TOPEX BATTERY OPERATIONS:
INSIGHTS INTO FLIGHT PERFORMANCE

Presented to the
1997 SPACE POWER WORKSHOP

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OUTLINE

THE CAUSES OF CAPACITY FADING
RECONDITIONING TO REGAIN CAPACITY
COMPARISON OF Ni-Cd and Ni-H₂ AGING
NEGATIVE LIMITED BEHAVIOR OF Ni-Cd’s ON CHARGE
SIMULATION OF NEGATIVE LIMITED CHARGING
LOW DOD, VT CHARGING OF Ni-Cd’s
CHARGE CURRENT EFFECTS
SUMMARY
CELL AGING EFFECTS

End of Night

Beginning of Life

End of Life

Cell Potential (Volts)

Time

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Boilerplate Cell Titration Curves - Prior to LEO Cycling

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Boilerplate Cell Titration Curves (After 846 40% LEO Cycles)

Nickel Potential vs. Ref.

Ampere-Hours

Cadmium Pot. vs. Ref.

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Ni-Cd CELL AGING EFFECTS

End of Night
Beginning of Life
End of Life

Cell Potential (Volts)

Time

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RATE VERSUS POTENTIAL TWO PLATEAUS

Low Rate
Medium Rate
High Rate

POTENTIAL

CAPACITY DISCHARGED

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EONV Prediction Ranges

23.5 Volts

Mission Time (years)

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TOPEX NWSC Crane 40°A DOD / 20°C Life Test

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END OF NIGHT MINIMUMUM VOLTAGES AT B' = 0

\[
y = -7 \times 10^{-5}x^5 + 6 \times 10^{-5}x^4 - 0.0019x^3 + 0.0233x^2 - 0.1536x + 27.668
\]

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Post Life Test Discharge: Crane Topex Test

Cell Voltage, V

Time (Minutes)

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BIPHASIC REACTION MECHANISM

- **Thin Platelet Form**: 
  - $\alpha$-Ni(OH)$_2$ \( n < 1.5 \) \( \longleftrightarrow \) \( \gamma\)-NiOOH \( n < 0.5 \)

- **Thick Platelet Form**: 
  - $\beta$-Ni(OH)$_2$ \( n < 1.0 \) \( \longleftrightarrow \) \( \beta\)-NiOOH

**Recrystallization**

**Overcharge**

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Estimated Gamma Fraction For Life Test

Percent Gamma Phase

Number of Cycles

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Predicted EON Voltages For Various Percent Gamma Phase

<table>
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<th>Voltage (V)</th>
<th>1.4</th>
<th>1.3</th>
<th>1.2</th>
<th>1.1</th>
<th>1.0</th>
<th>0.9</th>
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<td>2000</td>
<td>4000</td>
<td>6000</td>
<td>8000</td>
<td>10000</td>
</tr>
</tbody>
</table>

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Predicted Discharge Voltage For Cycled Cell at C/2 Rate

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VOLTAGE FADING IN NICKEL ELECTRODE

GENERATION OF GAMMA PHASE MATERIAL OVER LIFE
DEPLETION OF BETA MATERIAL (DISCHARGED FIRST)
FULLY DISCHARGED BETA PHASE IS HIGHLY RESISTIVE
DECREASING END-OF-NIGHT POTENTIALS RESULT
VARIATION BETWEEN CELL POTENTIALS EXIST
HIGHER VOLTAGE DIVERGENCE AT END-OF-NIGHT

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RECONDITIONING

RECONDITIONING DISCHARGES INTO SECOND PLATEAU

GAMMA PHASE REDUCTION PRODUCES ALPHA PHASE

ALPHA PHASE IS UNSTABLE, AND RECONVERTS TO BETA-II

RECOVERY OF BETA PHASE MATERIAL IS ACCOMPLISHED

THIS REDUCES THE BETA DEPLETION PROBLEM

SECOND PLATEAU IS MOVED FURTHER OUT ON DISCHARGE

AT LOWER DOD’s END-OF-NIGHT VOLTAGE INCREASES

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EFFECT OF AGING ON ELECTRODE CAPACITIES

Ni-Cd

Ni-H₂

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ARGUMENTS FOR RECONDITIONING
IMPROVES USABLE CAPACITY IN BATTERY
ALLOWS DISCHARGING AT HIGHER POTENTIAL
HELPS CONTROL PLATE SWELLING, REDUCED VOLUME
REDUCES NEGATIVE LIMITED BEHAVIOR IN Ni-Cd’s
REDUCED RATE OF HYDROGEN PRESSURE GROWTH IN NiH₂
EFFECT LASTS LONGER IN FLIGHT THAN ON GROUND
GROUND TESTS USE MORE OVERCHARGE THAN FLIGHT

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EFFECT OF AGING ON Ni-H$_2$ AND Ni-Cd BATTERIES

BOTH

INCREASED TOTAL CAPACITY IN NICKEL ELECTRODE
DECREASED USABLE CAPACITY IN NICKEL ELECTRODE
PHASE CHANGES LEAD TO PLATE SWELLING

NICKEL-CADMIUM

LESS OVERCHARGE PROTECTION IN CELL
SECOND PLATEAU IN Cd ELECTRODE DEVELOPES

NICKEL-HYDROGEN

HYDROGEN PRESSURE INCREASES OVER LIFE

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NEGATIVE LIMITED BEHAVIOR

DEFINITION:

HAVING INSUFFICIENT ACTIVE MATERIAL, OR MATERIAL WITH A HIGH ENOUGH ACTIVITY TO ALLOW NORMAL CELL OPERATION AT THE DESIRED RATE.

NOTE:

SUFFICIENT EXCESS NEGATIVE ACTIVE MATERIAL MAY BE PRESENT IN THE CELL, AND YET NOT BE ACCESSED DEPENDING UPON CONDITIONS.
NEGATIVE LIMITED BEHAVIOR ON CHARGING Ni-Cd’s
ANY BATTERY CAN BE MADE TO MISBEHAVE
SOME CELLS ARE MORE SUSCEPTIBLE THAN OTHERS
MANUFACTURING VARIATIONS ARE NOTABLE
AGING INCREASES
MOST BATTERIES CAN BE MADE TO BEHAVE, AS WELL
LIMITING OVERCHARGE AND INRUSH CURRENT ARE HELPFUL
PREDICTED ELECTRODE POTENTIALS FOR NEGATIVE LIMITED CELL

Negative Potential Versus lg/HgO

Positive Potential Versus Hg/HgO

Time (Minutes)

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EFFECT OF CHARGE RATE ON NEGATIVE LIMITED CASE

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WORST CASE CONDITIONS
HIGH RATE CHARGING (LARGE, COLD SOLAR ARRAYS IN LEO)
COLD BATTERY TEMPERATURE (POOR KINETICS AT Cd ELECTRODE)
HIGH CHARGE RETURN (HIGH INITIAL STATE OF CHARGE)
LOW DOD (HIGH SOC AT BEGINNING OF CHARGE)
AGED Cd ELECTRODES WITH PAS SIVATION AND AGGLOMERATION
VOLTAGE DISPERSION
VARIATION IN CELL AGING, CHARGE ACCEPTANCE
DIFFERENT LEVELS OF NEGATIVE LIMITED BEHAVIOR
RANGE OF CELL POTENTIALS ON CHARGE
VARIATION IN CHARGE EFFICIENCY OF CELLS
VARIATION IN THE STATES-OF-CHARGE IN A SERIES STRING
SEVERE CASES CREATE POOR CHARGE ACCEPTANCE, POOR PERFORMANCE ON DISCHARGE, DISABLING BATTERY
SEVERE CASE OF NEGATIVE LIMITED Ni-Cd CHARGING

5°C DOD @ 1.2C INRUSH TO 1045 VOLTCELL AT 50 CELSIUS

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END-OF-NIGHT VOLTAGE

TOPEX Season 19 End Of Night Voltage Plot

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BATTERY 1 DIFFERENTIAL VOLTAGE
Negative Limited Charge Diff. Voltages

Julian Day: 1997

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SPACECRAFT APPLICATIONS AFFECTED
ONLY AFFECTS Ni-Cd’s, NI-H₂ CELLS IMMUNE
MOSTLY LEO, GEO USES LOW CHARGE RATE
MOSTLY HIGH INCLINATION ORBITS, LOW DOD SEASONS
WORST IN VT BASED, DIRECT ENERGY TRANSFER SYSTEMS
WORST WITH HIGH SOLAR ARRAY CURRENT
WORST WITH COLD BATTERIES

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SOLUTIONS FOR AFFECTED SPACECRAFT

LIMIT SOLAR ARRAY CHARGE IN-RUSH CURRENT USING
SOLAR ARRAY OFFSET OR CHARGE ELECTRONICS

UTILIZE LOWEST PRACTICAL VT CURVE TO REDUCE SOC

PAY PARTICULAR ATTENTION TO LOW DOD ORBITS

USE DIFFERENTIAL VOLTAGE CHANNELS TO MONITOR
NEGATIVE LIMITED BEHAVIOR ON CHARGE

LOW OVERCHARGE MAINTAINS OVERCHARGE PROTECTION

REGULAR RECONDITIONING MAY ALSO BE EFFECTIVE

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REDUCING PEAK CHARGE CURRENT

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FACTORS EFFECTING BATTERY CHARGE CURRENT

SIZE OF ARRAY

DEGRADATION OF ARRAY

TEMPERATURE OF ARRAY

SOLAR FLUX

OFFSET ANGLE (BETA’)

S/C AND INSTRUMENT LOADS

PEAK POWER TRACKING FUNCTION

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SUMMARY

NICKEL ELECTRODE CAPACITY FADING MECHANISM DISCUSSED

RECONDITIONING OF NICKEL ELECTRODE EXPLAINED

EFFECTS OF PARTIAL RECONDITIONING IN SPACE SHOWN

DIFFERENCES IN Ni-Cd AND Ni-H2 CELL AGING DISCUSSED

NEGATIVE LIMITED BEHAVIOR IN Ni-Cd's ANALYZED

METHODS TO CONTROL CELL DISPERSION EXPLAINED
ACKNOWLEDGEMENTS

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