

Storage Characteristics of Lithium Ion Cells

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Mission Relevance

- **Mars Lander and Rovers**
 - **MSP 2001 Lander and MSR 2003 Rover**
 - **Require 2 years of calendar life (with one year Cruise)**
 - » **200 cycles in Martian environment**
 - » **Low temperature performance**

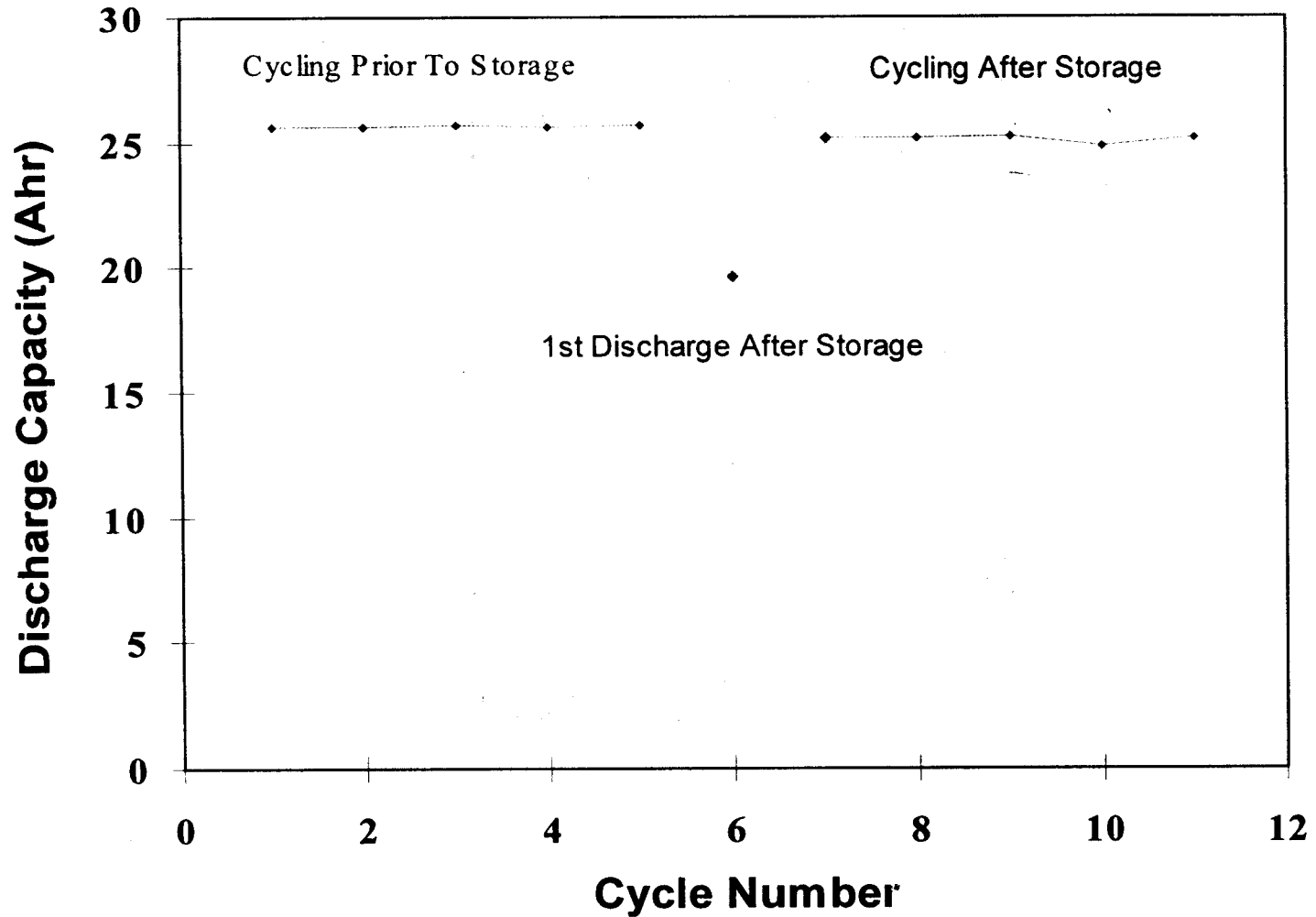
- **Outer planets Missions**
 - **Europa, Solar Probe and Pluto Fly-by**
 - **5-12 years of calendar life**
 - » **400 cycles of operation**



Storage Tests- Outline

- **Eight week storage under open circuit**
 - Two temperatures and two states of charge
- **Ten month storage under open circuit**
 - 40°C, 0°C at 100% and 50% SOC
- **Accelerated Storage tests- Design Experiments**
 - State of charge, Temperature, Time and mode of storage
- **Three Electrode Cells under Open Circuit**
 - 60°C and 55°C
- **Criteria**
 - Self Discharge, Permanent loss in Capacity, Low temperature performance, AC Impedance (EIS)

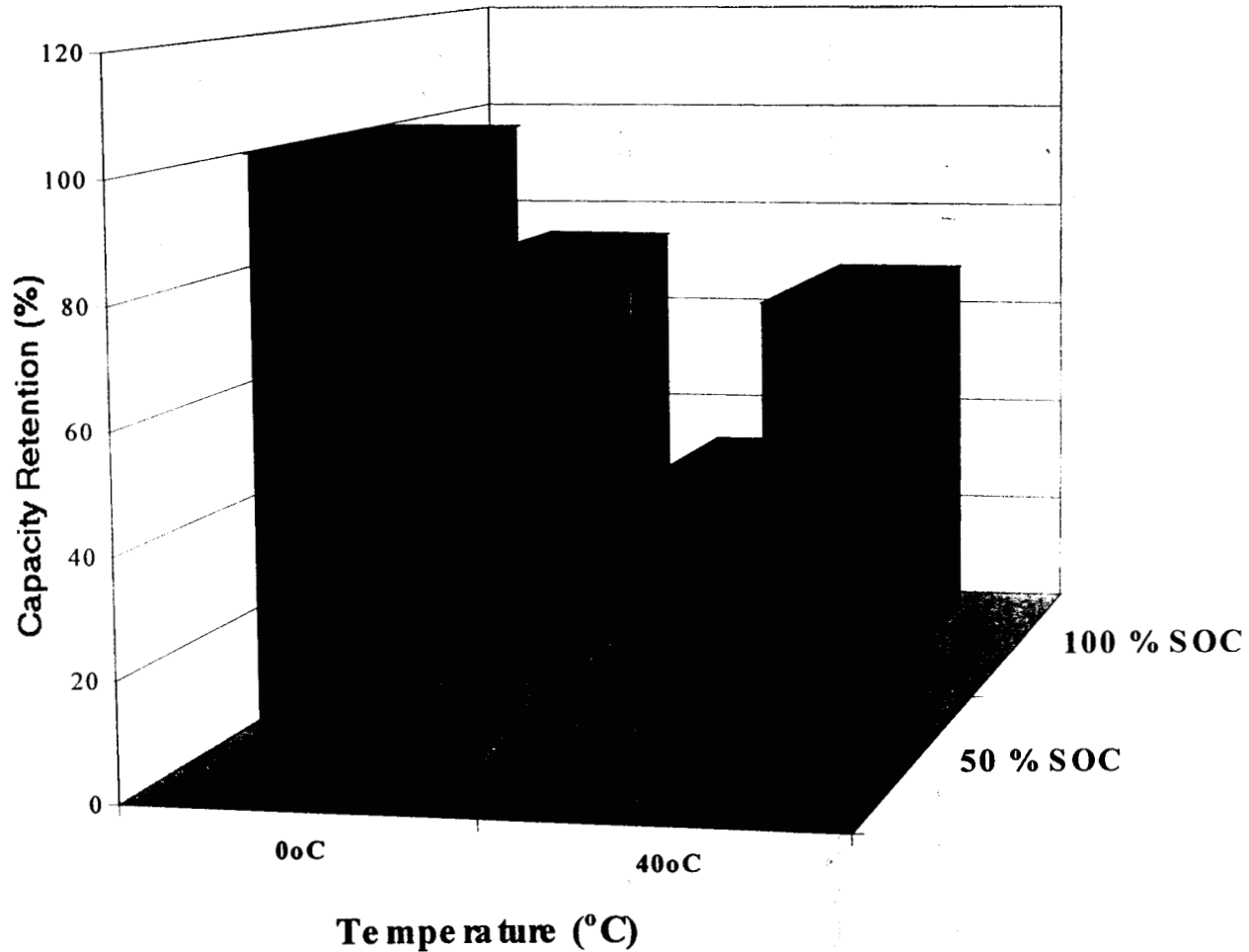
Storage Characteristics





Self-Discharge Characteristics

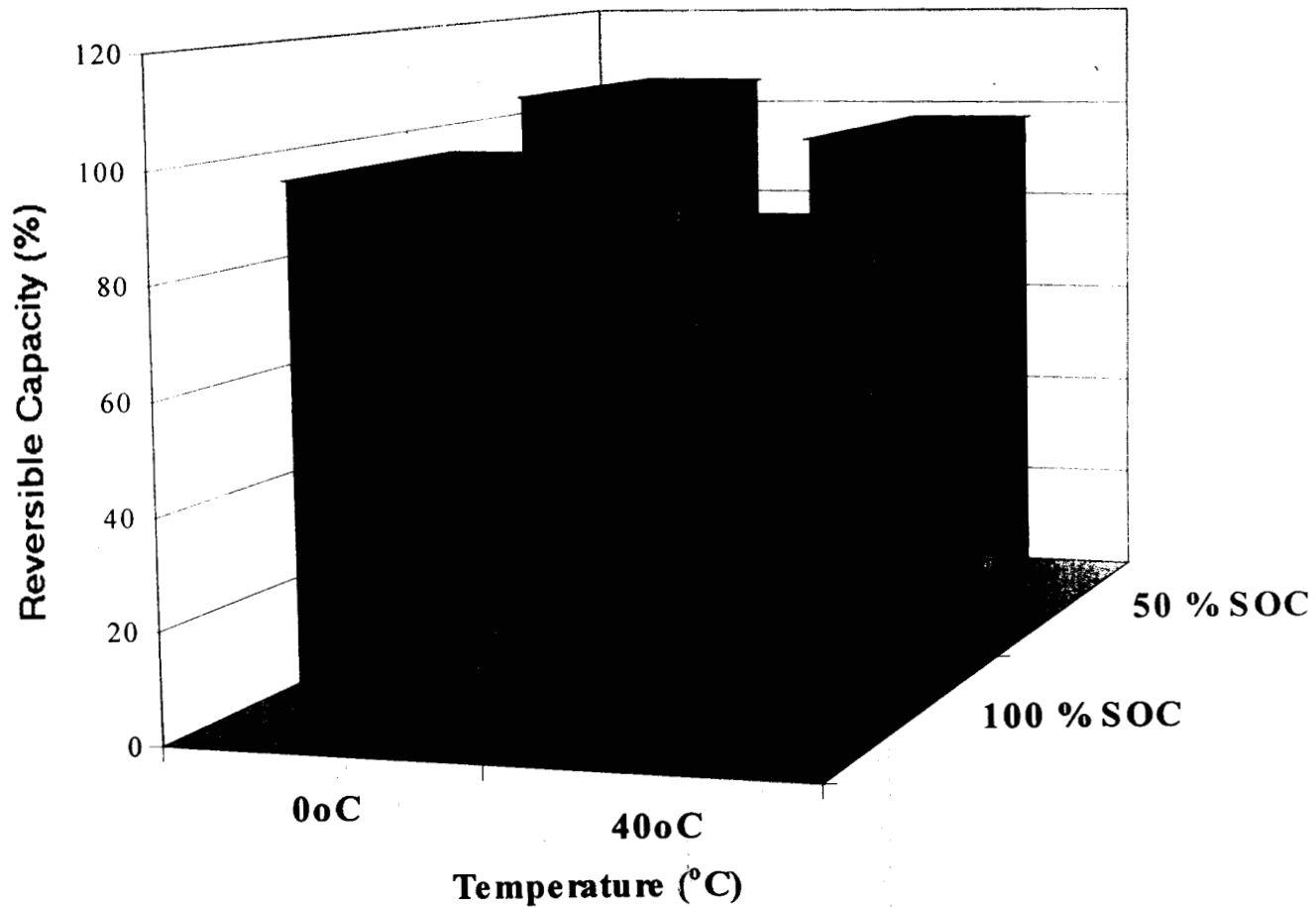
Vendor 1





Capacity Degradation on Storage

Vendor 1





Storage Characteristics

Vendor 2

Storage Temp (°C)	State of Charge	Capacity Loss (Ah)	Reversible Capacity
0	50 %	12.03 Ah	98.4 %
0	100 %	6.10 Ah	97.1 %
40	50 %	14.00 Ah	99.4 %
40	100 %	2.37 Ah	98.0 %



Storage Characteristics

Vendor 3

State of Charge	Temperature of Storage	Storage Time (Months)	Reversible Capacity (%)	Stored Capacity Loss (%)
50%	0°C	2	99.9	0.4
100%	0°C	2	97.5	7.88
50%	40°C	2	97.3	13
100%	40°C	2	92.9	13.3



Accelerated Storage

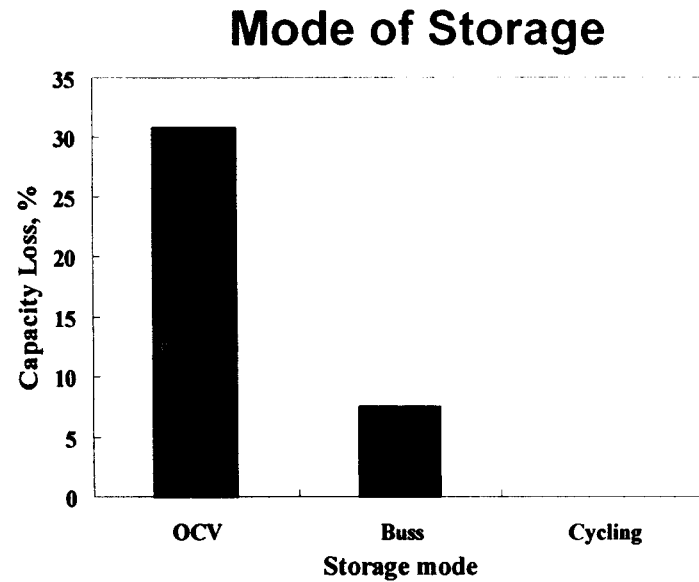
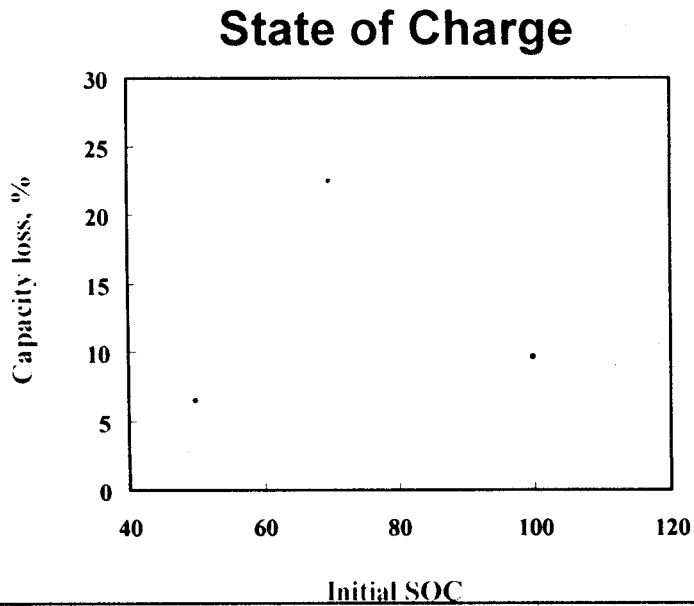
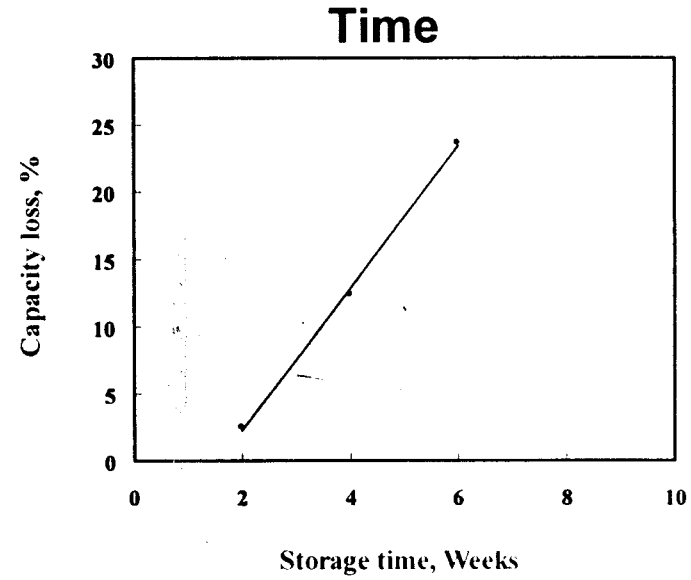
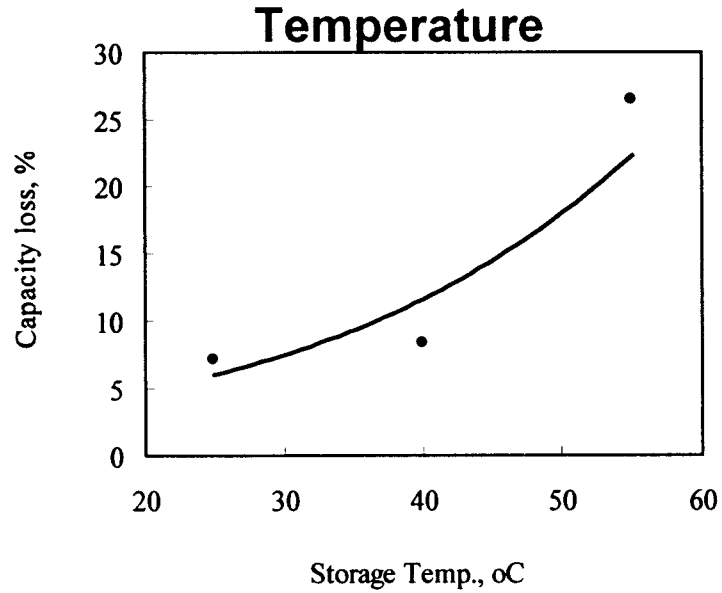


Design Experiments for Cruise Conditions

Experiment #	Storage time, weeks	Storage Temp	State of charge	Storage condition
1	2	25	50	Open Circuit
2	2	40	70	On Buss
3	2	55	100	Cycling
4	4	25	70	Cycling
5	4	40	100	Open Circuit
6	4	55	50	On Buss
7	6	25	100	On Buss
8	6	40	50	Cycling
9	6	55	70	Open Circuit

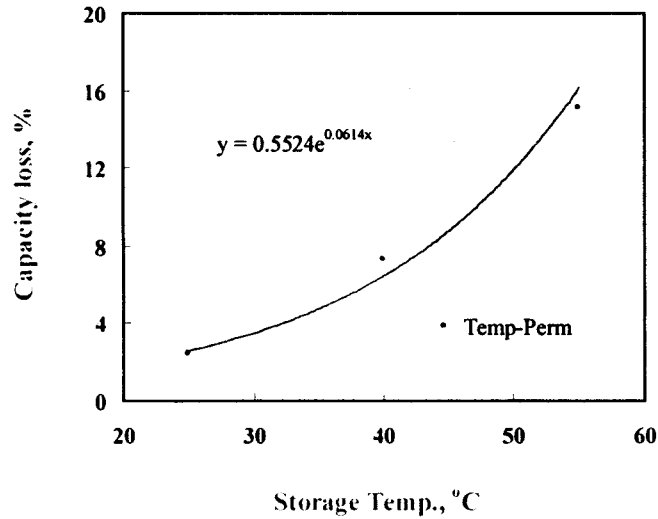


Design Experiments - Temporary Capacity loss

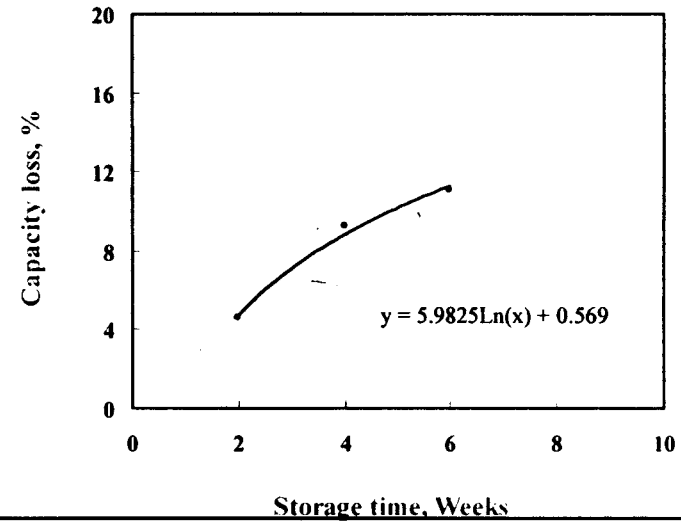


Design Experiments - Permanent Capacity loss

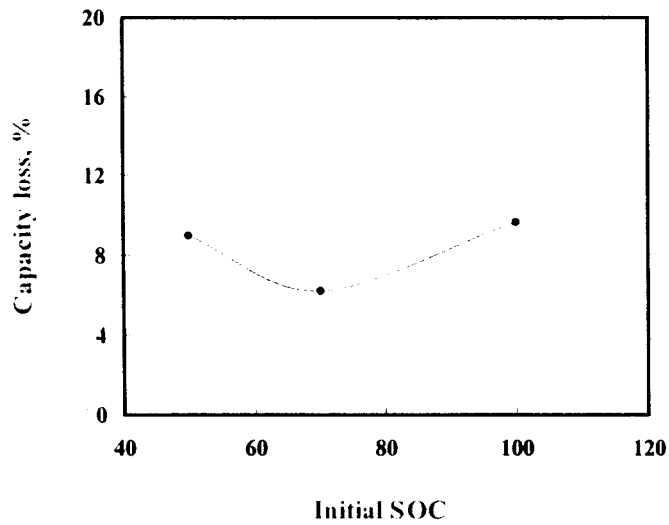
Effect of Temp on Permanent capacity loss



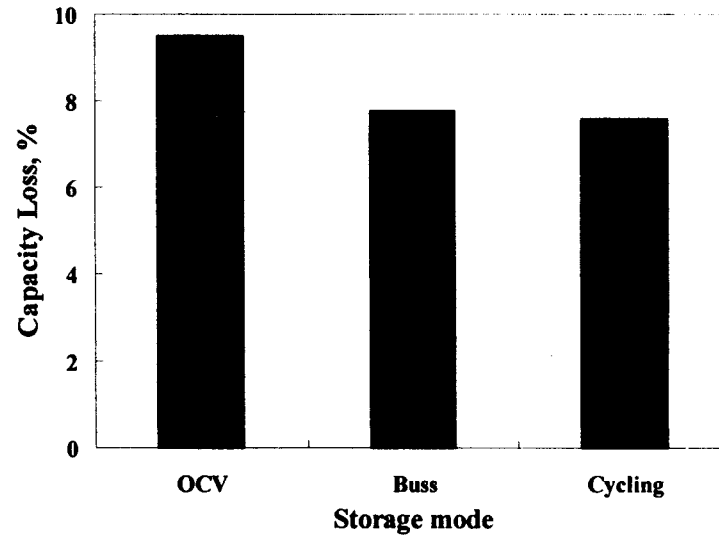
Effect of Time on Permanent capacity loss



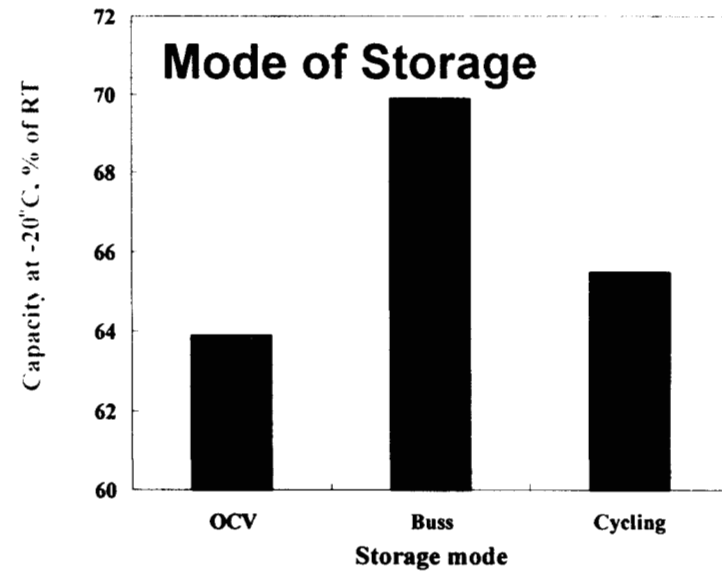
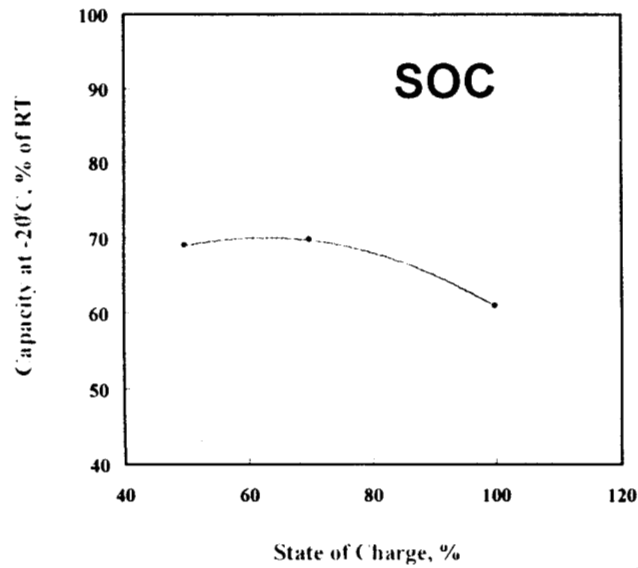
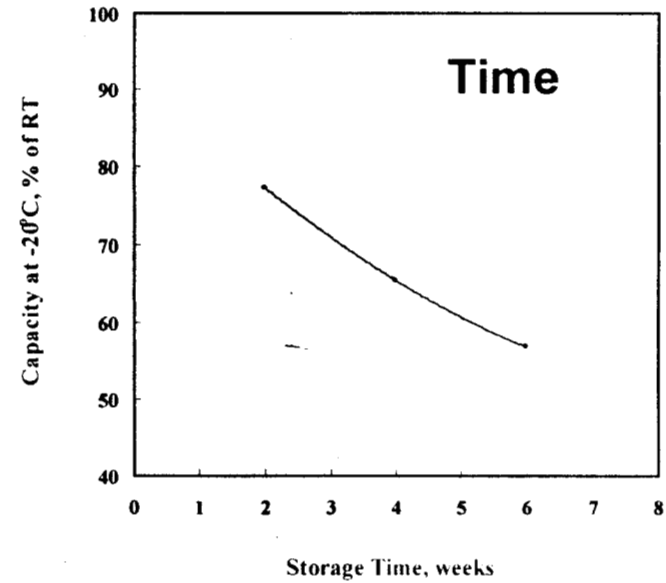
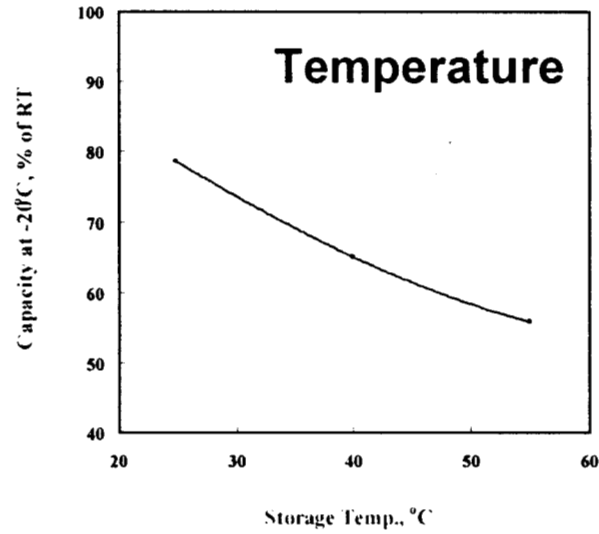
Effect of SOC on Permanent capacity loss



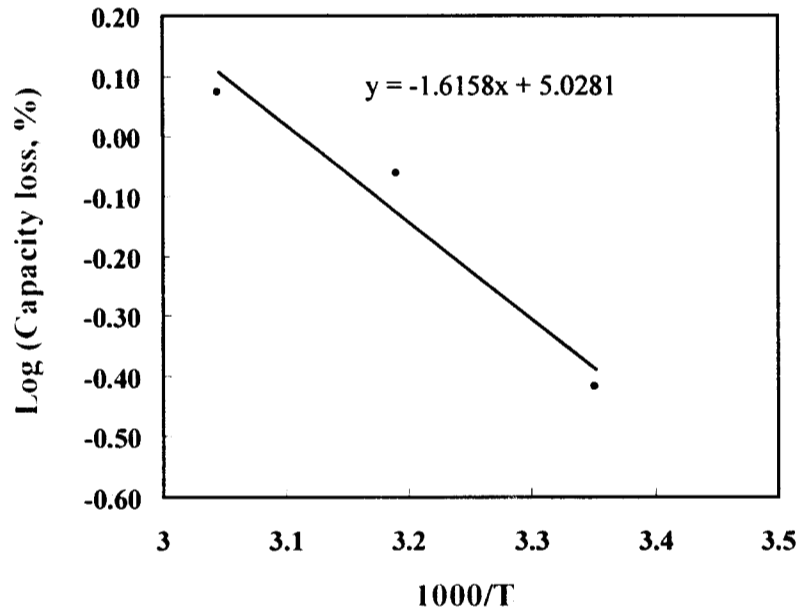
Effect of Storage mode on Permanent Capacity loss



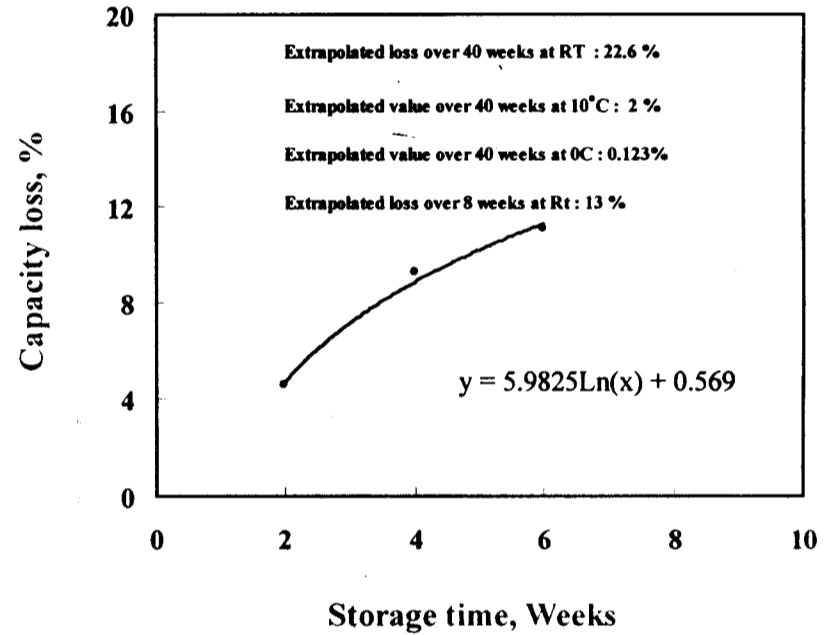
Design Experiments - LT Performance



Effect of Temp on Permanent capacity loss



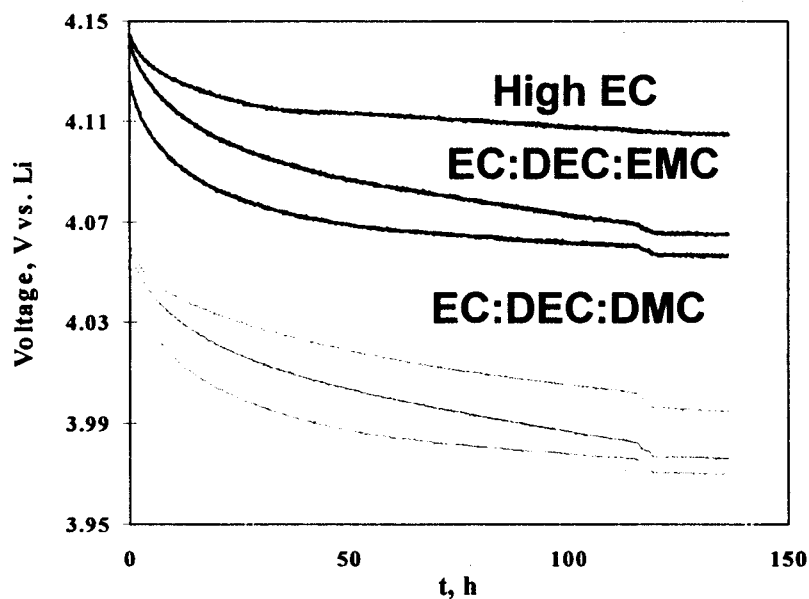
Effect of Time on Permanent capacity loss



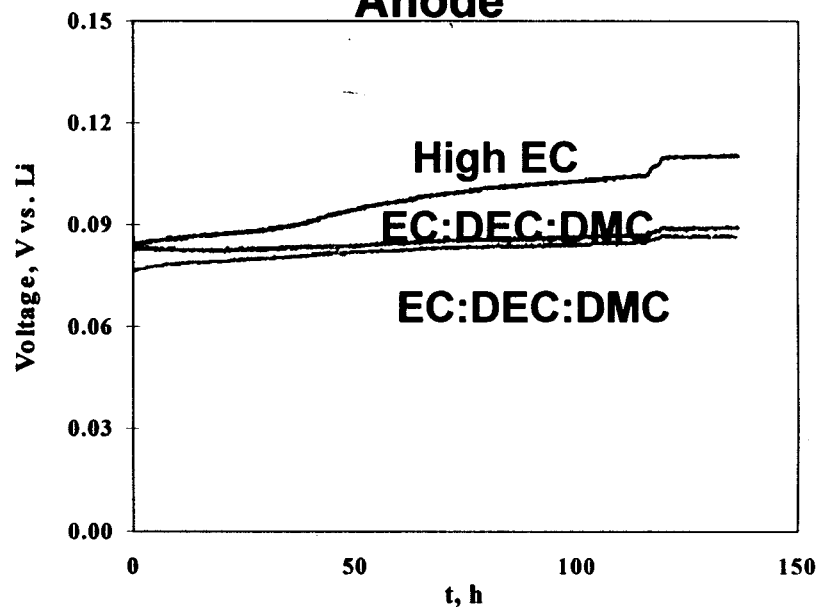
Storage Characteristics in 3-Electrode Cells

Self Discharge

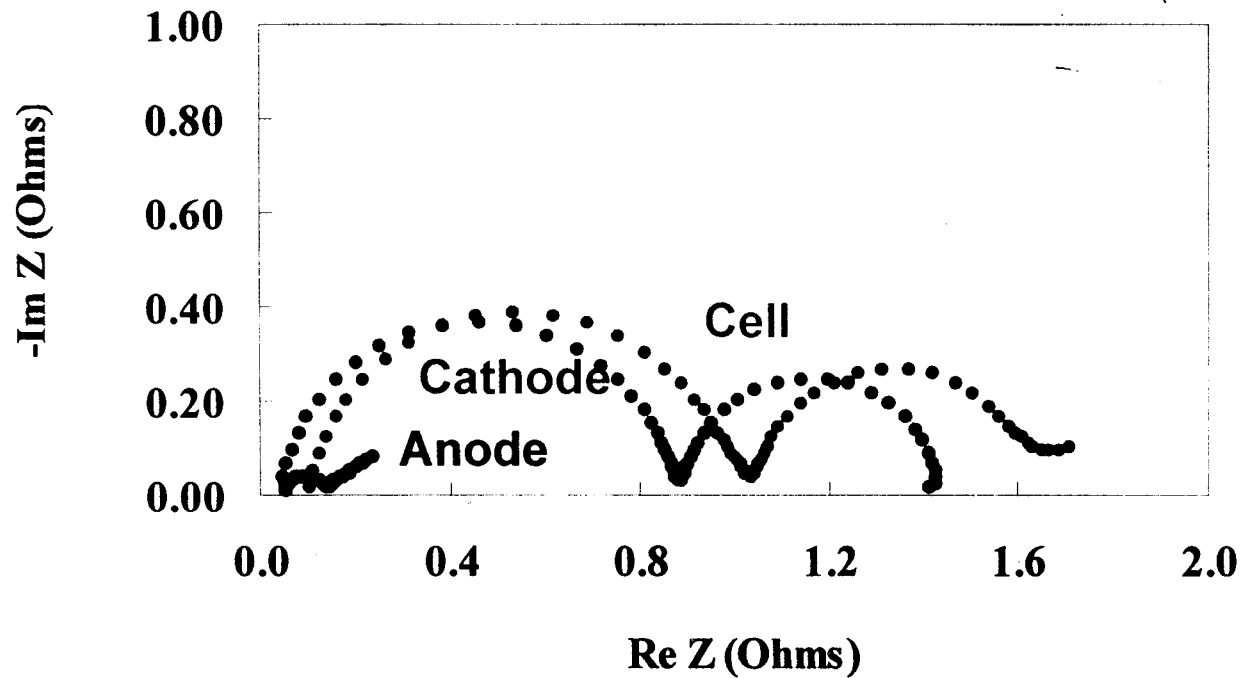
Cathode and Cell



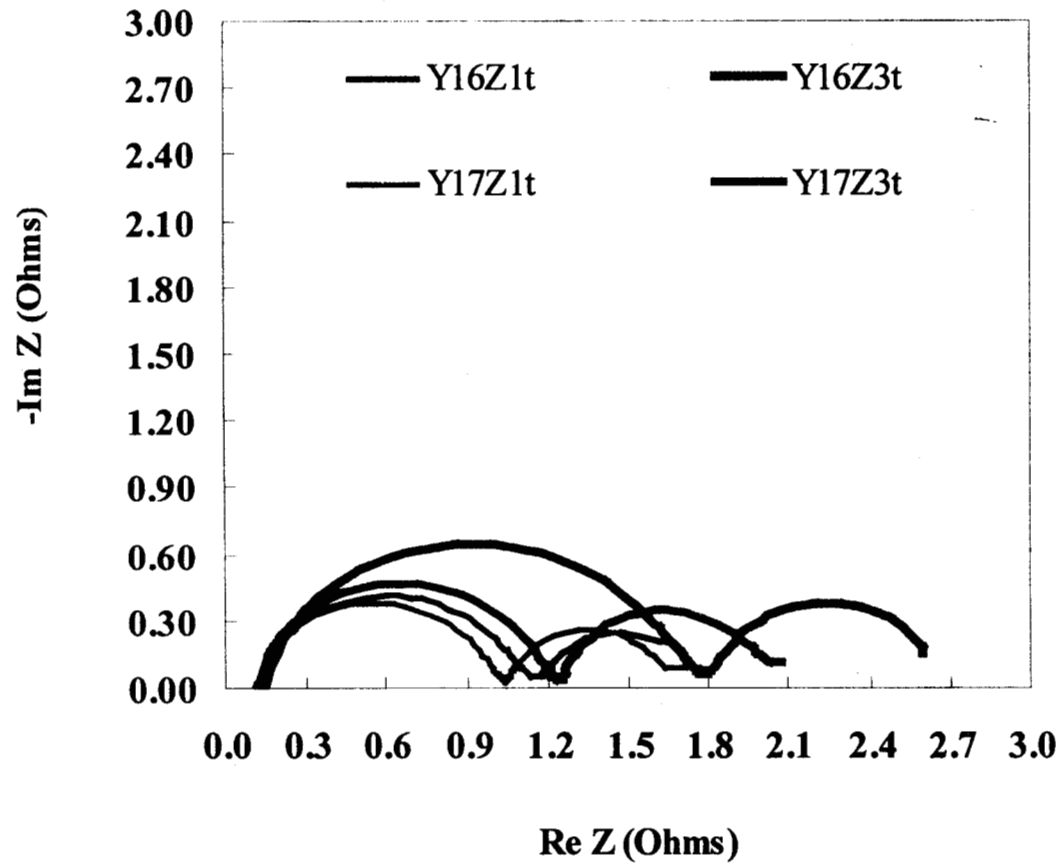
Anode



Storage Characteristics in 3-Electrode Cells



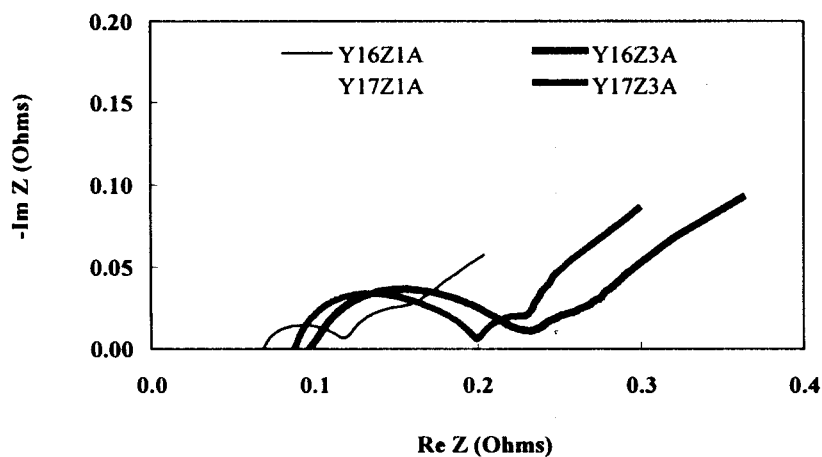
Storage Characteristics in 3-Electrode Cells



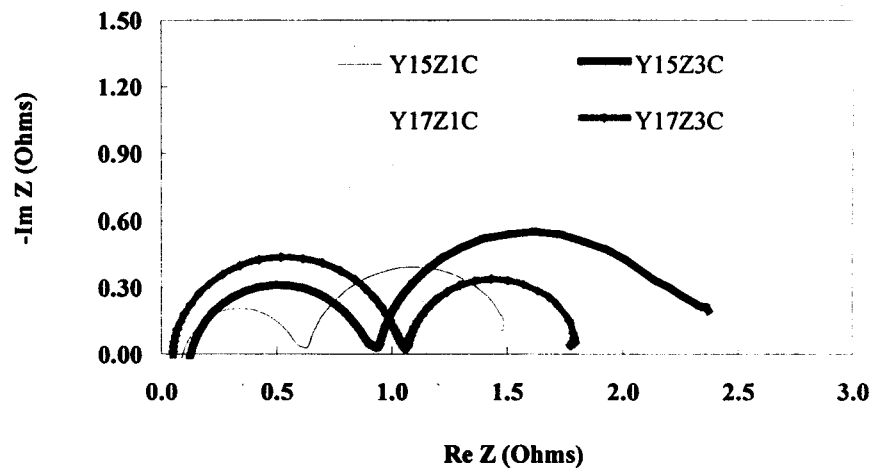
Stored at 60°C for 1 week

Storage Characteristics in 3-Electrode Cells

Carbon Anode

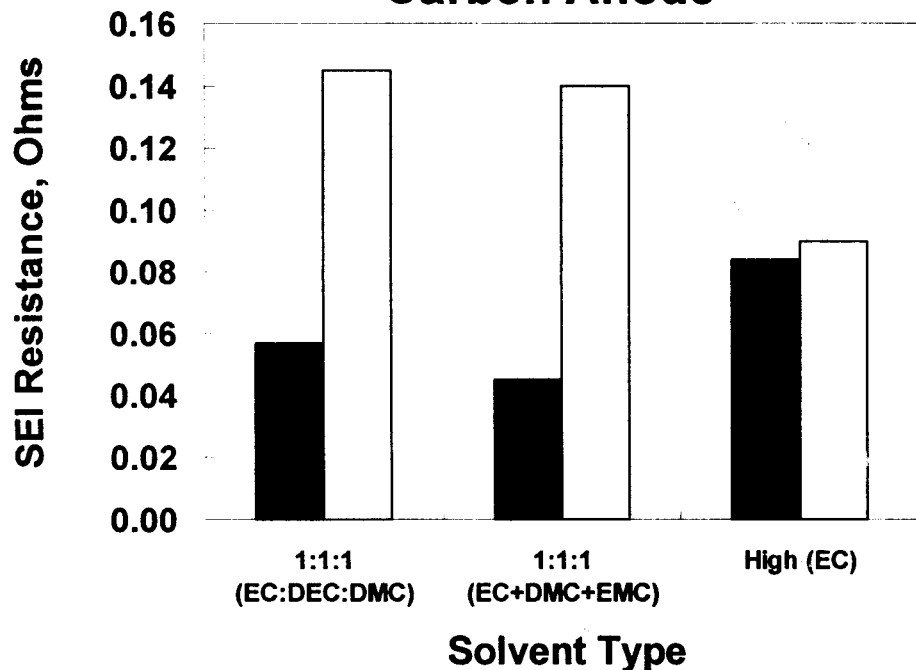


Li_x(NiCo)O₂ Cathode

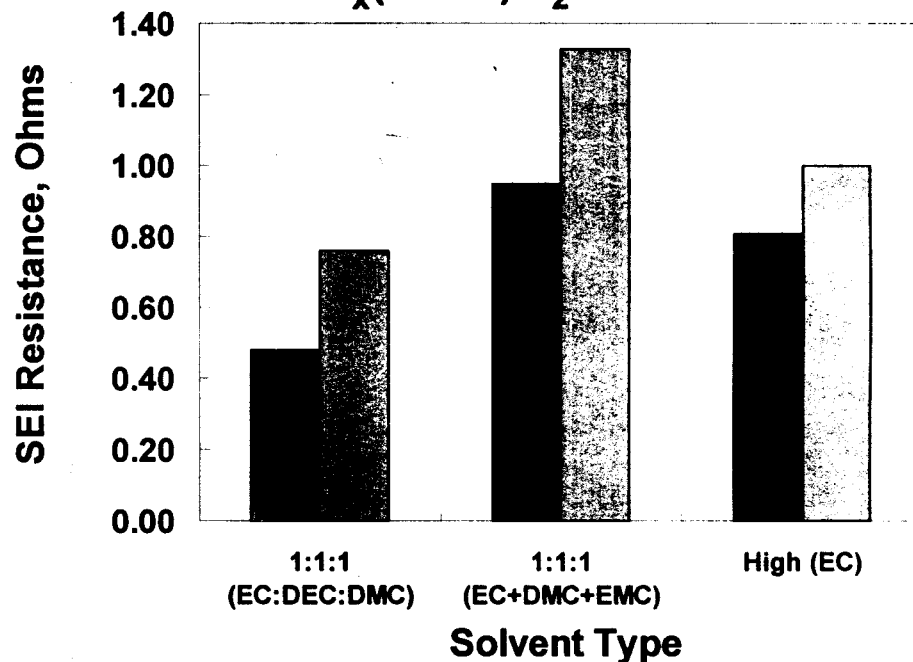


Stored at 60°C for 1 week

Carbon Anode



Li_x(NiCo)O₂ Cathode



Stored at 60°C for 1 week

Summary

- **Lithium ion cells sustain permanent capacity loss, in addition to the usual self-discharge, upon storage.**
- **The permanent capacity loss**
 - **increases with storage temperature and storage duration**
 - **increases marginally at high SOC**
 - **is reduced when connected to buss**
- **Upon storage, there is an irreversible change in the interfacial resistance at both the electrodes.**
- **Projected capacity losses are in the acceptable range for the Mars missions. Need to be verified by real-time tests.**



Acknowledgment

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