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CAPACITY FADE IN IN NICKEL CADMIUM AND NICKEL HYDROGEN CELLS

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CAPACITY FADE

A DEFINITION

- ✓ **TYPICALLY UP TO 20% LOSS IN PREVIOUSLY DEMONSTRATED CAPACITY**

- ✓ **NORMALLY SEEN AFTER A PERIOD OF CELL STORAGE**

- ✓ **SEEN IN NiH₂ & NiCd CELLS WITH ELECTROCHEMICALLY DEPOSITED POSITIVE PLATES**

SCOPE OF PRESENTATION

1 THEORETICAL CAUSES OF CAPACITY FADE

- ROLE OF CELL STORAGE
- ROLE OF POSITIVE ELECTRODE
- ROLE OF COBALT ADDITIVE

2 EXAMPLES OF OBSERVED CAPACITY FADE

- INTELSAT V (30 AH NiH₂)
- INTELSAT VI (48 AH NiH₂)
- EXPLORER PLATFORM (50 AH NiCd)

3 PREVENTION AND RECOVERY METHODS

- OPEN CIRCUIT STORAGE
- STORAGE UNDER TRICKEL CHARGE
- STORAGE FULLY CHARGED

4 CURRENT EAGLE PICHER/HUGHES RESEARCH STATUS

CAPACITY FADE THEORY OF PHENOMENON

- 1. ATTRIBUTED TO ACTIVE MATERIAL CHANGES IN THE POSITIVE PLATE AT LOW STATES OF CHARGE**
- 2. APPEARS TO BE SPECIFIC TO ELECTROCHEMICALLY DEPOSITED PLATES IN BOTH NiH₂ AND NiCD CELLS**
- 3. OCCURS AFTER A PERIOD OF STORAGE OPEN CIRCUIT DISCHARGED SHORTED CONDITION**
- 4. CAPACITY FADE HAS BEEN LINKED TO THE COBALT ADDITIVE AND ITS SEVERITY MAY BE ASSOCIATED WITH COBALT CONCENTRATION**
- 5. CHARGED ACTIVE MATERIAL IS UNABLE TO BE COMPLETELY DISCHARGED AT HIGHER RATES**
- 6. OVERALL CELL PERFORMANCE IS NOT AFFECTED AND CAPACITY IS RECOVERED THROUGH CYCLING AND USE**

CAPACITY FADE

ROLE OF THE POSITIVE ELECTRODE

1. ELECTROCHEMICALLY DEPOSITED POSITIVE ELECTRODES HAVE DISPLAYED CAPACITY FADE IN BOTH NICKEL CADMIUM AND NICKEL HYDROGEN CELLS

2. MANY RESEARCHERS BELIEVE THAT THE PHENOMENON IS LOCALIZED TO THE POSITIVE

3. CAPACITY FADE HAS NOT BEEN OBSERVED IN CHEMICALLY DEPOSITED POSITIVE ELECTRODES

4. SOME RESEARCHERS BELIEVE THAT CAPACITY FADE CAN BE ATTRIBUTED TO THE DEPTH OF DISCHARGE OF THE POSITIVE ELECTRODE.
 - THIS THEORY IS SUPPORTED BY THE ABSENCE OF FADING DURING CYCLING

 - THE FACT THAT FADING HAS BEEN GENERALLY SEEN AFTER STORAGE IN THE DISCHARGED CONDITION IS ALSO SUPPORTIVE OF THE THEORY.

CAPACITY FADE

ROLE OF STORAGE

1. CELL VOLTAGE AT START OF STORAGE IS A CRITICAL FACTOR
 - ▶ CAPACITY FADE HAS NOT BEEN OBSERVED IN CELLS STORED AT POTENTIALS BETWEEN 0.5 AND 1.0 VOLTS

2. HIGHER STORAGE TEMPERATURES APPEAR TO ACCELERATE CAPACITY FADING
 - ▶ OPTIMUM TEMPERATURES ARE BELOW 23° C

3. SHORTING CELLS FOR EXTENDED PERIODS DURING STORAGE HAS BEEN DEMONSTRATED TO INCREASE THE DEGREE OF CAPACITY FADE

4. THE LONGER THE STORAGE TIME THE MORE IMPORTANT THE FACTORS LISTED ABOVE BECOME.

CAPACITY FADE ROLE OF COBALT ADDITIVE

1. RESEARCH INDICATES A POSSIBLE CHEMICAL COMBINATION OF COBALT AND NICKEL

- ✓ THIS REACTION IS BELIEVED TO OCCUR AT LOW
STATES OF CHARGE IN THE ACTIVE MATERIAL**
- ✓ THE PRESENCE OF NICKEL IN THE CHARGED FORM
(NiOOH) APPEARS TO INHIBIT THE REACTION**
- ✓ THE RESULTANT HYBRID COMPOUND DRAMATICALLY
CHANGES THE DISCHARGE CHARACTERISTICS OF
THE ACTIVE MATERIAL**

2. SEVERITY OF CAPACITY FADE MAY BE LINKED TO COBALT CONCENTRATION

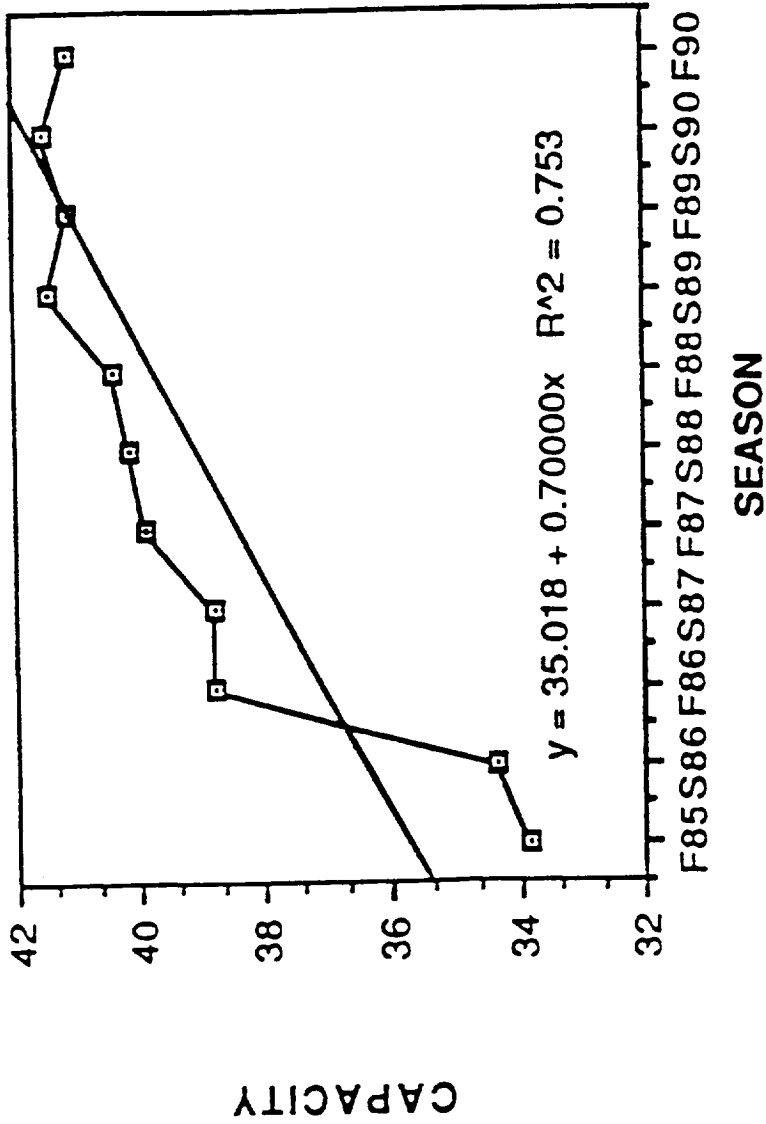
- ✓ HIGHER COBALT CONCENTRATION APPEARS
TO LEAD TO MORE PRONOUNCED FADING**

CAPACITY FADE OCCURANCE OF

1. CELLS WHICH EXHIBIT CAPACITY FADE HAVE:
 - a. NORMALLY BEEN THROUGH A PERIOD OF STORAGE
 - b. HAVE BEEN STORED IN A DISCHARGED CONDITION
 - c. HAVE BEEN STORED AT HIGHER THAN NORMAL TEMPERATURES ($\geq 23^{\circ}$ C)
 - d. HAVE IN MANY CASES BEEN SHORTED FOR ALL OR PART OF THE STORAGE TIME

2. TO BE CLASSIFIED AS CELLS WHICH EXHIBIT CAPACITY FADE THE CELLS SHOULD:
 - a. EXHIBIT A DECREASED CAPACITY THAT IS NOT RECOVERED THROUGH ROUTINE CYCLING
 - b. GENERALLY OCCURS EARLY IN CELL CYCLE LIFE
 - c. DEMONSTRATE NO OTHER ANOMALY WHICH WOULD CONTRIBUTE TO CAPACITY LOSS
 - d. PERFORM NORMALLY IN ALL OTHER RESPECTS

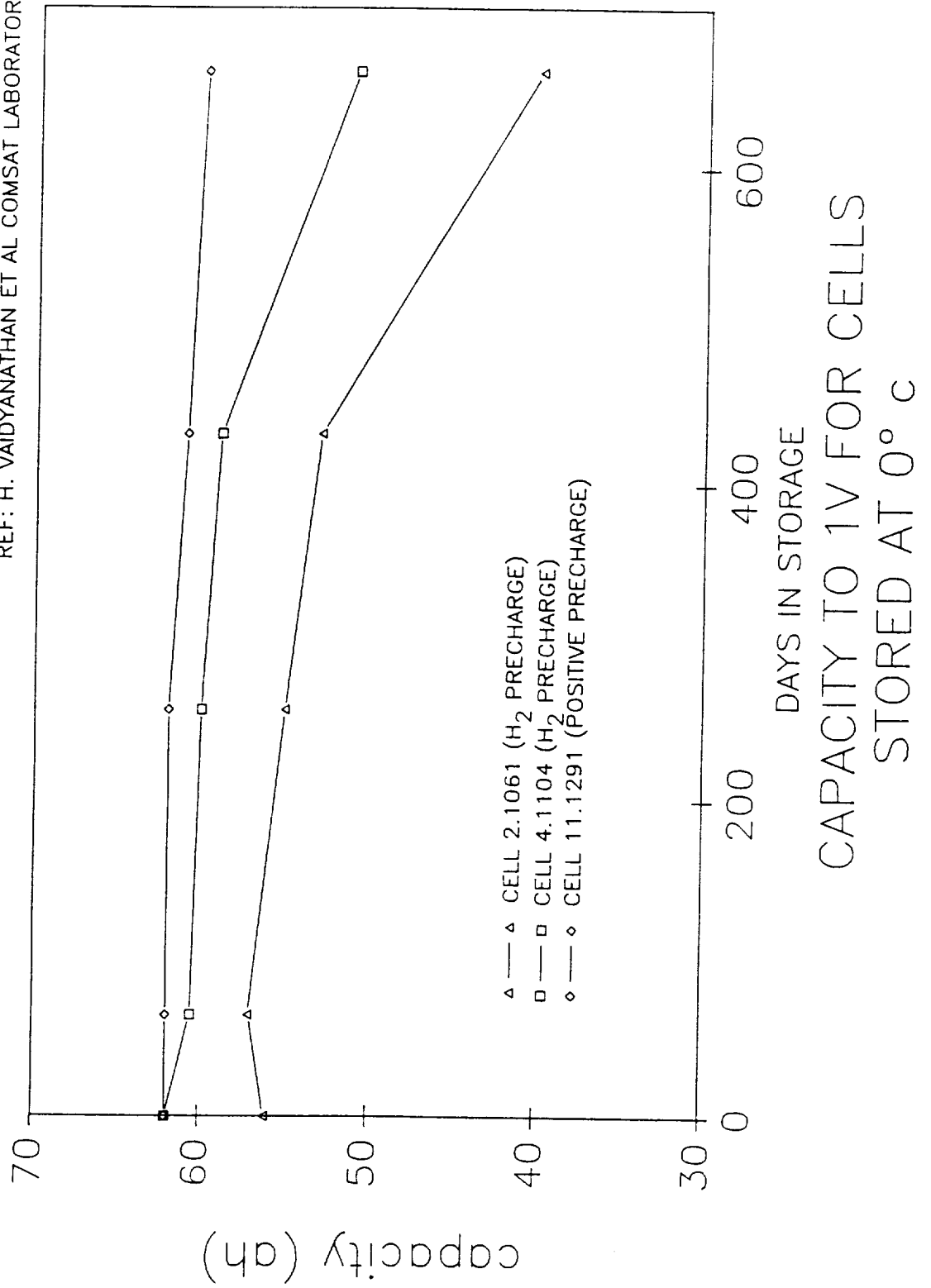
Capacity vs Eclipse Season Intelsat 5 F-10 Battery 2



Ref.: J. Dunlap
COMSAT

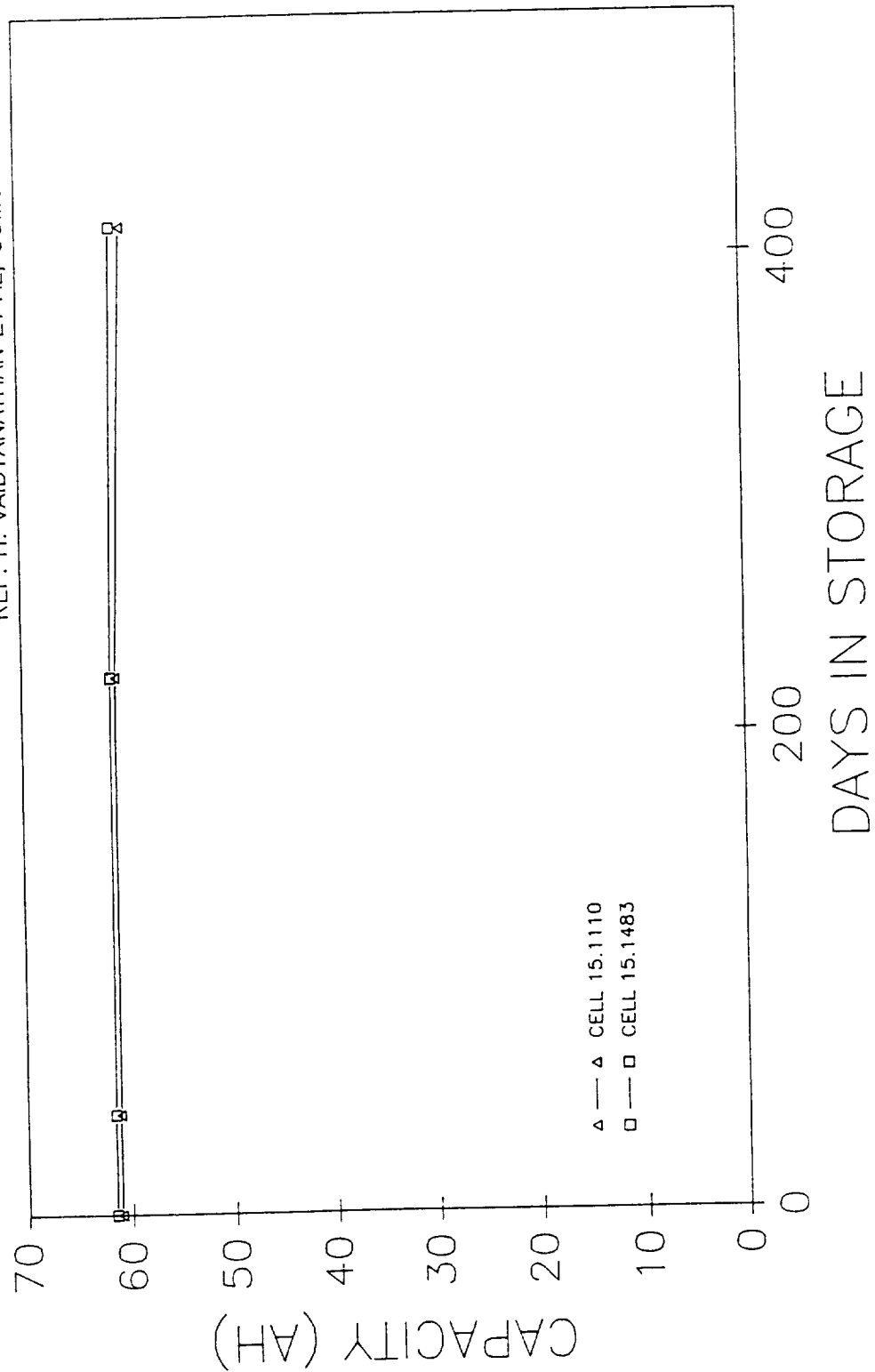
INTELSAT VI STORAGE STUDY

REF: H. VAIDYANATHAN ET AL COMSAT LABORATORIES



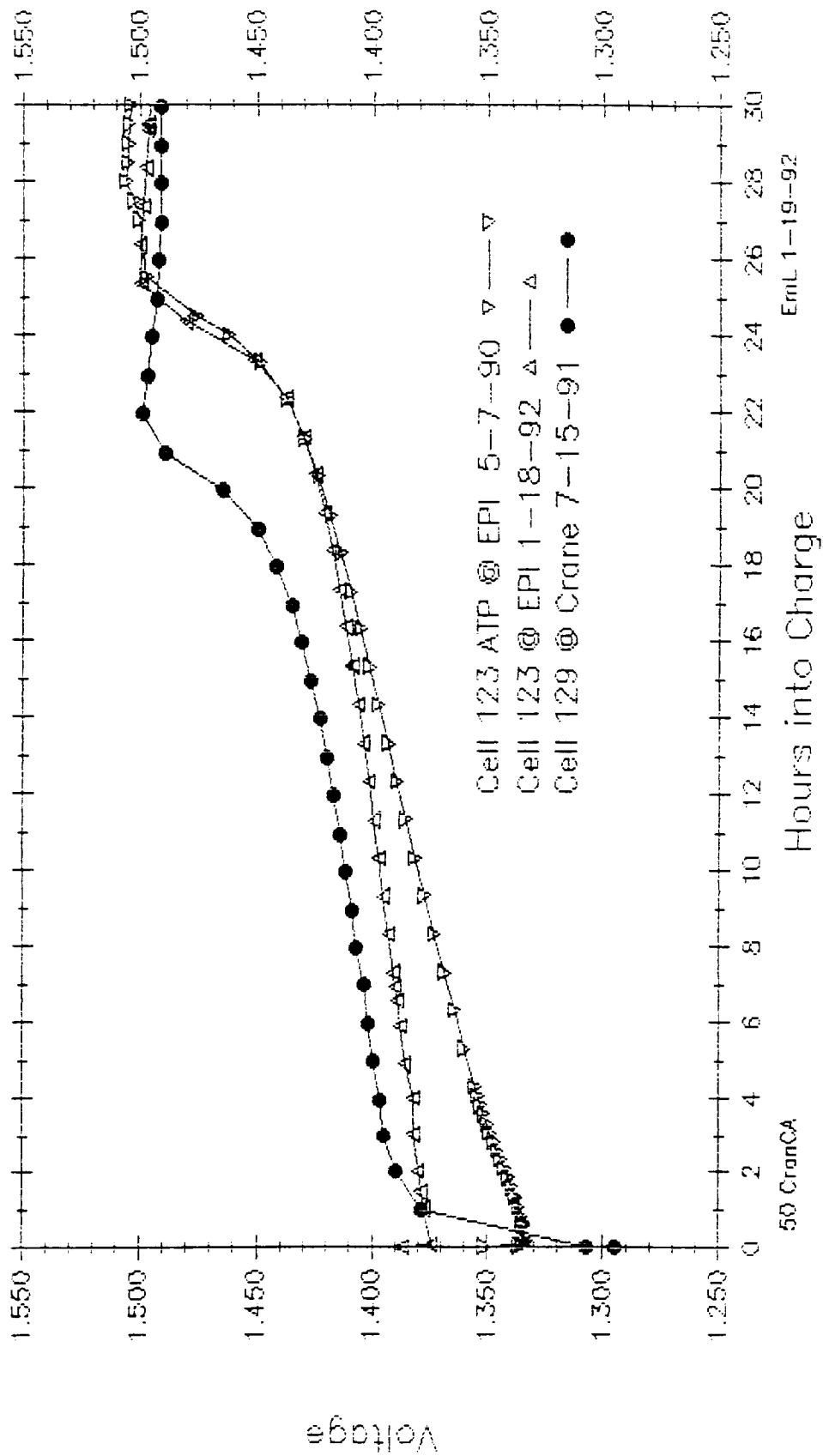
INTELSAT VI CAPACITY
BEHAVIOR WHEN STORED
ON TRICKLE-CHARGE

REF: H. VAIDYANATHAN ET AL; COMSAT LABORATORIES

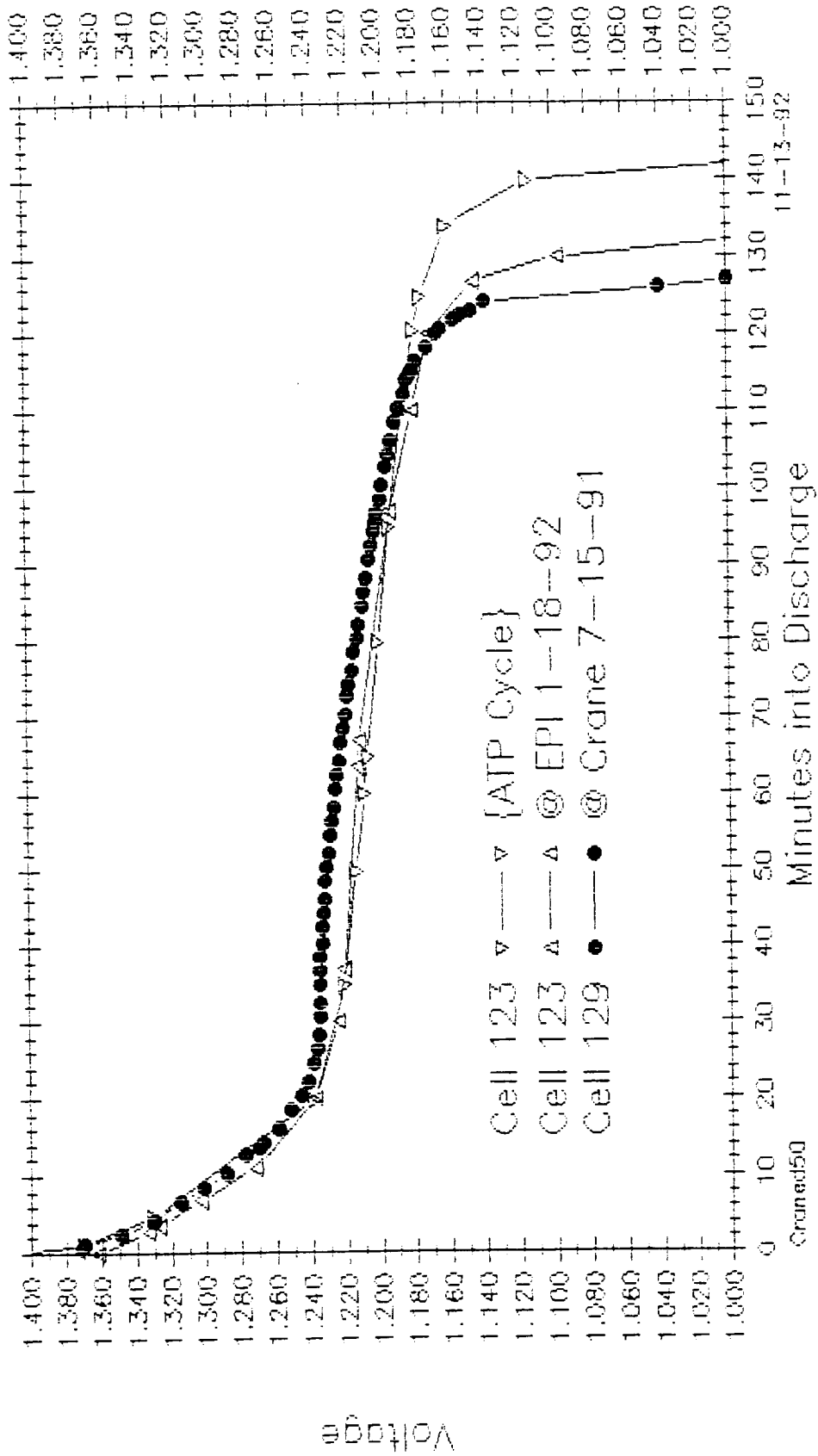


TEMPERATURE = 23° C

50AH Cells
 Comparison Between C/20 Charges @ 0°C
 {First 30 Hours of C/20 Charge}



50 AH Cells
 Comparison Between C/2 Discharges after 72 Hr C/20 Charge @ 0°C



CAPACITY FADE METHODS OF PREVENTION

**1. USE OF THE NICKEL PRECHARGE IN NICKEL
HYDROGEN CELLS**

**2. STORAGE OPEN CIRCUIT IN A DISCHARGED
CONDITION**

3. STORAGE IN A CHARGED CONDITION

4. STORAGE WITH TRICKLE CHARGE

CAPACITY FADE STORAGE UNDER TRICKLE CHARGE

CELL IS FULLY CHARGED

CELL IS STORED UNDER A LOW CURRENT CHARGE

- **C/80 IS USUAL TRICKLE CURRENT**
- **TEMPERATURE IS MAINTAINED AT $6 \pm 3^{\circ}$ C**
- **VOLTAGE AND CELL TEMPERATURE ARE MONITORED TO PREVENT DAMAGE TO CELLS**

TRICKLE STORAGE METHOD IS SUITABLE FOR LAUNCH PAD STORAGE

TRICKLE STORAGE METHOD IS ACCEPTABLE FOR UNSUPERVISED STORAGE

IT IS THE STORAGE METHOD OF CHOICE

CAPACITY FADE STORAGE CHARGED

CELL SHOULD BE FULLY CHARGED

- 100% CHARGE FOLLOWED BY EXTENDED TRICKLE CHARGE
TYPICAL PRE-STORAGE REGIME

MAINTAIN LOW STORAGE TEMPERATURE

- LOWEST TESTING TEMPERATURE (NORMALLY 0° C) IS
THE NORM

CELL RECEIVES A PERIODIC "TOP-OFF" CHARGE

- TRICKLE RATE IS RECOMMENDED CURRENT (C/80)
- FREQUENCY OF CHARGE DETERMINED BY SELF-DISCHARGE
RATE

ACCEPTABLE METHOD FOR LAUNCH PAD STORAGE

ACCEPTABLE FOR UNSUPERVISED STORAGE

RECOMMENDED BY EAGLE PICHER AND HUGHES AIRCRAFT

BEST WHEN CONSTANT CELL MONITORING IS NOT
FEASIBLE

CAPACITY FADE OPEN CIRCUIT STORAGE

**OPEN CIRCUIT STORAGE IS NOT HIGHLY
RECOMMENDED**

STORAGE TEMPERATURE MUST BE CONTROL

- **STORAGE AT LOWEST TESTING TEMPERATURE
(USUALLY 0° C) IS A GOOD RULE OF THUMB**

**IT IS ESSENTIAL TO AVOID SHORTING DURING
STORAGE**

**MAXIMUM 80% DEPTH OF DISCHARGE PRIOR TO
STORAGE**

**EAGLE PICHER BELIEVES THAT THIS IS A RISKY
METHOD OF STORAGE**

- **THIS METHOD SHOULD BE USED AS LAST RESORT**
- **NOT AN ACCEPTABLE METHOD FOR LAUNCH PAD
STORAGE**
- **NOT AN ACCEPTABLE METHOD FOR UNSUPERVISED
STORAGE**

CAPACITY FADE

RECOVERY OF CAPACITY

1. ALL CAPACITY FADE EXAMPLES HAVE DEMONSTRATED SOME DEGREE OF RECOVERY WITH CONTINUED CYCLING

- ▶ INTELSAT V IS CURRENTLY ON ORBIT WITHOUT A FAILURE
- ▶ INTELSAT VI HAS RECOVERED CAPACITY WITH CYCLING
- ▶ EXPLORER 50 AH IS PRESENTLY ON LEO STRESS TEST AT CRANE NWSC AND IS PERFORMING WELL.

2. EAGLE PICHER IS NOW TESTING CELLS TO IDENTIFY THE MOST APPROPRIATE RECOVERY REGIME

- ▶ THE OBJECTIVE OF THE STUDY IS TO SPEED RECOVERY
- ▶ A SECOND OBJECTIVE IS TO BETTER UNDERSTAND CAPACITY FADING.

SPECIFICALLY:

- HOW FADING IS AFFECTED BY TEMPERATURE
- HOW FADING IS AFFECTED BY RESTING VOLTAGE

HUGHES EXPERIENCE WITH CAPACITY FADING ON STORAGE

- I. Early Experiences
 - A. Lot 700 Plates Made at EPI, Colorado Springs for Flight Program
 1. Recovered almost completely by LEO cycling at 80% DOD.
 2. Maintained capacity in storage by methods:
 - a. Trickle charge storage
 - b. Periodic C/10 top-off charge
 - c. never hard shorting cells for more than a few hours!
 - B. Plates made from aqueous process for technology program.
 1. Partially recovered capacity by LEO cycling at 80% DOD.
 2. Plates analyzed by customer.
 - a. Capacity loss correlated with deficiency in residual charged material.
 - b. Loading levels on low side (1.4 - 1.5 g/cc void).

HUGHES EXPERIENCE WITH CAPACITY FADING ON STORAGE (Contd.)

II. INTELSAT VI Program

- A. Numerous tests conducted by both Hughes and COMSAT Laboratories aimed at prevention.
 - 1. Cold Storage
 - a. Without trickle charge (COMSAT) - Results reported at IECEC in 1986.
 - b. With trickle charge - used for some flight packs.
 - 2. Periodic Top-off.
 - a. Every two weeks at C/10, initially.
 - b. Every few weeks at C/10, eventually.
 - 3. Elimination of Hydrogen Precharge - Results Published by Stadnick & Lim.
 - a. Effect of 50 psi hydrogen - Capacity loss in about 4 days.
 - b. Effect of 14.7 psi hydrogen - Capacity loss in week or two.
 - c. Effect of nickel electrode precharge - No capacity loss after six months storage.
 - d. Life test conducted for 30 real time seasons.
 - (1) Cells with both Ni and H₂ precharge.
 - (2) Capacity measured at end of test - no loss for cells with either precharge.
 - (3) H₂ precharge cells had undergone capacity recovery
 - 100 80% DOD LEO cycles.
- B. Cells have performed per specification in orbit.

HUGHES EXPERIENCE WITH CAPACITY FADING ON STORAGE (Contd.)

- II. INTELSAT VI Program (Cont'd)
 - C. Cells furnished to USAF for tests at Crane
 - Nickel Precharge - prior to test.
 - ~20,000 cycles at 60% DOD.
 - D. Cells of similar designed furnished to NASA LeRC for Test
 - Both 26% and 31% KOH
 - Results reported on testing by John Smithrick and Steve Hall
- III. Other Nickel Hydrogen Program
 - INTELSAT VI Experienced Used - No capacity loss on storage.
- IV. Nickel Cadmium Programs
 - Capacity fading on early cells purchased from G.E. which had E.D. positive plates.
 - Capacity loss on flight lot of G.E./Gates cells when shorted during manufacturing.
 - First Super NiCd flight.
 - Capacity loss on commercial Super NiCd programs recovered (EPI, Colorado Springs Cells).
 - Low temperature overcharge at C/20 rate for 72 hours (repeated).
 - Extended (3-6 months) trickle charge at low temperature.
 - Handling procedures devised which appear to eliminate problem.
 - IR&D program in place to correct problem - initial results promising.

CAPACITY FADE

POTENTIAL CELL IMPROVEMENTS

- EAGLE PICHER HAS LOWERED THE COBALT ADDITIVE CONCENTRATION
- EAGLE PICHER IS CURRENTLY DEVELOPING A MORE "ROBUST" CELL DESIGN
 - ▶ THE CELL HAS A RESERVOIR OF UNAVAILABLE ACTIVE MATERIAL
 - ▶ THIS RESERVOIR HELPS TO PREVENT THE NICKEL - COBALT REACTION THAT IS SEEN IN CAPACITY FADE.

Boiler Plate Testing 6-26-92 thru 10-23-92
 Advanced Dry Sinter Ni Cd Design

