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# **Behavior of Li Ion Cells in High-intensity Radiation Environments**

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**ELECTROCHEMICAL TECHNOLOGIES GROUP**



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## Mission Critical Performance Characteristics



- **Long calendar life**
  - Cruise time of 6-8 years
- **Tolerance to high radiation environments**
  - 4 M Rad for Europa Orbiter
  - 8 Mrad including the qualification margin





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## Technology Demonstration Strategy for Radiation Tolerance



- **Obtain prototype cells from different aerospace vendors and evaluate radiation tolerance**
  - **DD cells from SAFT (PC-EC-DMC)**
    - High and low dosage rates
  - **7 Ah Prismatic cells from Yardney (EC+DMC+DEC)**
    - High and Low Dosage Rates
  - **18650 cells from Sony/AEA/Comdev**
    - High and Low Dosage Rates with blanks for both
  - **Three electrode cells and Li ion cell components**
    - Tonin Separator, YTP electrodes and EC:DMC (1:1) electrolyte





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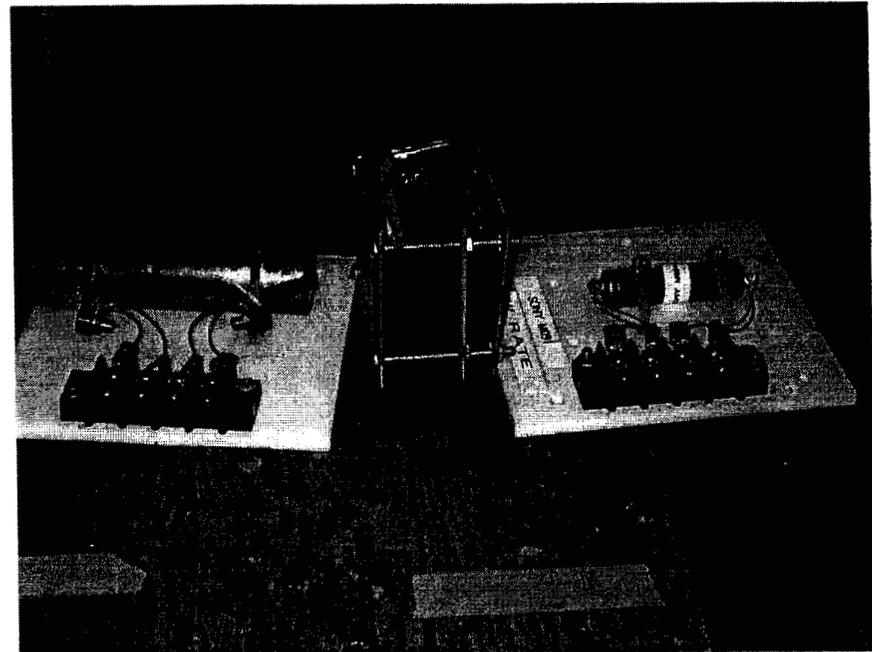
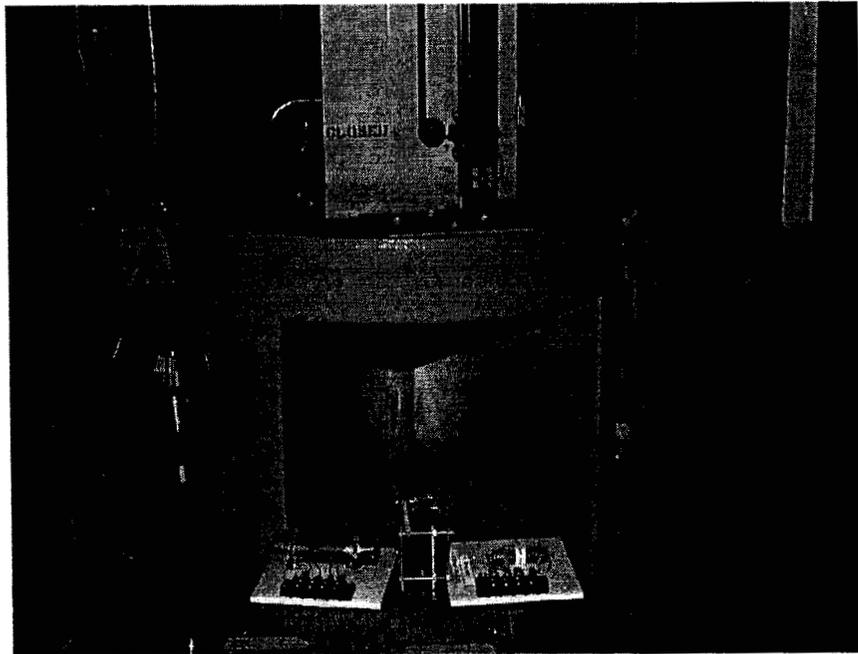
# RADIATION TOLERANCE TESTS

- **Cobalt 60 radiation at low and high dosage rates.**
- **Radiation levels in increments of 1.5 M rad and test to failure.**
- **Five cycles at C/5 charge and C/5 (to 4.1 V for three hours) and C/5 discharge to 3.0 V**
- **EIS in the fully charged state**
- **Irradiation in the discharged state.**





# RADIATION TEST FACILITY



- **Cylindrical cells**
  - **Radiation in a direction to the electrodes**
- **Prismatic cell**
  - **Radiation in a direction parallel to the electrode plates (to avoid attenuation from the preload fixtures)**

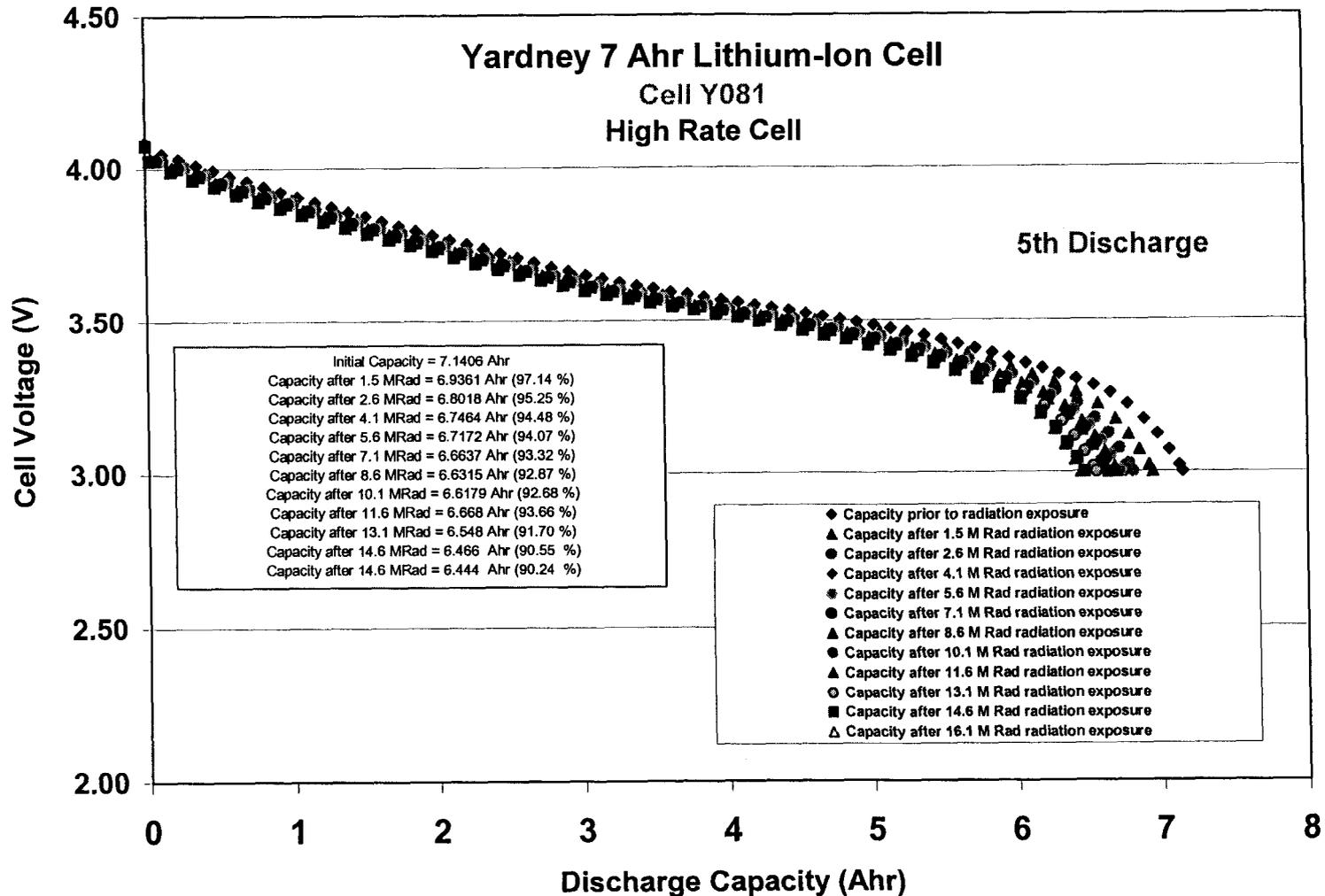




# Lithium-Ion Cells for Future Outer Planets Program Applications

## Status of Yardney 7 Ahr Cells: Effects of Radiation Testing (High Rate)

### Reversible Capacity at 23°C

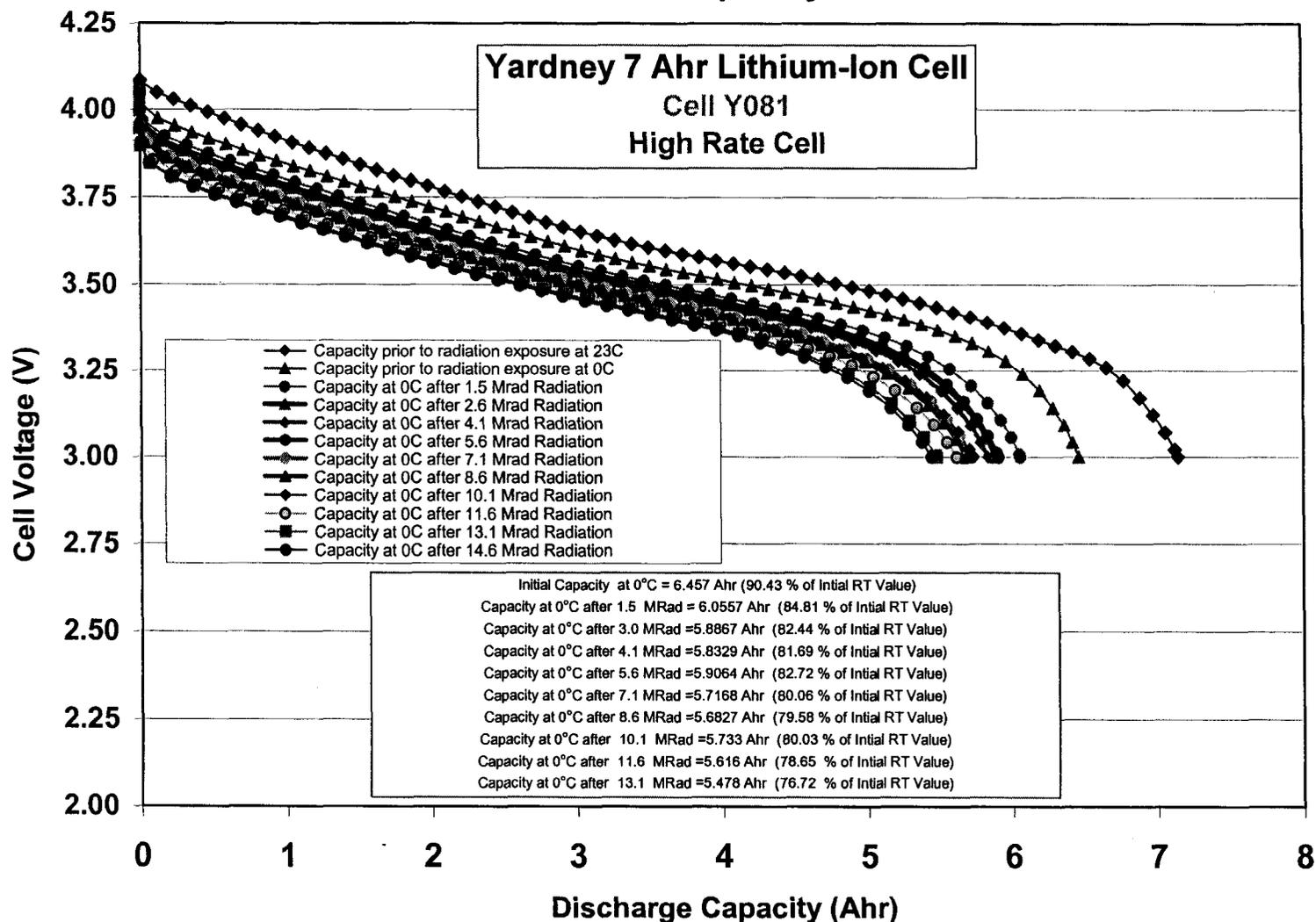


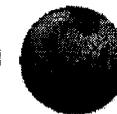


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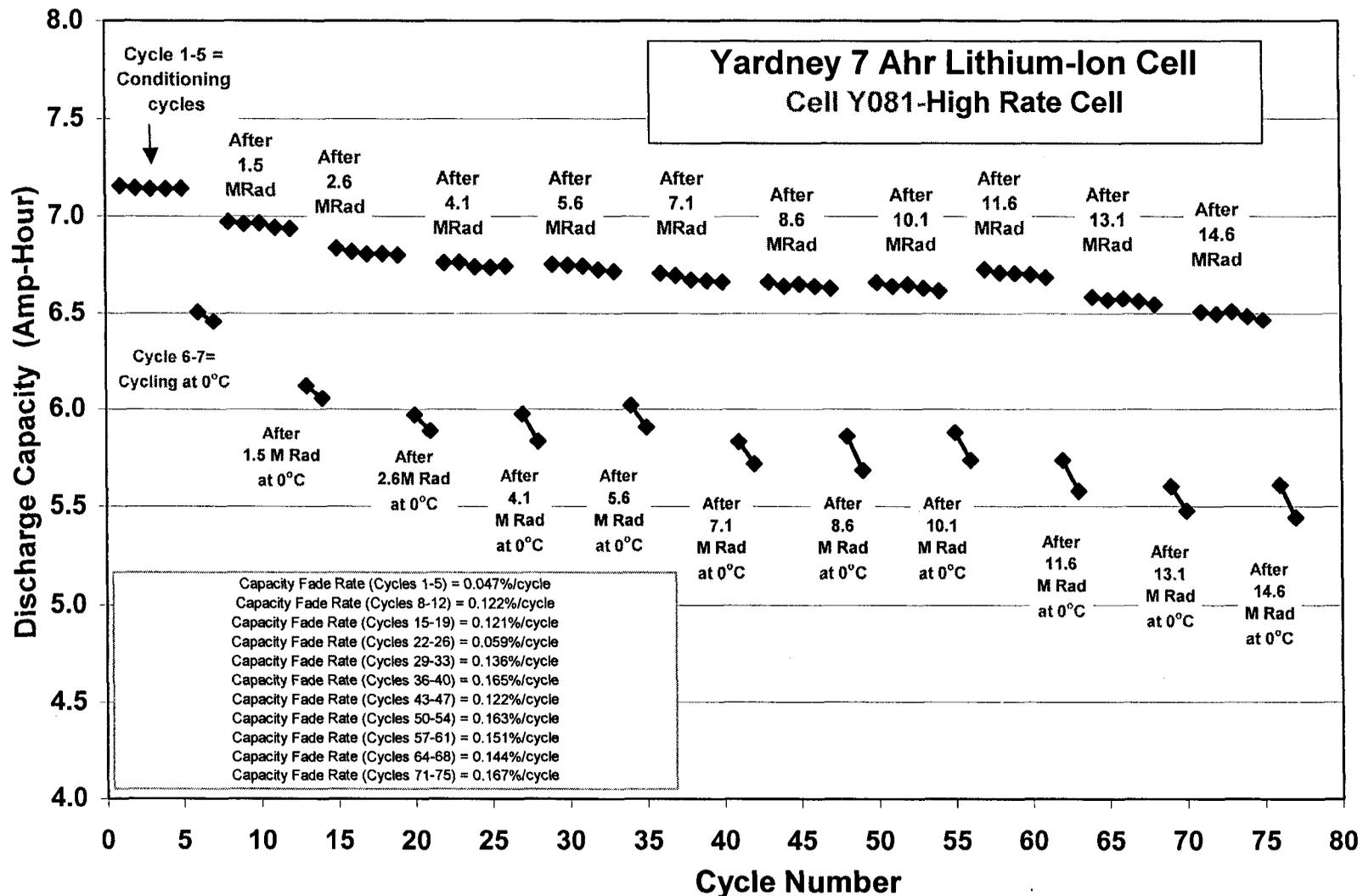
### Reversible Capacity at 0°C





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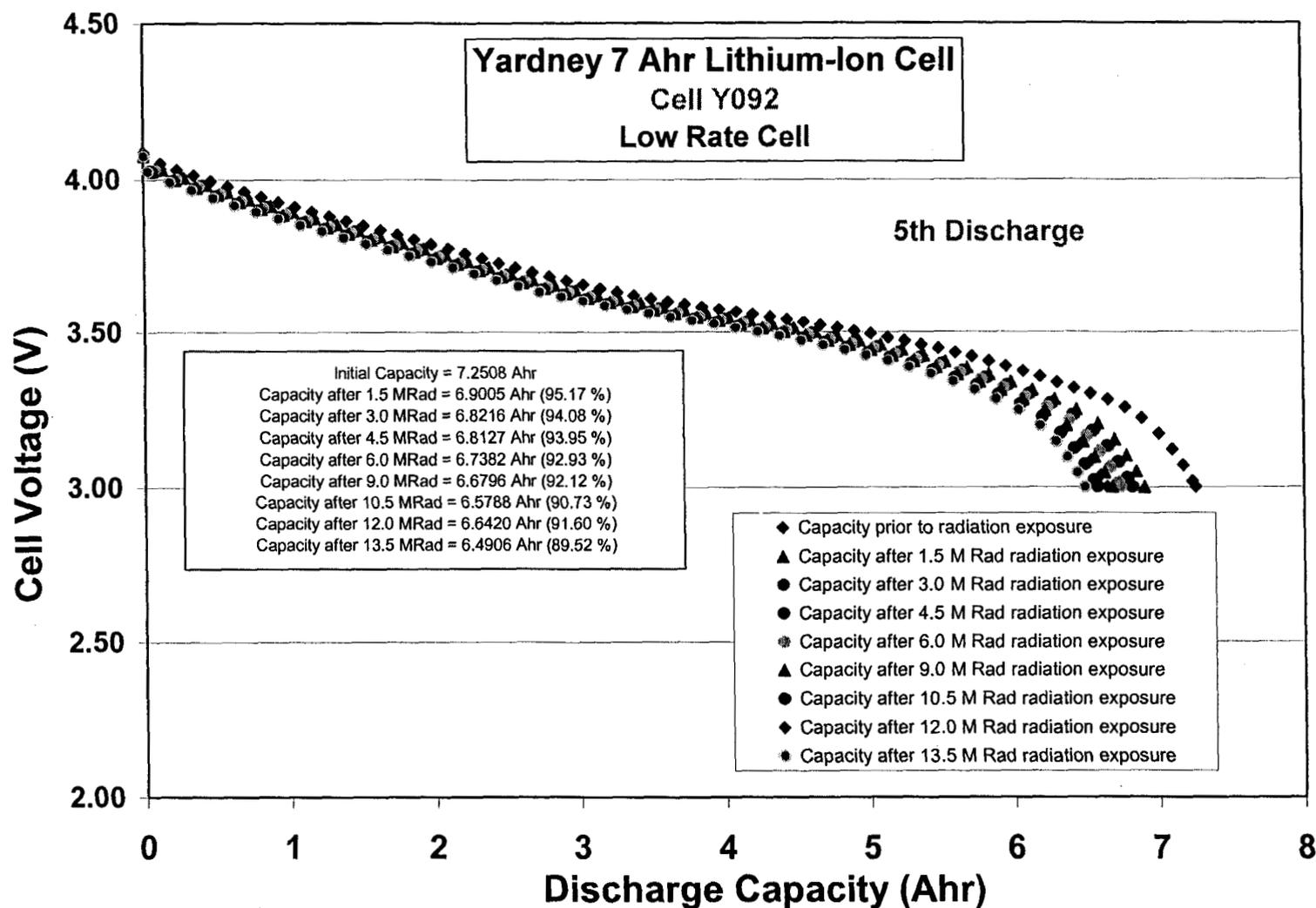




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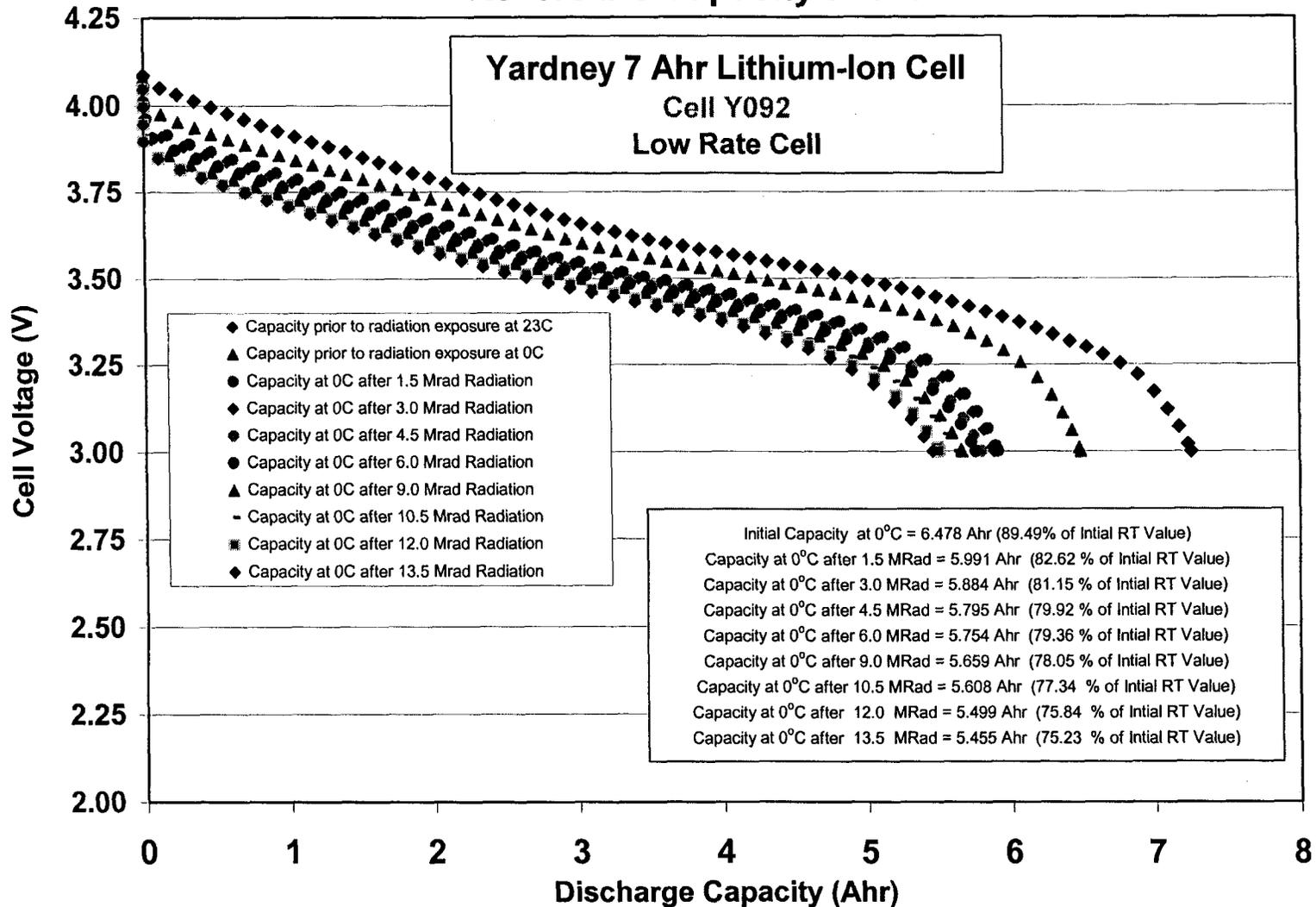




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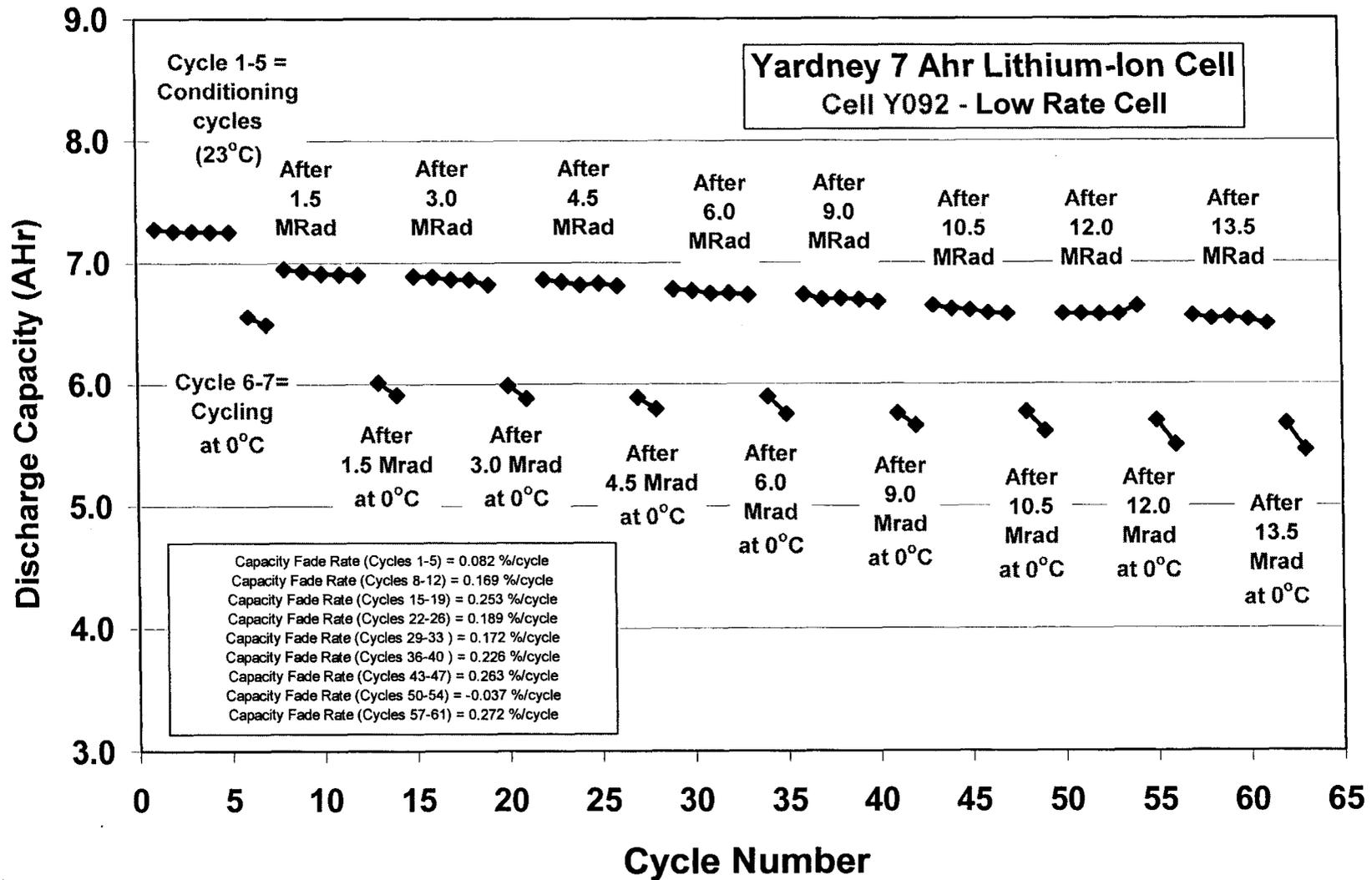
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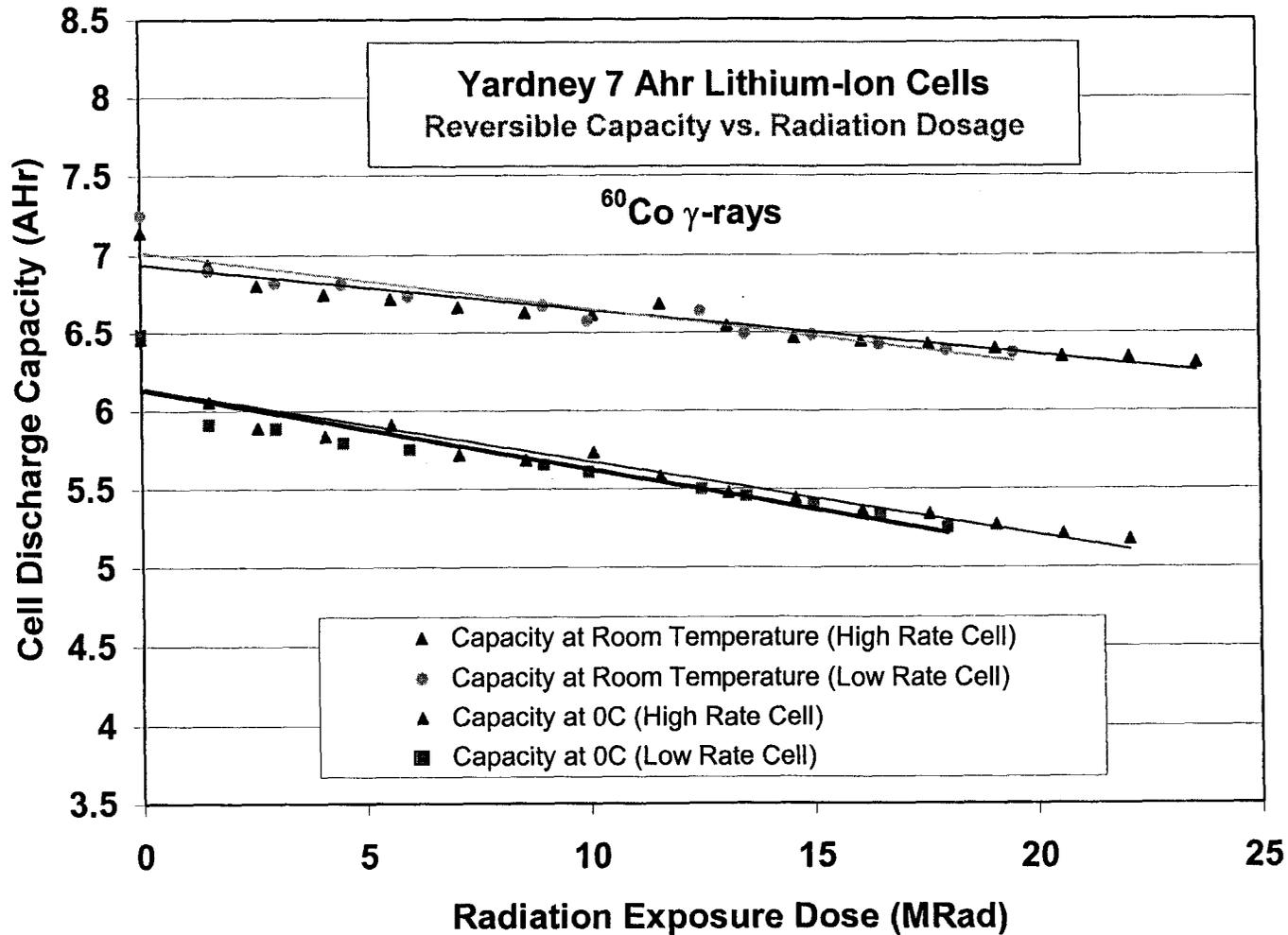




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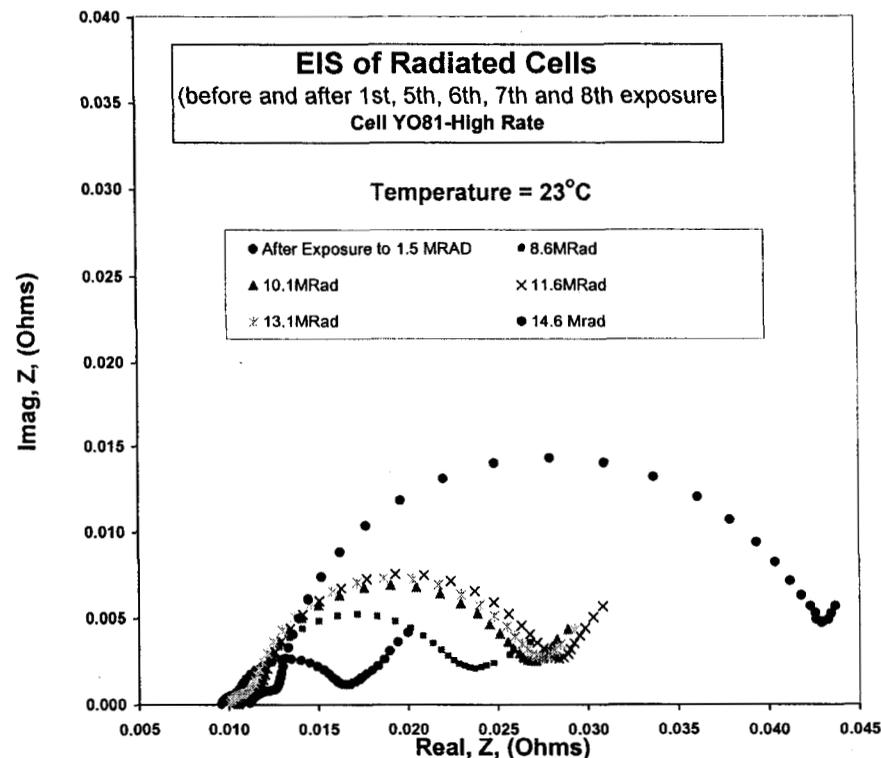
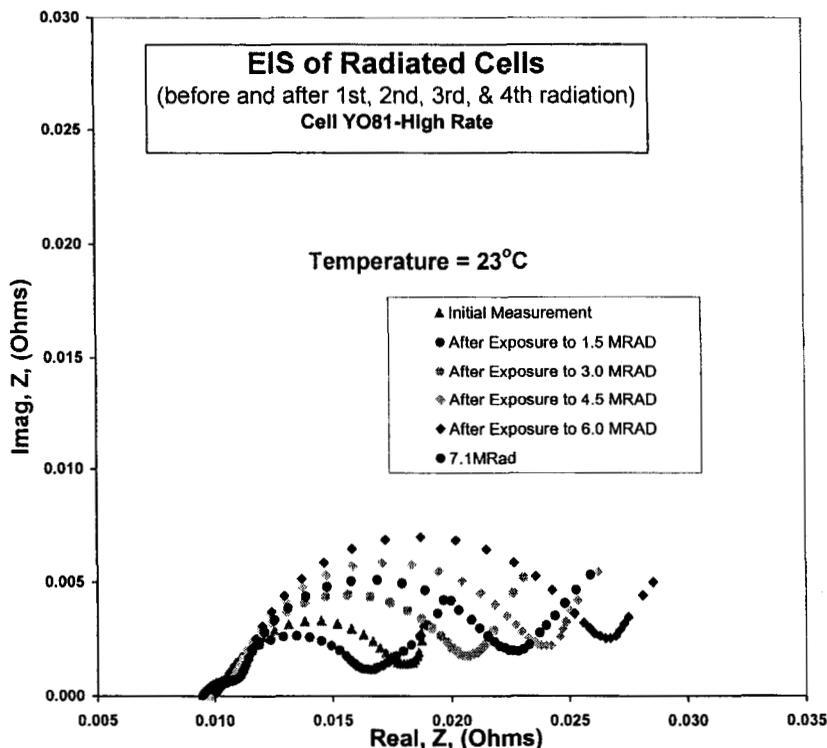
## Status of Yardney 7 Ahr Cells: Effects of Radiation Testing

### High Rate vs. Low Rate





# Electrochemical Impedance Spectroscopy High Rate



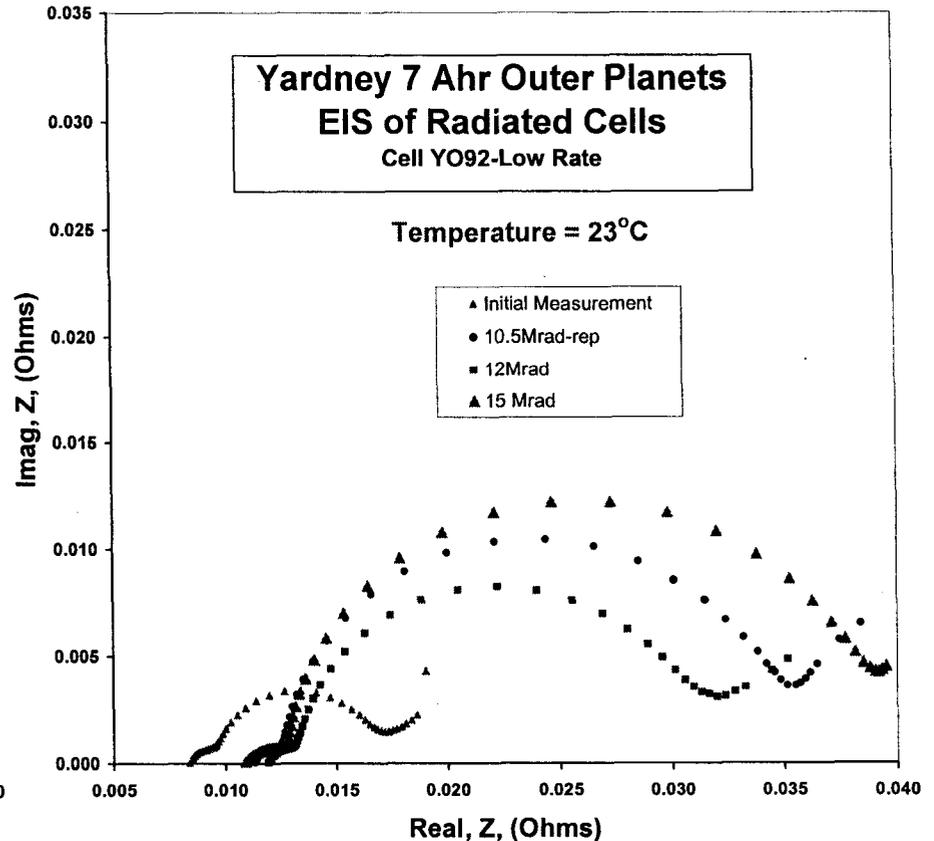
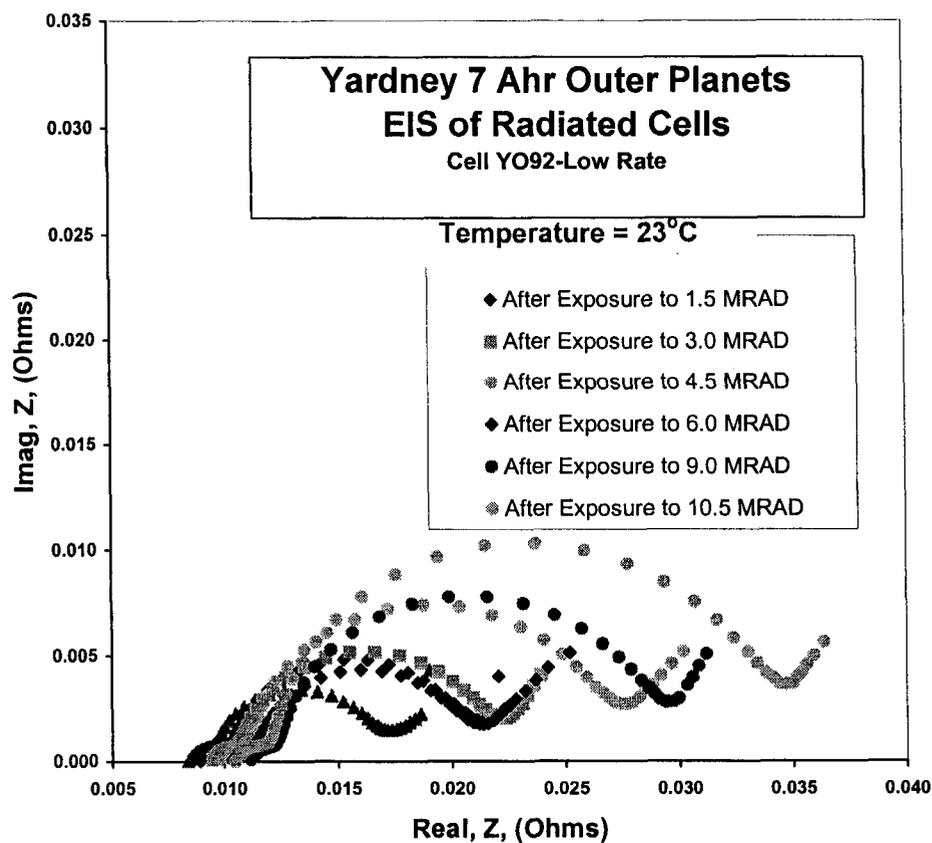
- Little change in the series resistance indicative of small changes in the ionic (electrolyte) and electronic (electrode) conductivities.
- Increase in the low frequency impedance (attributed to the cathode kinetics) which might affect the high rate/low temperature performance.





# Electrochemical Impedance Spectroscopy

## Low Rate



- Slightly higher increase in the series resistance compared to the high rate impedance data, may be attributed to ageing.
- Also, marginally higher impedance at low frequencies compared to high rate exposure data, may be attributed to cell ageing

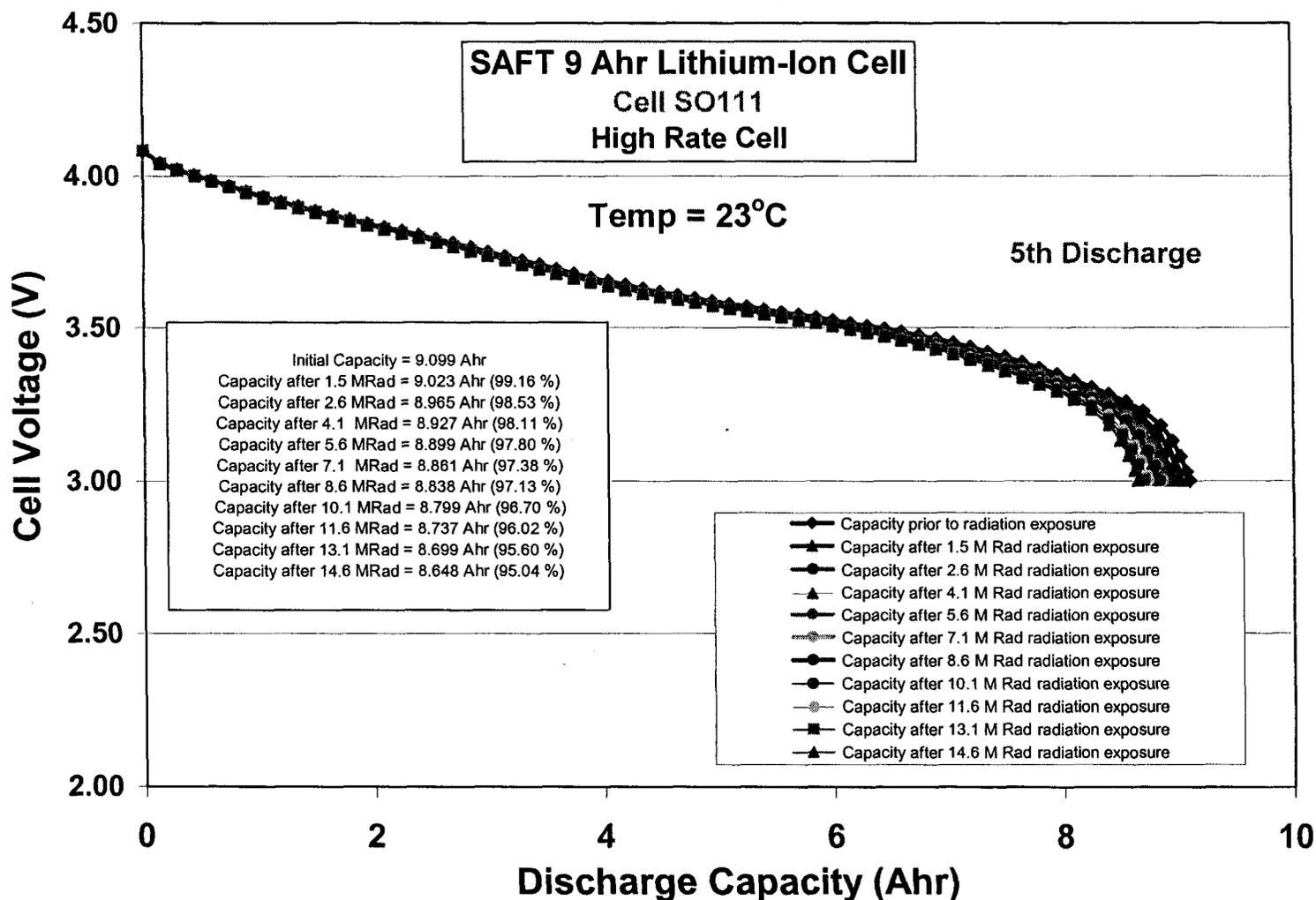




# Lithium-Ion Cells for Future Outer Planets Program Applications

## Status of SAFT DD-Size Cells: Effects of Radiation Testing (High Rate)

### Reversible Capacity at 23°C

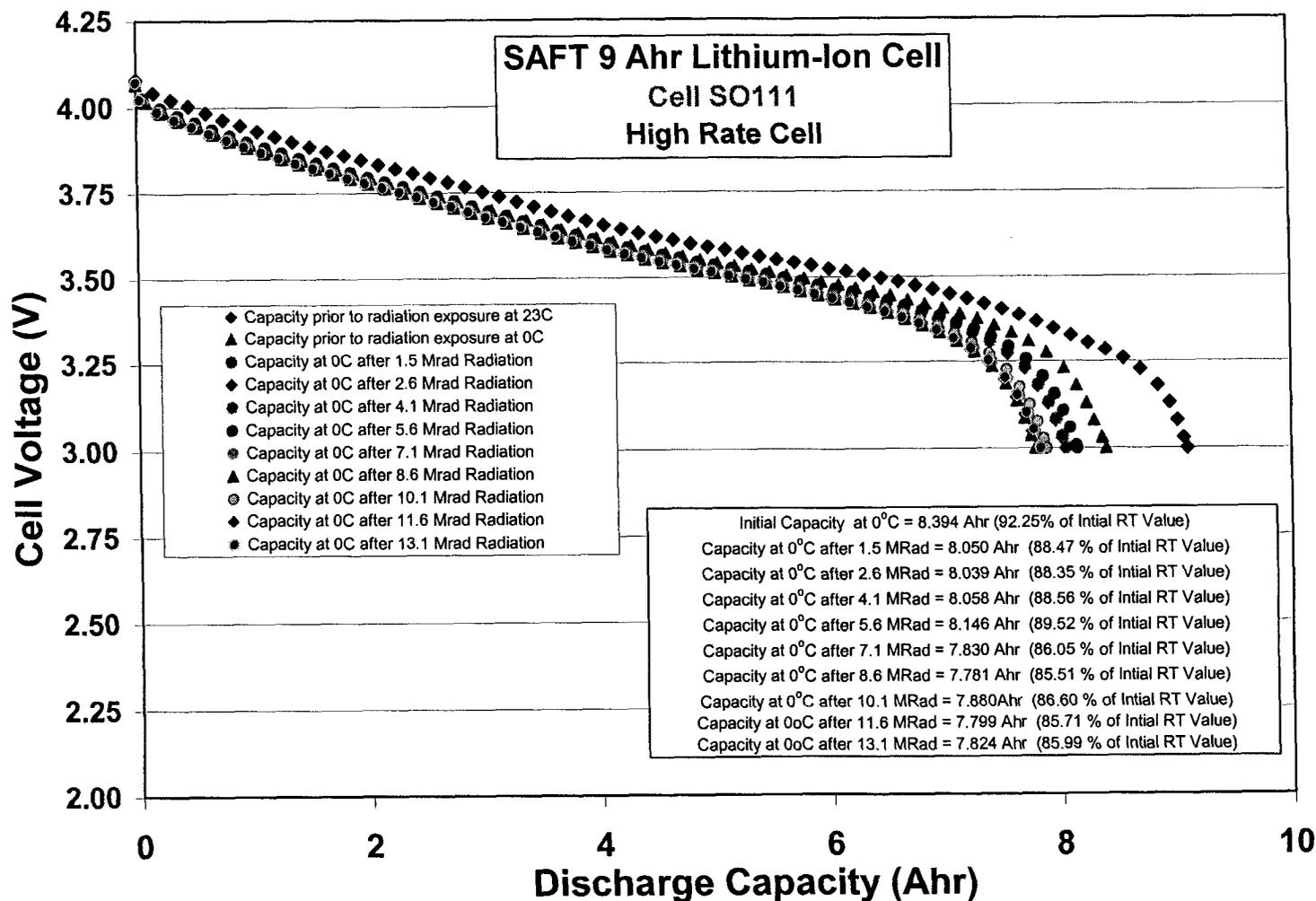




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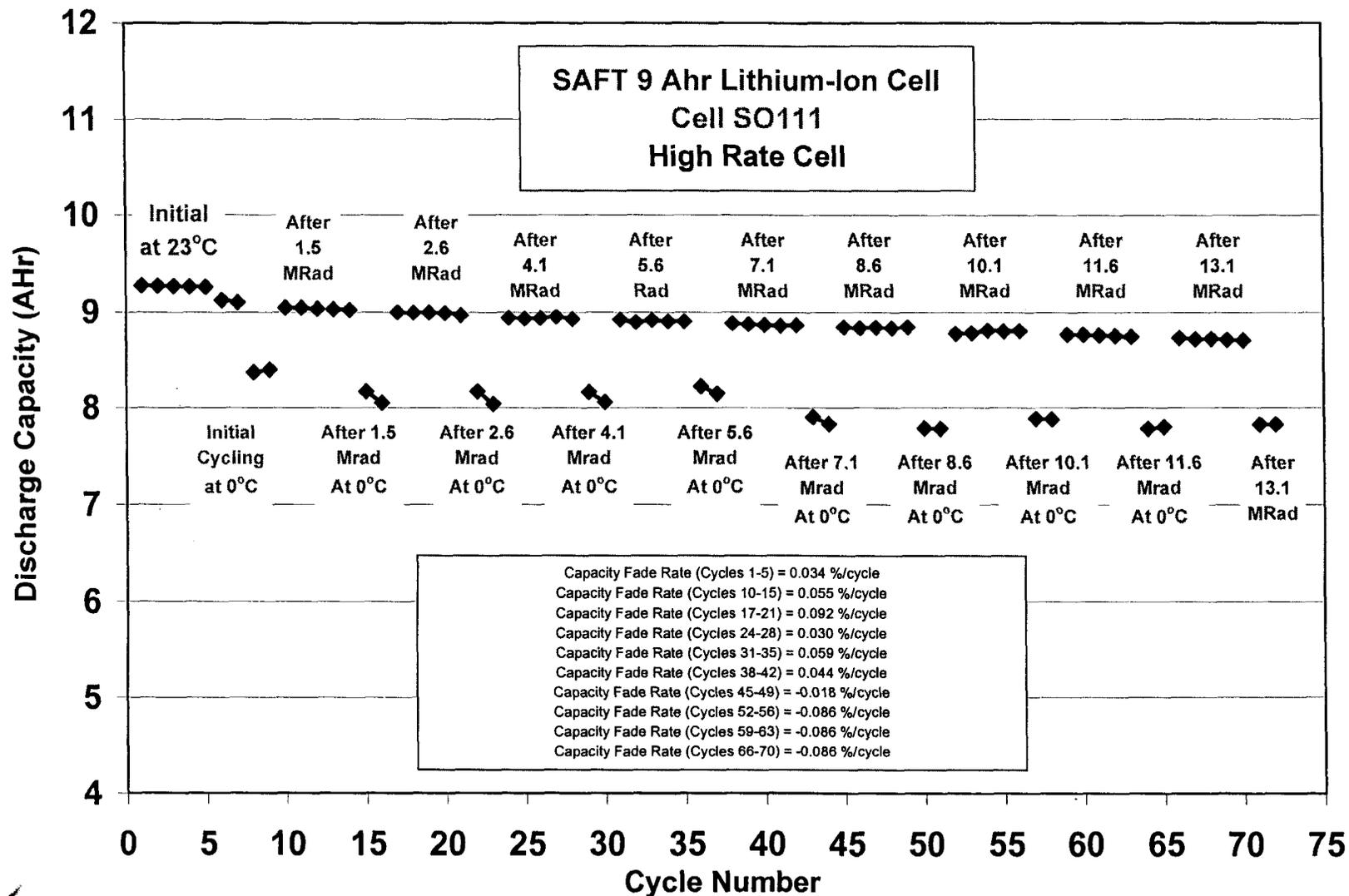
### Reversible Capacity at 0°C





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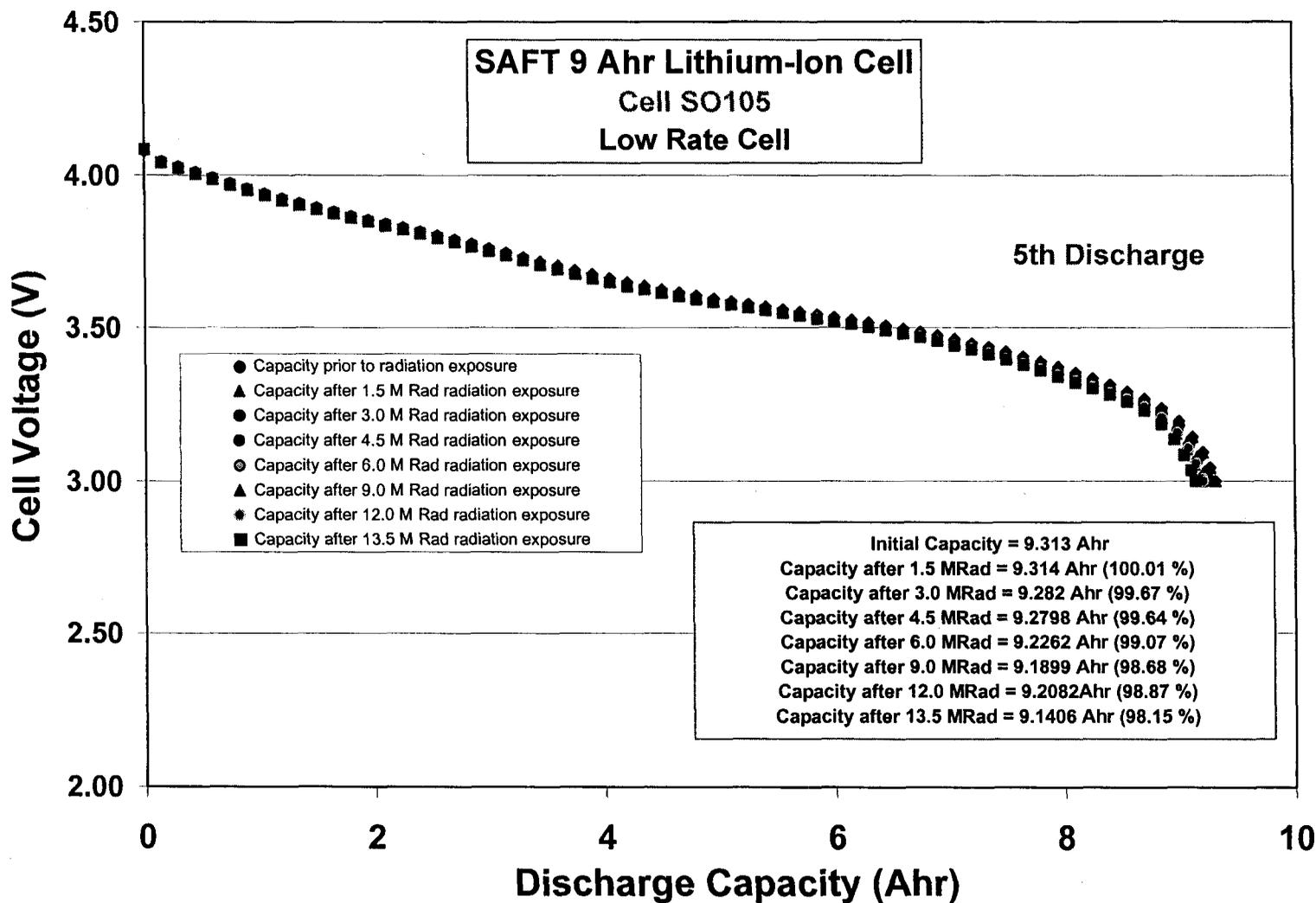




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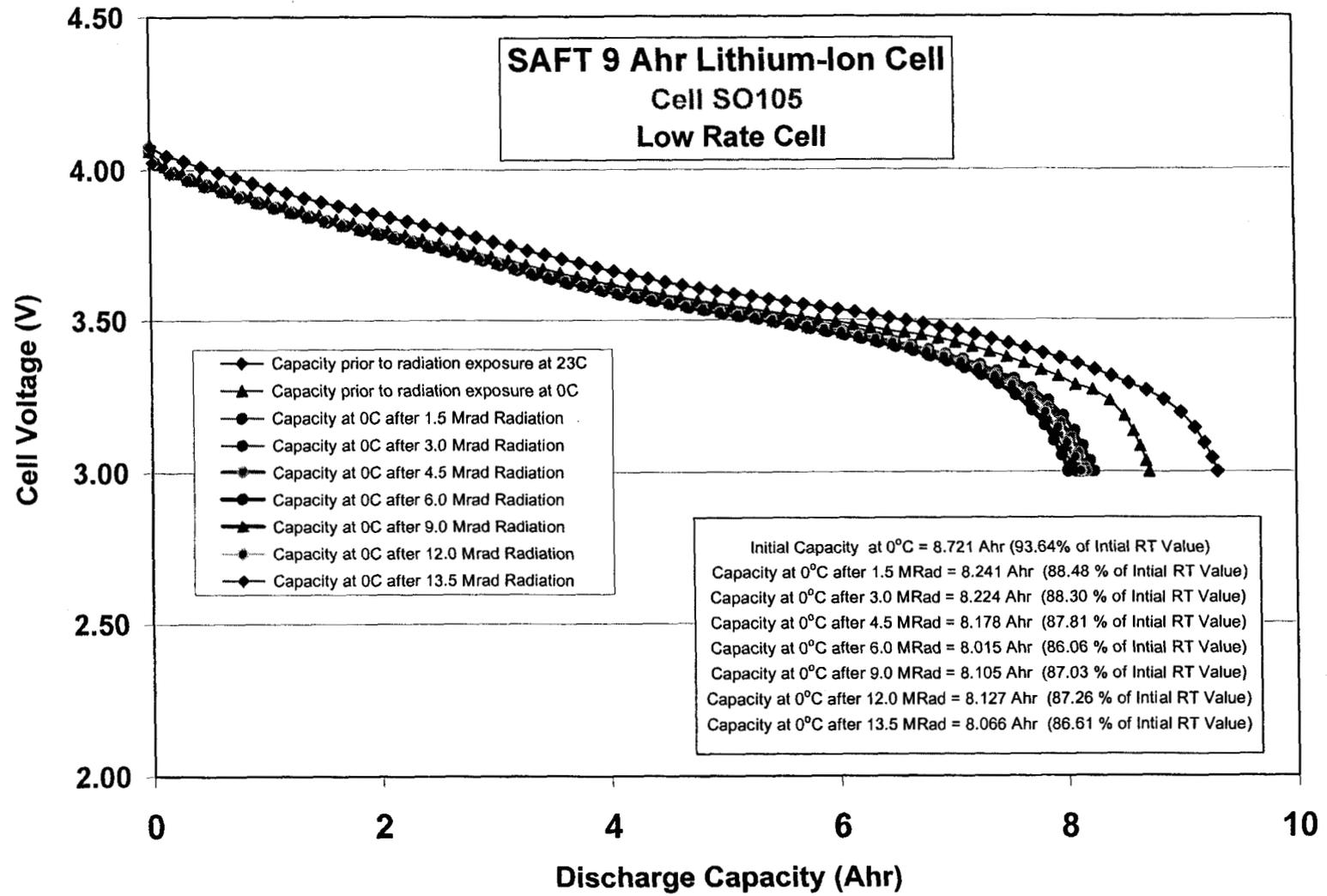




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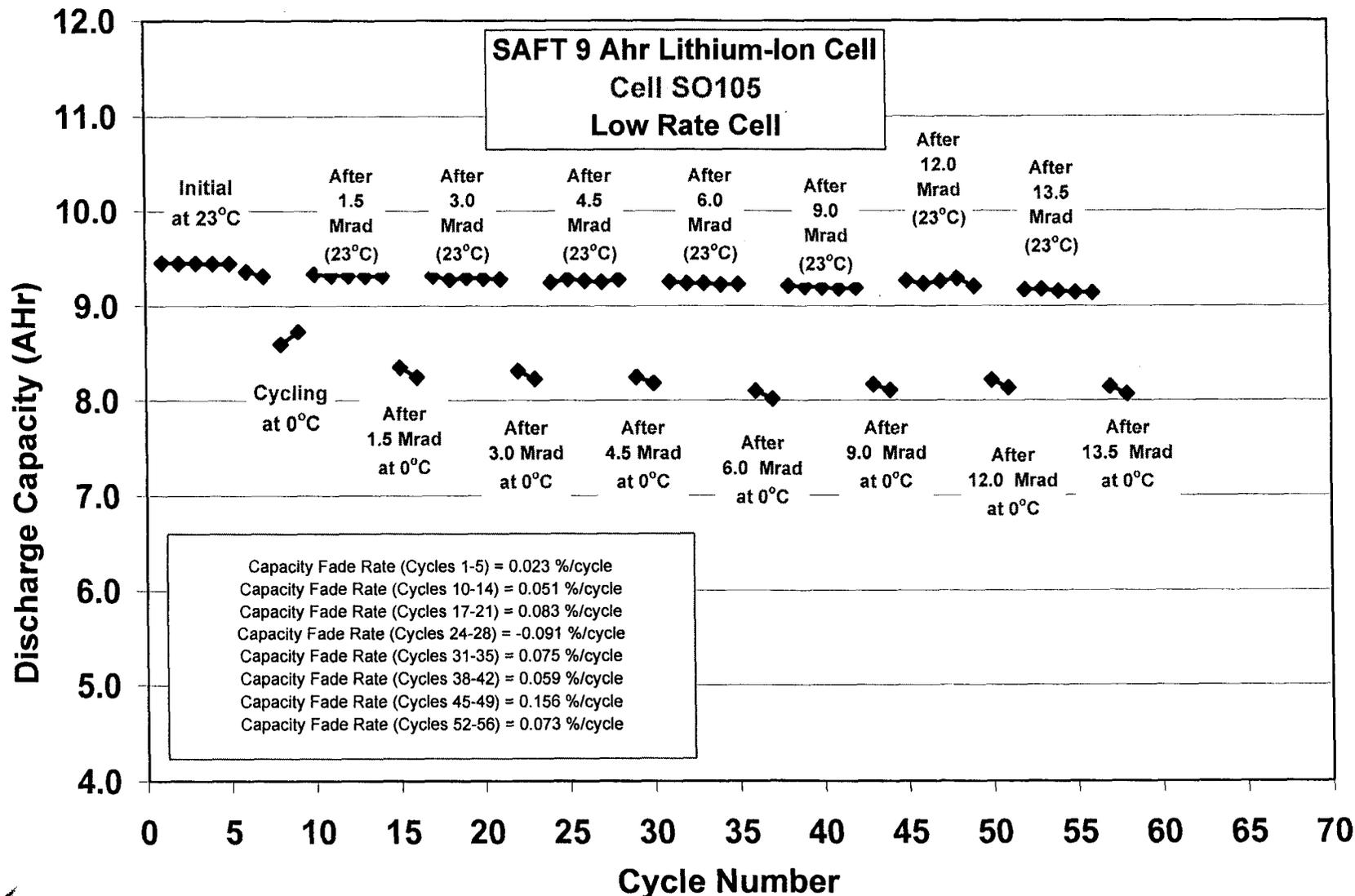
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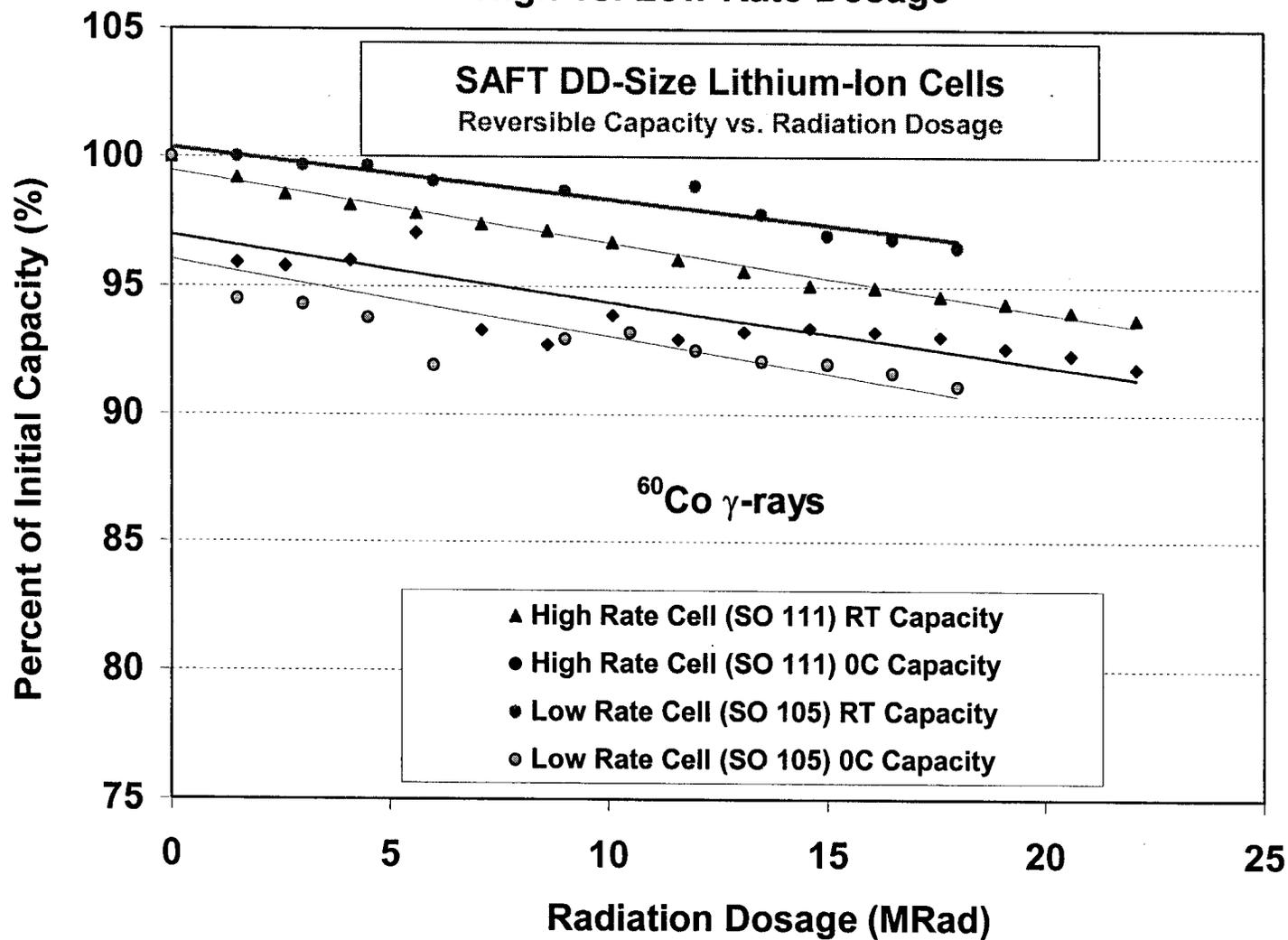




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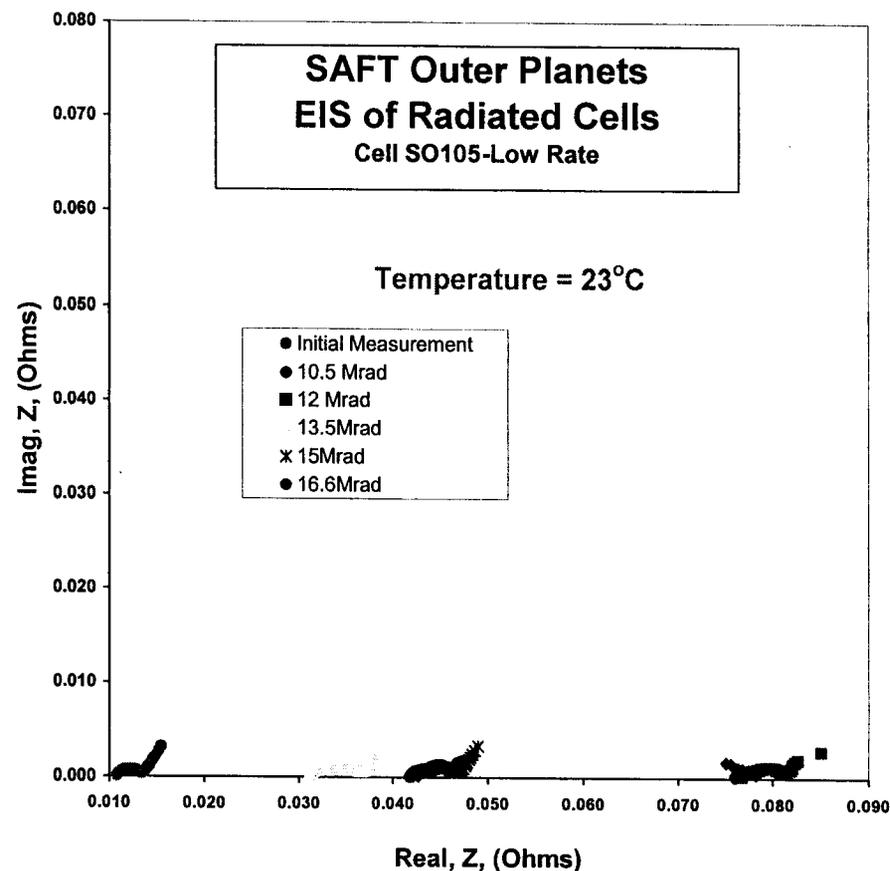
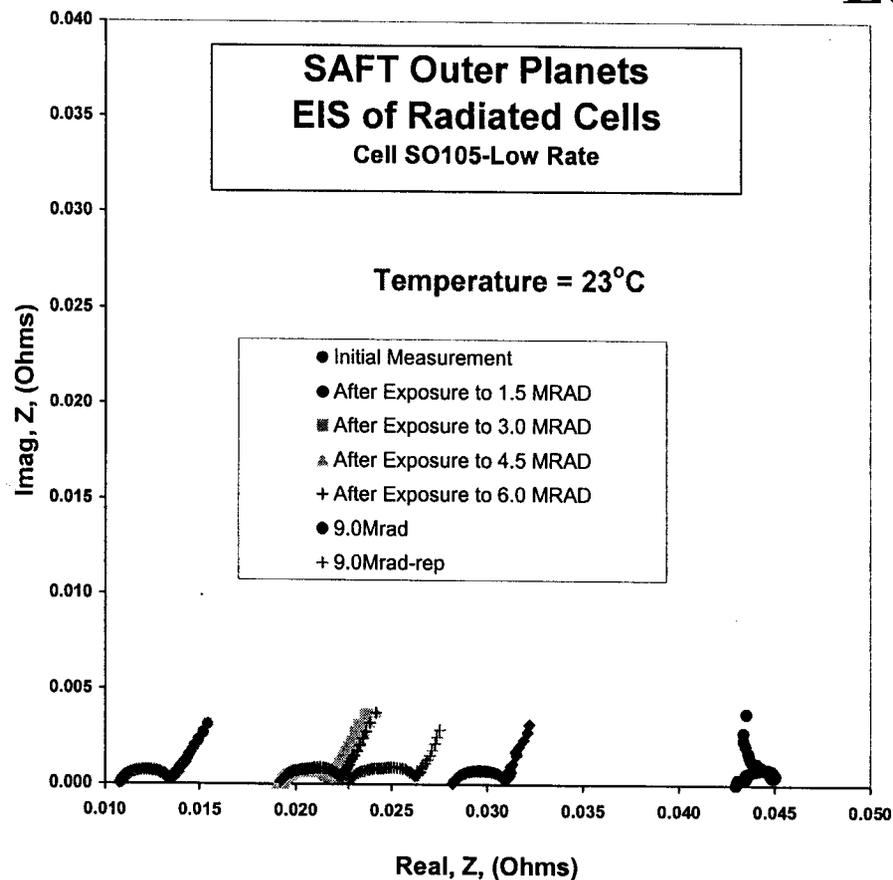
### High vs. Low Rate Dosage





# Electrochemical Impedance Spectroscopy

## Low Rate

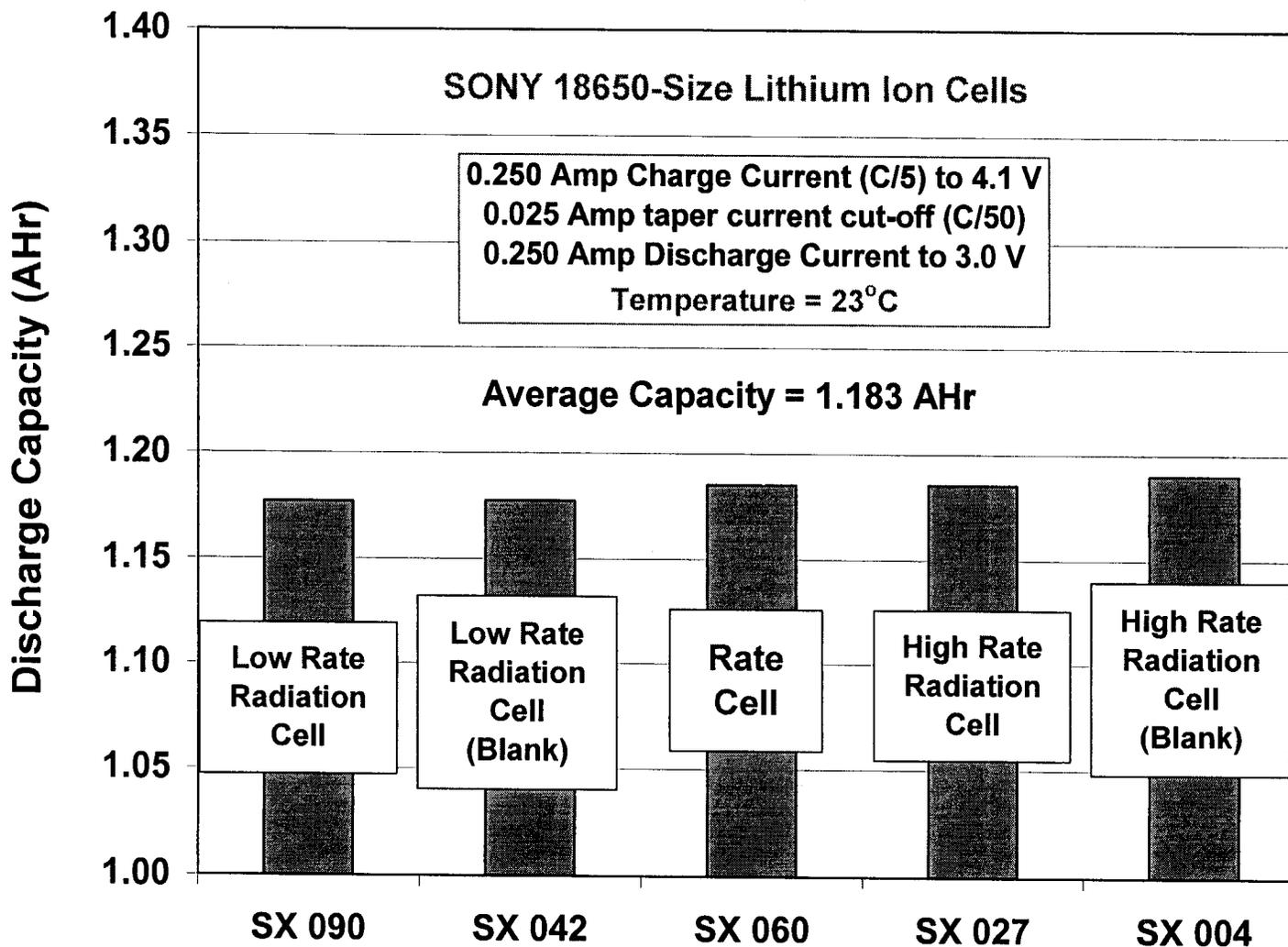


- Similar scatter in the impedance pattern, mainly increase in the series resistance, as in the high dose cells.
- EIS measurements/interpretation may be difficult when the case is polarized (-ve terminal).



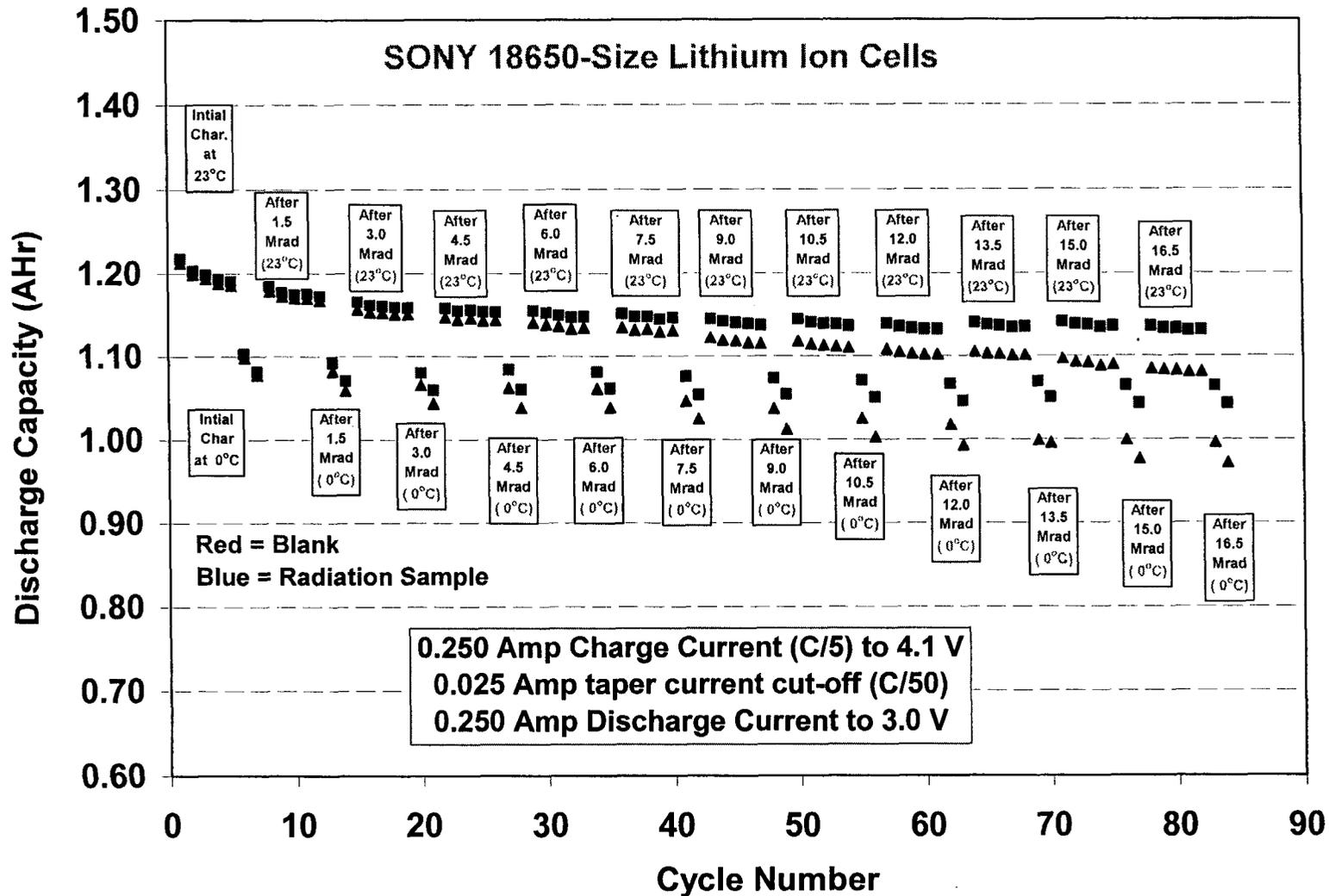


# SONY 18650-Size (1.2 Ahr) Lithium-Ion Cells (AEA) Effect of Radiation Upon Cell Performance ( $^{60}\text{Co}$ $\gamma$ -rays) Test Assignment



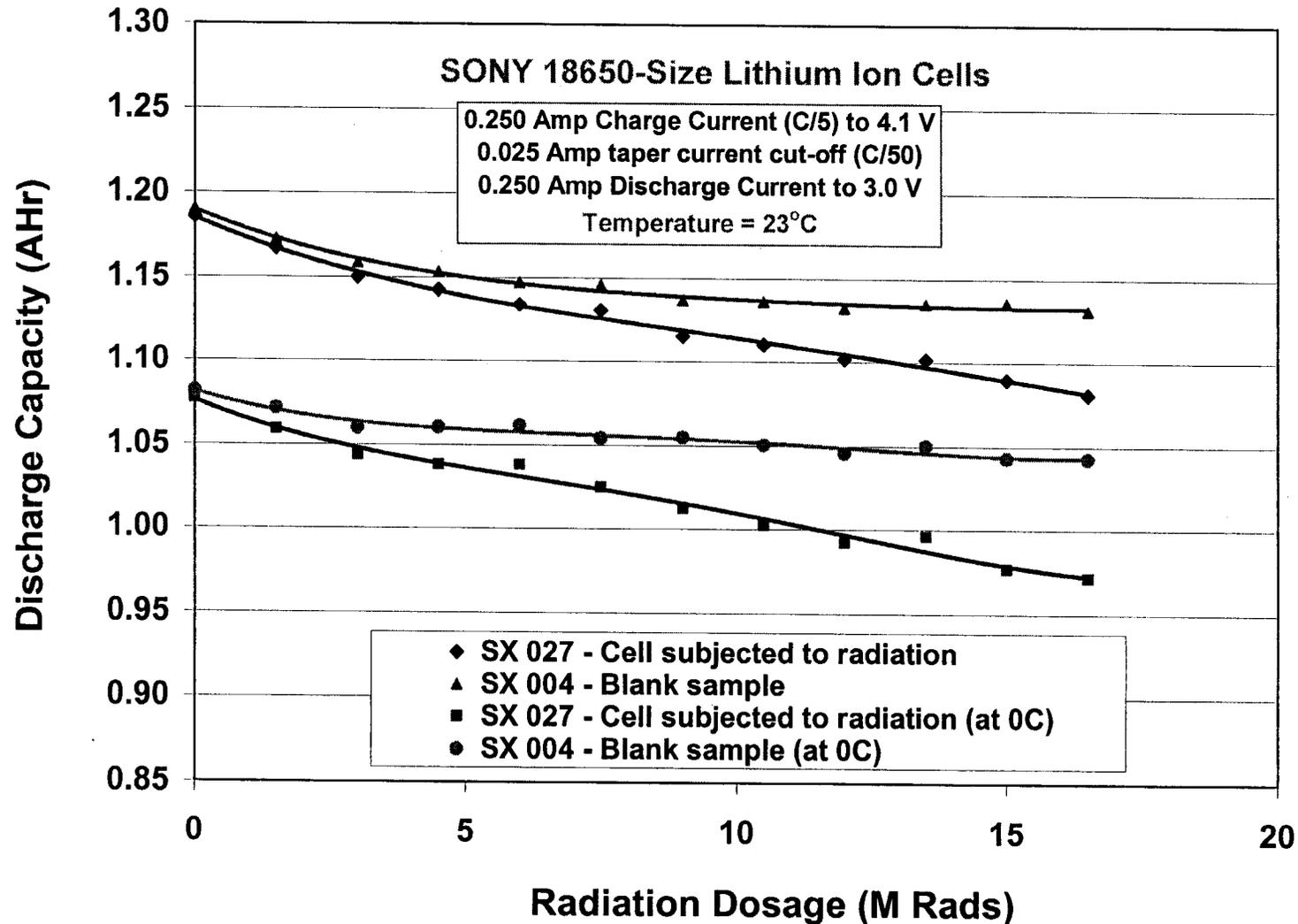


# SONY 18650-Size (1.2 Ahr) Lithium-Ion Cells (AEA) Effect of Radiation Upon Cell Performance ( $^{60}\text{Co}$ $\gamma$ -rays) High Rate Radiation Test (Test Sample vs. Blank)



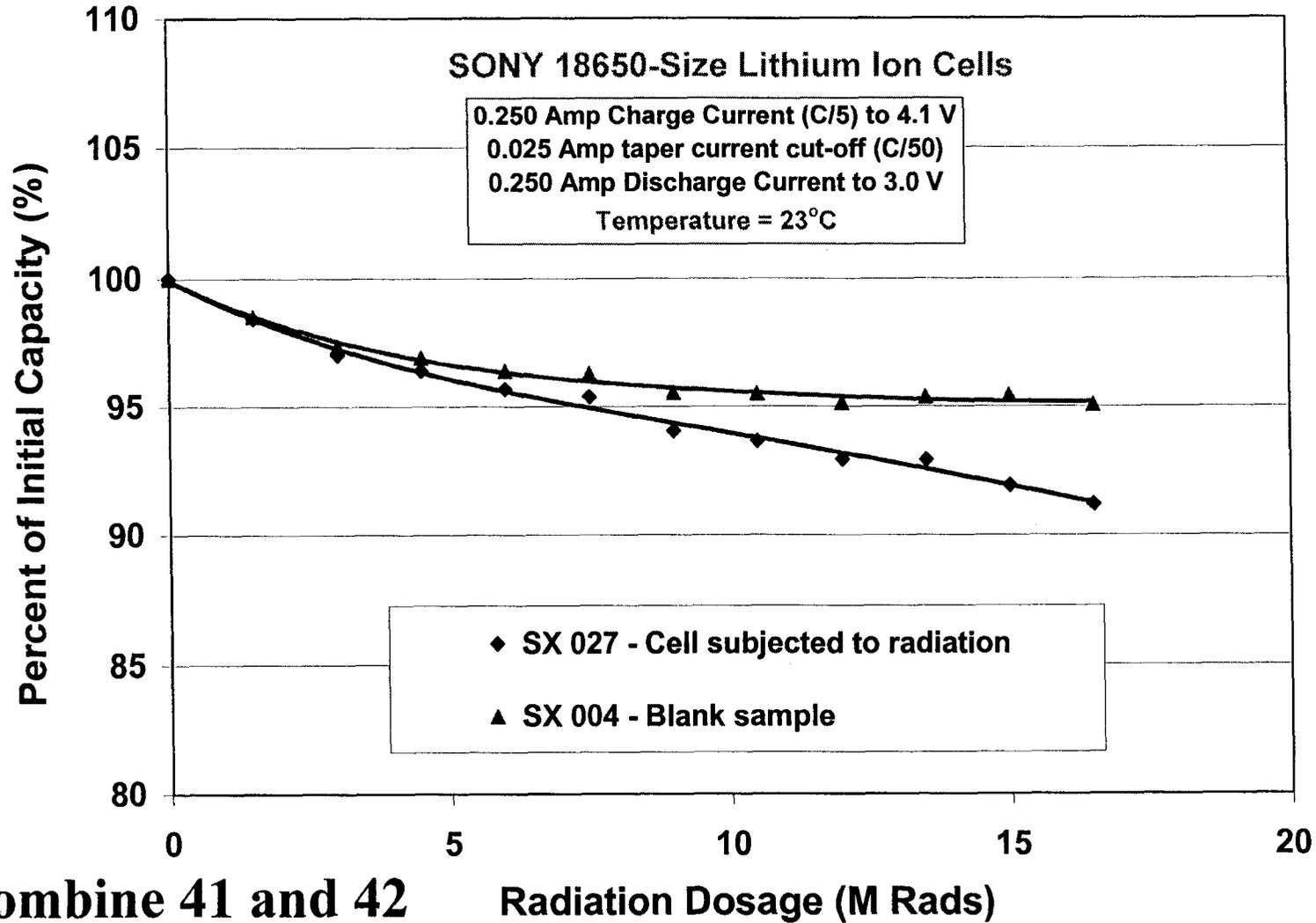


# SONY 18650-Size (1.2 Ahr) Lithium-Ion Cells (AEA) Effect of Radiation Upon Cell Performance ( $^{60}\text{Co}$ $\gamma$ -rays) High Rate Cell - Reversible Capacity (23°C)





# SONY 18650-Size (1.2 Ahr) Lithium-Ion Cells (AEA) Effect of Radiation Upon Cell Performance ( $^{60}\text{Co}$ $\gamma$ -rays) High Rate Cell - Reversible Capacity (23°C)

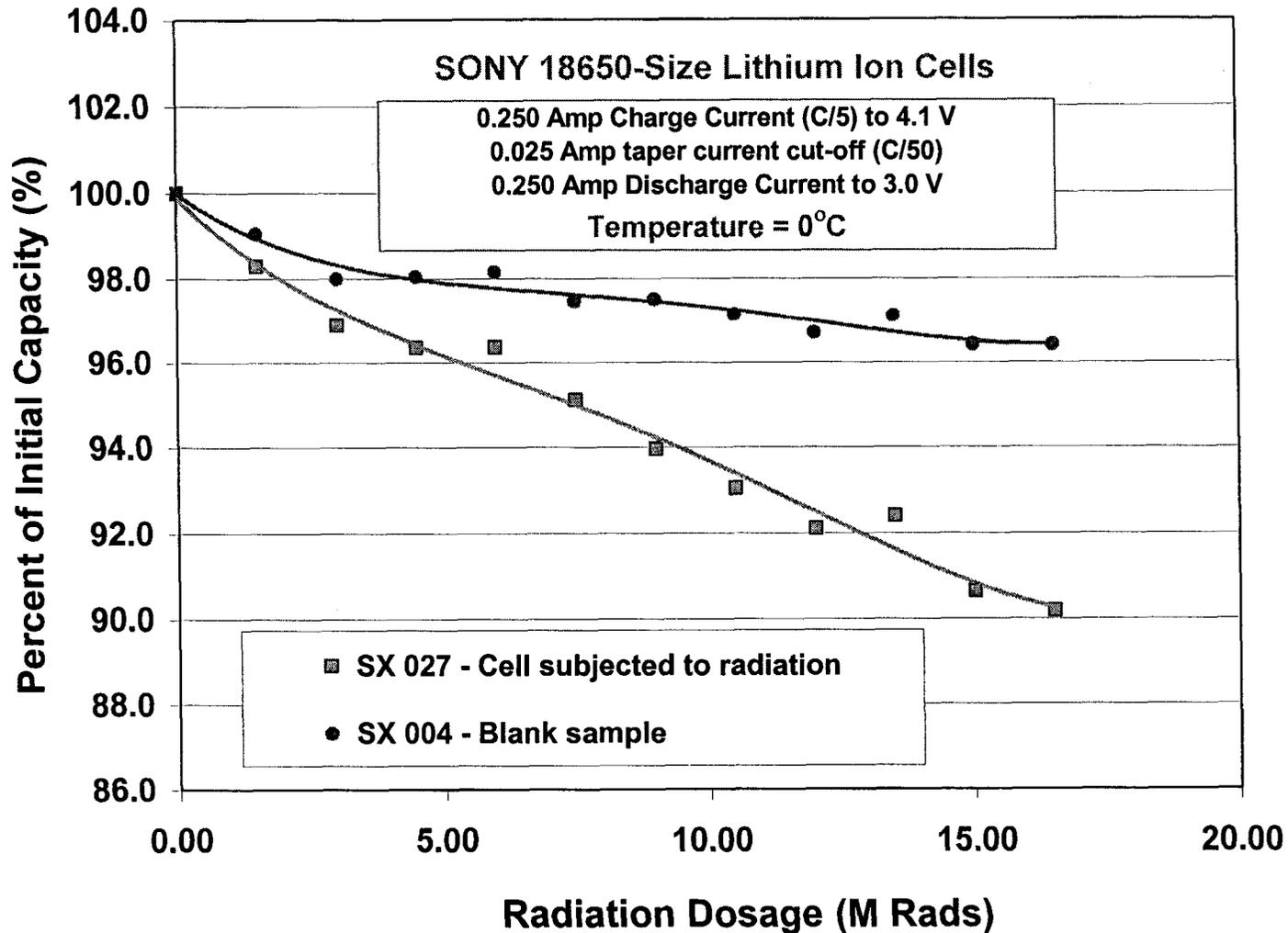


Combine 41 and 42

Radiation Dosage (M Rads)

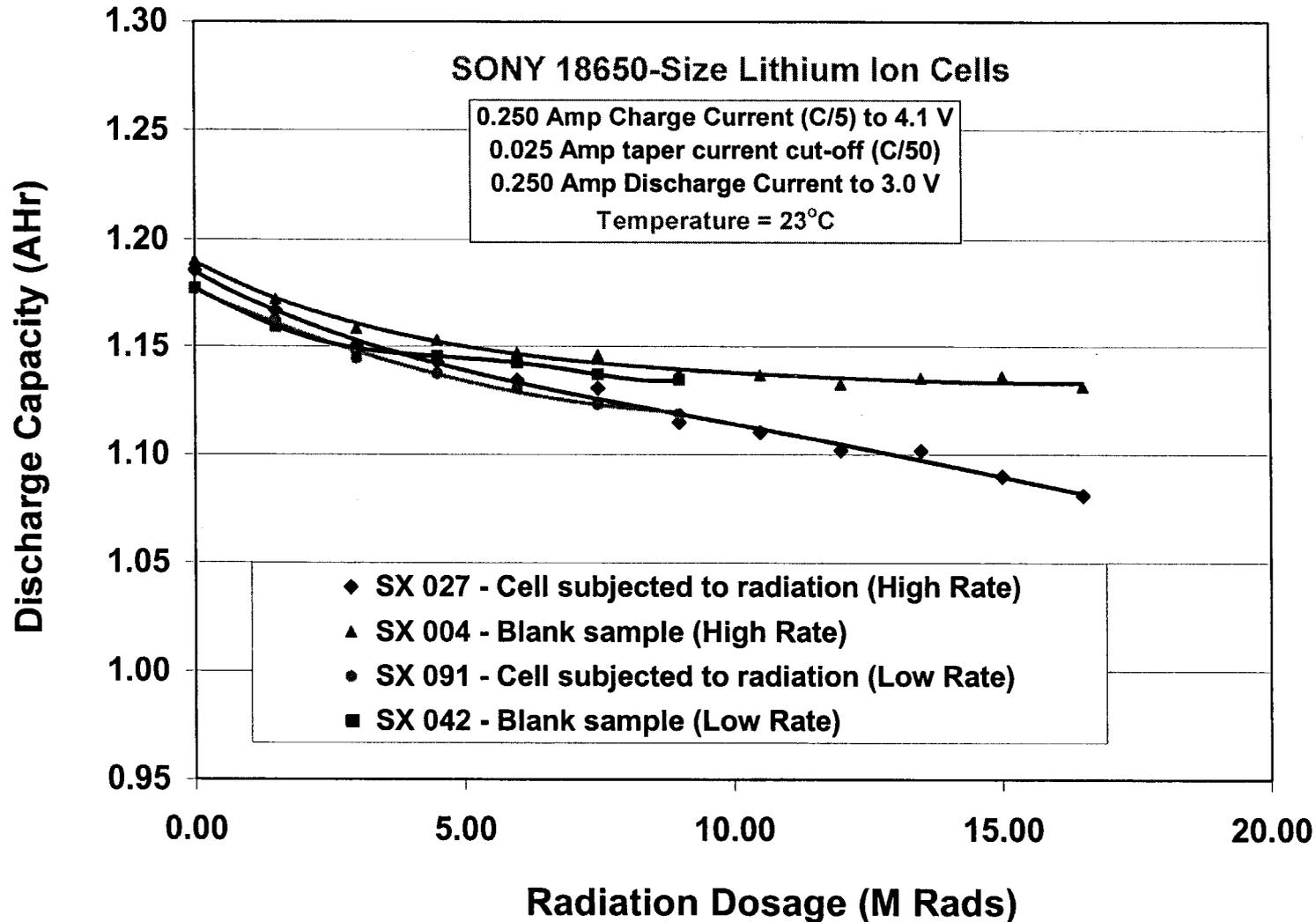


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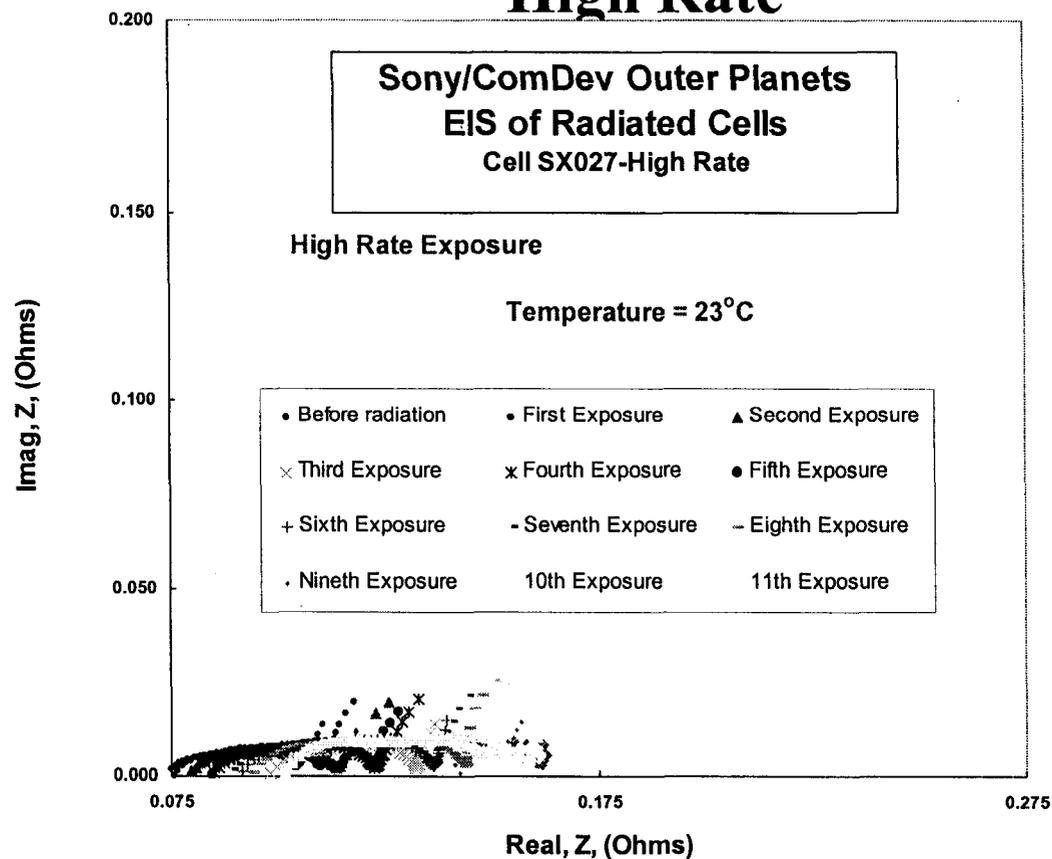
# SONY 18650-Size (1.2 Ahr) Lithium-Ion Cells (AEA) Effect of Radiation Upon Cell Performance ( $^{60}\text{Co}$ $\gamma$ -rays) Low Rate vs. High Rate Cell - Reversible Capacity (23°C)





# Electrochemical Impedance Spectroscopy

## High Rate



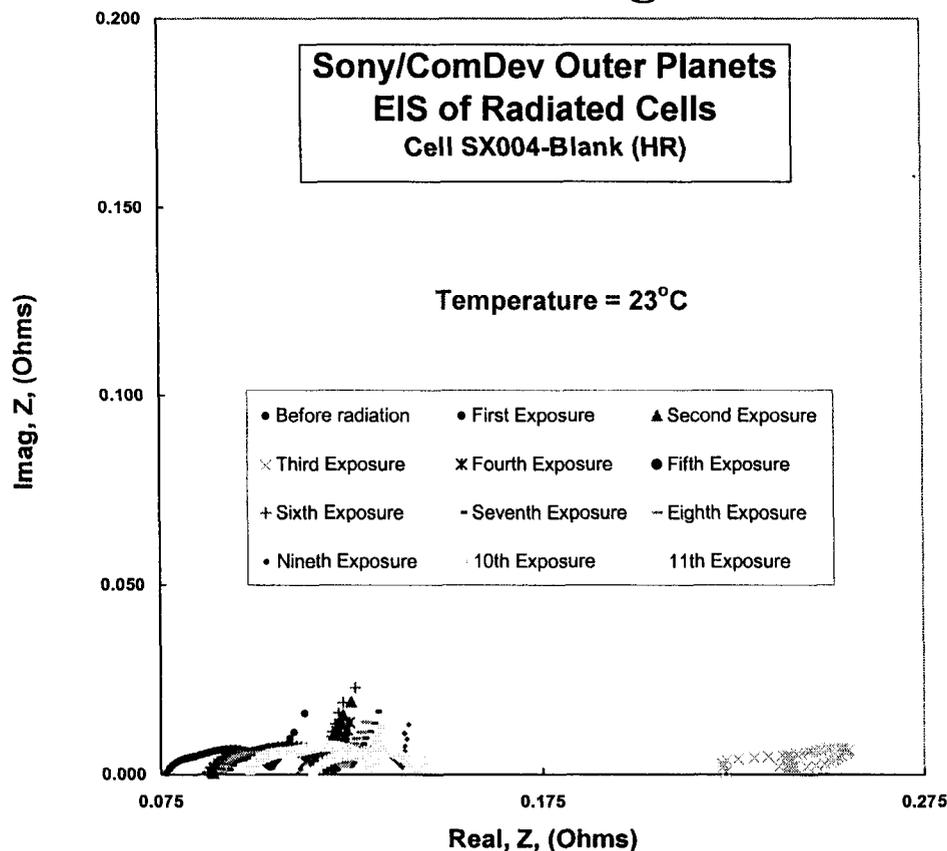
- Increase in the series resistance, may be related to the cell case being Scatter not as much as with SAFT cells .
- The low frequency impedance (attributed to the cathode kinetics) appears be unaffected by radiation exposure.





# Electrochemical Impedance Spectroscopy

## Control-High Rate



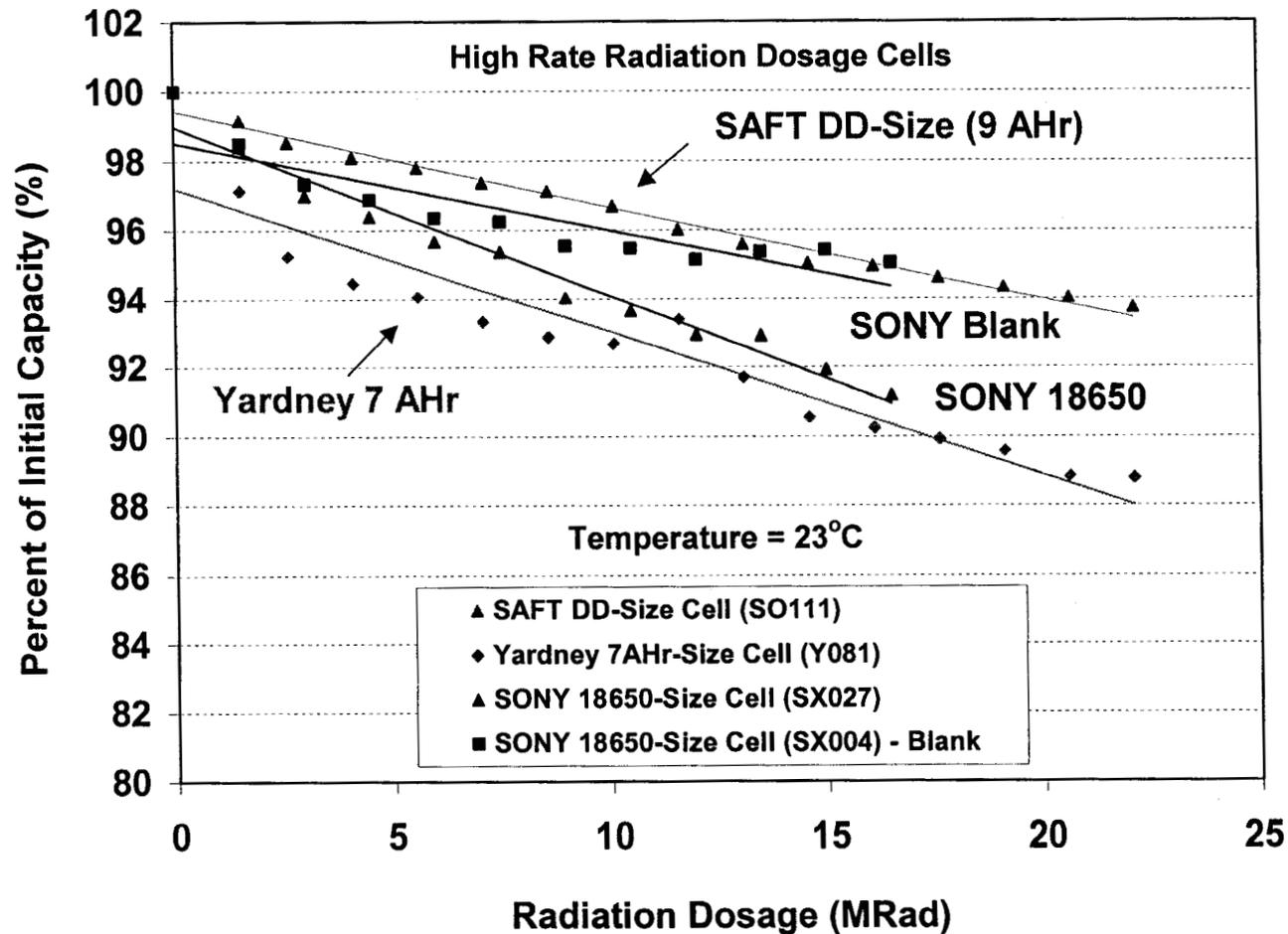
- Changes in the impedance pattern, more specifically on the series resistance are also observed in the control cell, which suggests that the performance decay on storage is significant compared to that occurring on  $\gamma$ -irradiation.



# Lithium-Ion Cells for Future Outer Planets Program Applications

## Effect of Radiation Upon Cell Performance (High Rate)

### Comparison of Cell Design/Vendor - Reversible Capacity at 23°C

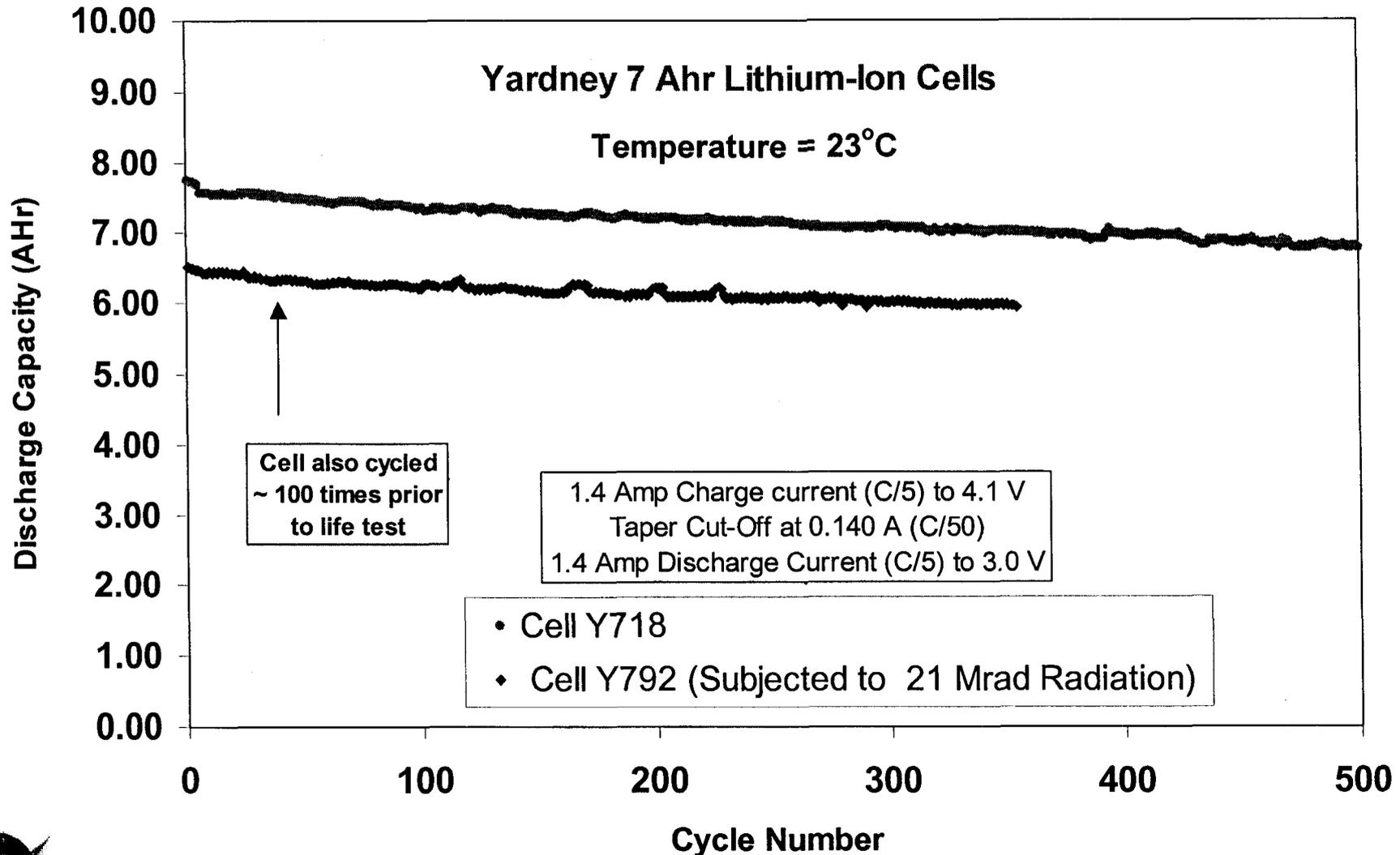




# Lithium-Ion Cells for Future Outer Planets Program Applications

## Effect of Radiation Upon Cell Performance (High Rate)

### Post-radiation cycling of Yardney Cells at 100% DOD

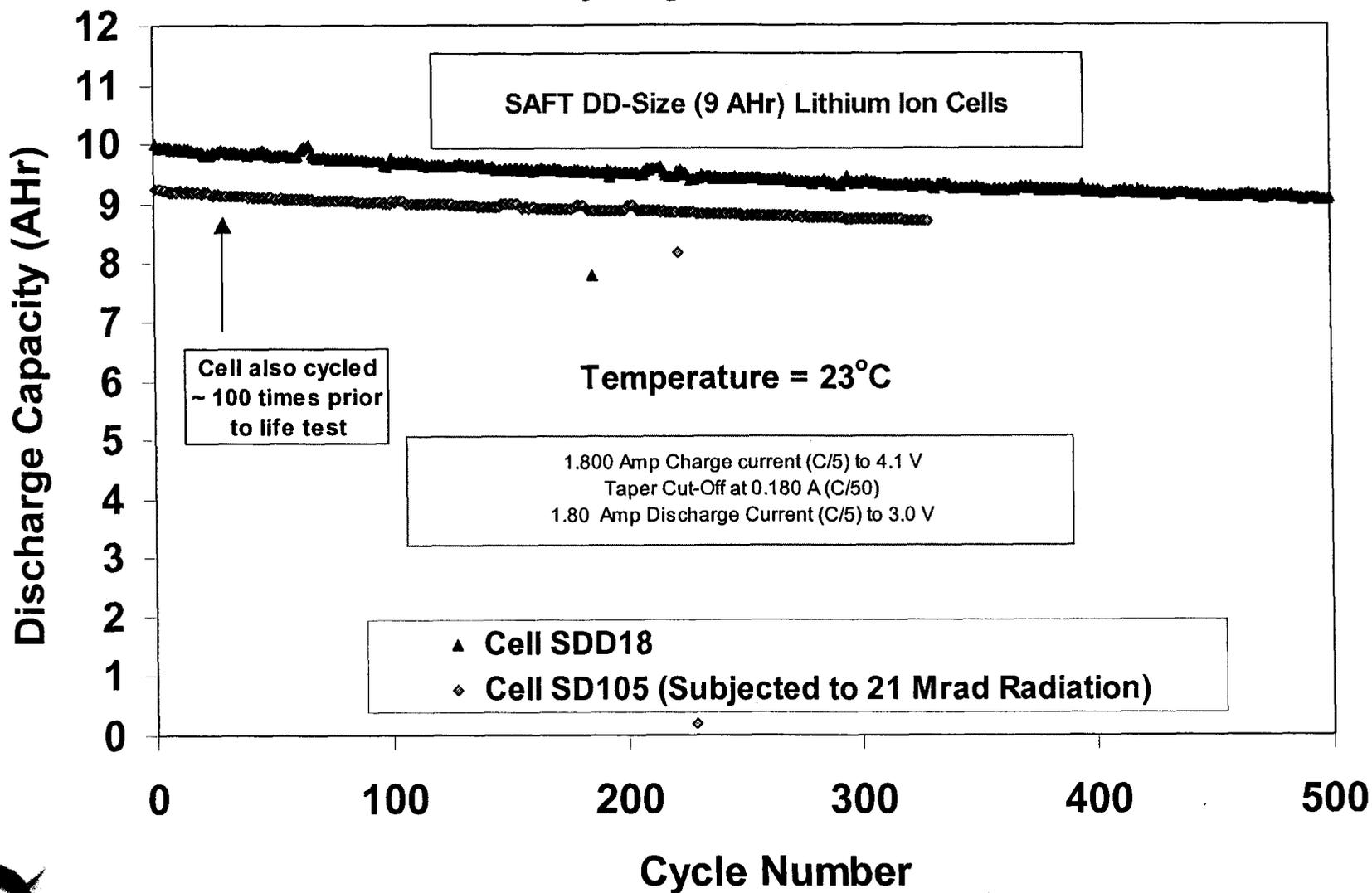




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## Effect of Radiation Upon Cell Performance (High Rate)

### Post-radiation cycling of SAFT cells at 100% DOD

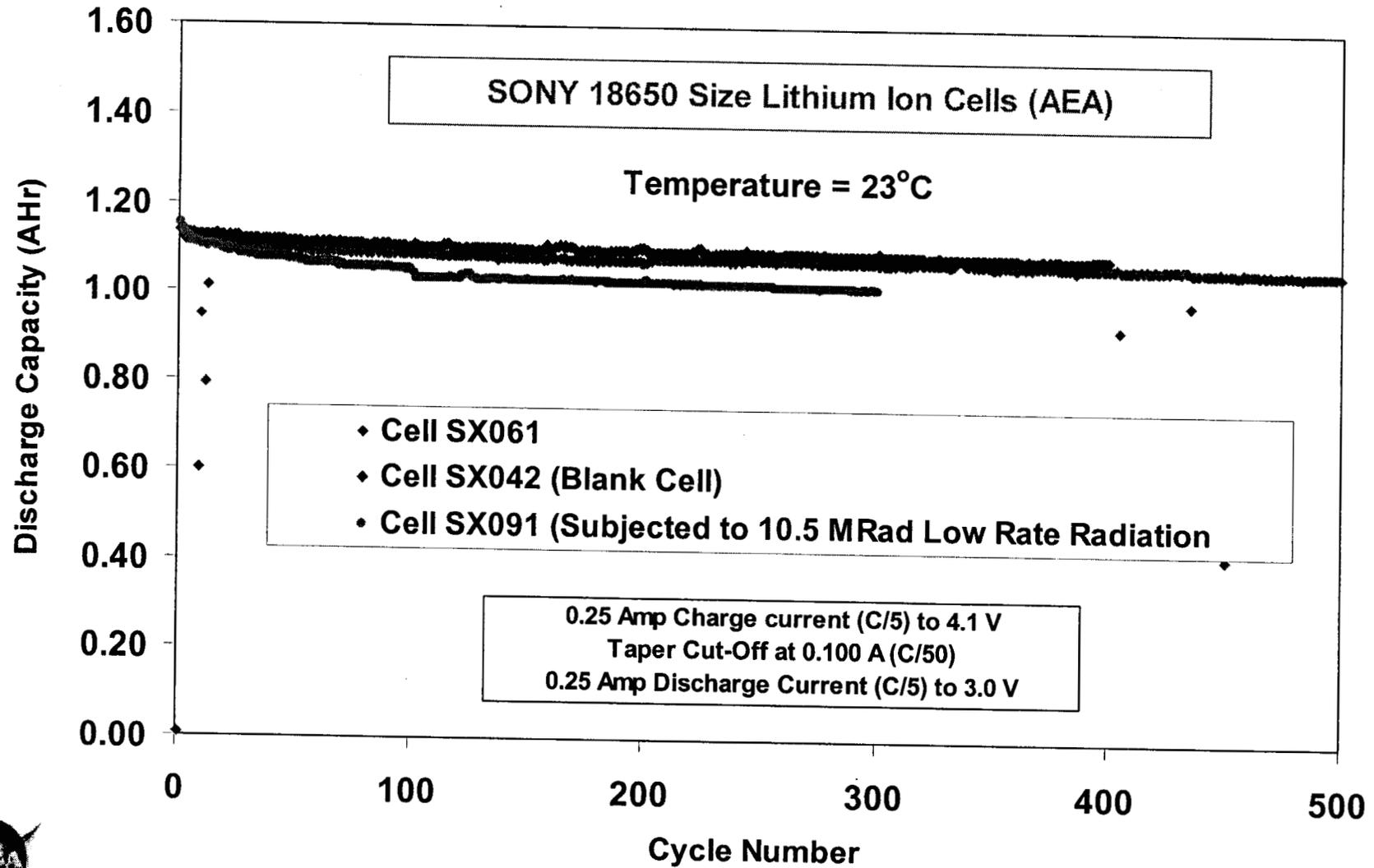




# Lithium-Ion Cells for Future Outer Planets Program Applications

## Effect of Radiation Upon Cell Performance (High Rate)

### Post-radiation cycling of Sony/Comdev cells at 100% DOD





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## Summary and Conclusions

- **Li ion prototype cells have been subjected to Co-60 radiation exposure to dosage levels exceeding 20 Mrad.**
- **Lithium ion cells sustain mild capacity loss, more noticeably in low temperature discharges.**
  - **Capacity loss is independent of the dosage rate**
  - **Control tests performed on the Sony/Comdev/AEA cells reveal that a significant portion of the capacity loss is due to storage, rather than irradiation, at least until the first 5 exposures.**
  - **Among the three types of cells tested, i.e., Yardney Prismatic 7 Ah cells, SAFT DD cylindrical 9 Ah cells and Sony/Comdev/AEA 18650 cells, SAFT cells have the highest tolerance followed by Sony and Yardney.**
  - **Post-radiation cycling show of Yardney, SAFT and Sony/Comdev cells show no ill effects of radiation on capacity fade rate.**





# Acknowledgments

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