Lithium Ion Batteries for Aerospace Applications

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JPL

IBA-HBC2003 Yeager Memorial Symposium

Big Island of Hawaii, January 7-10, 2003

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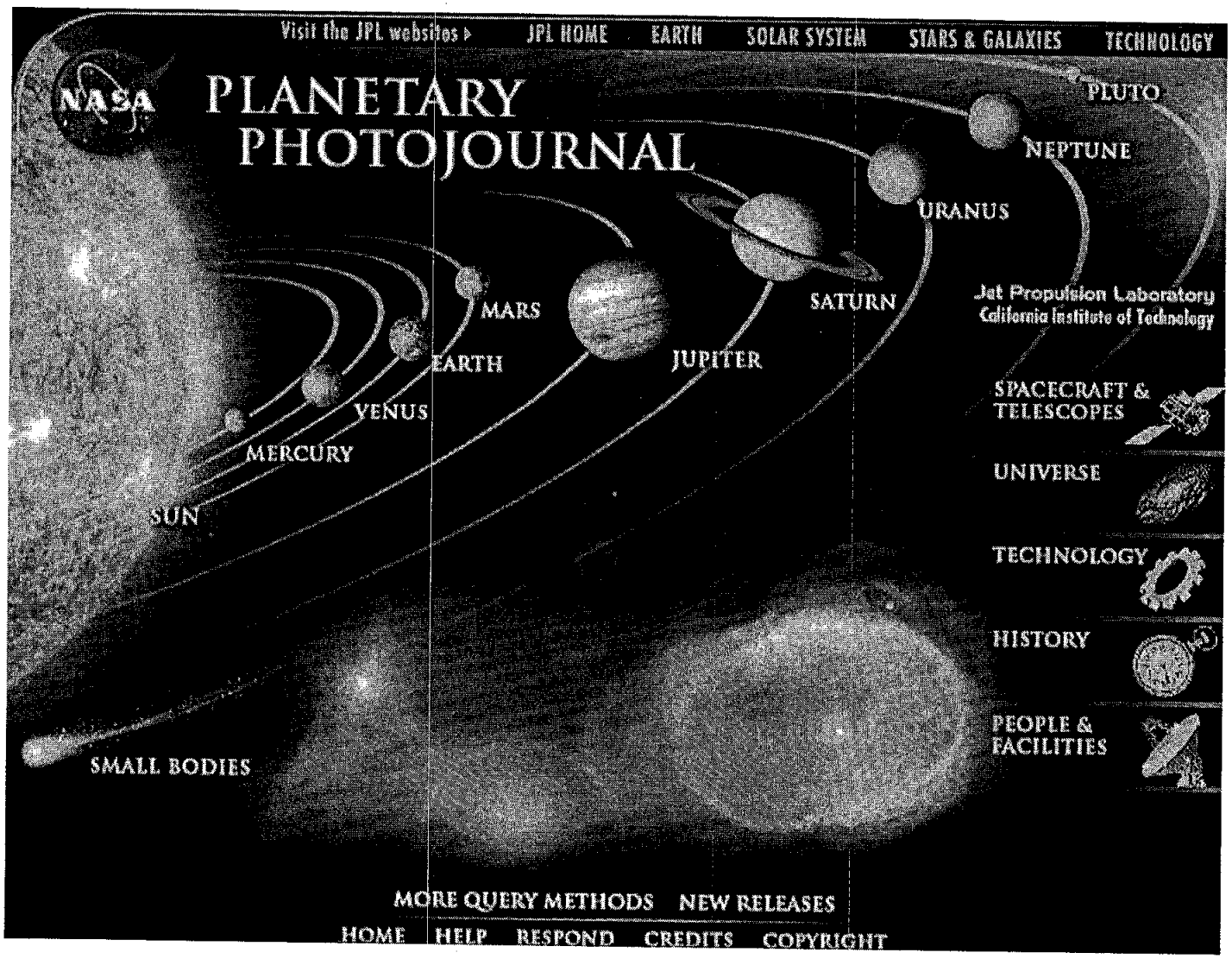
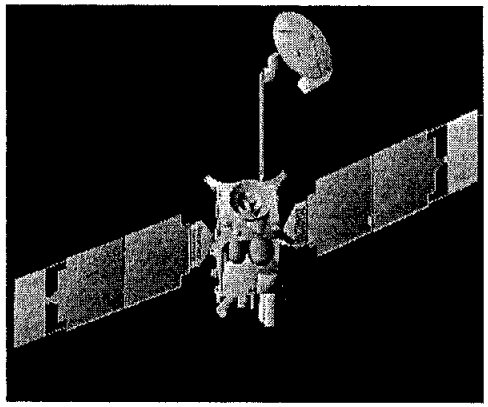


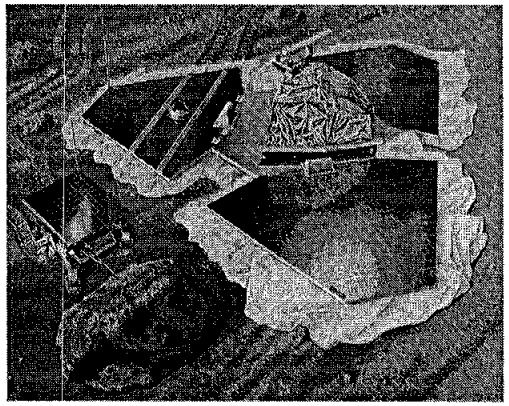
- **Search for life. Are we alone in the universe?**

NASA Applications

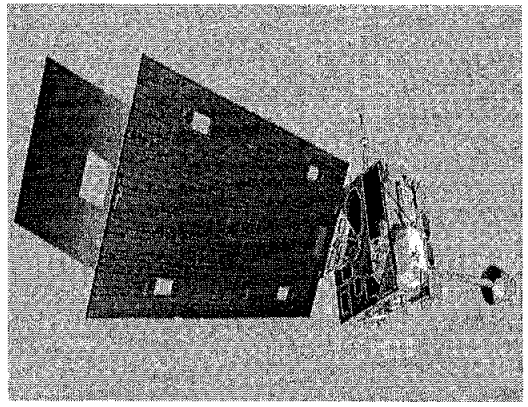
Planetary Orbiters



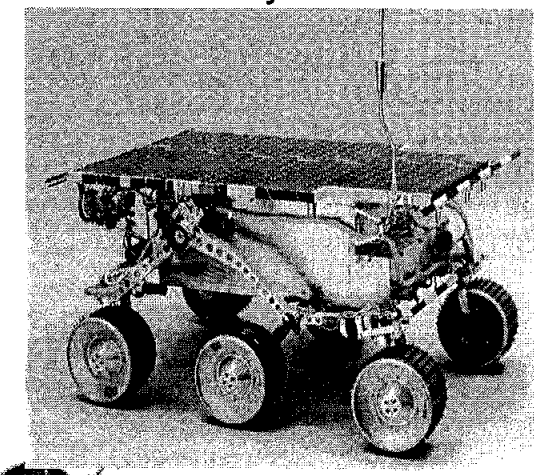
Planetary Lander



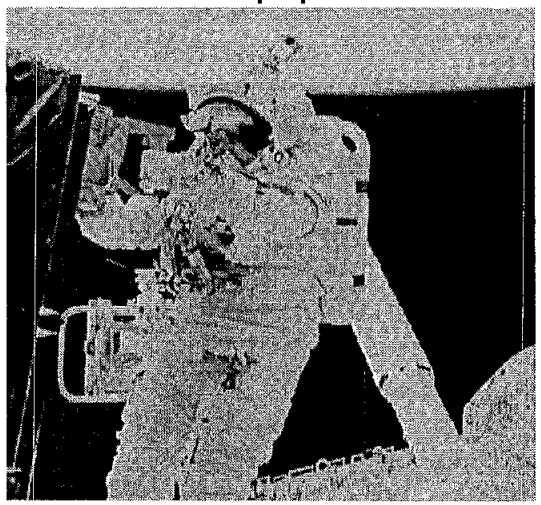
GEO Spacecraft



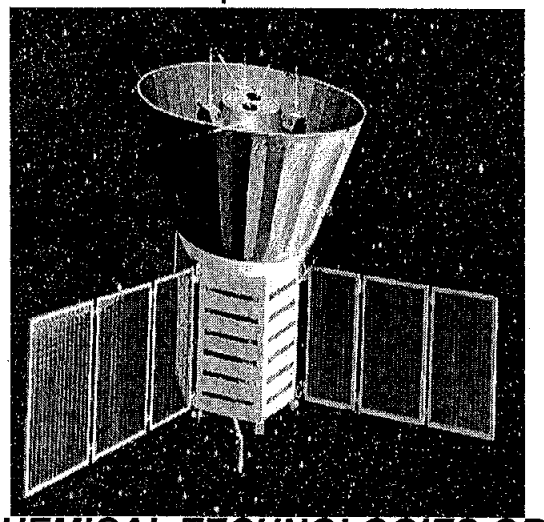
Planetary Rover



Astronaut Equipment



LEO Spacecraft



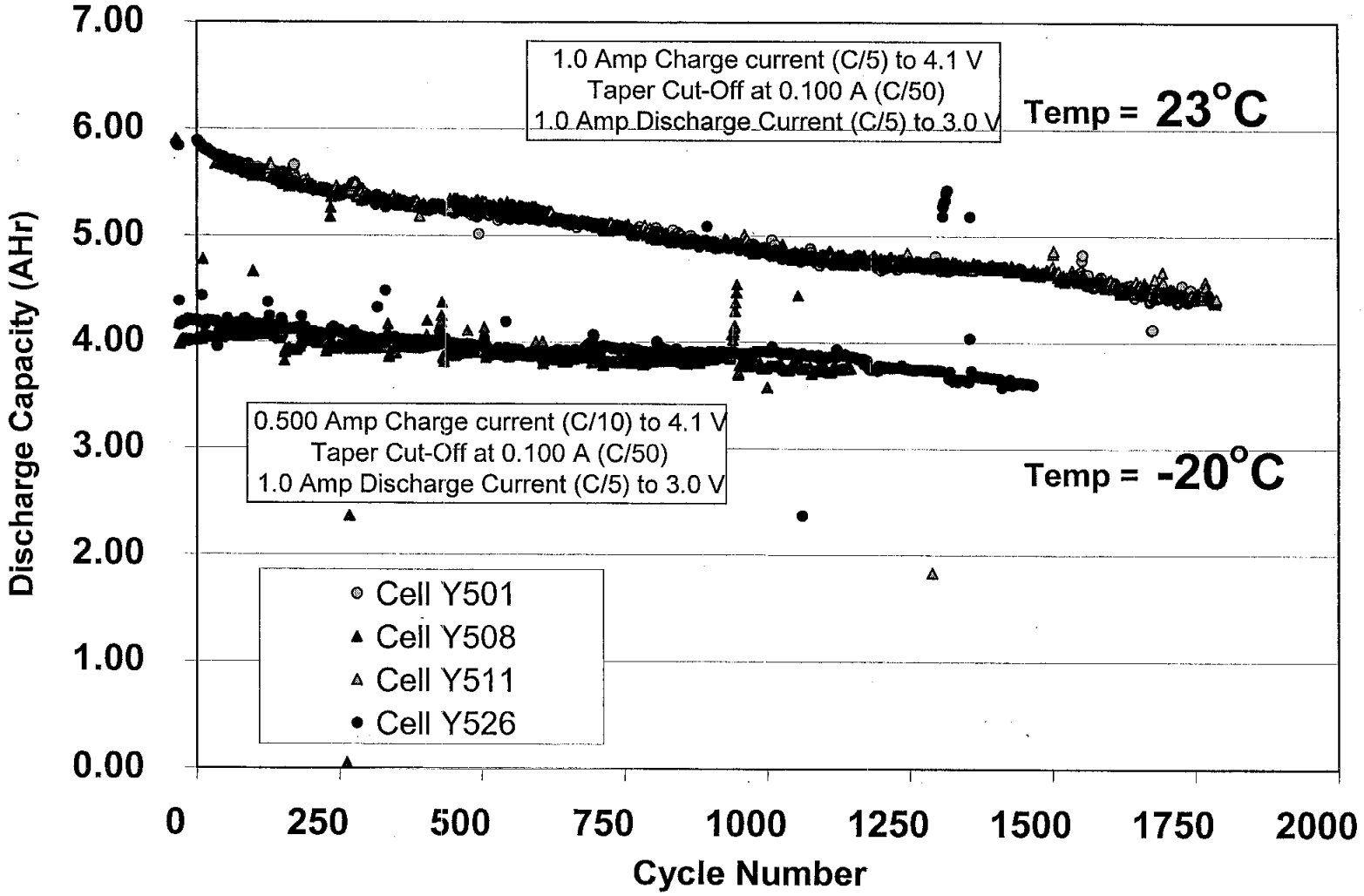
NASA Applications-Uniqueness

- Mars Exploration
  - Planetary Landers and Rovers require batteries with good low temperature with moderate cycle life
- Exploration of Outer planets
  - Planetary orbiters and landers require long calendar life

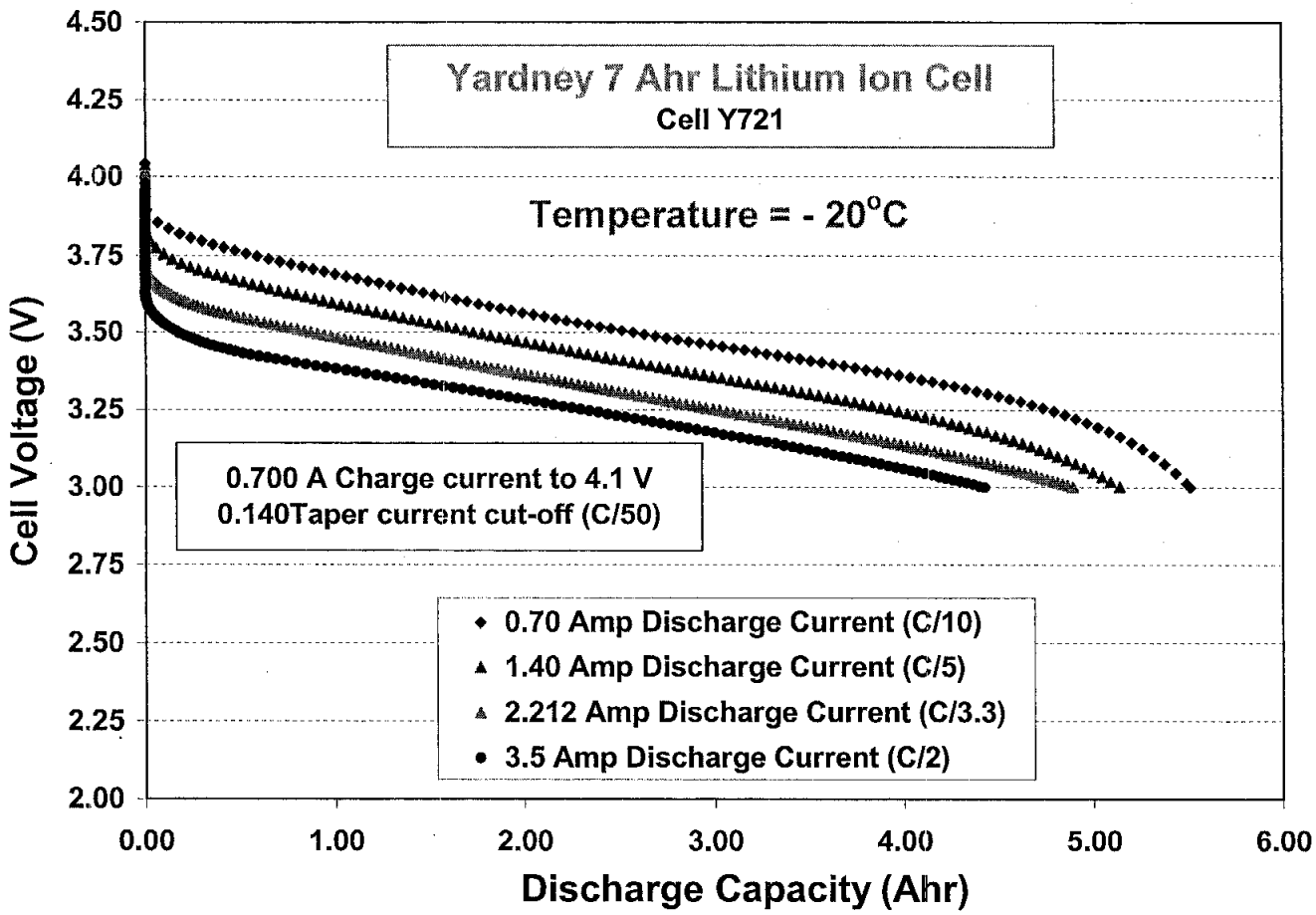
Li Ion Batteries for Mars Landers and Rovers

- High specific energy and energy density
- Low temperature performance
  - -20°C both charge and discharge at C/5 for Mars Exploration Rover
  - -40°C for Mars Science Lander (2009)
  - Simultaneously high temperature resilience
- Good Pulse capability for supporting pyro events
- Long cycle life at 100% DOD (500-1000 Cycles)
- Adequate storage life (about 2years at high State of charge)

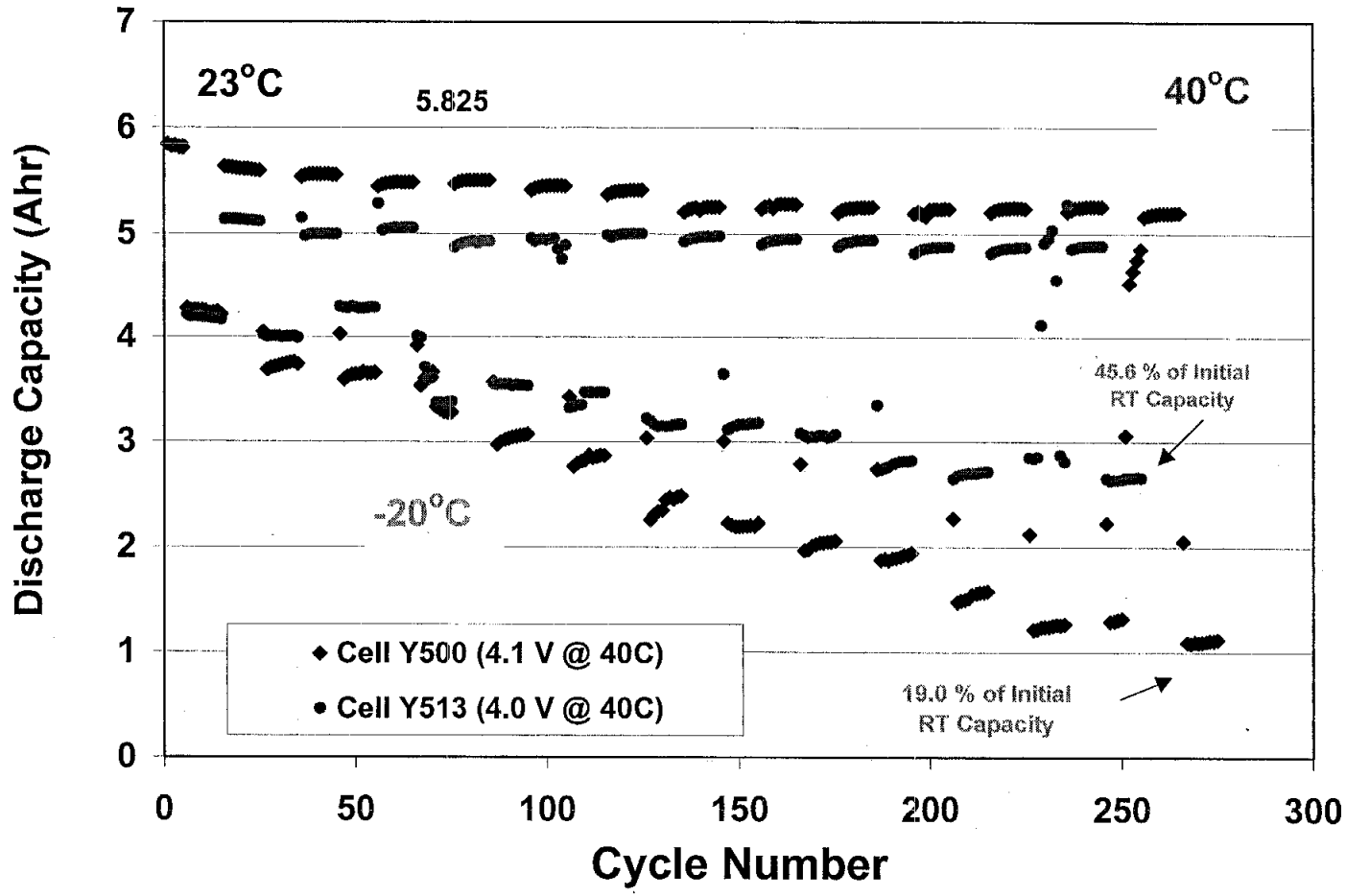
Cycle Life at RT and LT



Low Temperature Performance



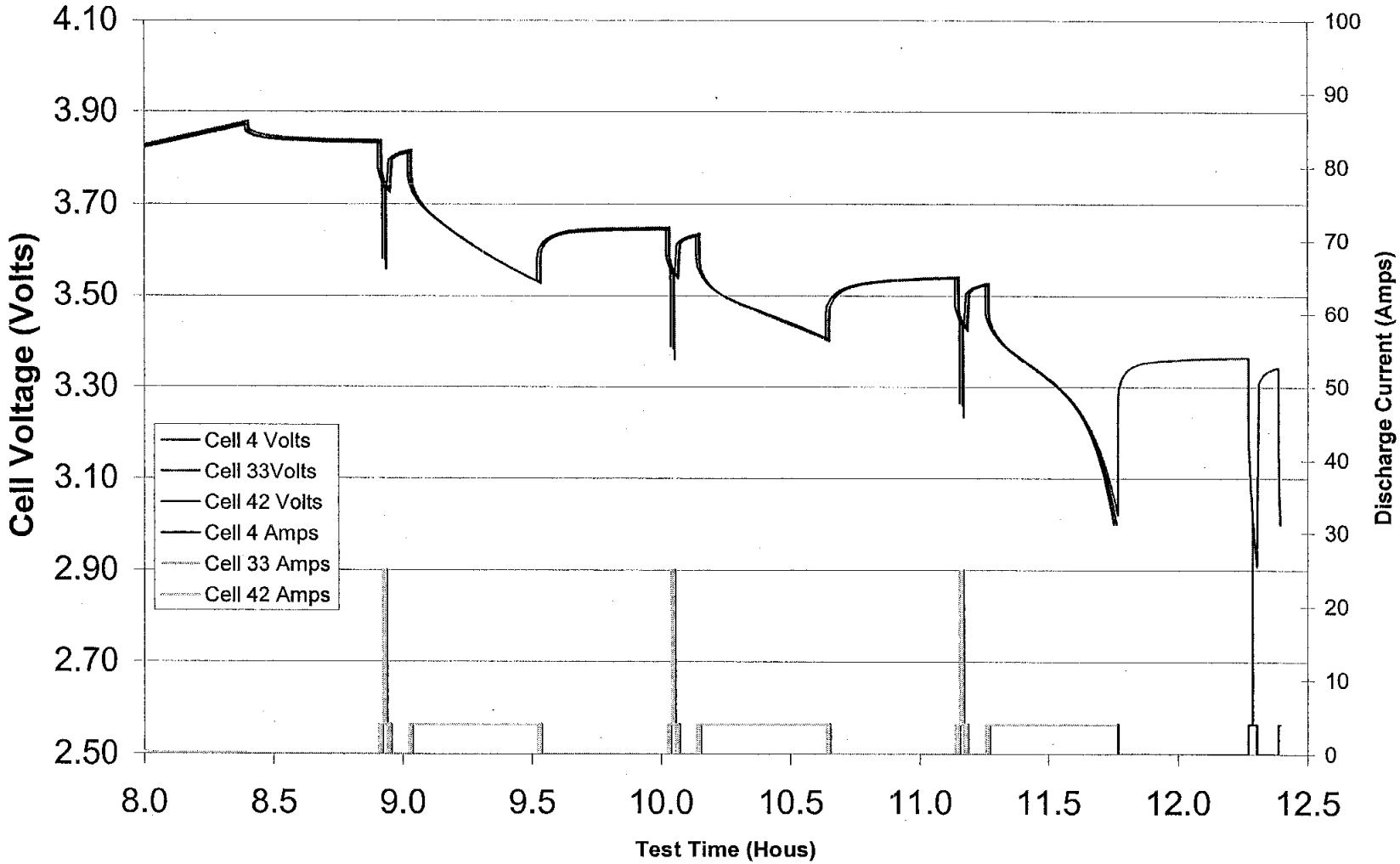
Variable Temperature Cycling



Storage Characteristics

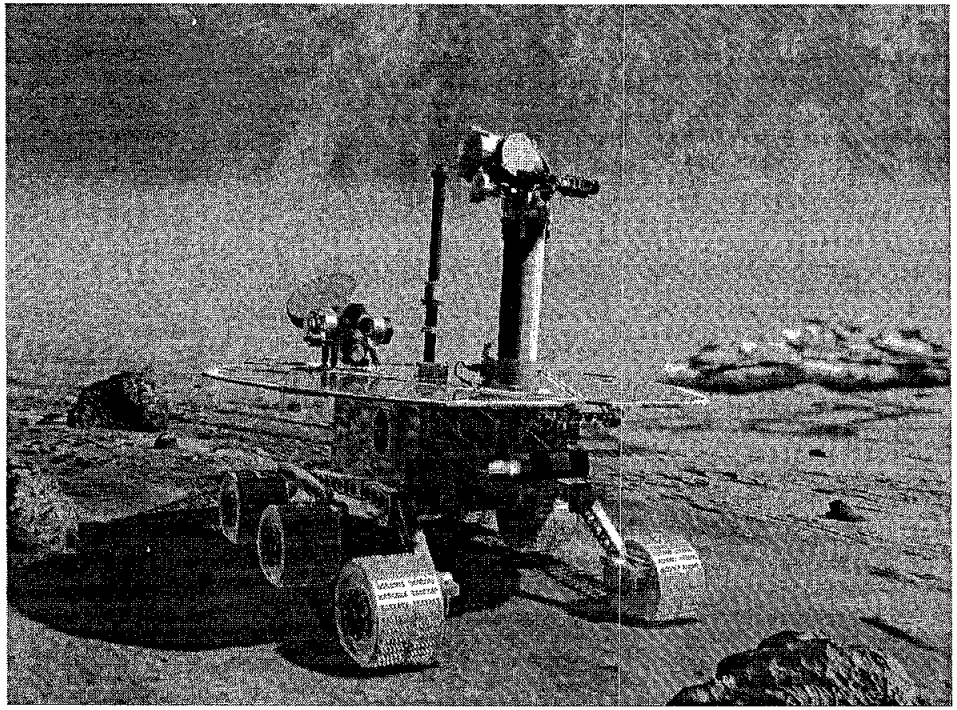
Cell Number	SOC on Bus	Initial Capacity 23°C (2nd Cycle)	Capacity Prior To Buss Storage at -20°C (2nd Cycle)	Capacity After 2 Years Buss Storage 23°C (6th Cycle)	% of Initial Capacity After 2 Years Buss Storage 23°C	Capacity After 2 Years Buss Storage -20°C (3rd Cycle)	% of Initial Capacity Prior to Buss Storage -20°C
Y003	**30%**	**34.0201**	21.8307	33.5936	**98.7464**	20.9120	95.79
Y004	**50%**	**33.9624**	22.4870	32.8729	**96.7922**	20.7299	92.19
Y028	**70%**	**33.4789**	----	33.5205	**100.1242**	19.2257	

Pulse Capability at LT

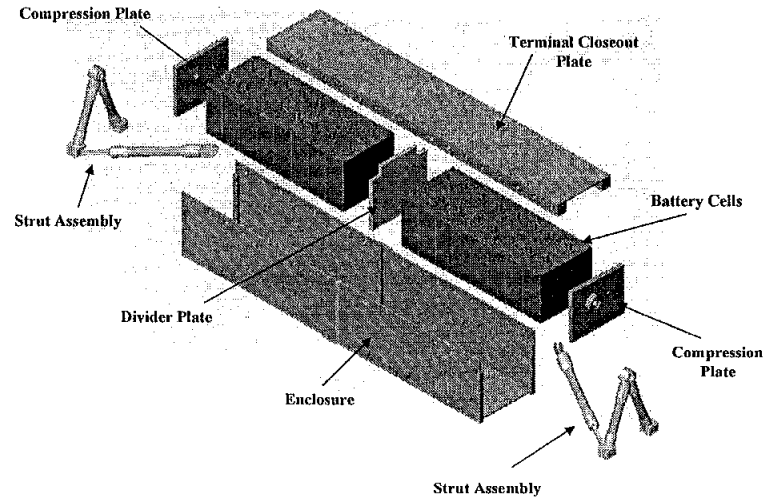


Lithium Ion Batteries for Aerospace Applications

The Mars Exploration Rover An in situ science mission to Mars



Li Ion Battery

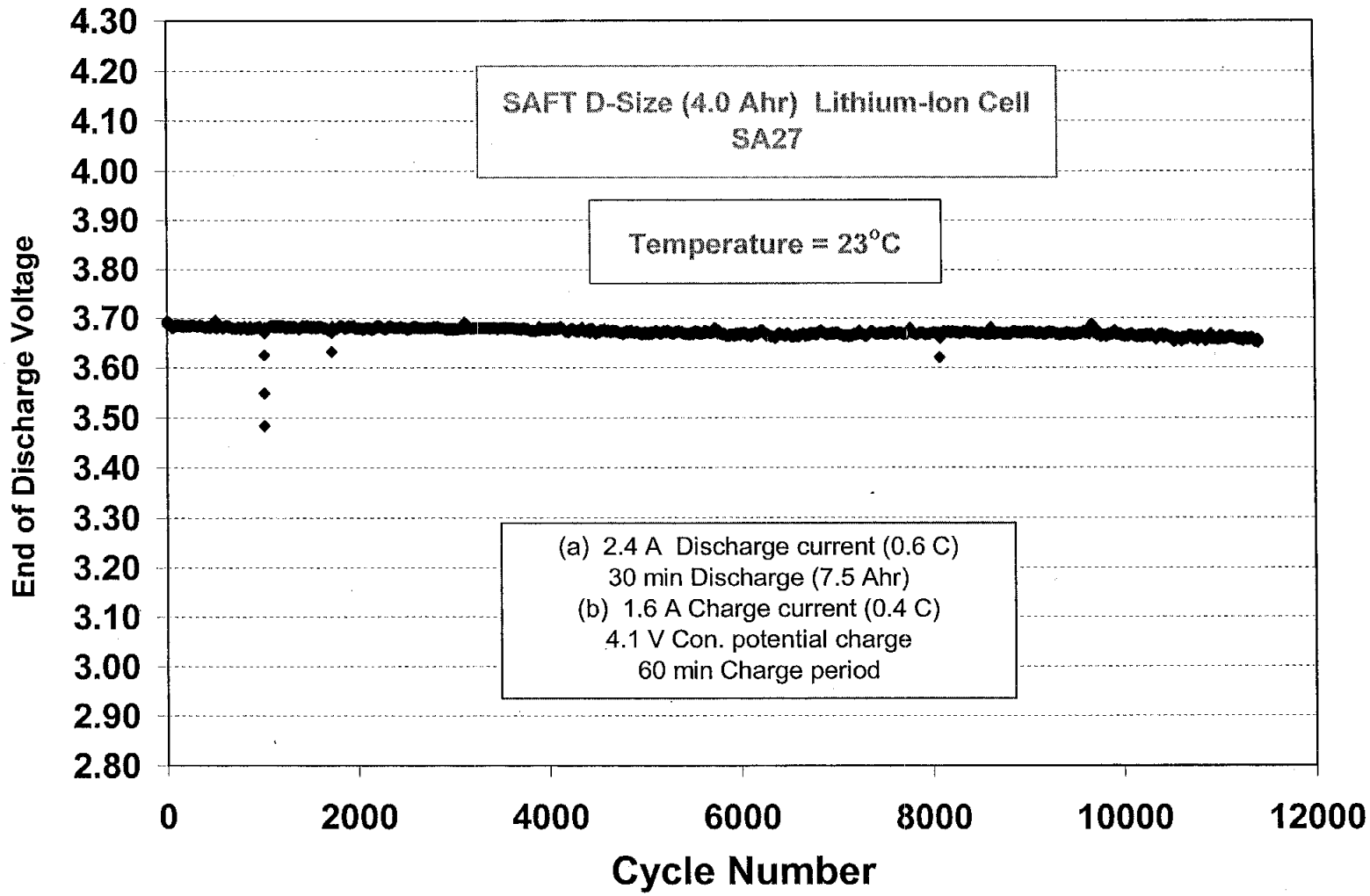


- Two identical landers to be launched in May-July 2003; landing in January and February 2004
- The scientific pay load on each rover for understanding the geology of Marian rocks includes
  - Mini Thermal Emission Spectrometer (Mini-TES) Near and mid-IR spectrometer
  - Mossbauer Spectrometer and Alpha Particle X-ray Spectrometer (APXS) for elemental chemistry.
  - Rock Abrasion Tool (RAT) to penetrate thro' rock dust

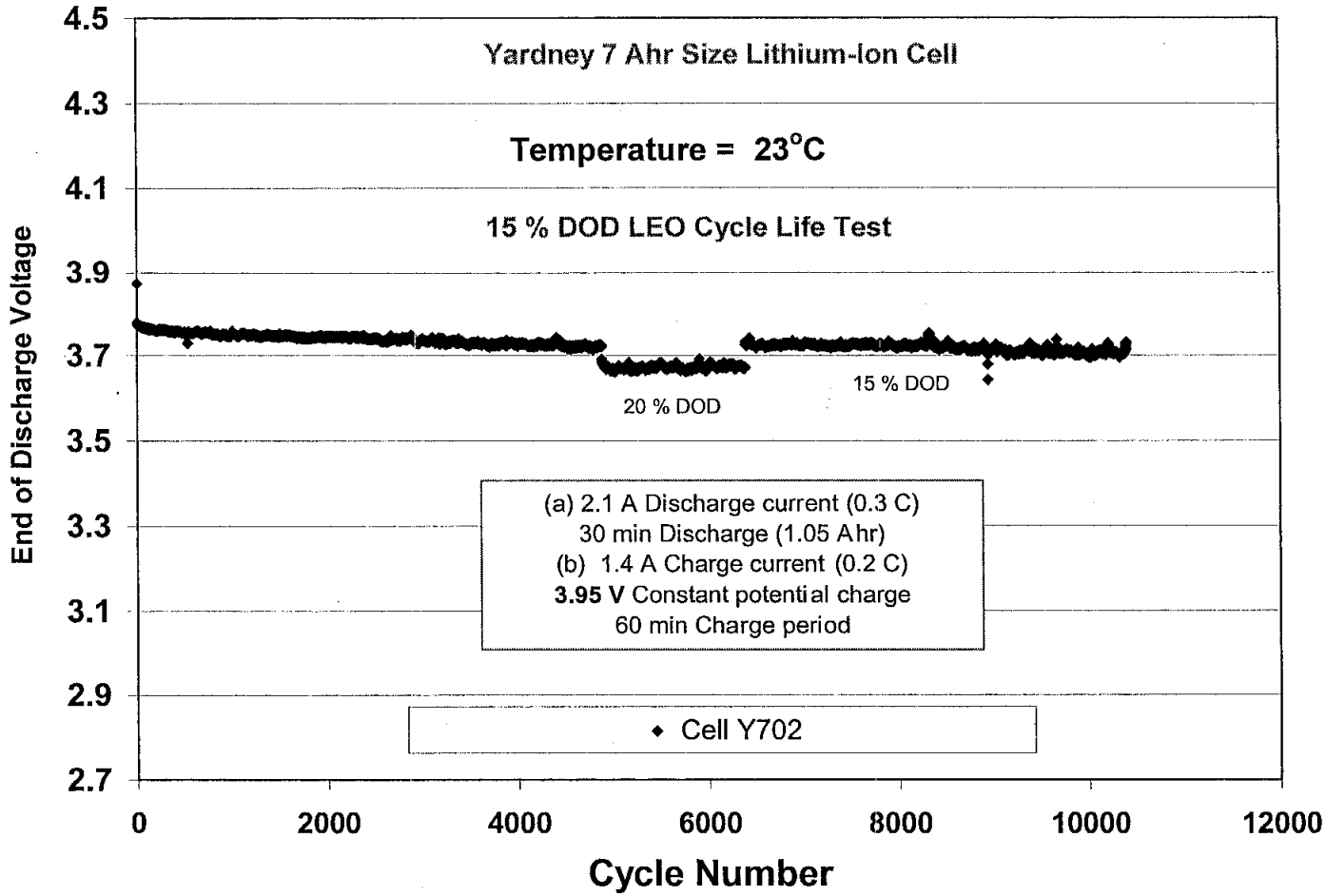
Li Ion Batteries for Mars Orbiters and Earth Satellites

- **High specific energy and energy density.**
- **Long cycle life at partial DoD**
  - **20-40% and 30,000 - 40,000 cycles**
- **Adequate wet life (5-10 years)**
- **Variables**
  - **Depth of Discharge**
  - **Charge Voltage**
  - **Temperature**

SAFT D-Size Lithium-Ion Cells 30% DOD LEO Cycling (23°C)

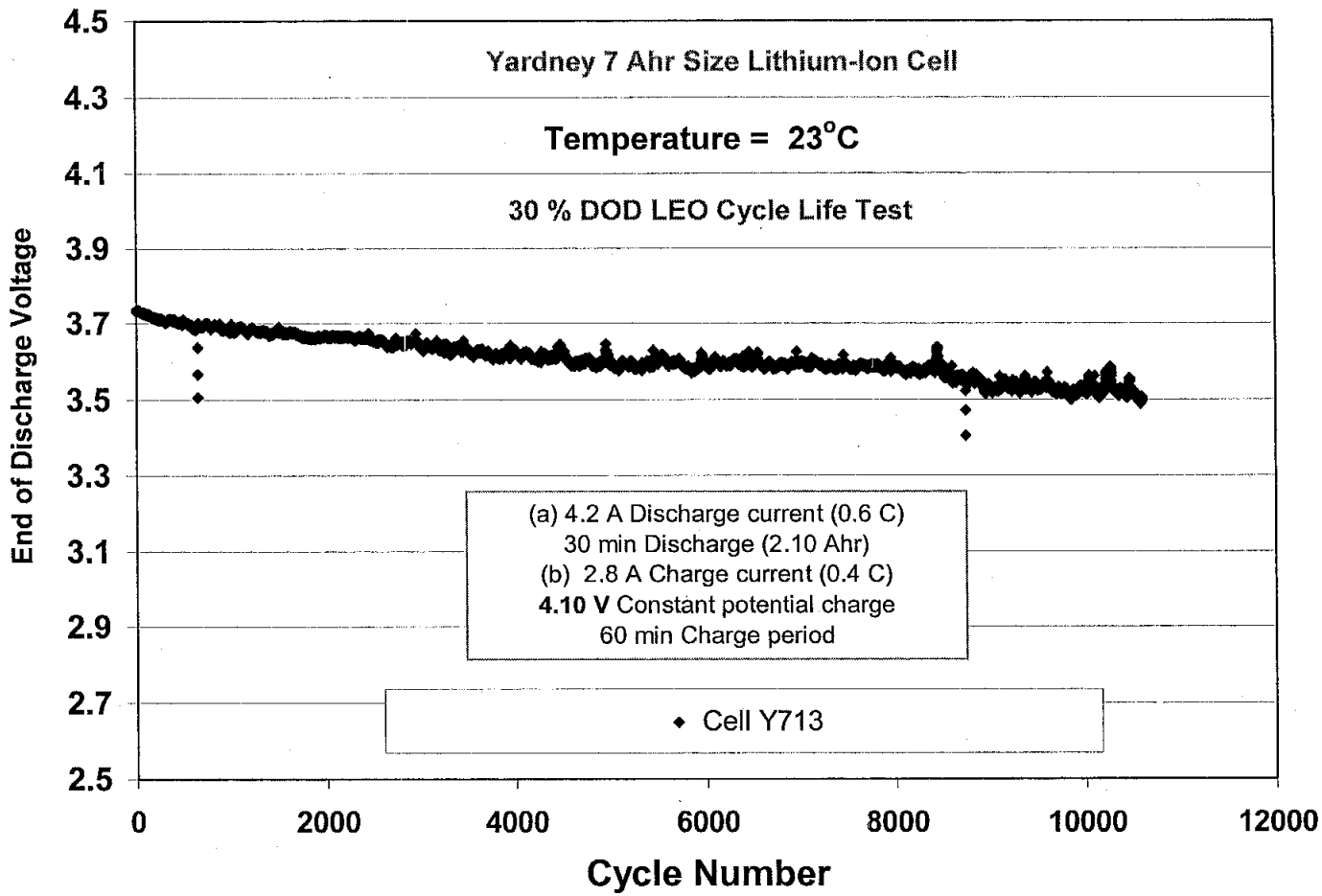


Yardney 7 AHr Lithium-Ion Cells for Future Aerospace Applications
15% DOD LEO Cycling (23°C) (3.95 V Charge)



- Test started 12-29-1999 (~25 months total)

Yardney 7 AHr Lithium-Ion Cells for Future Aerospace Applications
30% DOD LEO Cycling (23°C) (4.10 V Charge)

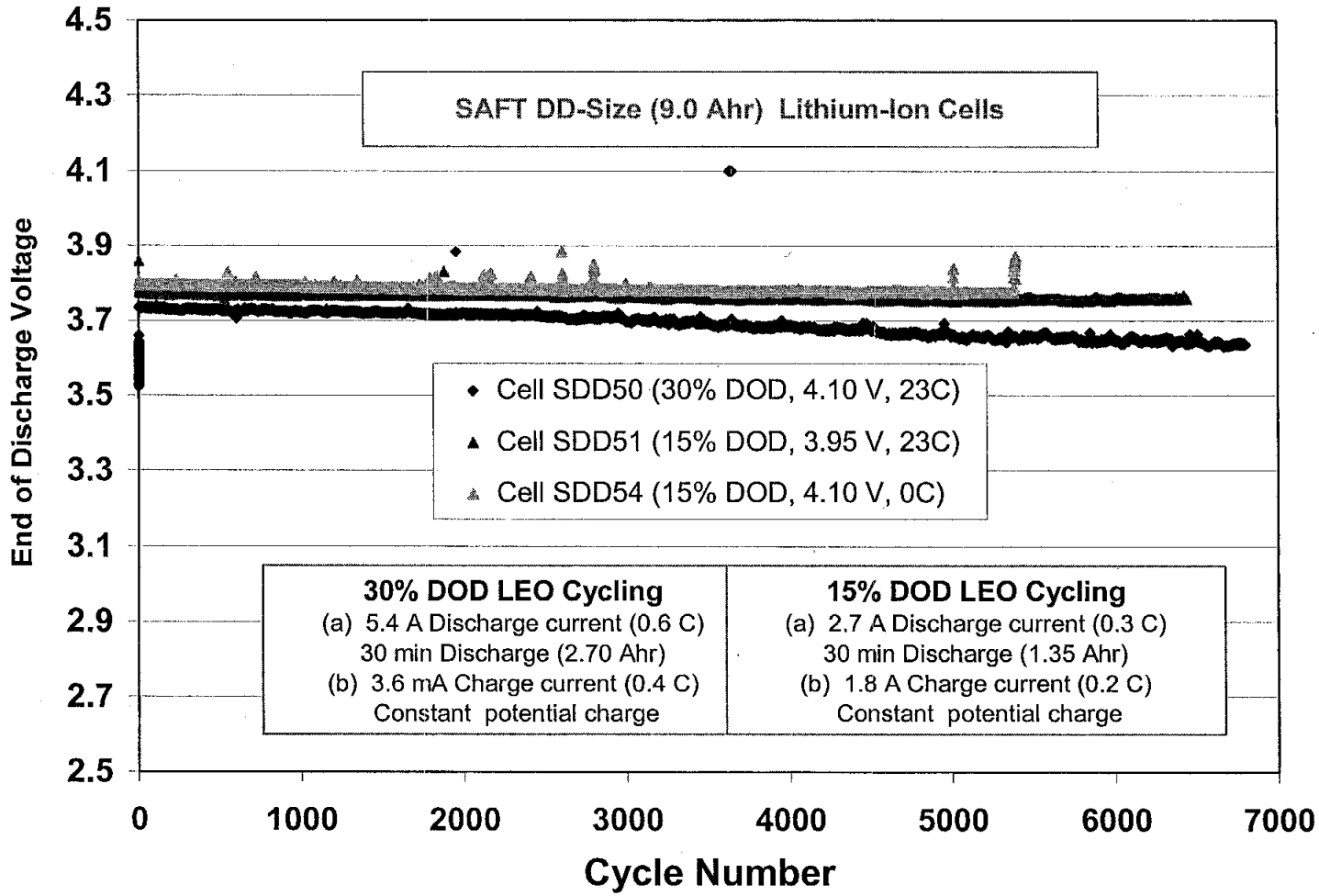


- Test started 12-29-1999 (~25 months total)

SAFT DD-Size Lithium-Ion Cells for Future Aerospace Applications

SAFT Low Temperature Electrolyte Cells

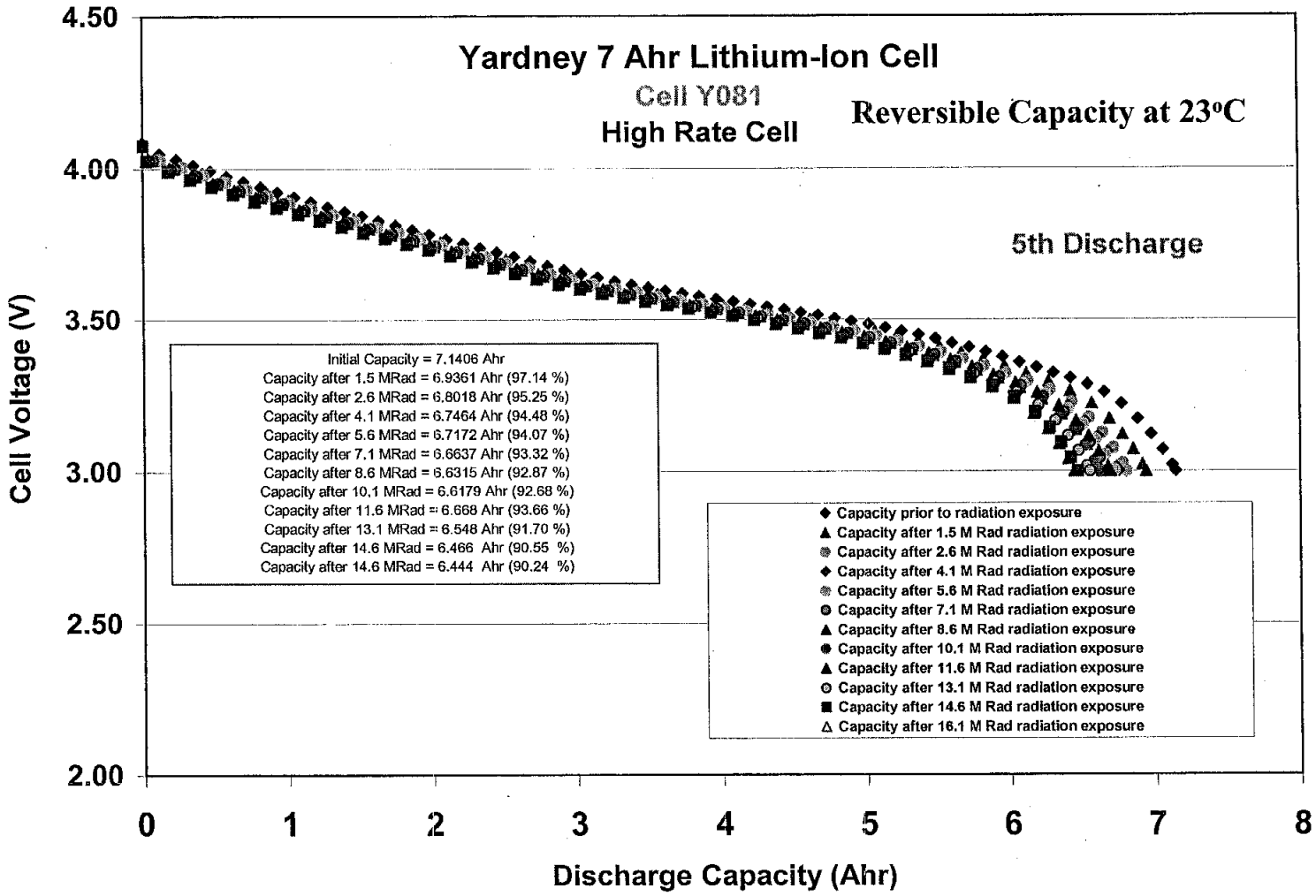
Effect of DOD and Charge Voltage Upon LEO Performance



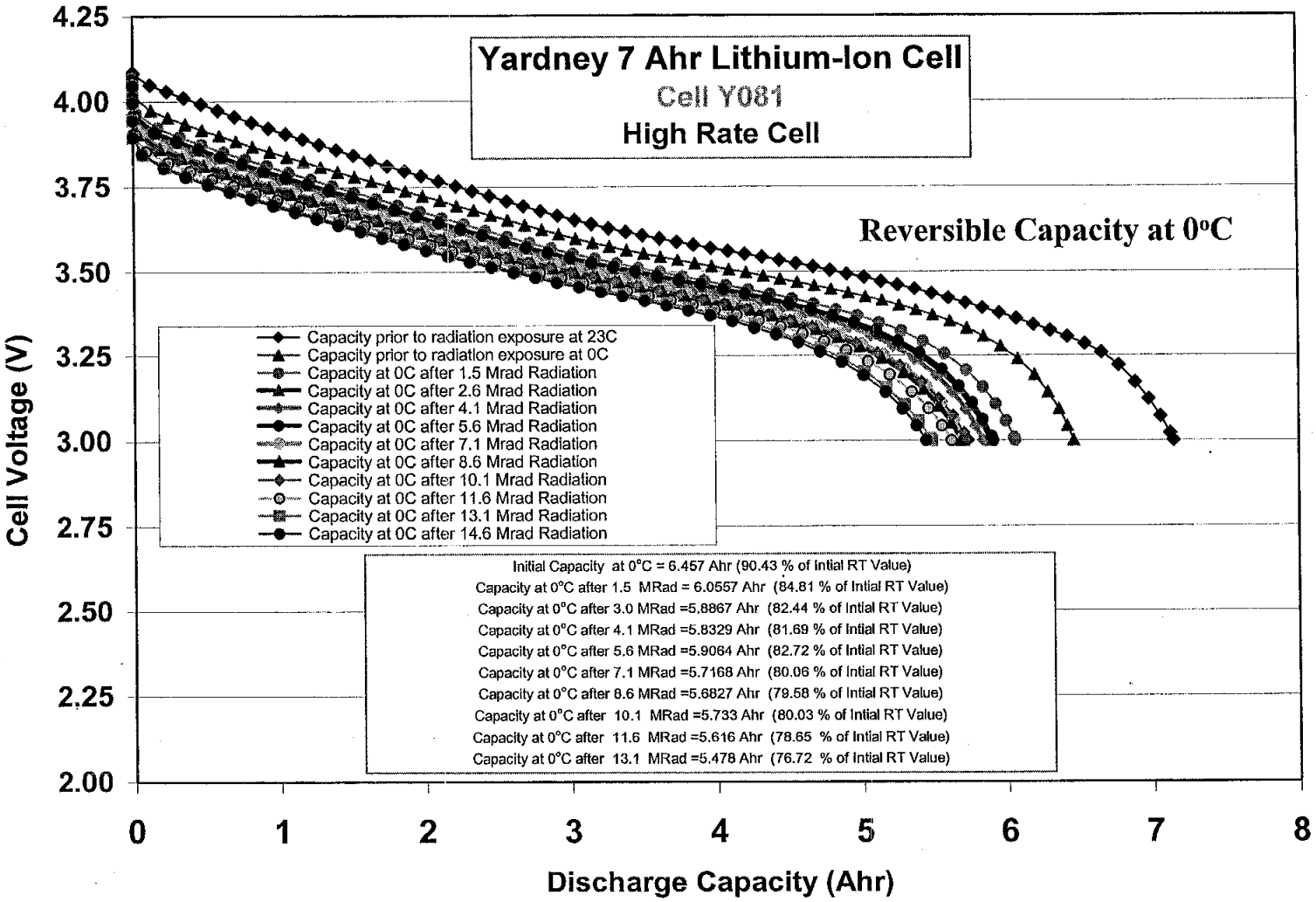
Missions to Jupiter and Beyond

- Tolerance to high radiations
  - As Jupiter rotates, a giant magnetic field is generated in its electrically conducting liquid interior. Trapped within Jupiter's magnetosphere are enough charged particles to make the inner portions of Jupiter's magnetosphere the most deadly radiation environment of any of the planets, both for humans and for electronic equipment.
  - Extends as far as Saturn's orbit; Jupiter's rings and moons are embedded in an intense radiation belt of electrons and ions trapped in the magnetic field.
- Long calendar life (Long cruise periods)
  - 6-15 years
- Light weight and compact
- High poser densities
  - For load leveling with Radioisotope Thermoelectric Generator (RTG)

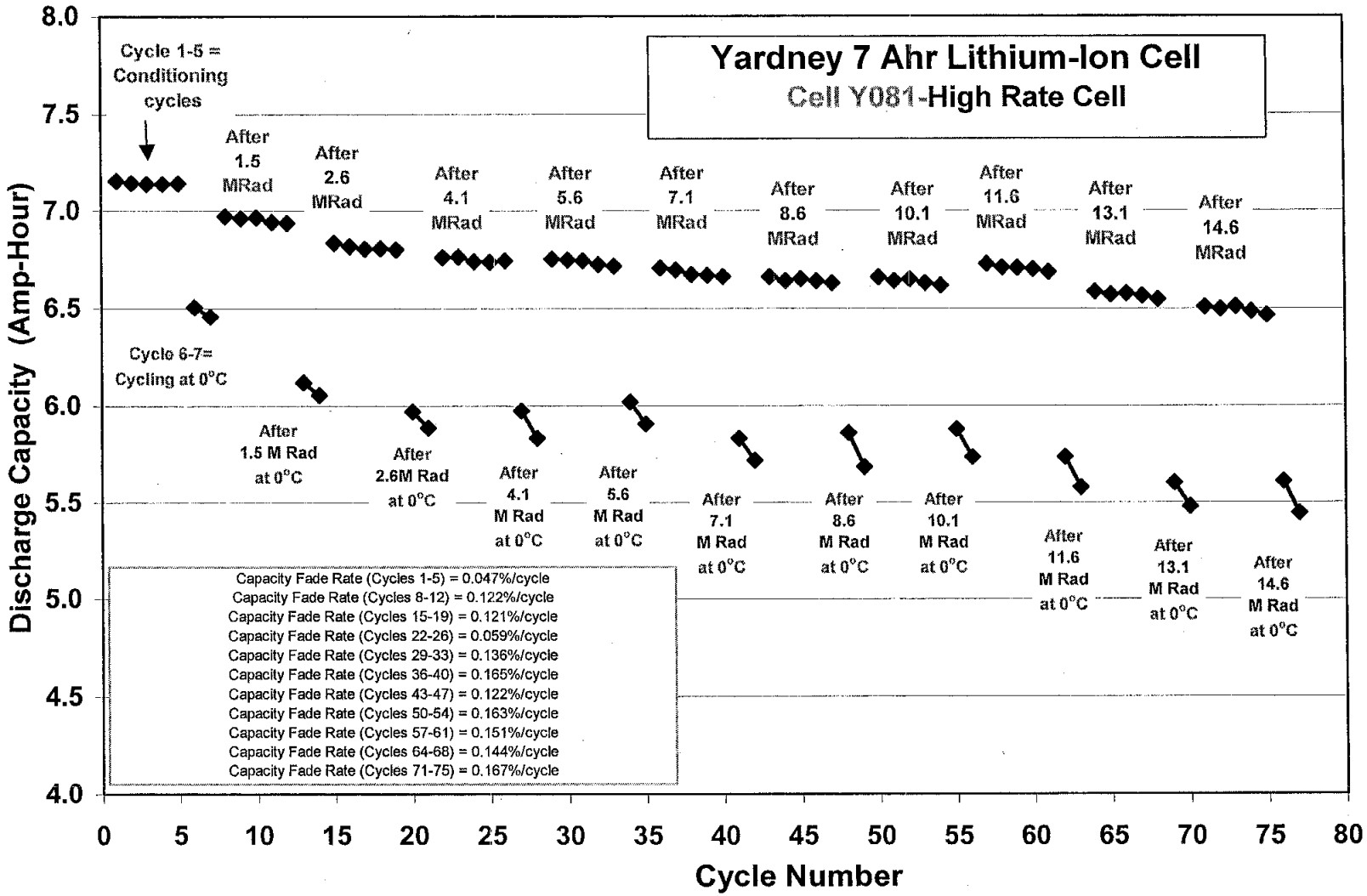
Radiation Tolerance of Lithium-Ion Cells



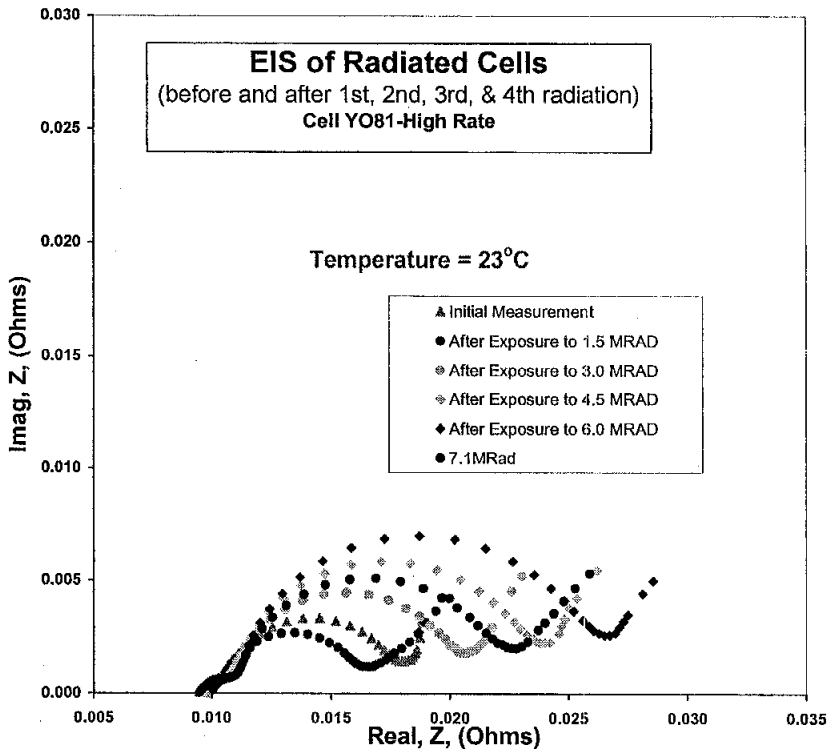
Radiation Tolerance of Lithium-Ion Cells

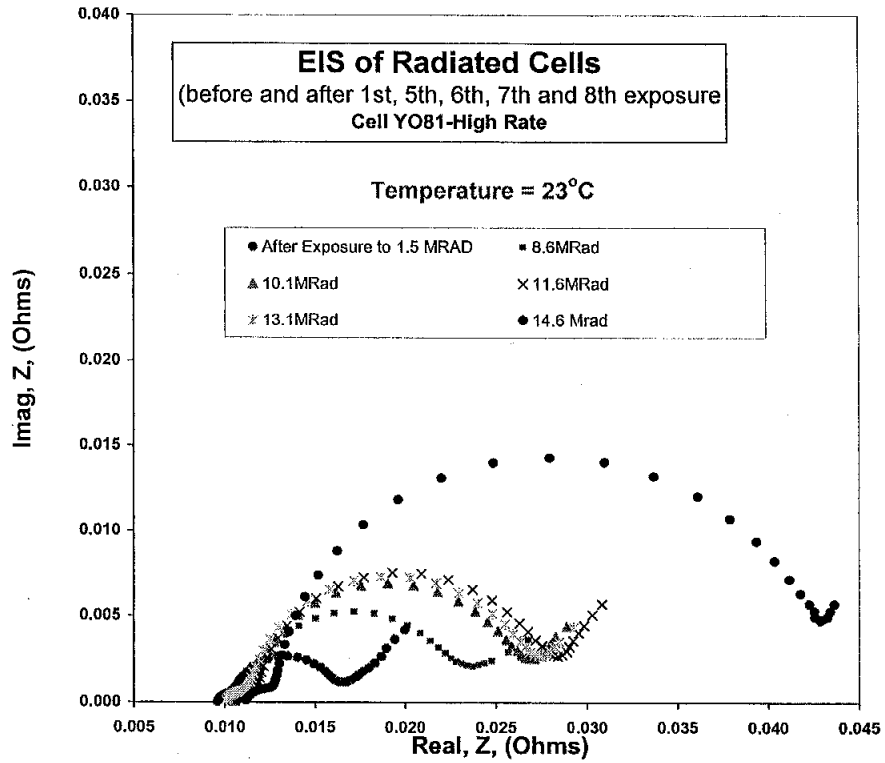


Radiation Tolerance of Lithium-Ion Cells



Electrochemical Impedance Spectroscopy

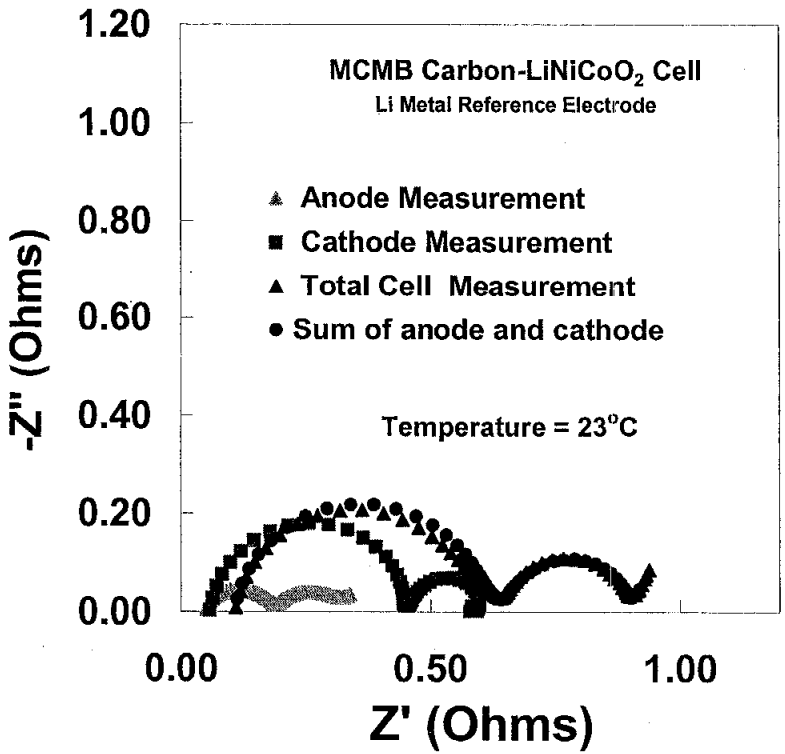




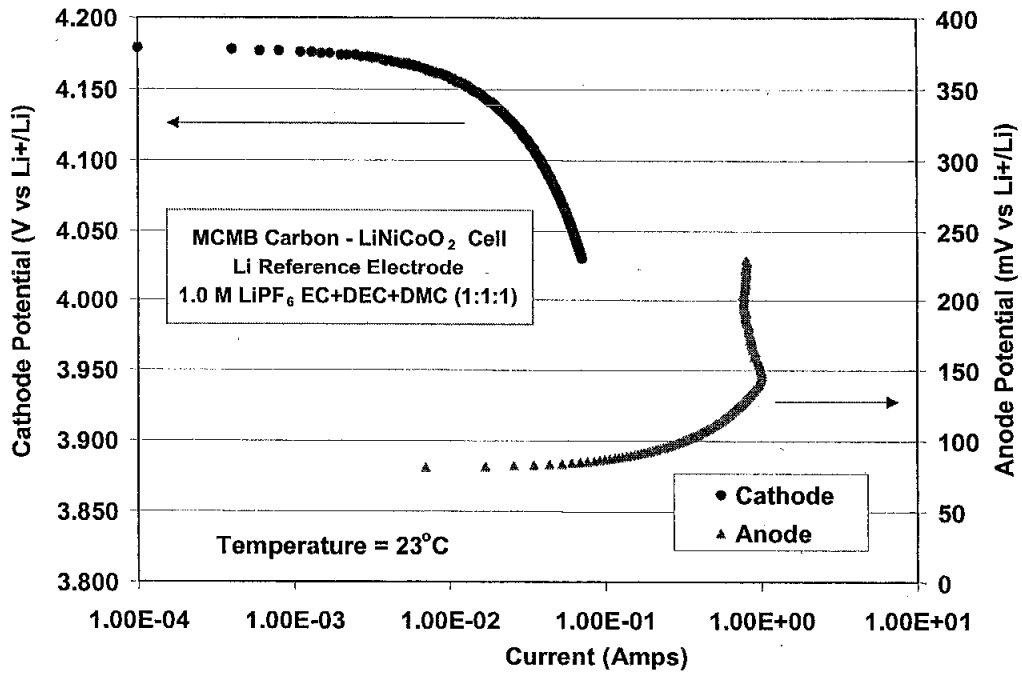
- Little change in the series resistance indicative of small changes in the ionic (electrolyte) and electronic (electrode) conductivities.
- Increase in the low frequency impedance (attributed to the cathode kinetics) which might affect the high rate/low temperature performance.

Impedances in a Li Ion Cell

EIS of a Li Ion Cell

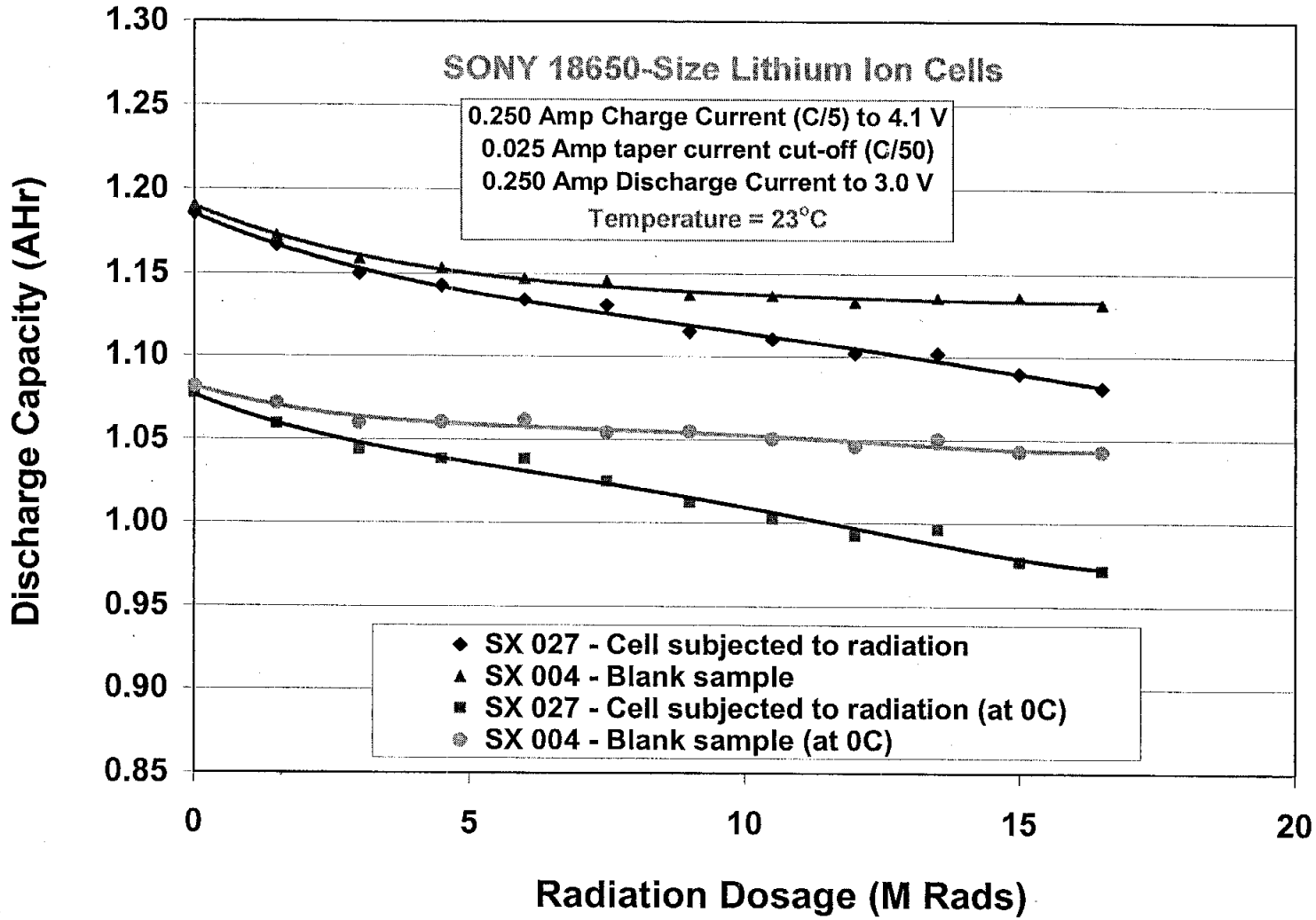


DC Polarizations in Li Ion Cell

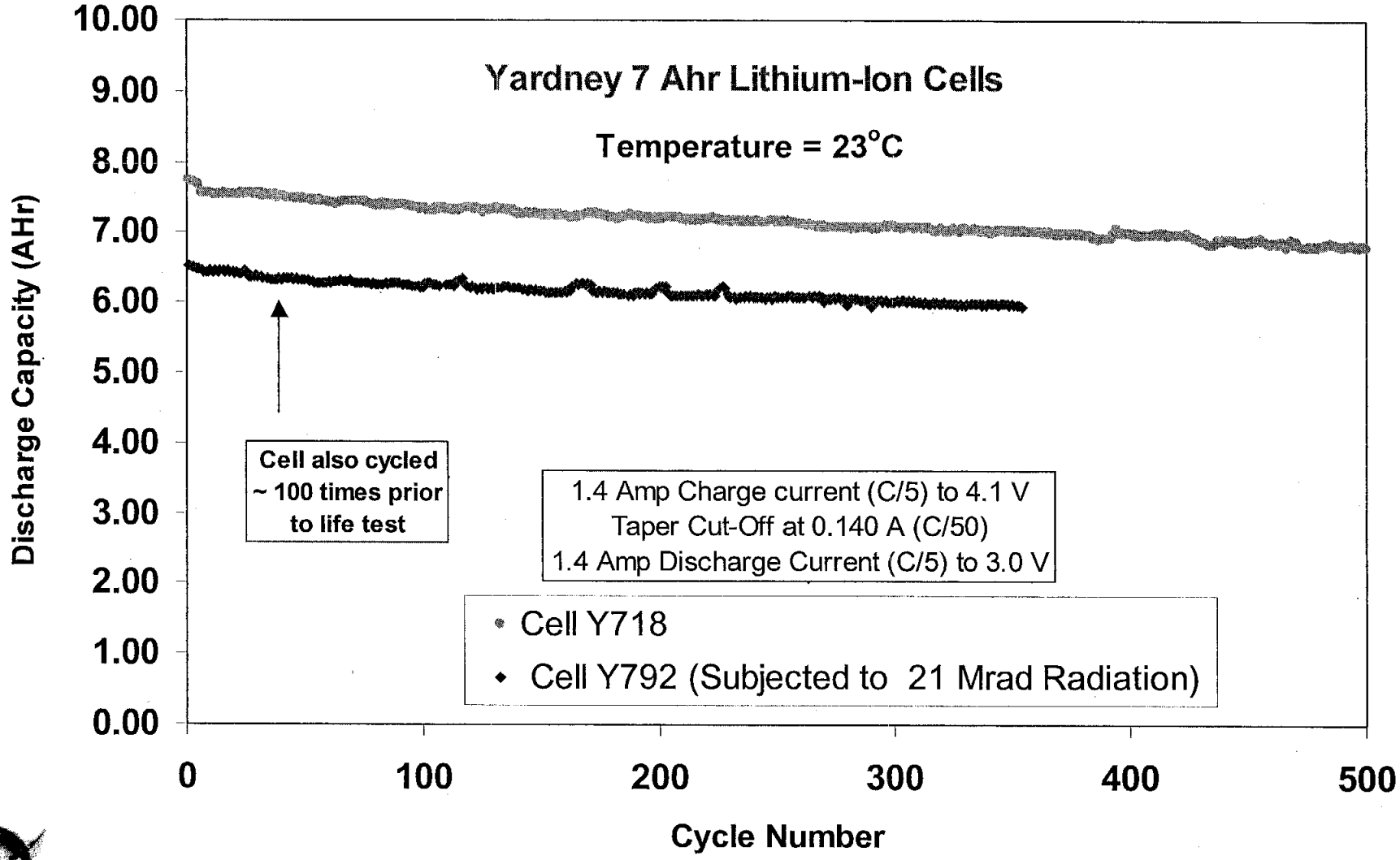


- EIS response dictated essentially by the cathode, though anode impedance is imbedded in that.
- Confirmed by DC Tafel polarization studies

Radiation Tolerance of Lithium-Ion Cells



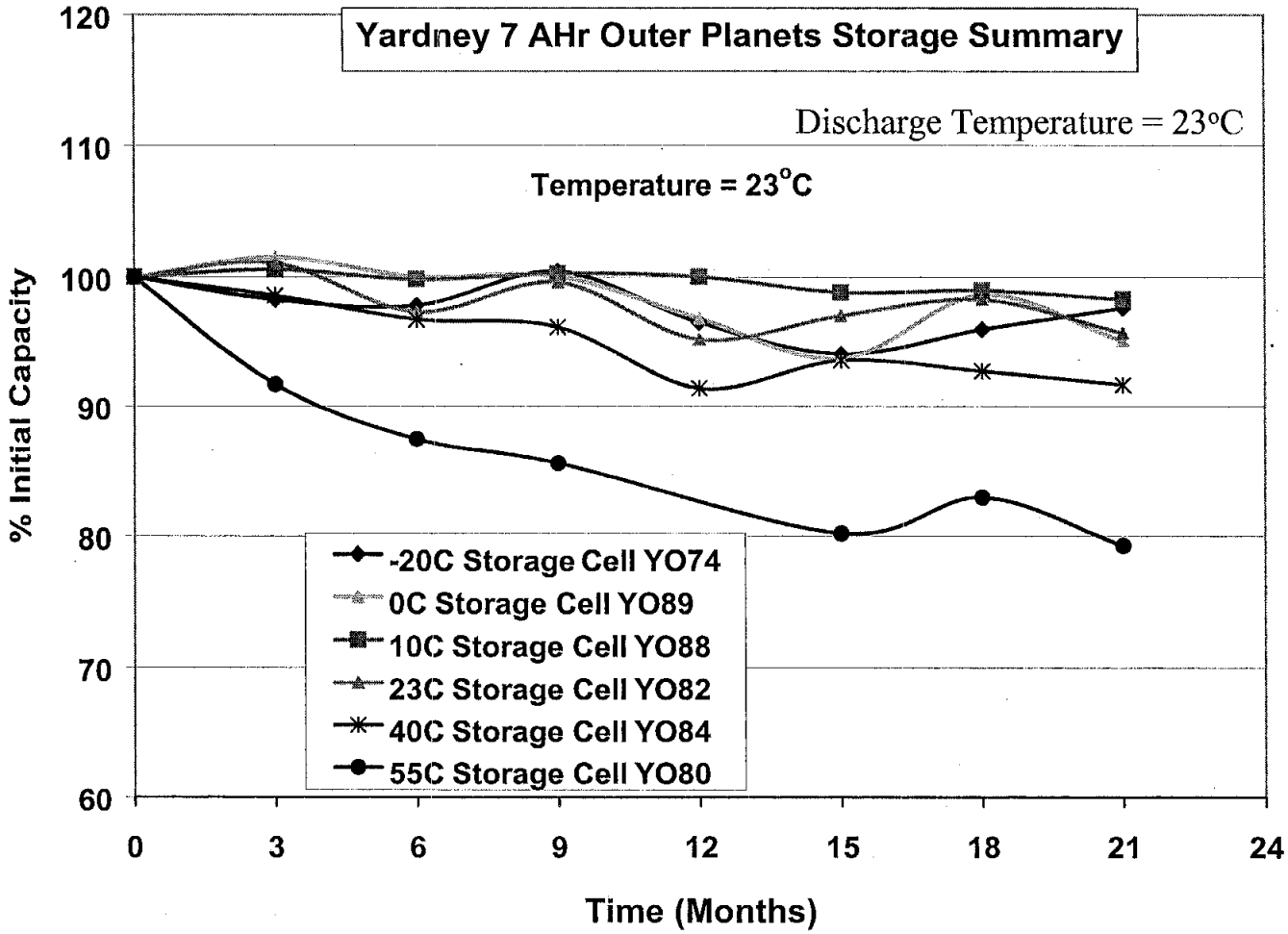
Post-radiation cycling Li Ion cells



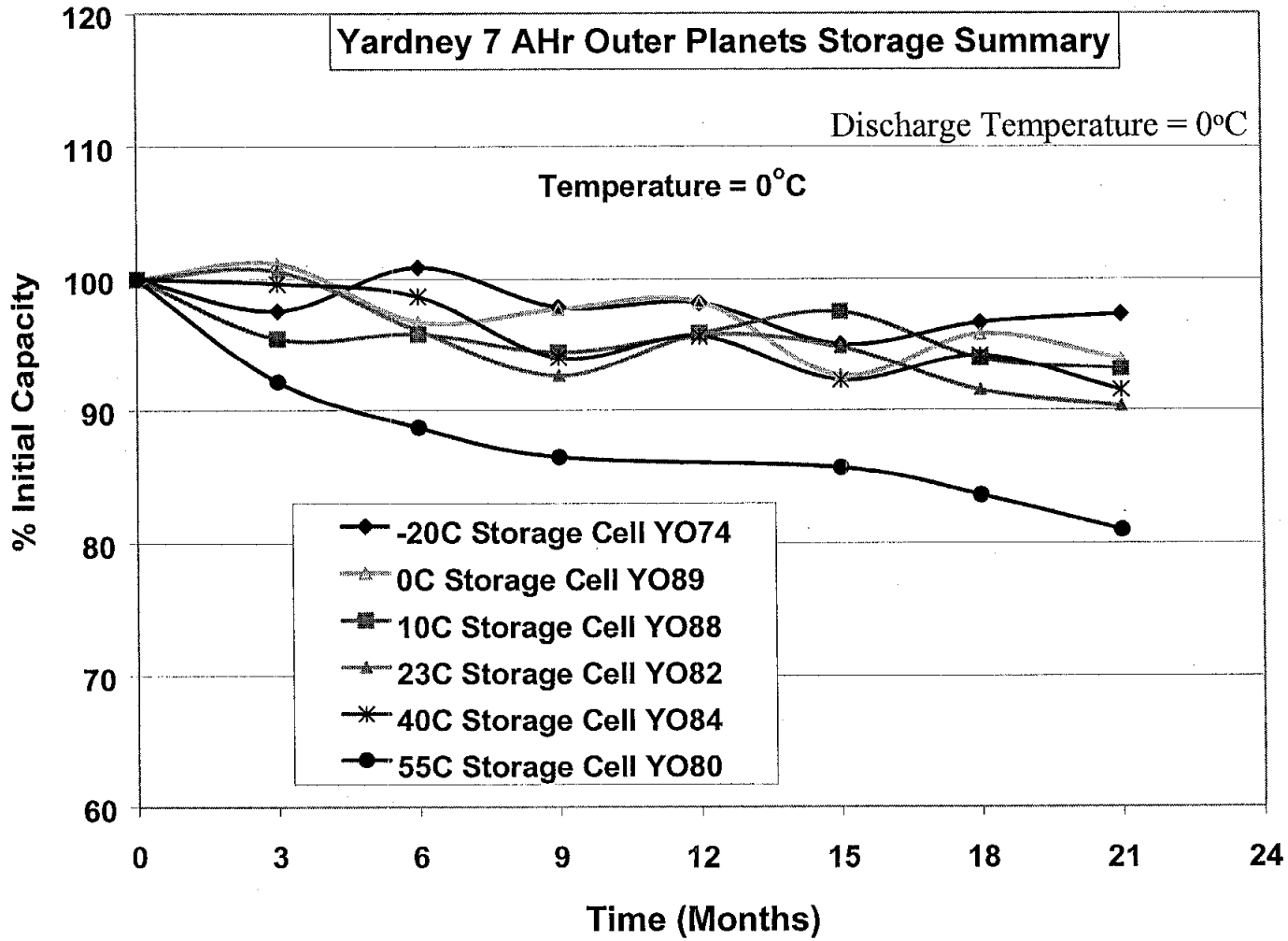
Calendar life Studies-Parameters

- On-buss storage at 50% State of charge, i.e. at a constant voltage of 3.65 V
- Five Storage Temperatures of 55°C, 40°C, 23°C, 10°C, 0°C, and -20°C.
- Capacity Checks after incremental 3 Month Storage at 23°C and 0°C.
- EIS measurements at 23°C after each 3 Month Storage period.
- Two types of prototypes
  - Yardney prismatic cells (7Ah) and
  - SAFT Cylindrical cells (DD, 9 Ah)

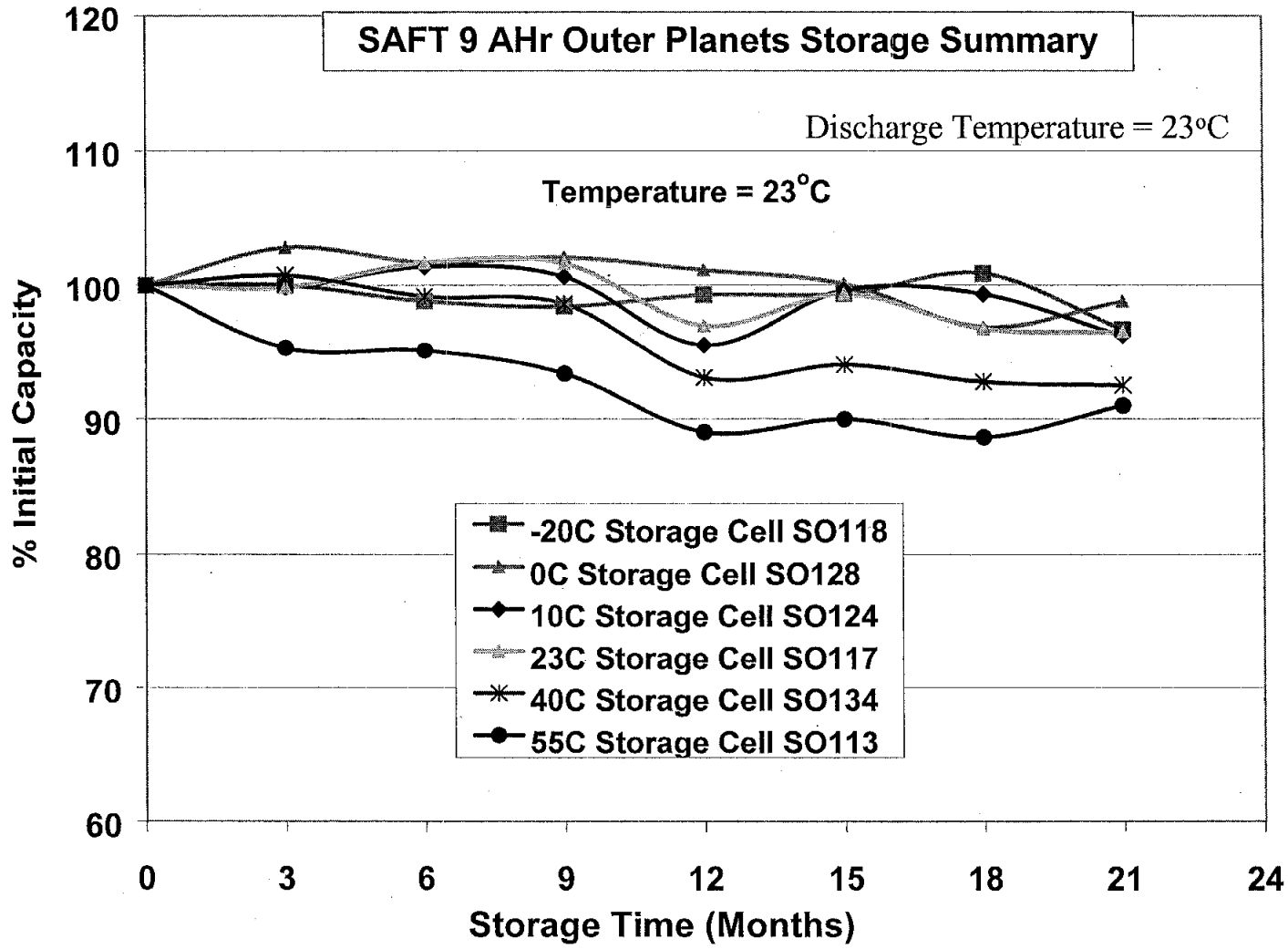
Capacity Retention on Storage-Yardney Cells



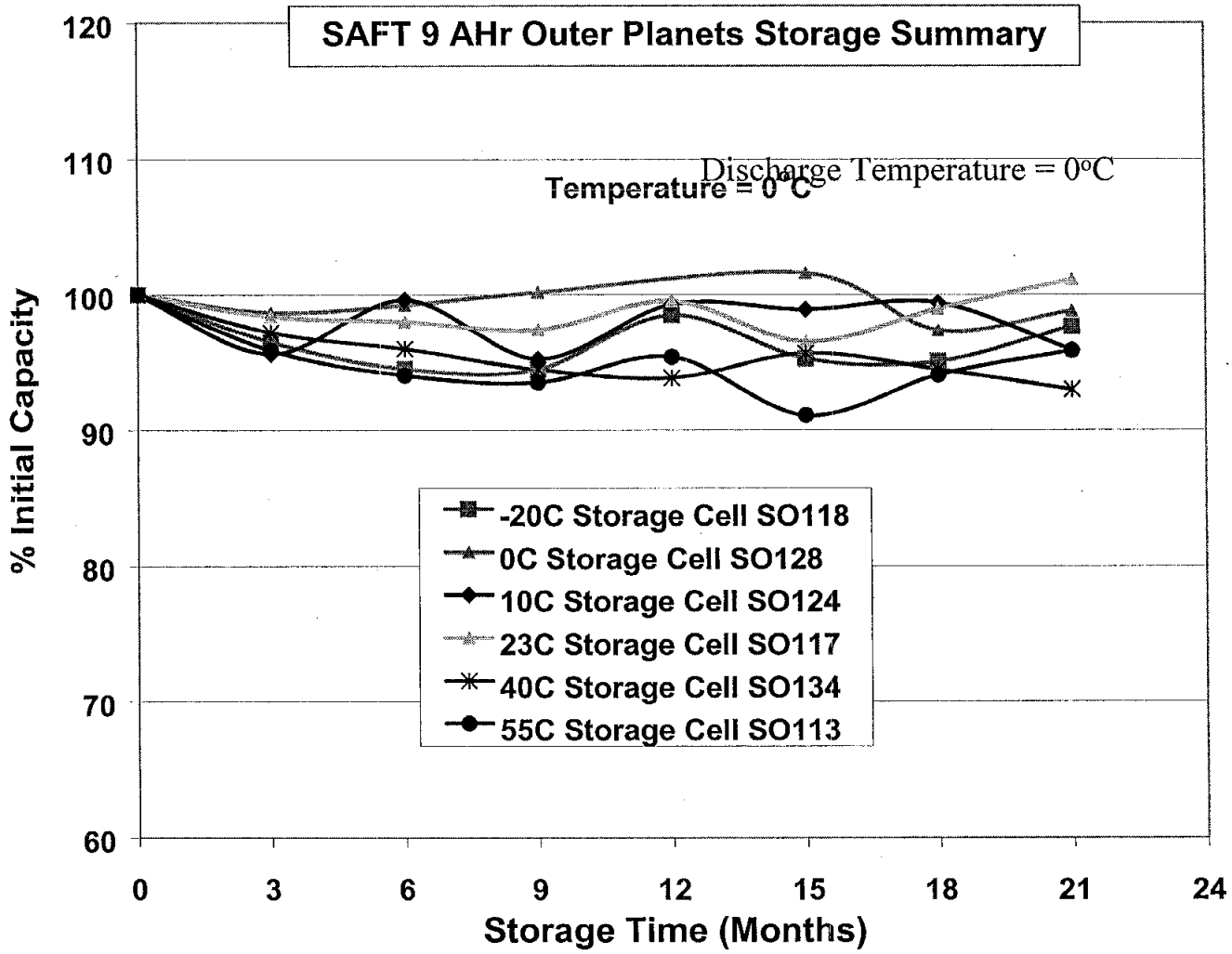
Capacity Retention on Storage – Yardney Cells



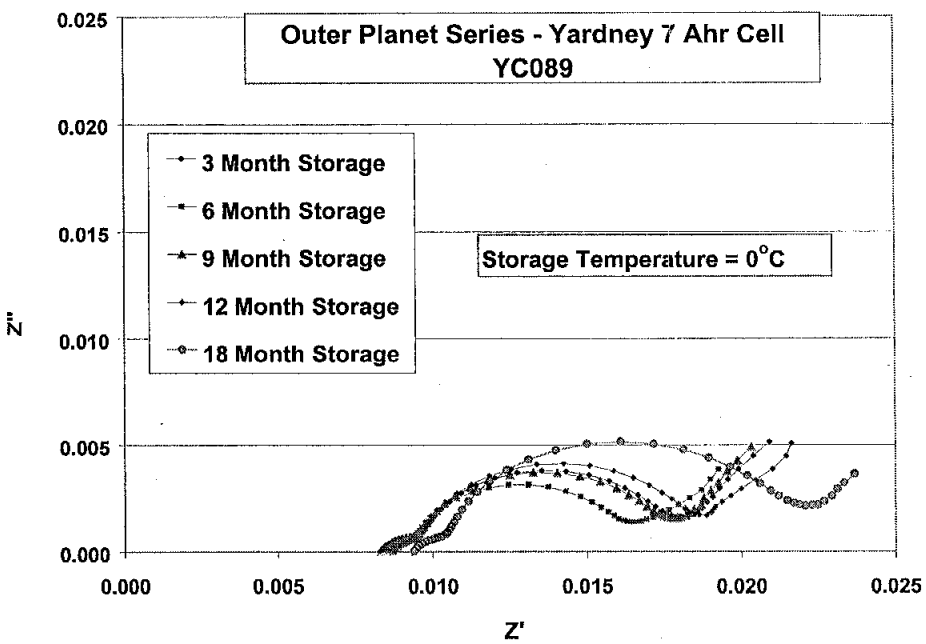
Capacity Retention During 21 Month Storage

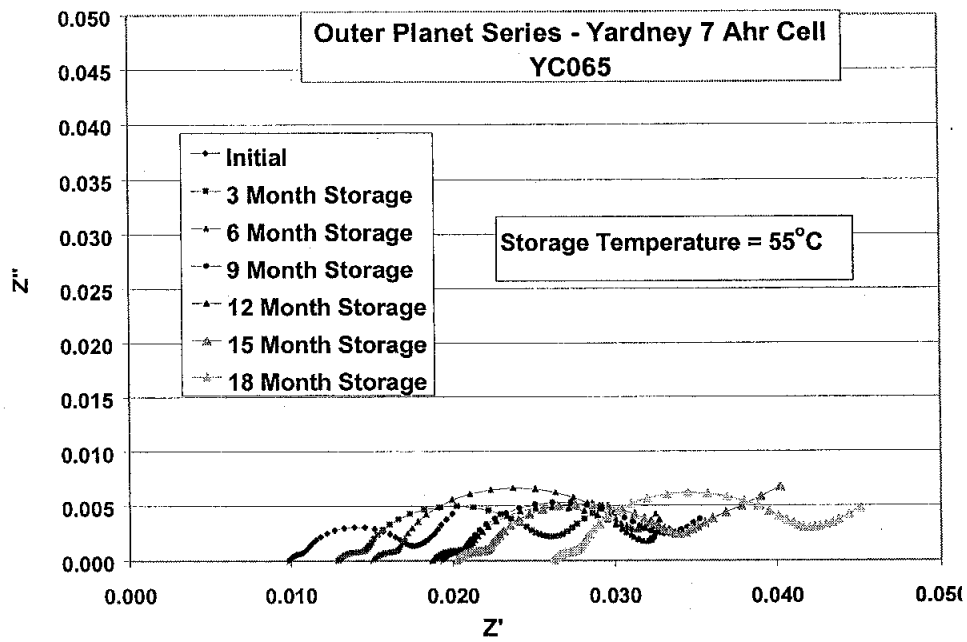


Capacity Retention During 21 Month Storage

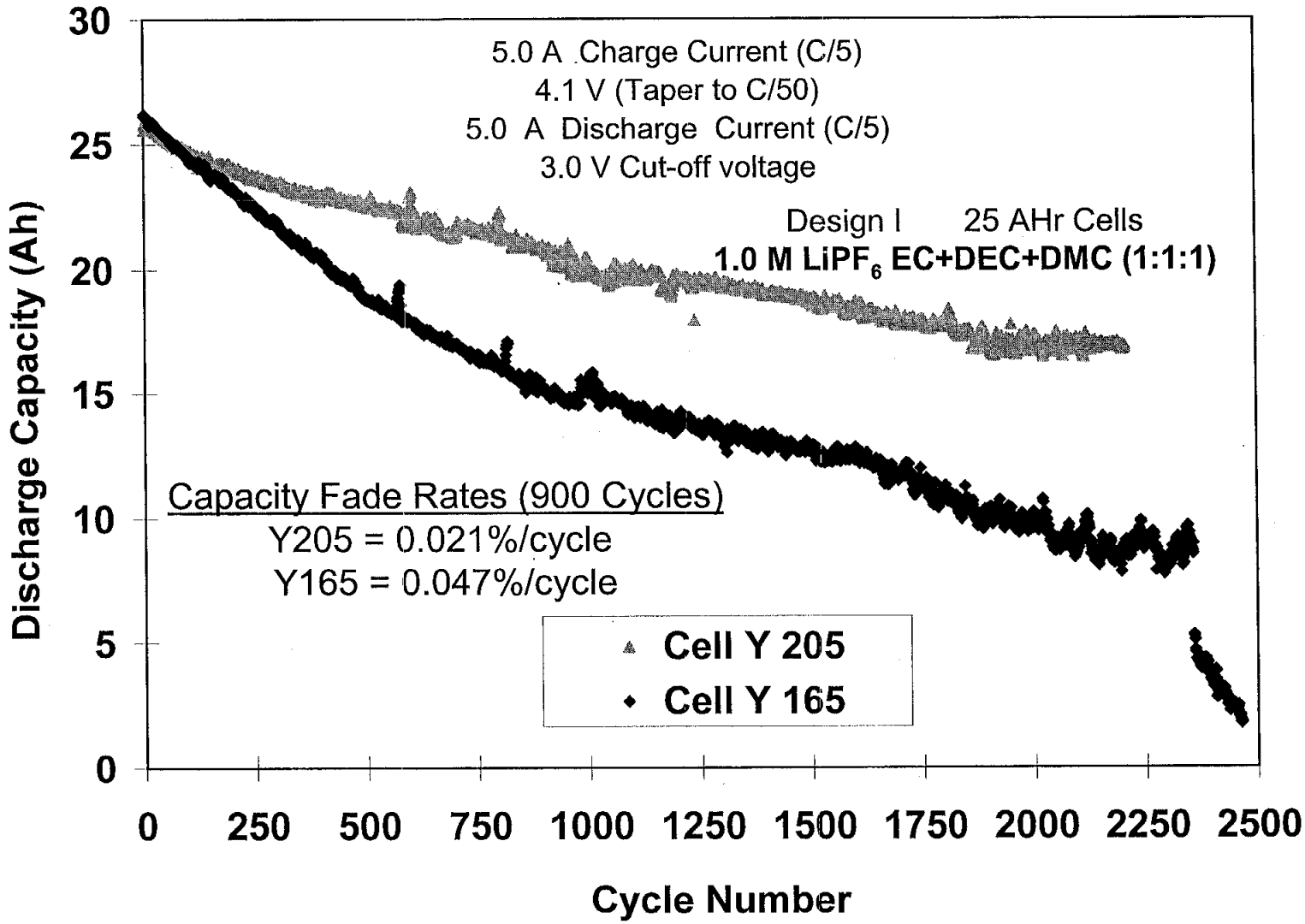


EIS During Storage-Yardney cells

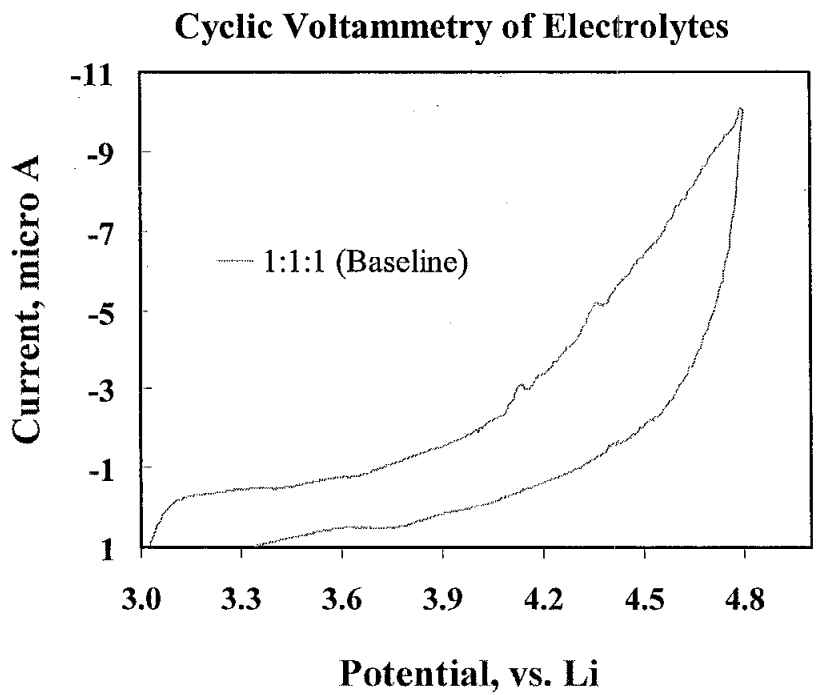


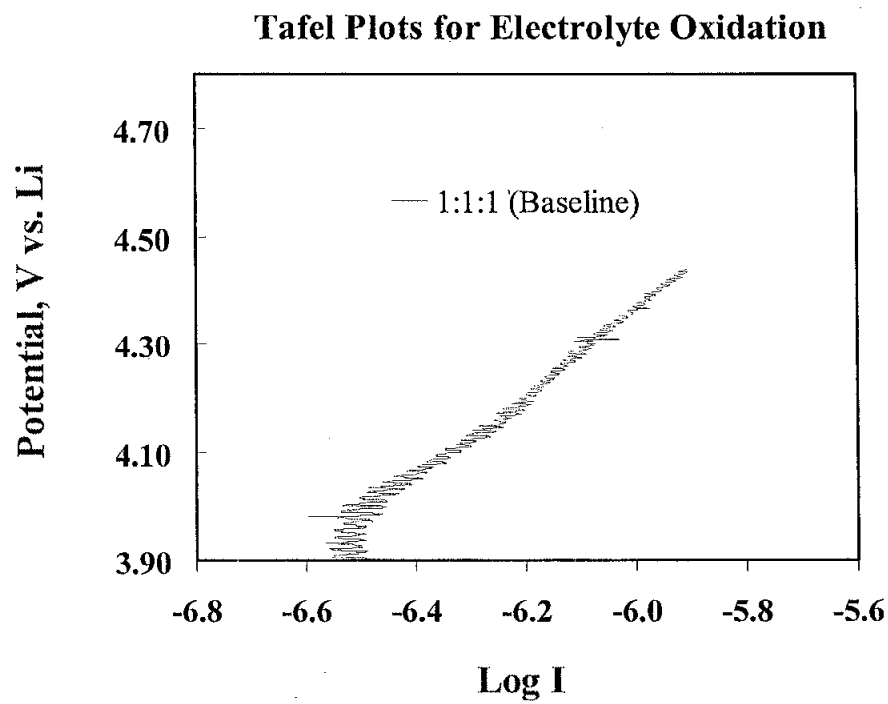


Safety and Reliability



Electro-oxidation of Solvents





Summary

- Lithium Prototypes have displayed excellent characteristics for Mars Rover and Lander applications
  - High specific energy (>120 Wh/kg) and Energy density (3900 Wh/l)
  - Good low temperature performance down to –40°C.
  - Excellent storage characteristics over 2 years at 50-70% storage
  - Good pulse capability up to 3C to support pyros
- Lithium ion technology is approaching the half-way mark for planetary orbiter and Leo satellites
  - About 15,000 cycles and three years of operation demonstrated.
- Lithium ion cells are tolerant to high gamma radiations prevailing in Jupiter environments.
- Real-time data are encouraging for missions requiring long calendar life
  - Capacity loss less than 5 % over 2 years of storage.
- Reliability for long term operation with extended cycling is yet to established.
  - Electrolyte oxidation may be mitigated with appropriate operating conditions.

Acknowledgments

The work described here was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA) and was supported by NASA Mars Exploration, Europa Orbiter and NASA Code R Advanced Battery Programs.