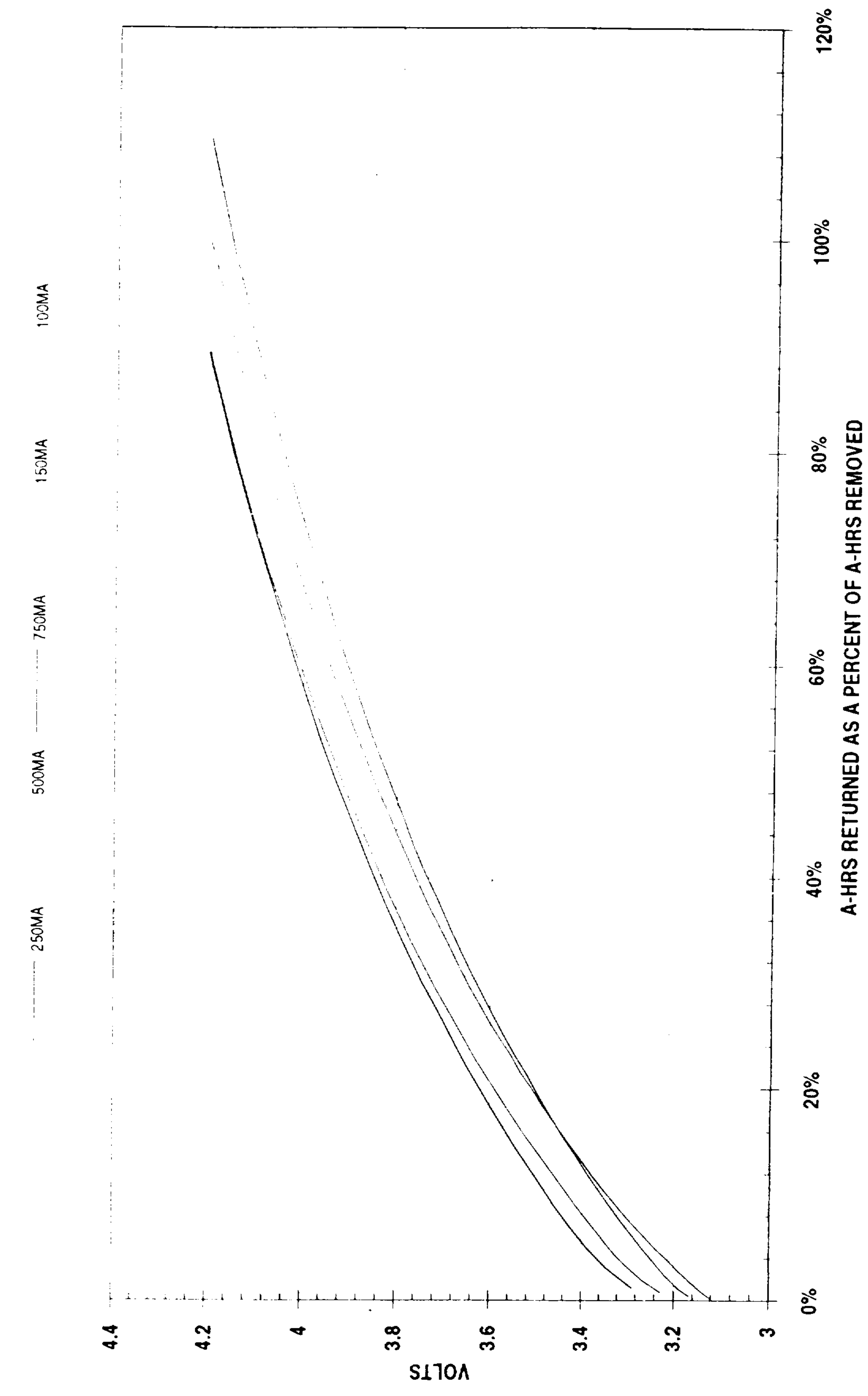
Charge Rate Characterization

↓

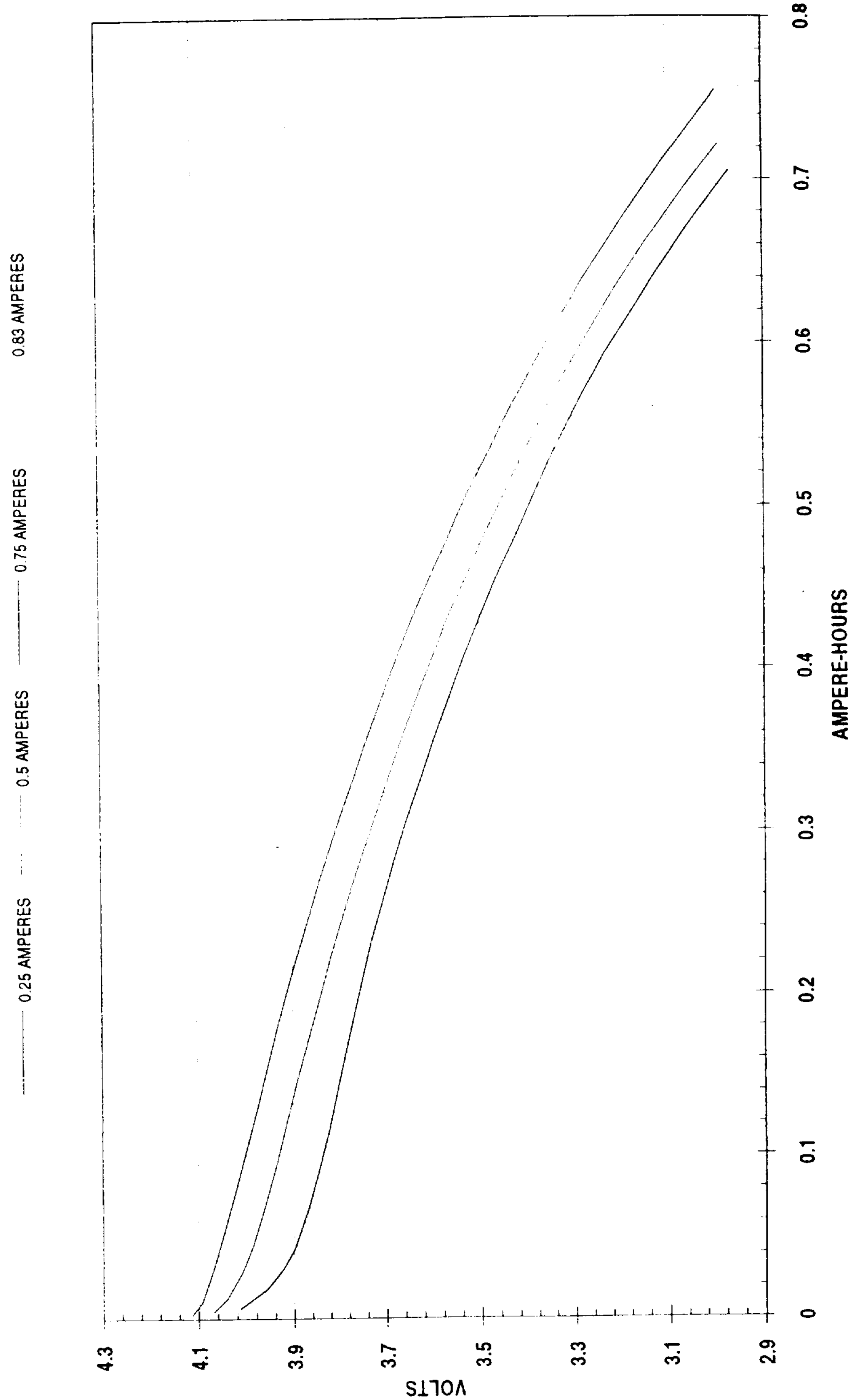
Cycle Life Tests


SONY LI-ION CELL PERFORMANCE AT 31 DEGREES CELSIUS
0.2 AMPERE DISCHARGE TO 3.0 VOLTS PER CELL CUT OFF
CYCLE 2
CYCLE 3
CYCLE 4
500MA CC CHARGE TO 4.2 VOLTS
VOLTS
4.1
3.9
3.7
3.5
3.3
3.1
2.9
AMPERE-HOURS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

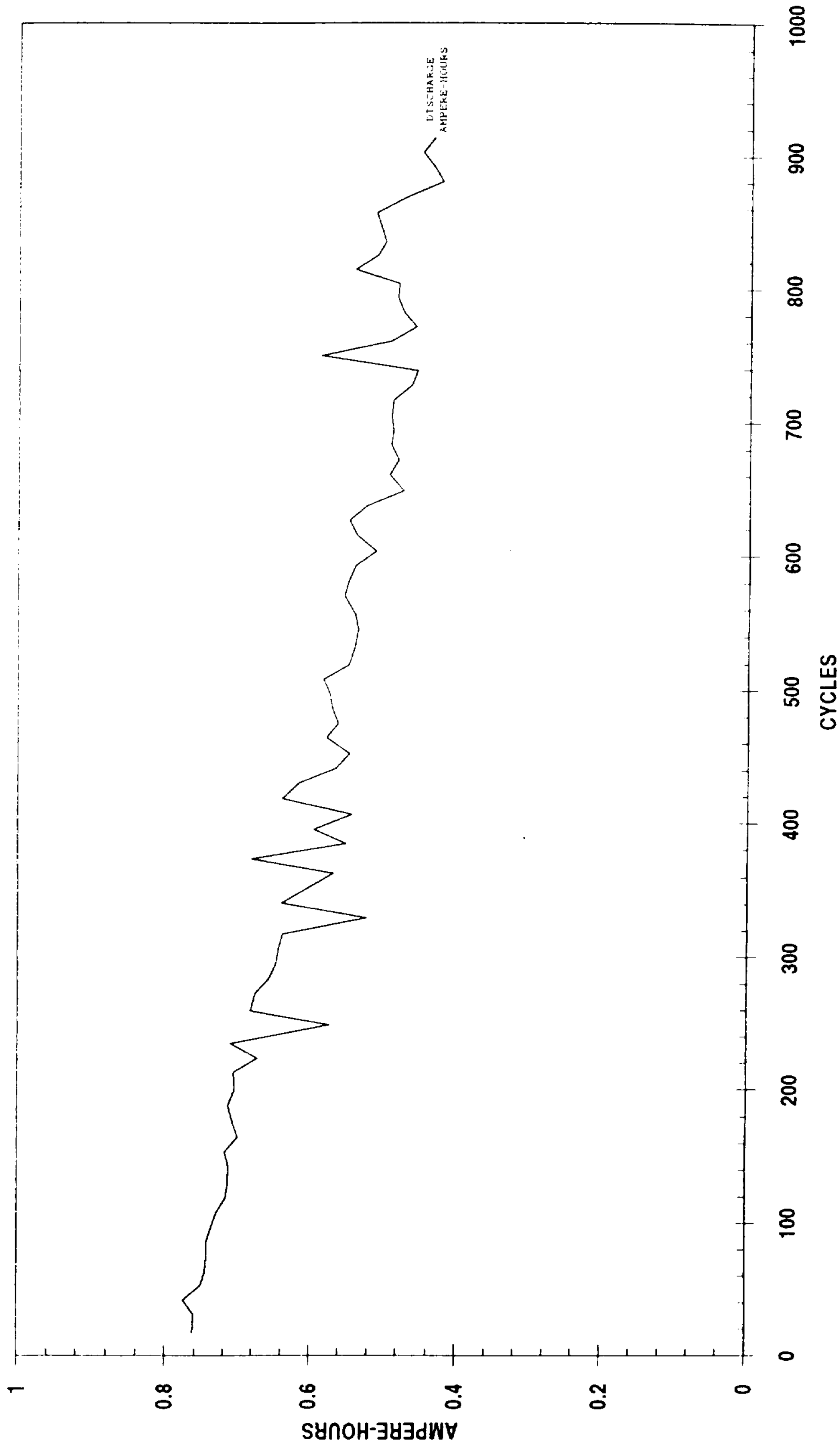
SONY Li-ION CELL - CONSTANT CURRENT CHARGE CHARACTERISTIC

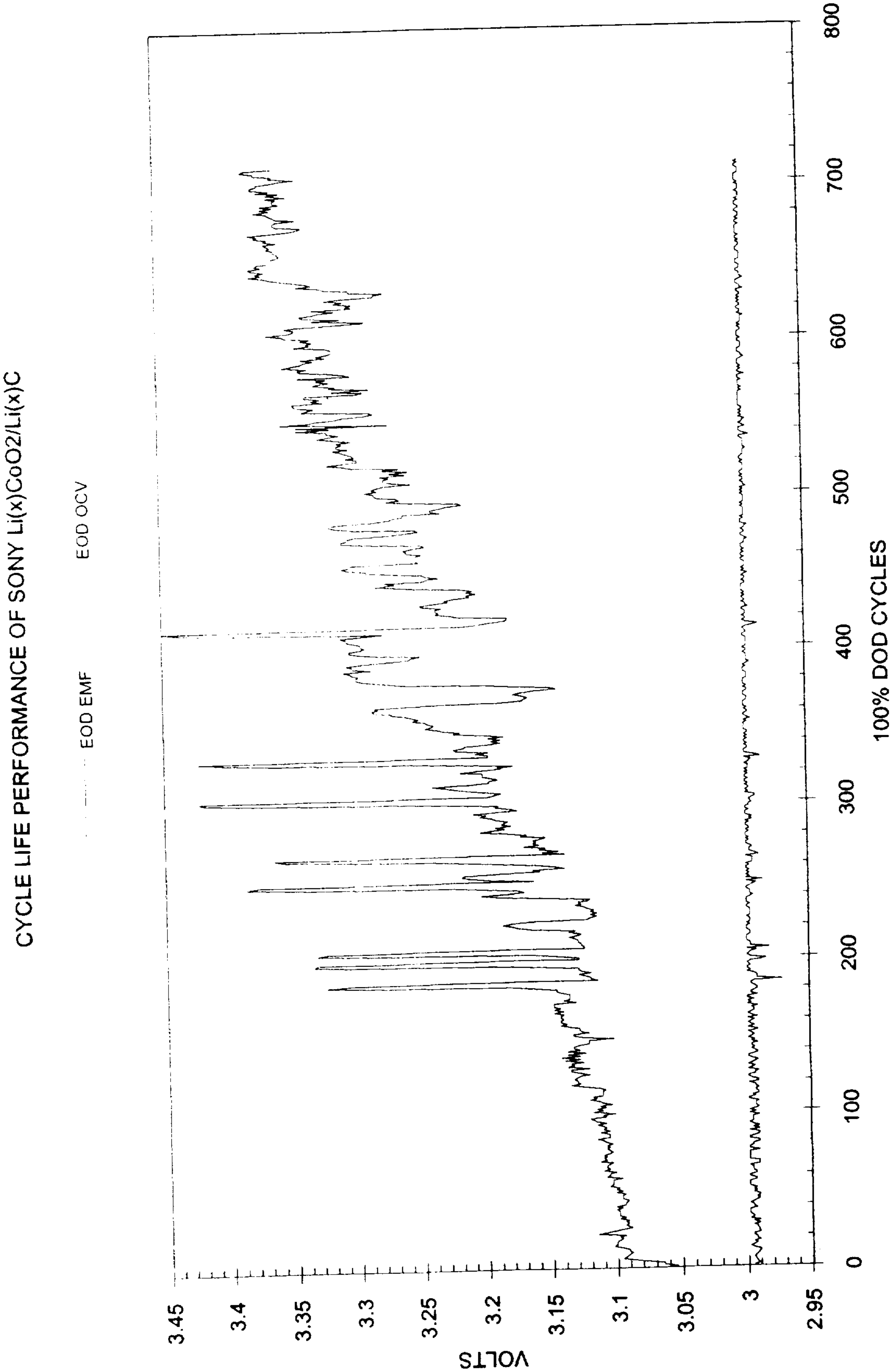


SONY Li-ION CELL - DISCHARGE PERFORMANCE AT VARIOUS CURRENTS AT 25 DEGREES CELSIUS

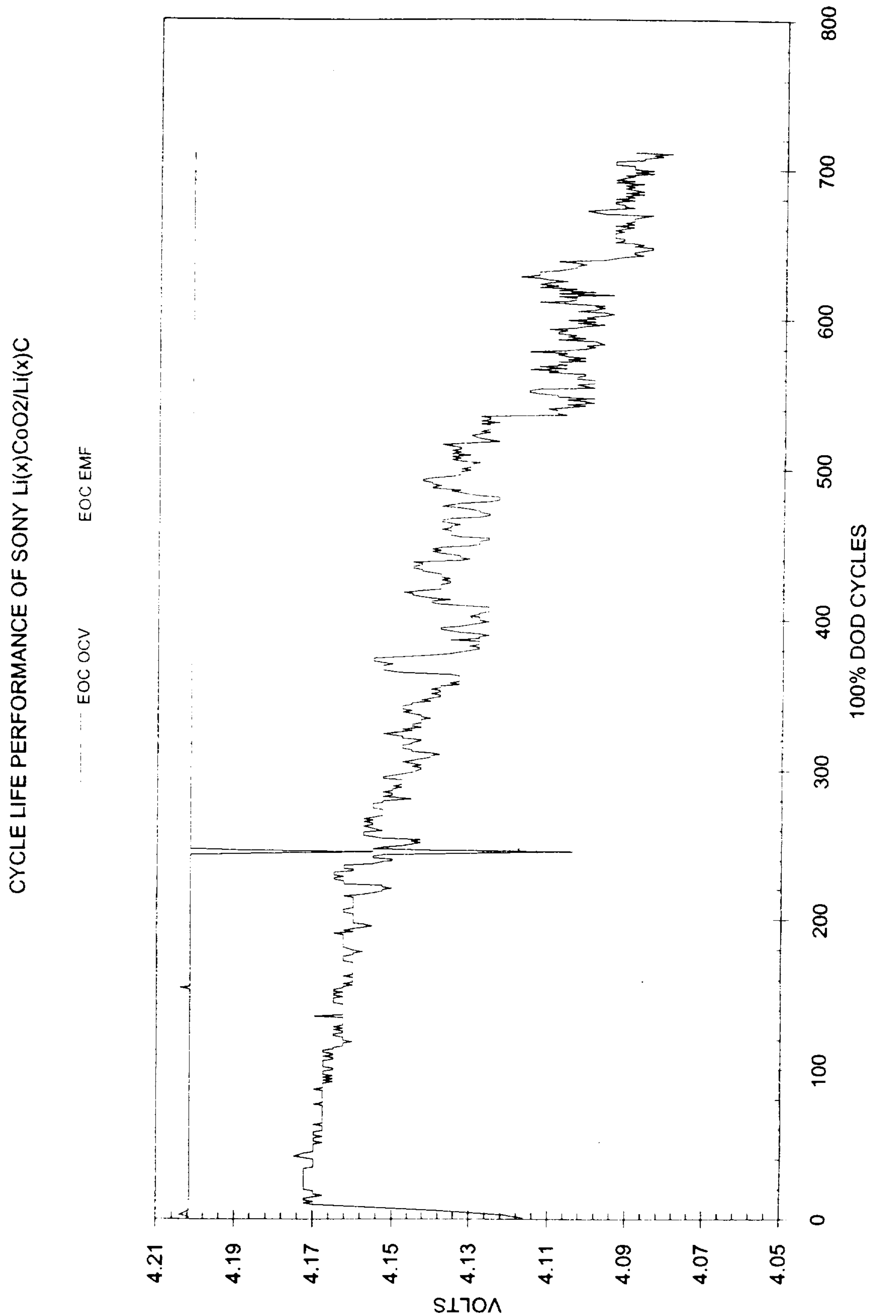


100% DOD CYCLE LIFE PERFORMANCE OF SONY SAMPLE 03022-50
0.2 AMPERES DISCHARGE TO 3.0 VOLTS AND 0.1 AMPERES CHARGE TO 4.2 VOLTS

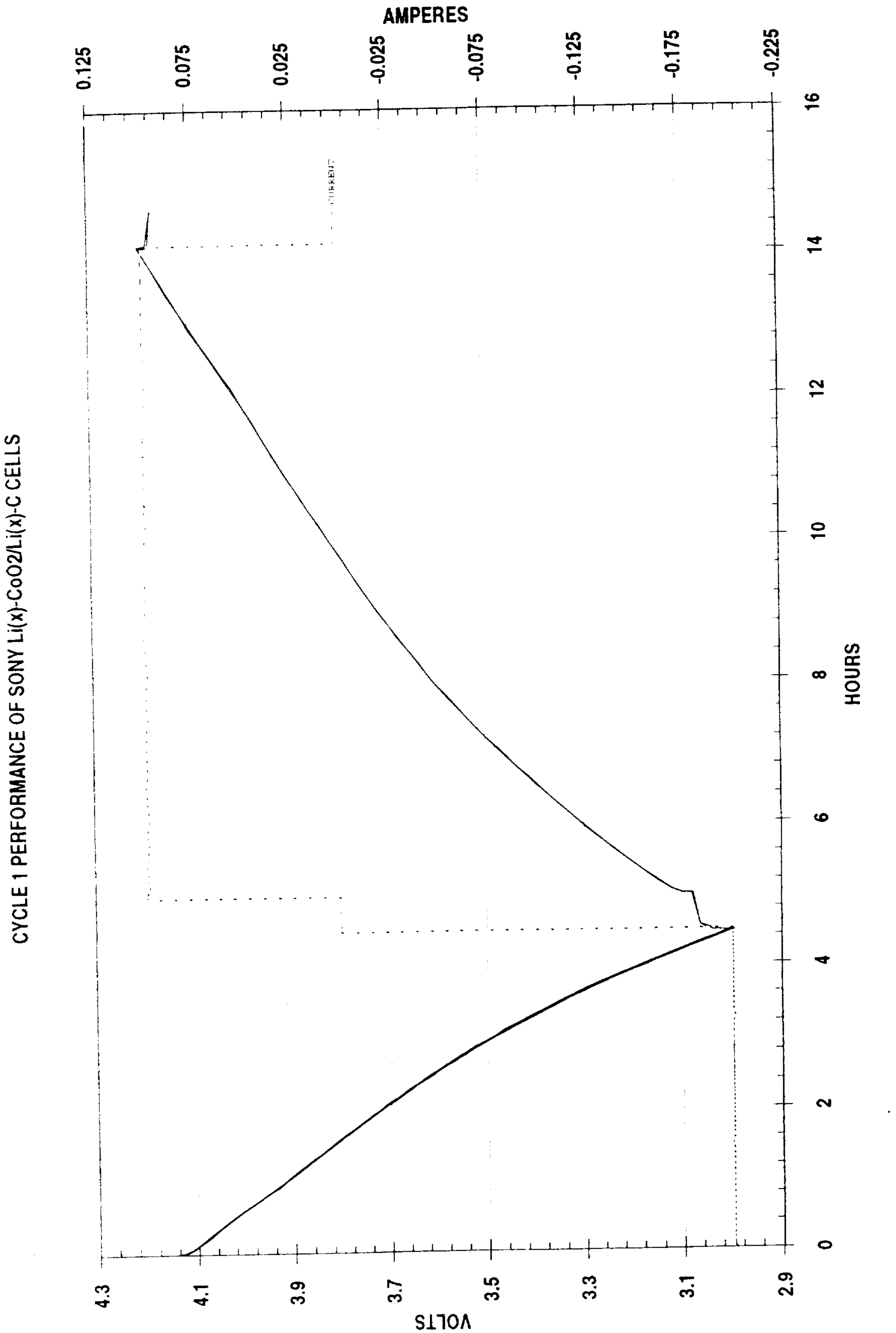




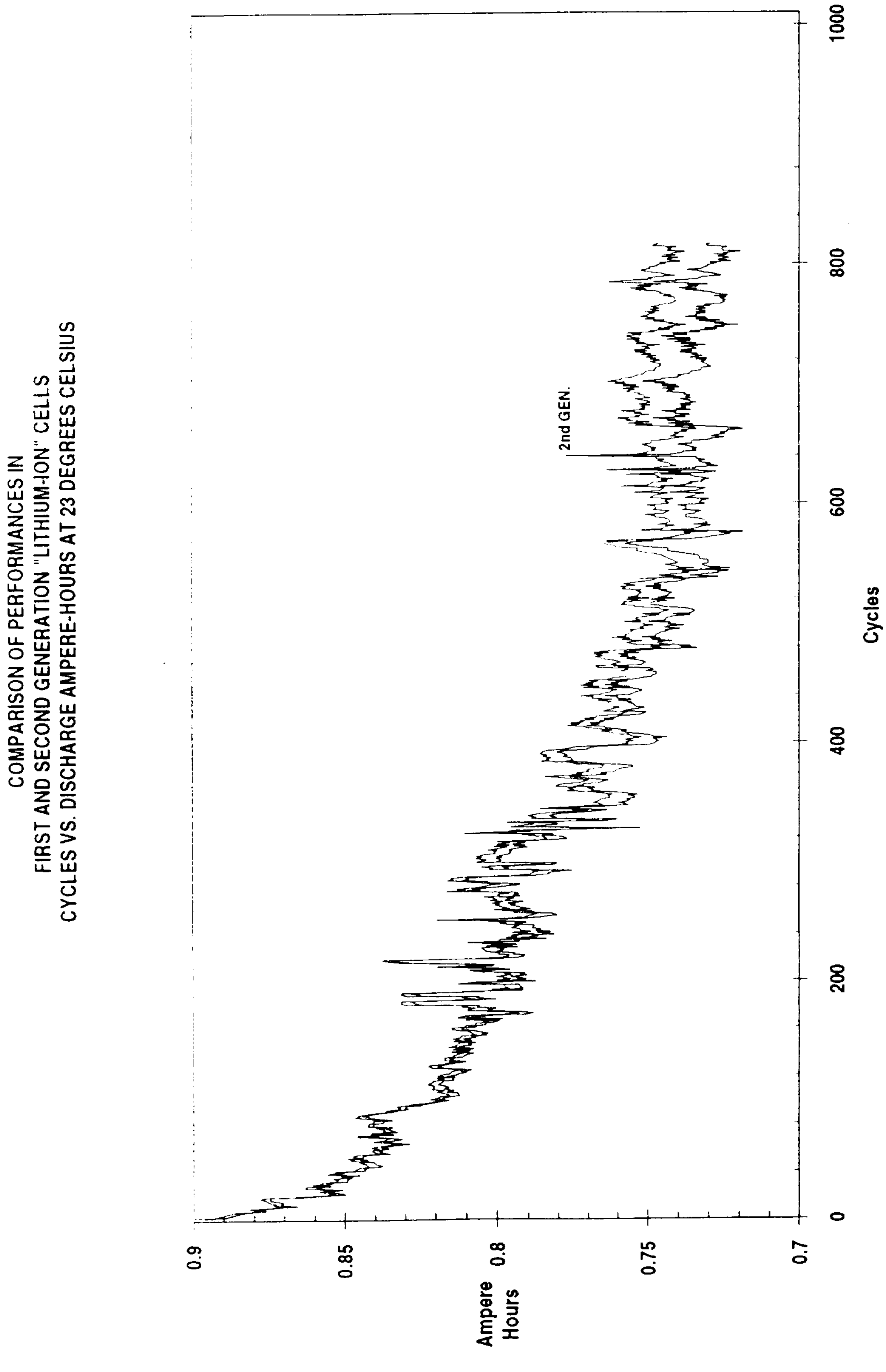
CYCLE LIFE PERFORMANCE OF SONY Li(x)CoO2/Li(x)C
EOD EMF
EOD OCV
VOLTS
3.45
3.4
3.35
3.3
3.25
3.2
3.15
3.1
3.05
3
2.95
100% DOD CYCLES
0
100
200
300
400
500
600
700
800

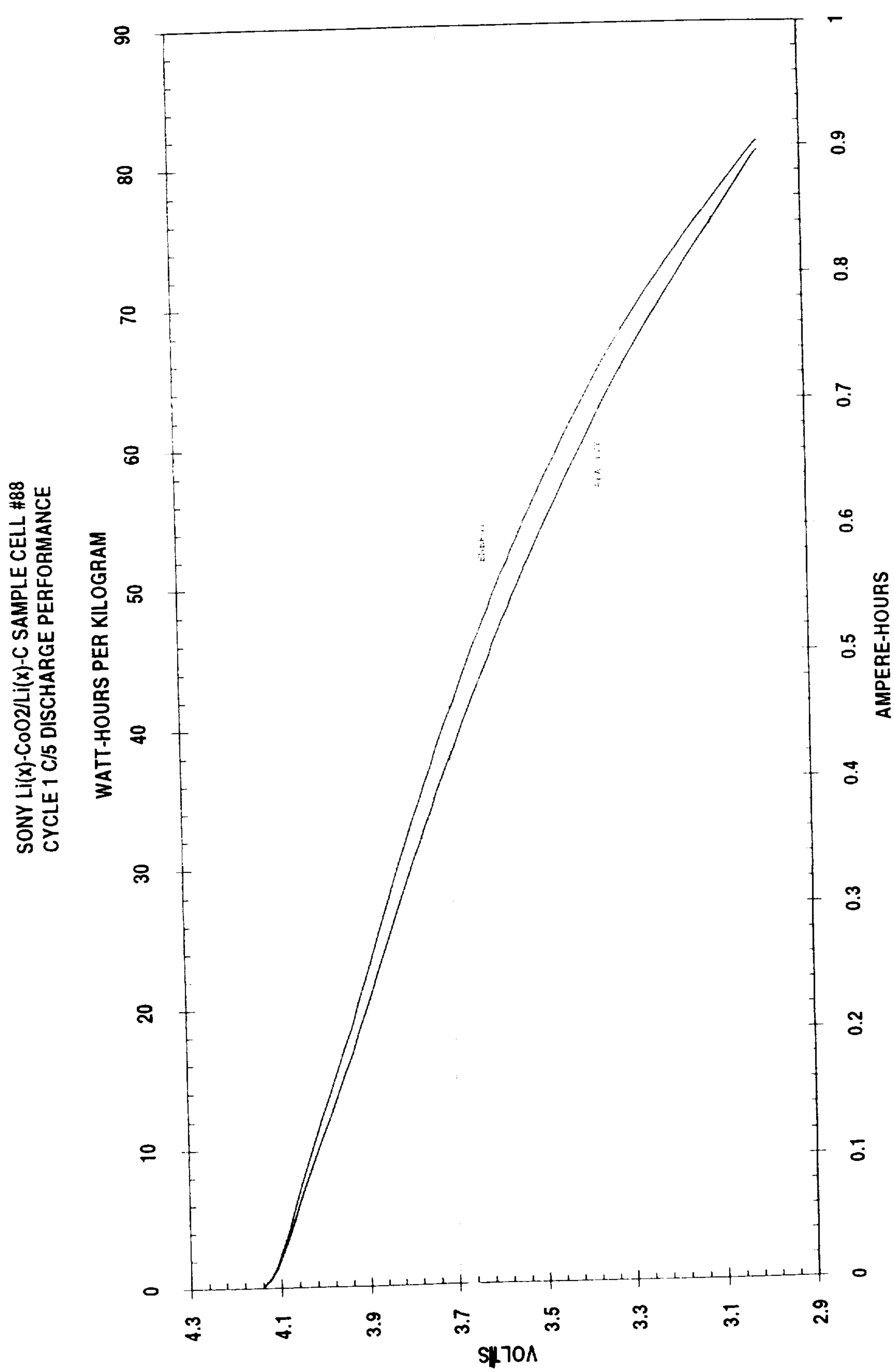


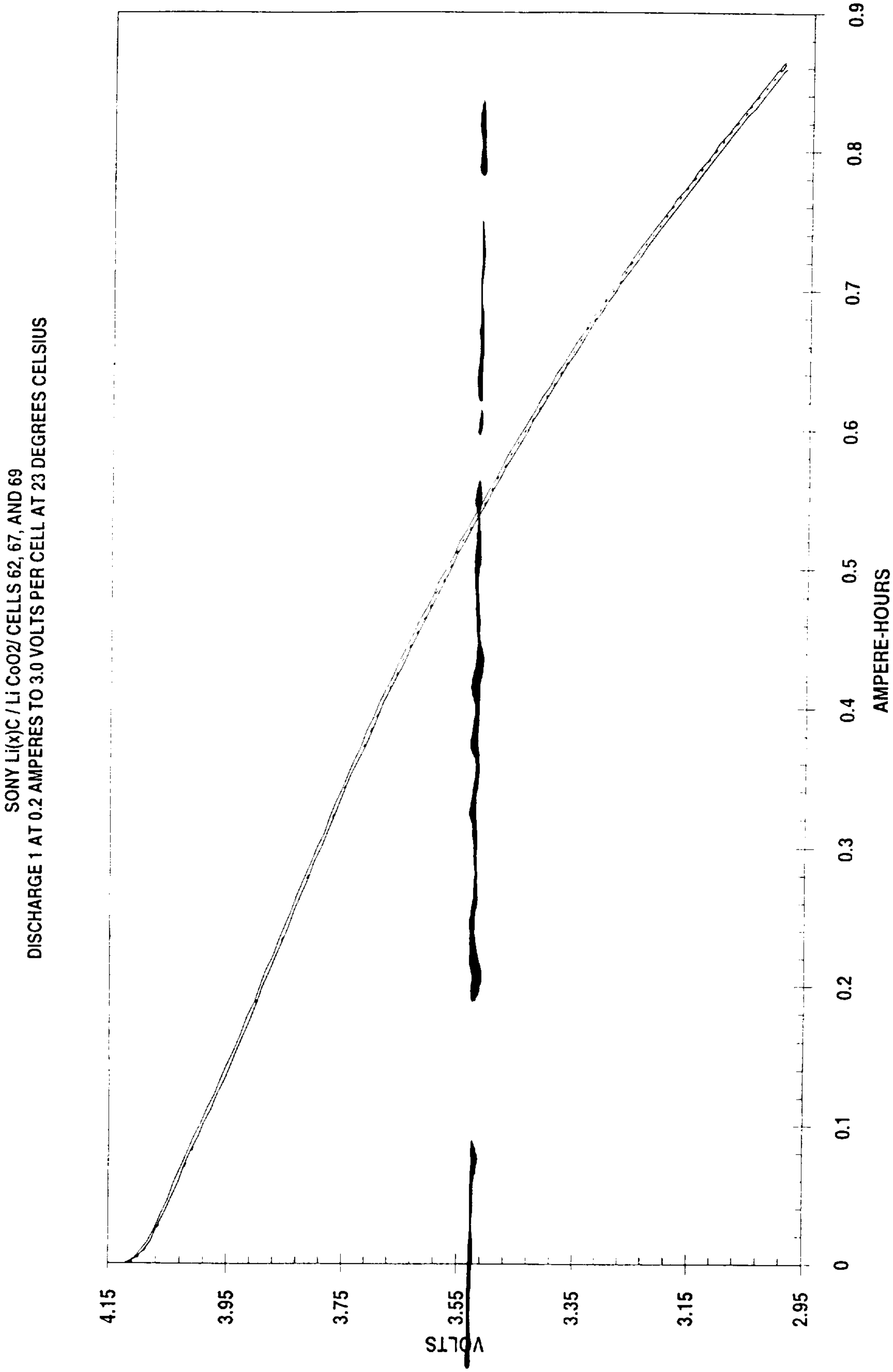
CYCLE LIFE PERFORMANCE OF SONY Li(x)CoO2/Li(x)C
EOC OCV
EOC EMF
VOLTS
4.21
4.19
4.17
4.15
4.13
4.11
4.09
4.07
4.05
100% DOD CYCLES
0
100
200
300
400
500
600
700
800

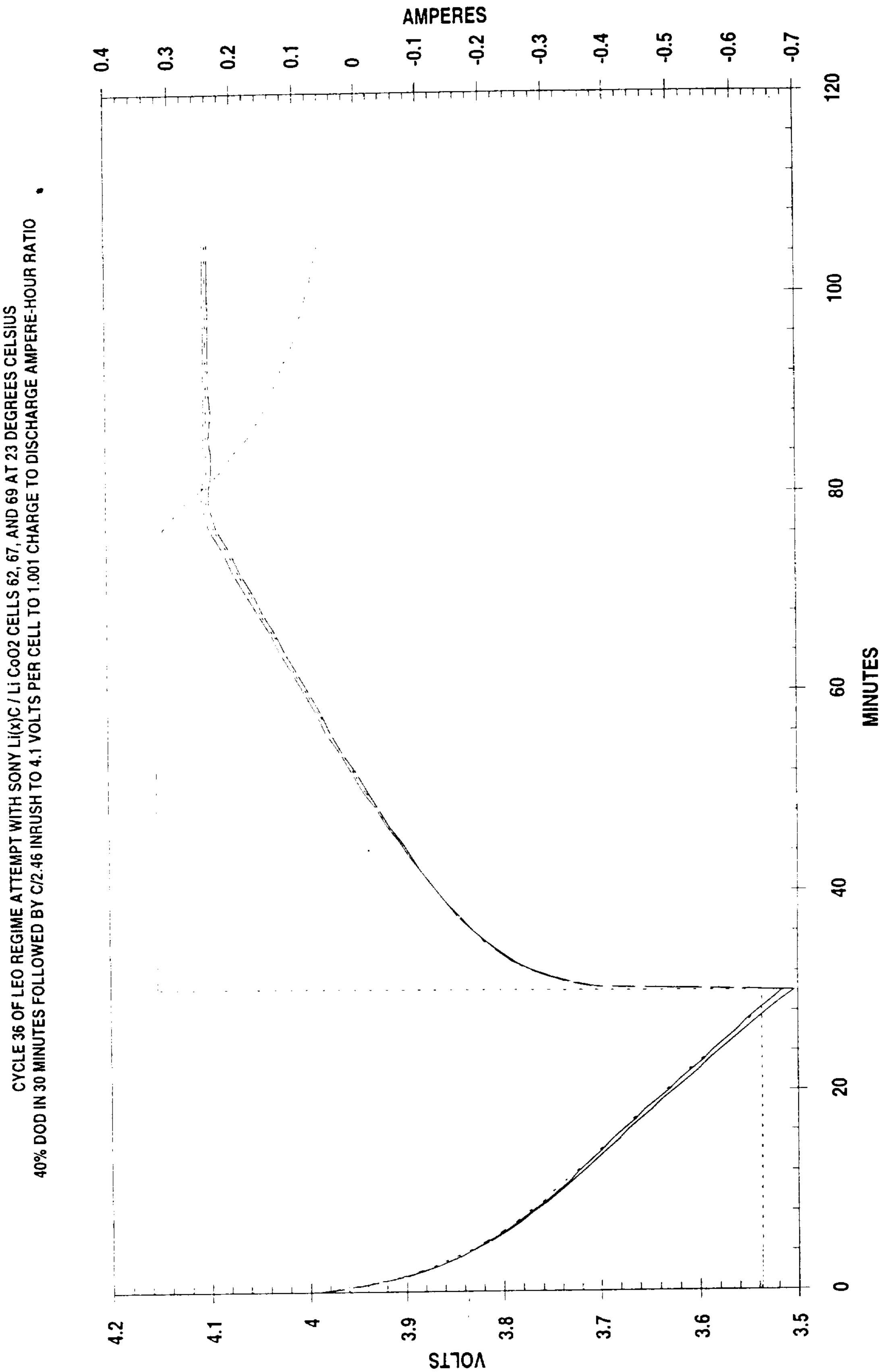


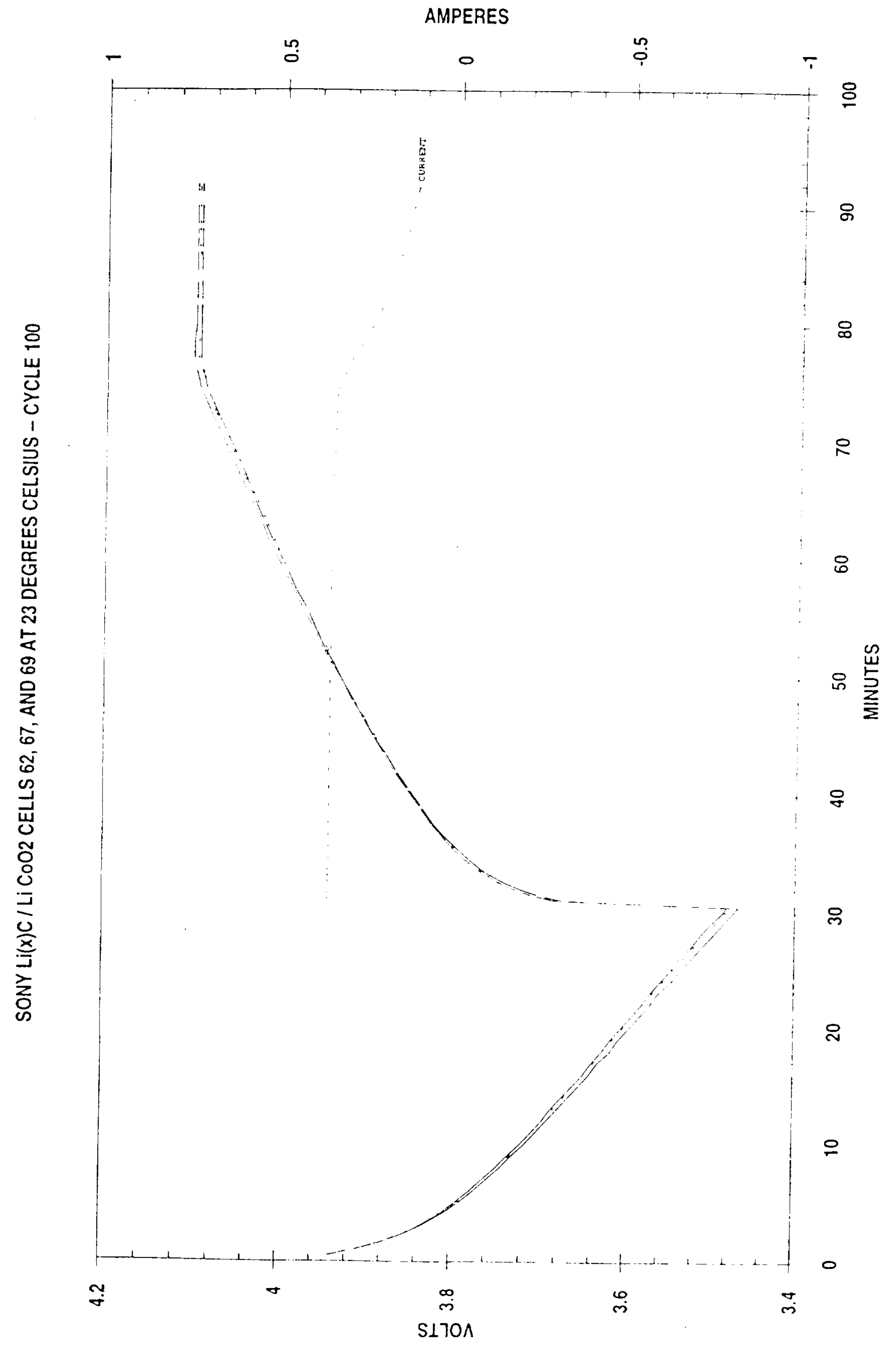
CYCLE 1 PERFORMANCE OF SONY Li(x)-CoO2/Li(x)-C CELLS
AMPERES
0.125
0.075
0.025
-0.025
-0.075
-0.125
-0.175
-0.225
VOLTS
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
HOURS
0
2
4
6
8
10
12
14
16

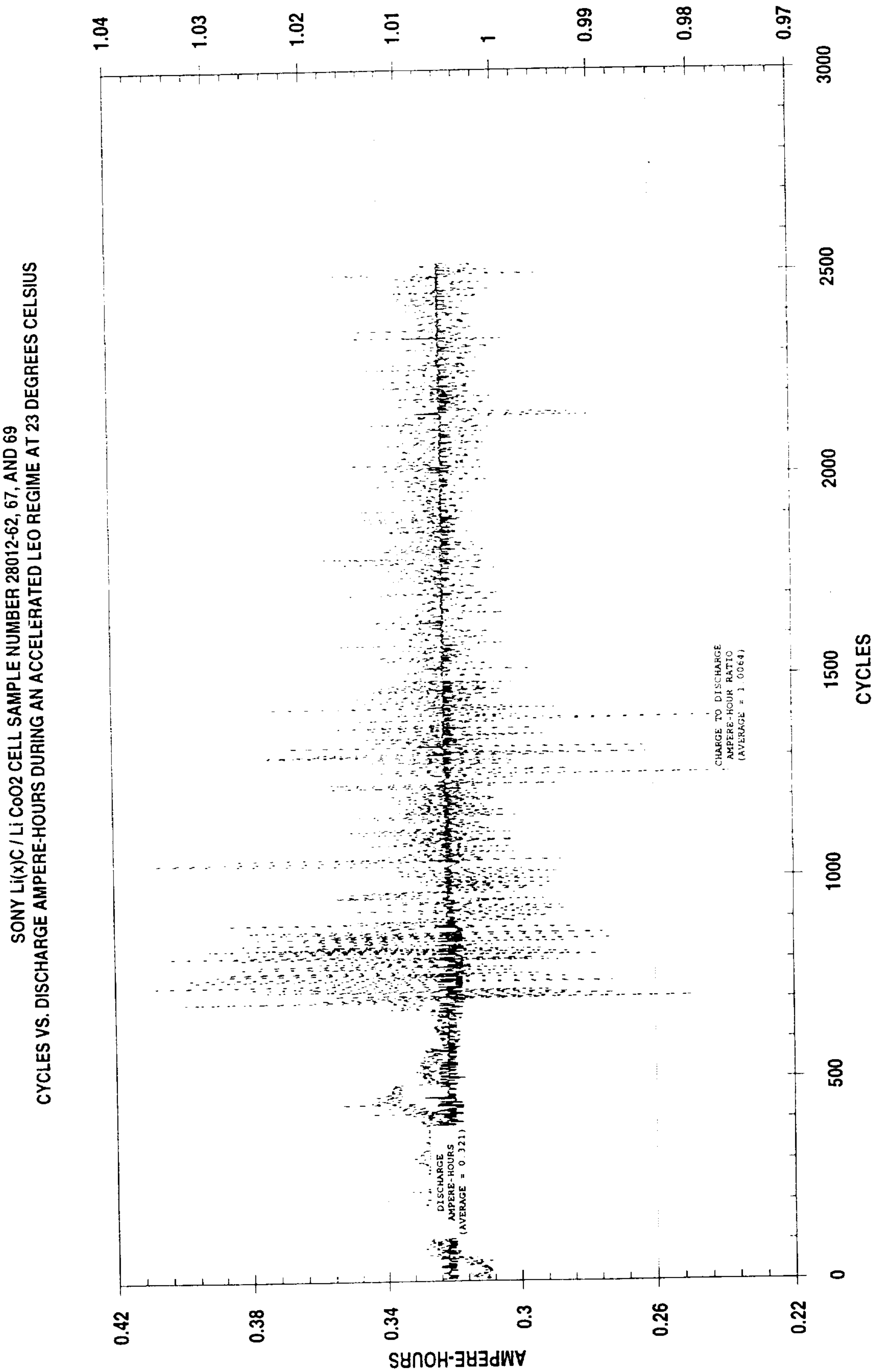

COMPARISON OF PERFORMANCES IN
FIRST AND SECOND GENERATION "LITHIUM-ION" CELLS
CYCLES VS. DISCHARGE AMPERE-HOURS AT 23 DEGREES CELSIUS
2nd GEN.
Ampere Hours
0.9
0.85
0.8
0.75
0.7
0
200
400
600
800
1000
Cycles


SONY Li(x)-CoO2/Li(x)-C SAMPLE CELL #88
CYCLE 1 C/5 DISCHARGE PERFORMANCE
WATT-HOURS PER KILOGRAM
0
10
20
30
40
50
60
70
80
90
AMPERE-HOURS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
VOLTS
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9

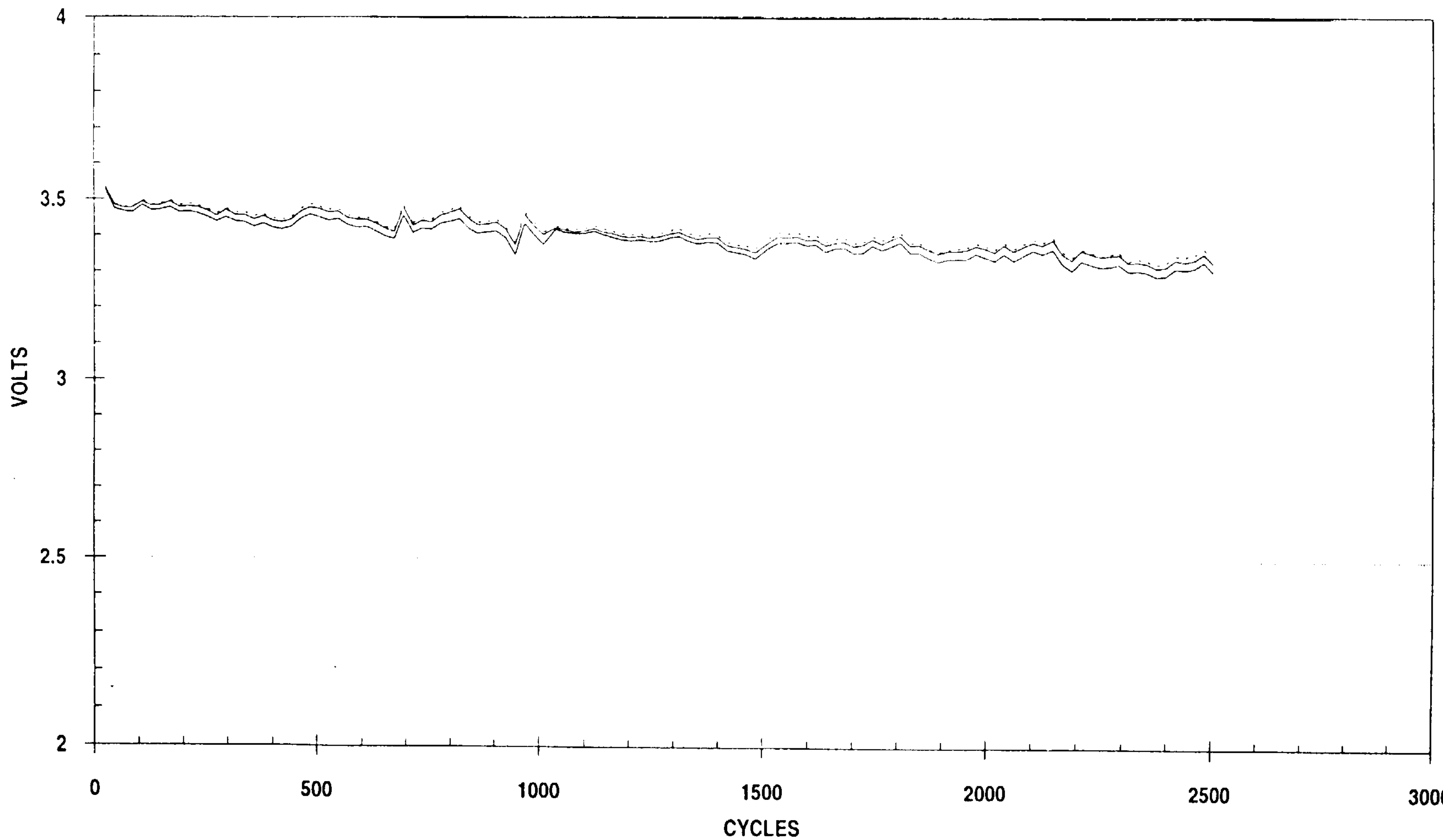

SONY Li(x)C / Li CoO2/ CELLS 62, 67, AND 69
DISCHARGE 1 AT 0.2 AMPERES TO 3.0 VOLTS PER CELL AT 23 DEGREES CELSIUS
VOLTS
4.15
3.95
3.75
3.55
3.35
3.15
2.95
AMPERE-HOURS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


CYCLE 36 OF LEO REGIME ATTEMPT WITH SONY Li(x)C / Li CoO2 CELLS 62, 67, AND 69 AT 23 DEGREES CELSIUS
40% DOD IN 30 MINUTES FOLLOWED BY C/2.46 INRUSH TO 4.1 VOLTS PER CELL TO 1.001 CHARGE TO DISCHARGE AMPERE-HOUR RATIO
AMPERES
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
VOLTS
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
MINUTES
0
20
40
60
80
100
120

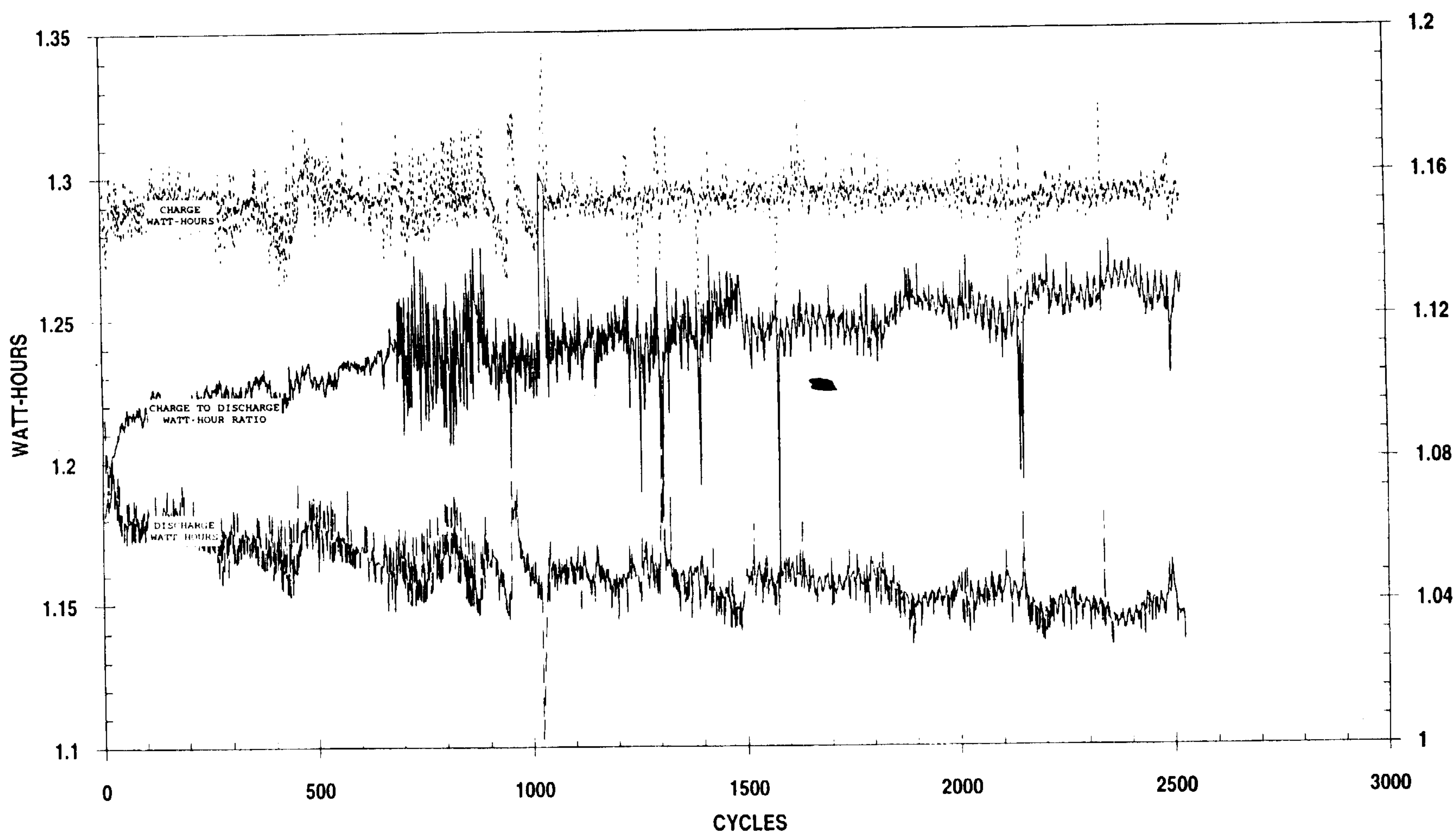

SONY Li(x)C / Li CoO2 CELLS 62, 67, AND 69 AT 23 DEGREES CELSIUS – CYCLE 100
AMPERES
1
0.5
0
-0.5
-1
VOLTS
4.2
4
3.8
3.6
3.4
MINUTES
0
10
20
30
40
50
60
70
80
90
100
CURRENT


SONY Li(x)C / Li CoO2 CELL SAMPLE NUMBER 28012-62, 67, AND 69
CYCLES VS. DISCHARGE AMPERE-HOURS DURING AN ACCELERATED LEO REGIME AT 23 DEGREES CELSIUS
CHARGE TO DISCHARGE AMPERE-HOUR RATIO (AVERAGE = 1.0064)
DISCHARGE AMPERE-HOURS (AVERAGE = 0.321)
AMPERE-HOURS
CYCLES
0.42
0.38
0.34
0.3
0.26
0.22
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0
500
1000
1500
2000
2500
3000

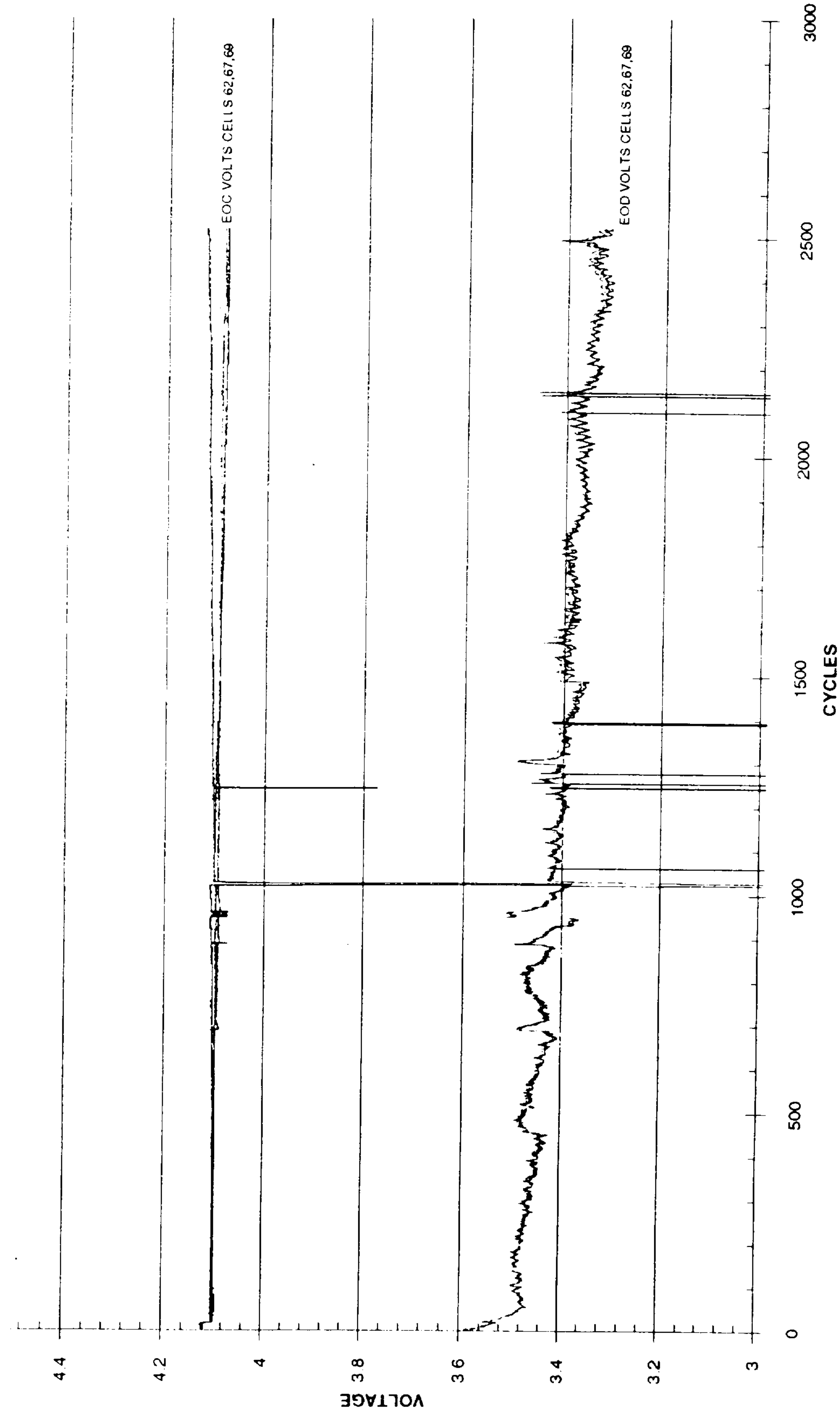
SONY Li(x)C / Li CoO2 CELL SAMPLE NUMBER 28012-62, 67, AND 69 AT 23 DEGREES CELSIUS
CYCLES VS. END OF DISCHARGE CELL VOLTAGES DURING AN ACCELERATED LEO REGIME



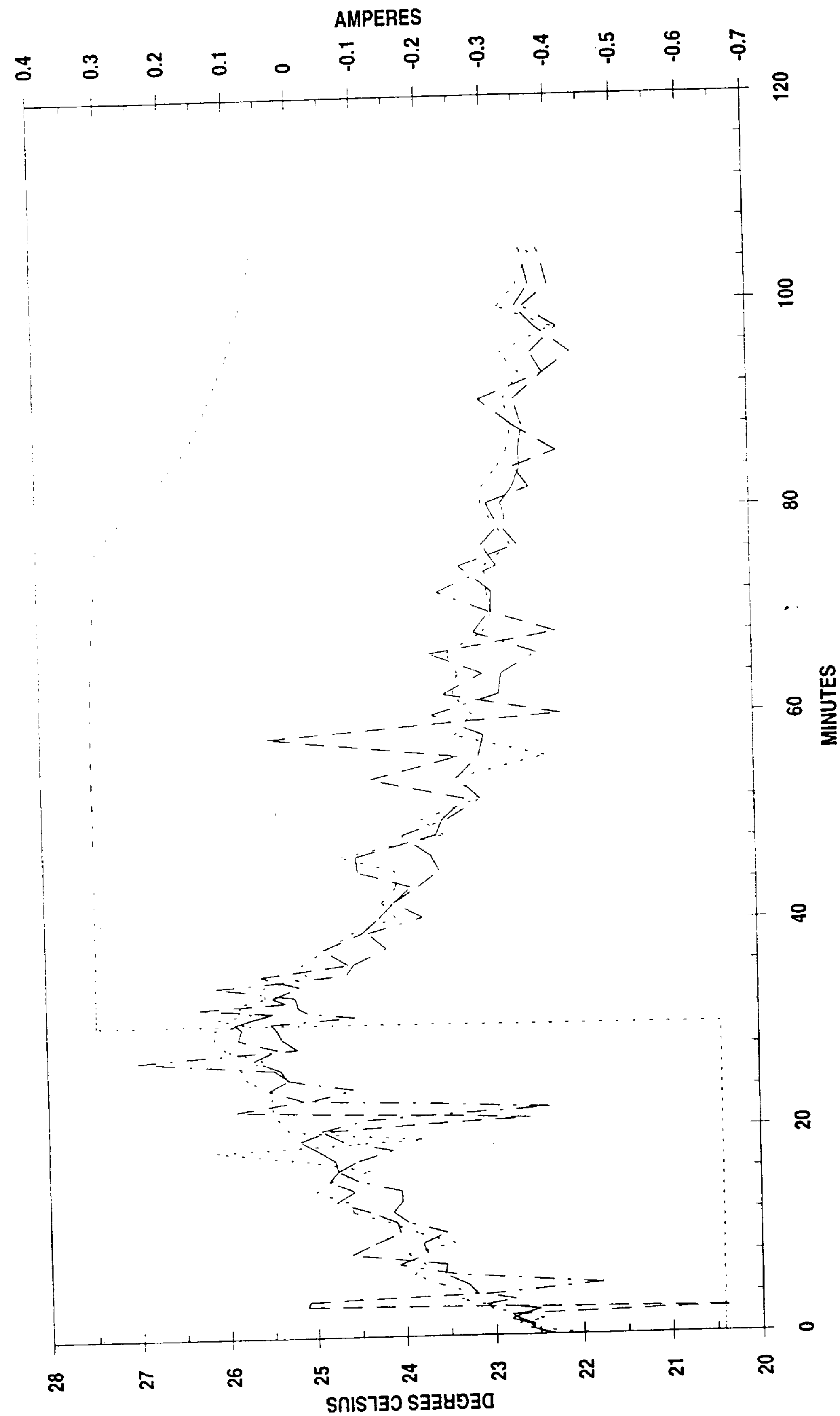
SONY Li(x)C / Li CoO2 CELL SAMPLE NUMBER 28012-62, 67, AND 69
CYCLES VS. AVERAGE WATT-HOURS DURING AN ACCELERATED LEO REGIME AT 23 DEGREES CELSIUS



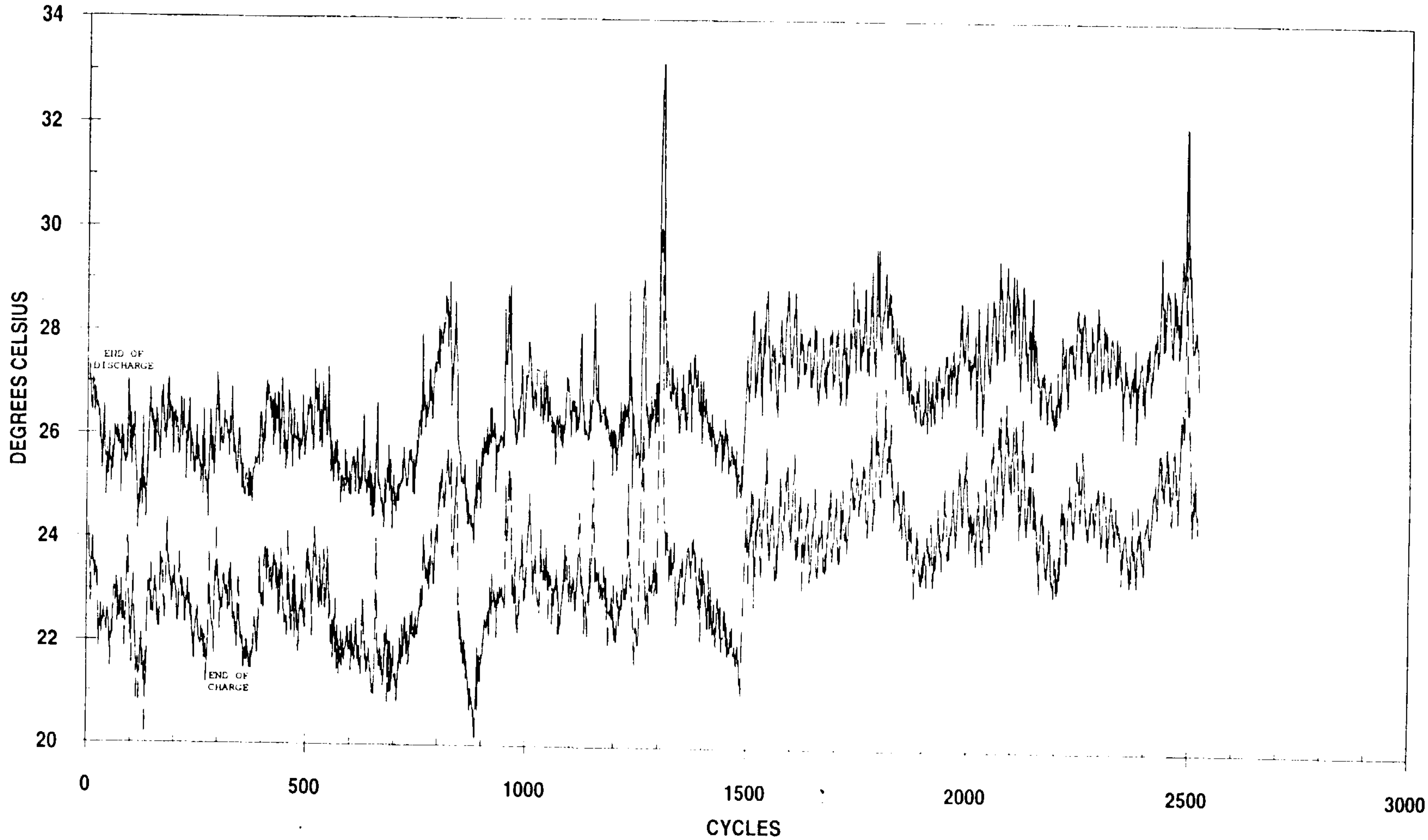
# SONY LI-ION END OF CHARGE/END OF DISCHARGE VOLTS VS CYCLES



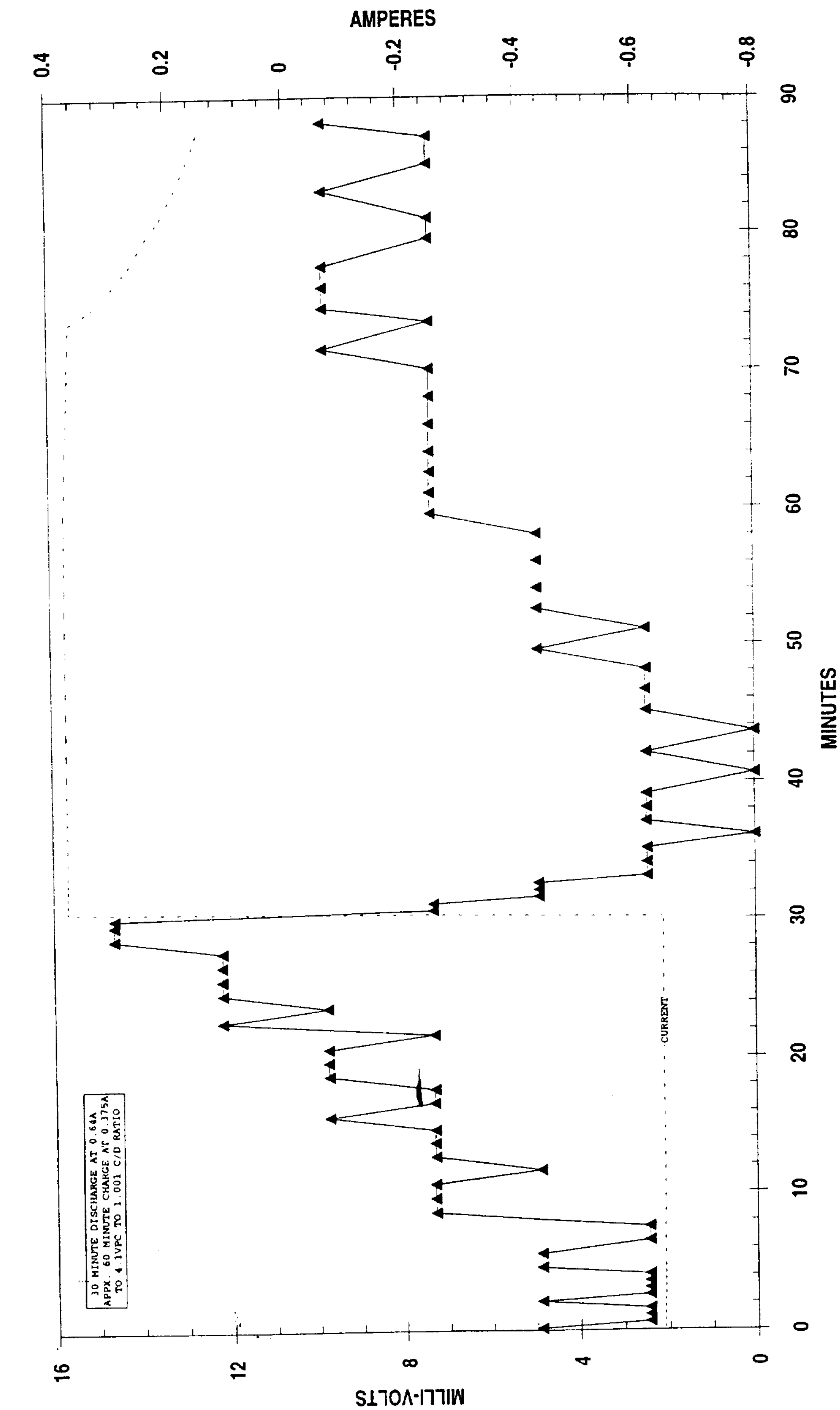
CYCLE 36 OF LEO REGIME ATTEMPT WITH SONY Li(x)C / Li CoO2 CELLS 62, 67, AND 69 AT 23 DEGREES CELSIUS
40% DOD IN 30 MINUTES FOLLOWED BY C/2.46 INRUSH TO 4.1 VOLTS PER CELL TO 1.001 CHARGE TO DISCHARGE AMPERE-HOUR RATIO



SONY Li(x)C / Li CoO2 CELL SAMPLE NUMBER 28012-62, 67, AND 69
AVERAGE CELL TEMPERATURES MEASURED ON CASE DURING AN ACCELERATED LEO REGIME AT 23 DEGREES CELSIUS



SONY Li(x)C / Li CoO2 CELL SAMPLE NUMBER 28012-62, 67, AND 69 AT 23 DEGREES CELSIUS
CELL DIVERGENCE = 1000 x (MAXEMF(1:3)) - (MINEMF(1:3))



# Summary

1) First Generation Cell yielded 780 mAh capacity, second generation cell delivered 860 mAh capacity.

2) Cycle life performance of the second generation cell appears to exceed the first.

3) Accelerated "LEO" testing has already demonstrated 2500 cycles at 40% DOD, and continues to cycle.

4) Energy density per volume is larger with the second generation cells.

5) Cell performance is consistent which demonstrates good fabrication techniques.

**Round Table Discussion of Advanced Technology for Space Applications**
Gerald Halpert, Jet Propulsion Laboratory

NASA BATTERY WORKSHOP
MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
November 1994

OPEN DISCUSSION
On the Subject of

WHAT WILL IT TAKE TO GET ADVANCED BATTERY TECHNOLOGY INTO SPACE APPLICATIONS?

Chairman: Gerald Halpert
Jet Propulsion Laboratory
Notes by Michelle Manzo, NASA LeRC

OPENING REMARKS - G. Halpert
New battery technologies have been improving over the last several years. It took almost 20 years for NASA to use a Ni-H2 battery. Even then it was used on Hubble Space Telescope as a replacement for a Ni-Cd battery in which life limiting concerns had been raised. What do we have to do to use Ni-MH or Li-ion batteries in space? How do we qualify cells and batteries for space missions?

If you ask the spacecraft Manager or project manager, he or she will ask where has it been used previously and what is the experience with the device? Even though there may be significant test data, and the mass and volume is lower or the mission capability can be increased, the project manager will generally opt for a previously used battery system. The philosophy is "Not on my spacecraft."

The subject is open for discussion to all attendees. I hope you will participate. The first speaker is Dave Pickett from Hughes.

ATTENDEE PARTICIPATION
Pickett - It took 8 years to fly modern Ni-Cd and 11 years to for Ni-H2. A compelling reason is needed for implementation of new technology, whether it be economics, or other. It takes time, and someone willing to take the risk. Usually, commercial needs lead the way.

The new technologies are Ni-MH, Li-ion, and CPV Ni-H2. Larger IPV are being considered as well as CPV. Predictions for spaceflight of Ni-MH , 5 years, and Li Ion 8-10 years. This is the time it takes from cell test to battery integration.

E. Darcy - Safety issues with Li make Ni-MH more of a near term option.

J. Firmin - Safety tests have been conducted. Requirements need to be defined and tech must meet the requirements.

G. Methlie - Agreement with safety issue. Ni-MH intermediate term is needed. Difficult to accelerate verification.

M. Klein - Ni-MH is the battery of choice for next 10-15 years. Aerospace should leverage off commercial.

C. Lurie - High cost for qualification of Ni-Cd to Ni-MH. Not clear that it offers significant advantages at battery level. Li-Ion will probably ultimately replace Ni-MH. Probably cannot justify costs.

G. Dudley - Wh efficiency less for Ni-MH than Ni-Cd.

C. Lurie - Ni-MH advantage is improved round trip efficiency, thus, smaller array.

W. Tracinski - Possible use for all technologies to optimize for all applications.

G. Methlie - Project forward by looking backward. If end up with one system, you better be right. Also need multiple vendors.

D. Maurer - Need all technologies. Li-Ion a long way off. Need several technologies going at once. The mechanism for demo in space will be in small s/c.

A. Dunnett - Cheaper and faster, not better. No new battery systems seen without compelling reason. Ni-MH will not be qualified with Ni-Cd and Ni-MH available. Li-Ion is the next step.

G. Halpert - What is the necessary incentive to go Li-Ion? Does your company support R&D on Li-Ion?

A. Dunnett - Lower battery weight, more propellant, increase in payload. My organization does not support Li-Ion or other R & D.

E. Darcy - The time line is long without terrestrial applications. Ni-MH make sense in todays environment.

C. Lurie - Small satellites are new visions for aerospace. They become the platform for new technology.

M. Anderman - Ni-MH advantages depend on DOD capability and life as a function of DOD.

V. Kennedy -Responding to a question on Na-S, acceptance and abuse tests are being worked.

Johnson -Go on to far term technologies. Let other Intermediates develop in commercial technology. Sponsor research in space for space applications.

G. Methlie - Commercial base does not guarantee success in space.

J.Firmin - Same battery as EV commercial? Need to begin improvement at early stages to influence development.

P. O'Donnell - Need dual-use drivers. Can't take terrestrial alone. Need to work on parallel paths.

J. Firman - Limit documentation for qualification of new technologies for space. Documentation is costly.

C. Lurie - Dual answer. Small satellites, Yes, DOD/NASA, no.

C. Lurie - On the capacity fade issue - It still exists but we have an understanding. TRW prefers to deal with Ni precharge issues.

G. Halpert - Managers want low cost but also want guarantees that product will work. Thus, costs will remain high. However, we are careful. Not always battery failures, e.g., Magellan - failure was arrays not battery.

S. House - Phillips Lab will not support development of Ni-Mh. Lithium-ion possible substitution to Na-S and Ni-H2. 7 year test is required.

M. Toft - To get new technology into orbit, which product has been shown to be best understood. Elimination of documentation and visibility is the wrong way to go. Vendor data is valuable. It holds clues to success. If you show understanding, customers will be willing to pay.

C. Bennett - There is a large database for Ni-H2. Varied parameters, no consistent production. Need to use a model.

G. Halpert - Why do we have all these variations in product? (No response)

J. Armantrout - Historically we have used database for decisions. Develop a standard for a 5Kw satellite. Need more standardized designs.

J. Wheeler - The process is: The manufacturer recommends to the customer, then customer has strong preferences including plate and cell designs. The manufacturer is at the customer's mercy. There are multiple paths to success. Let the customer make the selection.

C. Garner - Cooperative efforts work well.

G. Methlie - Commercial look at products.

S. Surampudi - Technology is driven by customer. Customer was leader. Leader disappeared replaced by managers. They want the best products without supporting costs.

G. Halpert - Are there any planned Ni-Mh flights?

B. Bragg - Shuttle orbiter GFE. Ni-MH flown in IBM think pad. To be flown in helmet light. NASA/JSC approves specific designs and specific applications - no blanket chemistry approval. OSHA and EPA have environmental concerns. Japanese Ni-MH flight in 1998 will follow European's and Amercians.

A. Dunnett - The delta performance improvement does not warrant development of Ni-Mh over Ni-Cd.

G. Halpert - Are there any planned Li-Ion flights?

S. Surampudi - JPL use in 1997. Small spacecraft 5-10 Ah cells. 45 new technologies evaluated for new spacecraft. Li-Ion was selected. Looking at Li-Ion instead of Ni-MH because no apparent payoff over Ni-H2. The fallback is Ni-Cd compelling reason is size.

Session adjourned

Many thanks to Michelle Manzo for taking these notes

# Nickel-Hydrogen / Nickel-Cadmium Data Session