Super NiCd Open-Circuit Storage and Low Earth Orbit (LEO) Life Test Evaluation

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Background

- Super NiCd cells studied as potential replacement for existing conventional NiCd designs in Air Force programs
  - Lack of Air Force test data on larger cell sizes
  - Handling and storage required active charging
- 50 Ah cells manufactured by Eagle-Picher/Colorado Springs
    - Advanced cell design with improved separator material and electrode making processes
    - Used in several NASA and commercial programs
        - Handling and storage required active charging
    - Three 5-cell packs on test with variations in temperature
        - Initial open-circuit periods to simulate worst case handling
        - Life tests follow characterization and charged

Background (Cont'd)

  - open-circuit storage
  - NASA funded testing at Crane/NSWC (as part of a joint NASA/Air Force program)
- Purpose of testing
  - To evaluate the impact of various periods of charged, open-circuit storage on the initial and cycle life performance
  - To evaluate the life capabilities for generic cell qualification in Air Force programs

Test Plan

- Initial characterization tests: 10°C, 20°C and 30°C capacity; 0°C overcharge; and 20°C impedance, charge retention, charge efficiency and 24 hour voltage recovery
- Charged, open-circuit storage tests:
  - Pack 1 (Lot 3) stored at 1, 2 and 3 months at 20°C
  - Pack 2 (Lot 3) stored at 1, 2 and 3 months at 0°C
  - Pack 3 (Lot 2) stored at 1, 2, 3 and 6 months at 0°C
  - 20°C and 0°C capacities measured prior to first storage period and after each storage period
- Post storage characterization tests (same as initial)
- Accelerated LEO life tests at 40% DoD
  - Pack 1 at 20°C
  - Packs 2 and 3 at 0°C

Initial Characterization Tests

- The average cell values - pre storage tests:
  (in Ah, unless otherwise noted)

	10°C	20°C	30°C	0°C Ovch.	20°C Imp.	20°C Ch Ret
Pack 1	55.6	52.5	52.3	57.7	52.0	91.2%
Pack 2	54.9	52.0	51.2	56.5	51.6	90.2%
Pack 3	48.3	49.1	49.7	48.2	49.2	88.2%

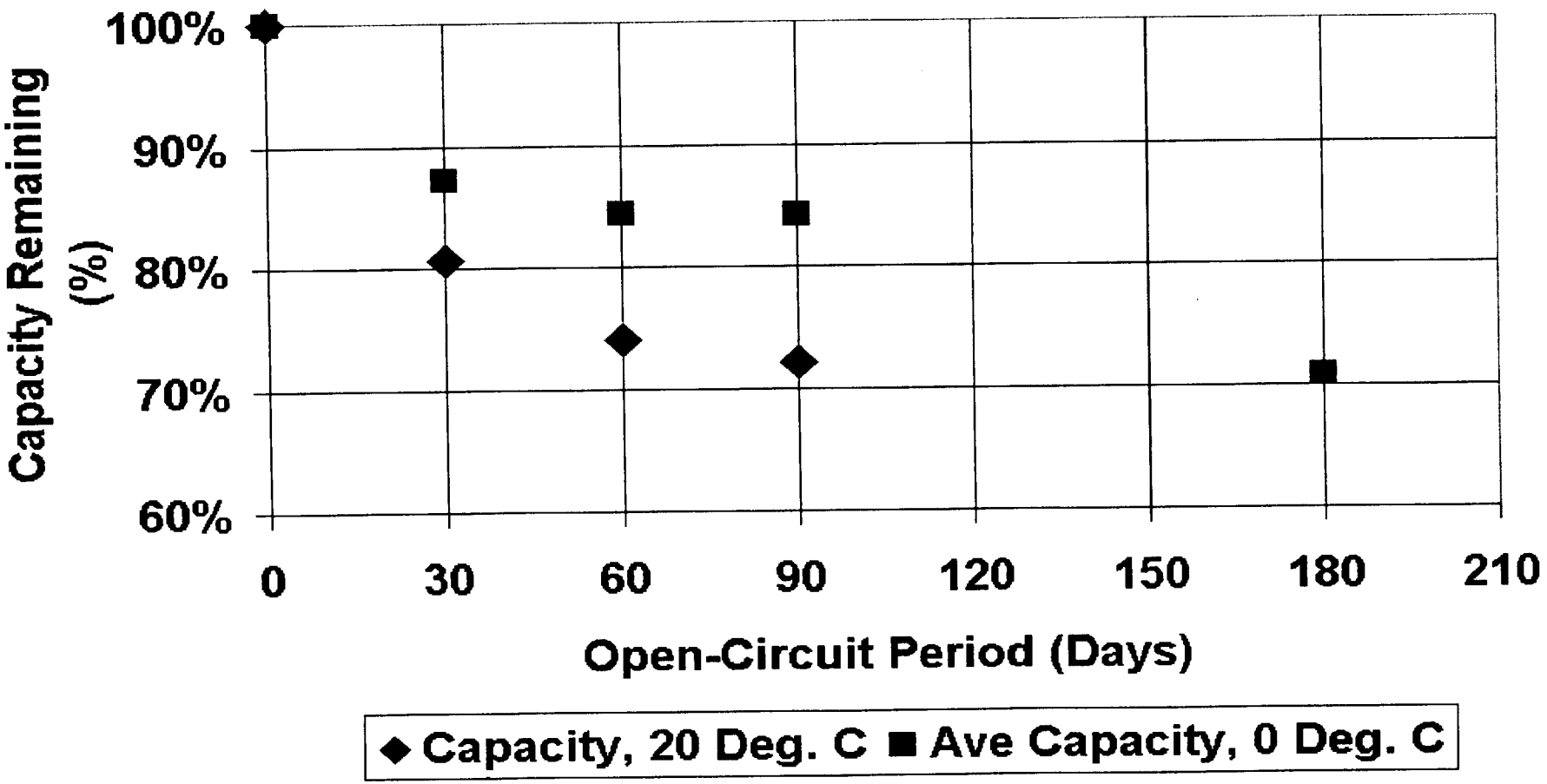
Open-Circuit Storage Tests

- Comparison of capacities after charged, open-circuit stand to their pre-30-day open-circuit values:
  - Pack 1 at 20^{0}C: 80.7% after 30-day-period to 72.1% after 90-day-period
  - Pack 2 at 0^{0}C: 88.9% after 30-day-period to 85.4% after 90-day-period
  - Pack 3 at 0^{0}C: 85.6% after 30-day-period to 70.9% after 180-day-period
  - Ave capacity at 0^{0}C: 87.3% after 30-day-period to 70.9% after 180-day-period

Open-Circuit Storage Tests

- Comparison of capacities after charged, open-circuit stand to their pre-30-day open-circuit values:
  - Pack 1 at 20°C: 80.7% after 30-day-period to 72.1% after 90- day period
  - Pack 2 at 0°C: 88.9% after 30-day-period to 85.4% after 90-day period
  - Pack 3 at 0°C: 85.6% after 30-day-period to 83.0% after 90-day period to 70.9% after 180-day period
  - Ave capacity at 0°C: 87.3% after 30-day-period to 84.2% after 90-day period to 70.9% after 180-day period

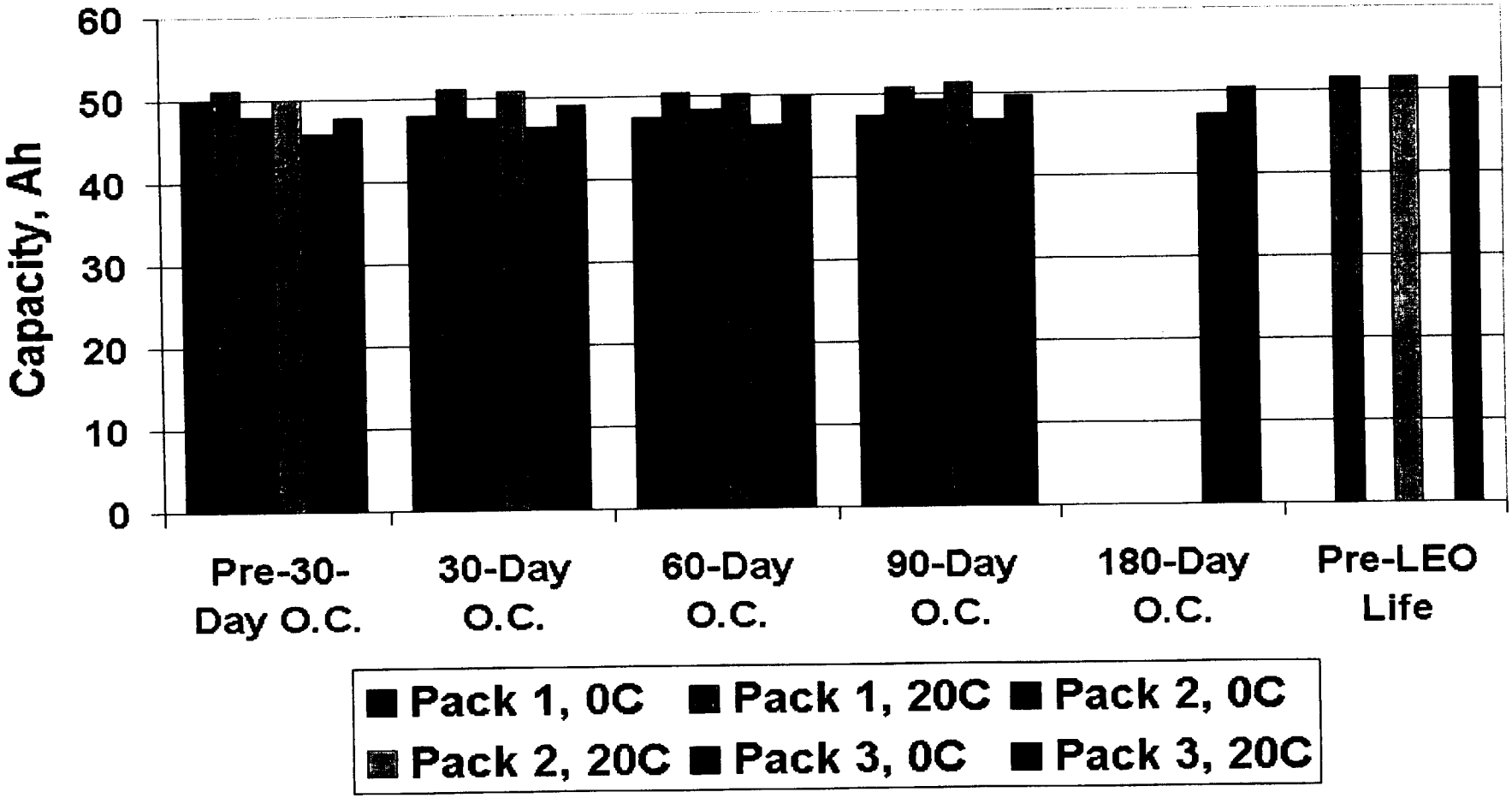
Capacity after Charged, Open-Circuit Periods



Open-Circuit Storage Tests (Cont'd)

- 0°C and 20°C capacities post open-circuit storage:
  - There is generally a small decrease in capacities post 20°C open-circuit storage (Pack 1)
    - Within 3 Ahrs of pre-30-day storage values
  - Generally, there is a slight increase in capacities post 0 °C open-circuit storage (Pack 2)
    - Within 1.5 Ahrs of pre-30-day storage values
  - There is a small increase in capacities post 0°C open-circuit storage (Pack 3)
    - Within 3 Ahrs of pre-30-day storage values
- Long term impacts need to be assessed

0°C and 20°C Pack Capacities



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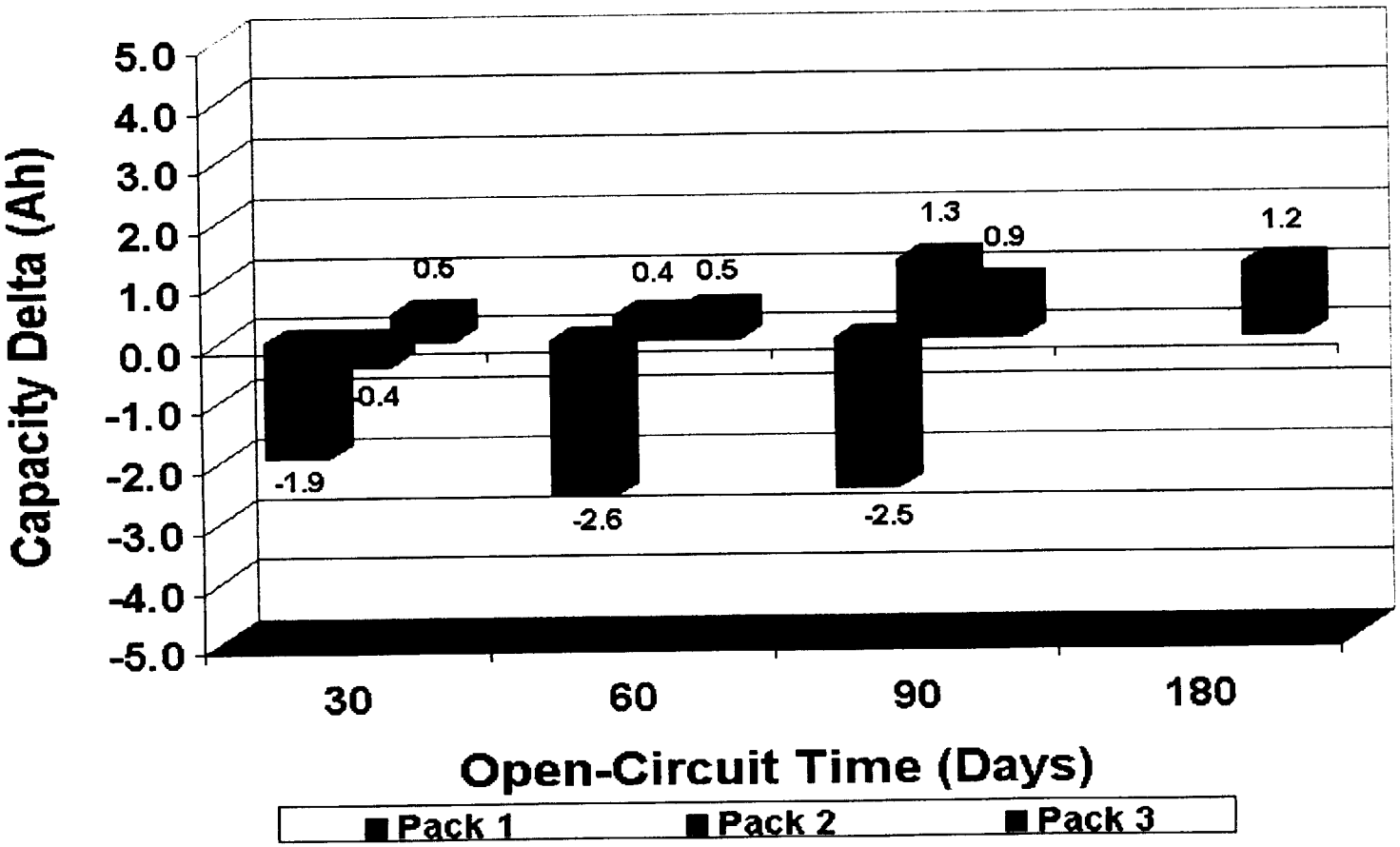
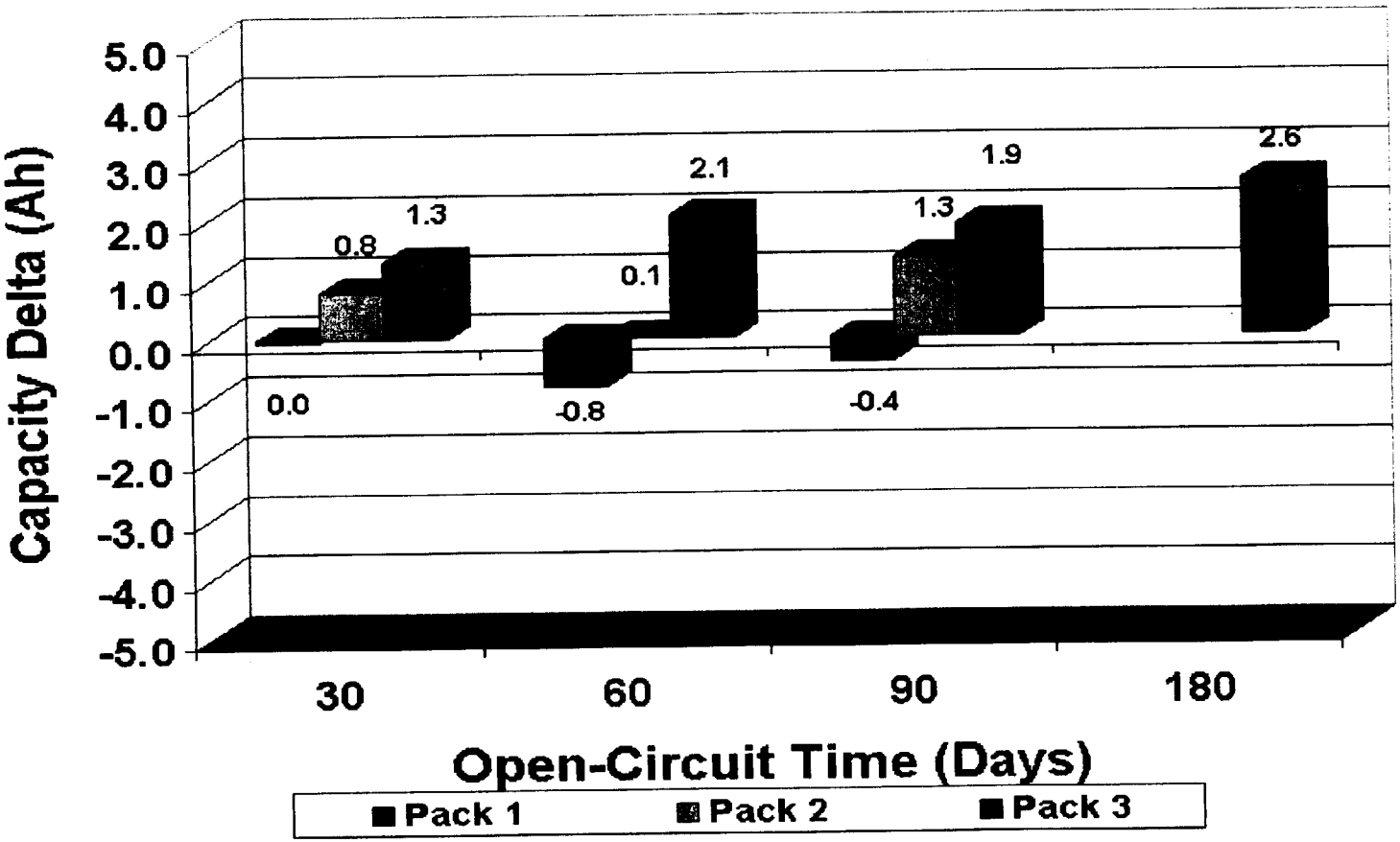
Change in Post Storage Capacity at 0°C With Reference to Pre-30-Day Storage Capacities



Change in Post Storage Capacity at 20°C With Reference to Pre-30-Day Storage Capacities



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Post Storage Characterization Tests

- The average cell values - post storage tests:
  (in Ah, unless otherwise noted)

	10°C	20°C	30°C	0°C Ovch.	20°C Imp.	20°C Ch Ret
Pack 1	51.1	51.6	52.3	50.1	51.3	88.8%
Pack 2	53.5	51.5	51.5	53.4	51.1	92.7%
Pack 3	51.6	51.4	51.9	50.9	51.1	89.6%

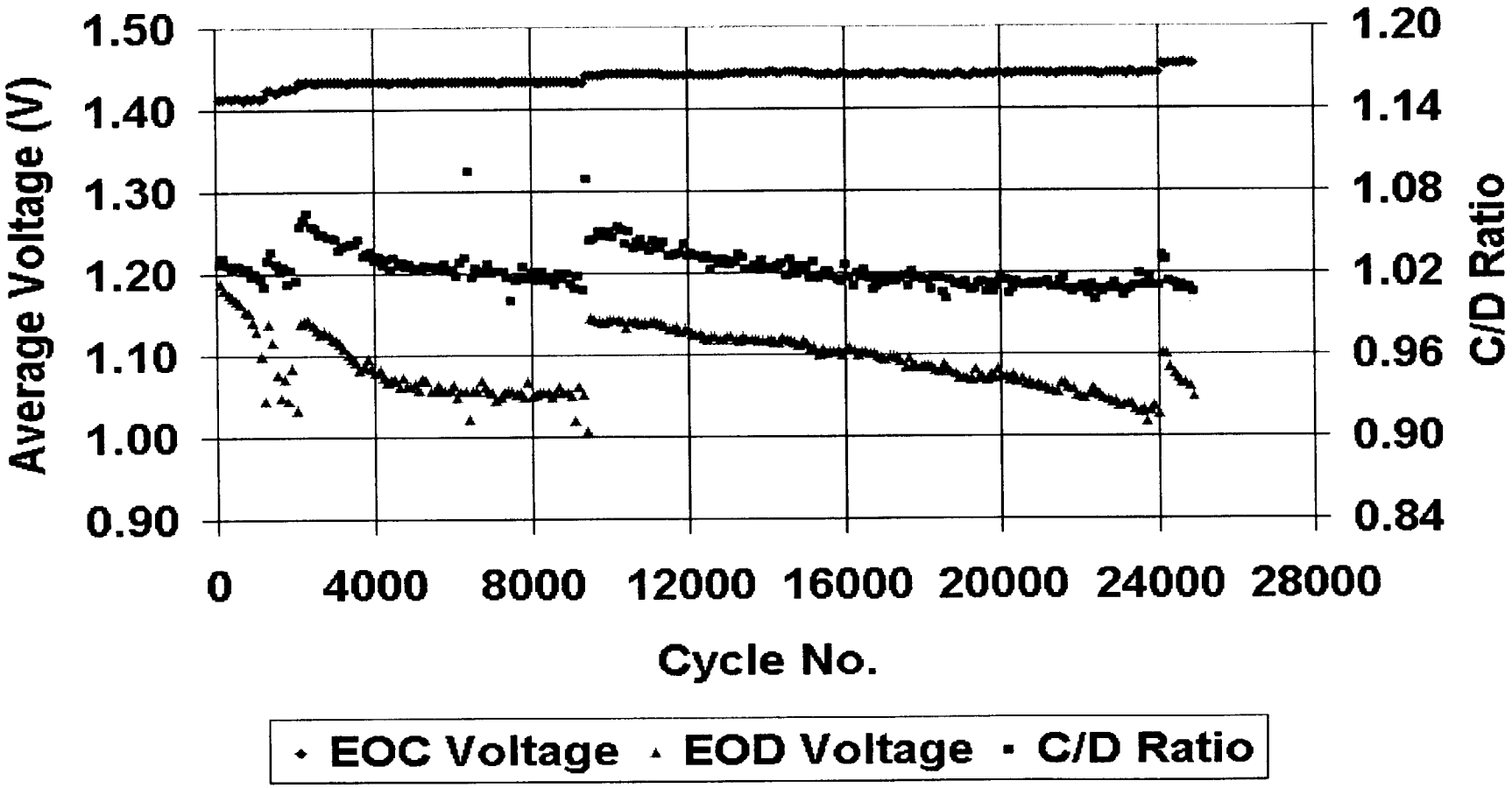
Post-Storage Accelerated LEO Life Tests

- For each of the three 5-cell packs, a life cycle simulates a 90-minute orbit
  - Discharge at 40 A for 0.5 hr, 40% DoD
    - Per initial test plan, failure defined as < 1.0 V/cell
  - Charge at a high-rate current of 40 A, followed by a taper charge for an hour of total duration.
    - Temperature-compensated V/T levels
- Pack 1 consists of five lot 3 cells
  - 20°C test started on 8/11/97
  - Initial V/T = 1.414 V/cell. Incrementally increased to current value of 1.454 V/cell during cycle 24088
    - Low EODVs

Post-Storage Accelerated LEO Life Tests (Cont'd)

- As of 2/8/02, 24900 cycles have been completed.
  - Average EOCV = 1.454 V
  - EOC cell voltage differential = 7.5 mV
  - C/D = 1.005
  - Average EODV = 1.050 V
  - EOD cell voltage differential = 19.2 mV

Pack 1: Average Voltage and C/D (Pre-Life Storage @ 20°C: 1, 2, 3 Mos.)



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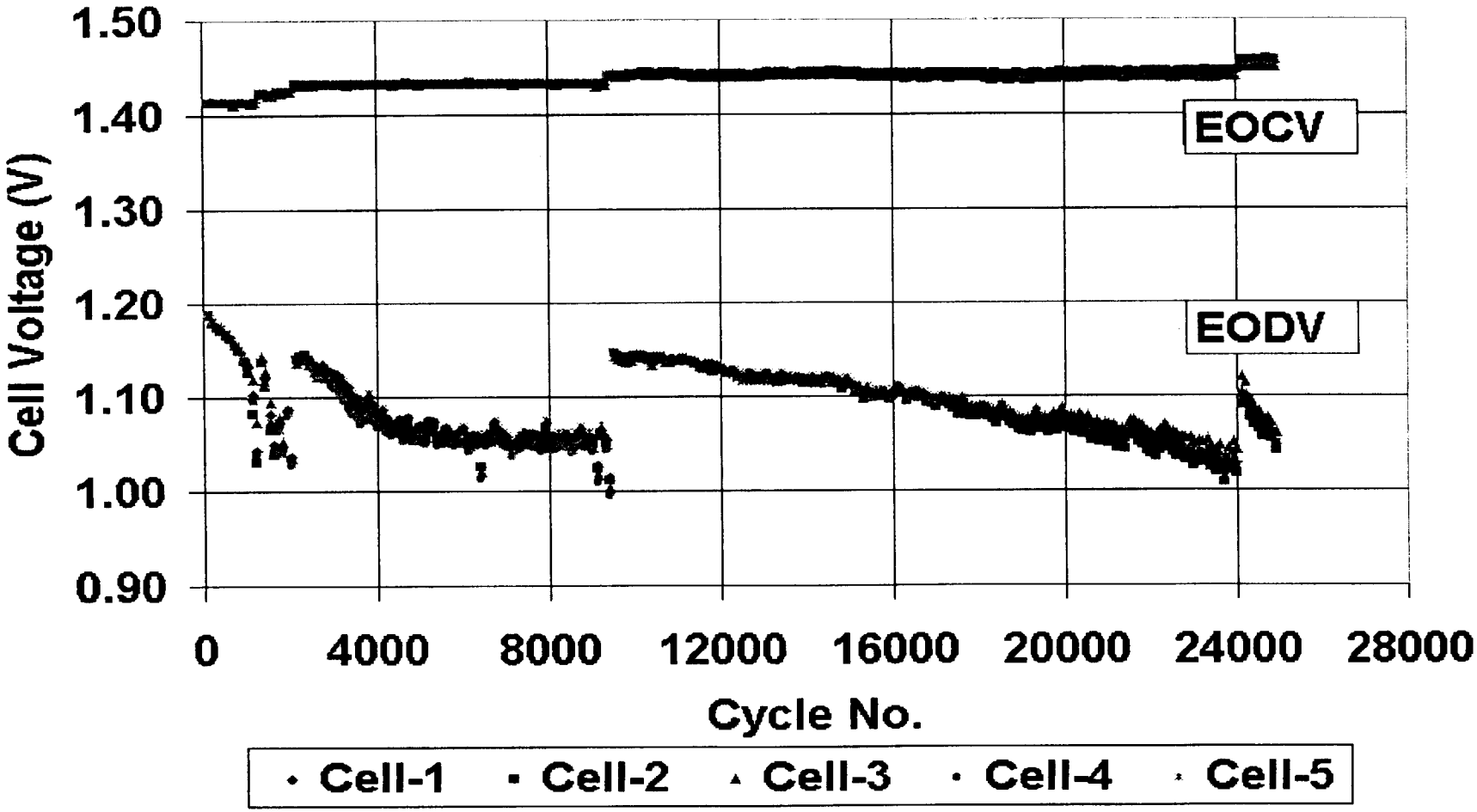
Pack 1: EOCV and EODV
(Pre-Life Storage @ 20°C: 1, 2, 3 Mos.)



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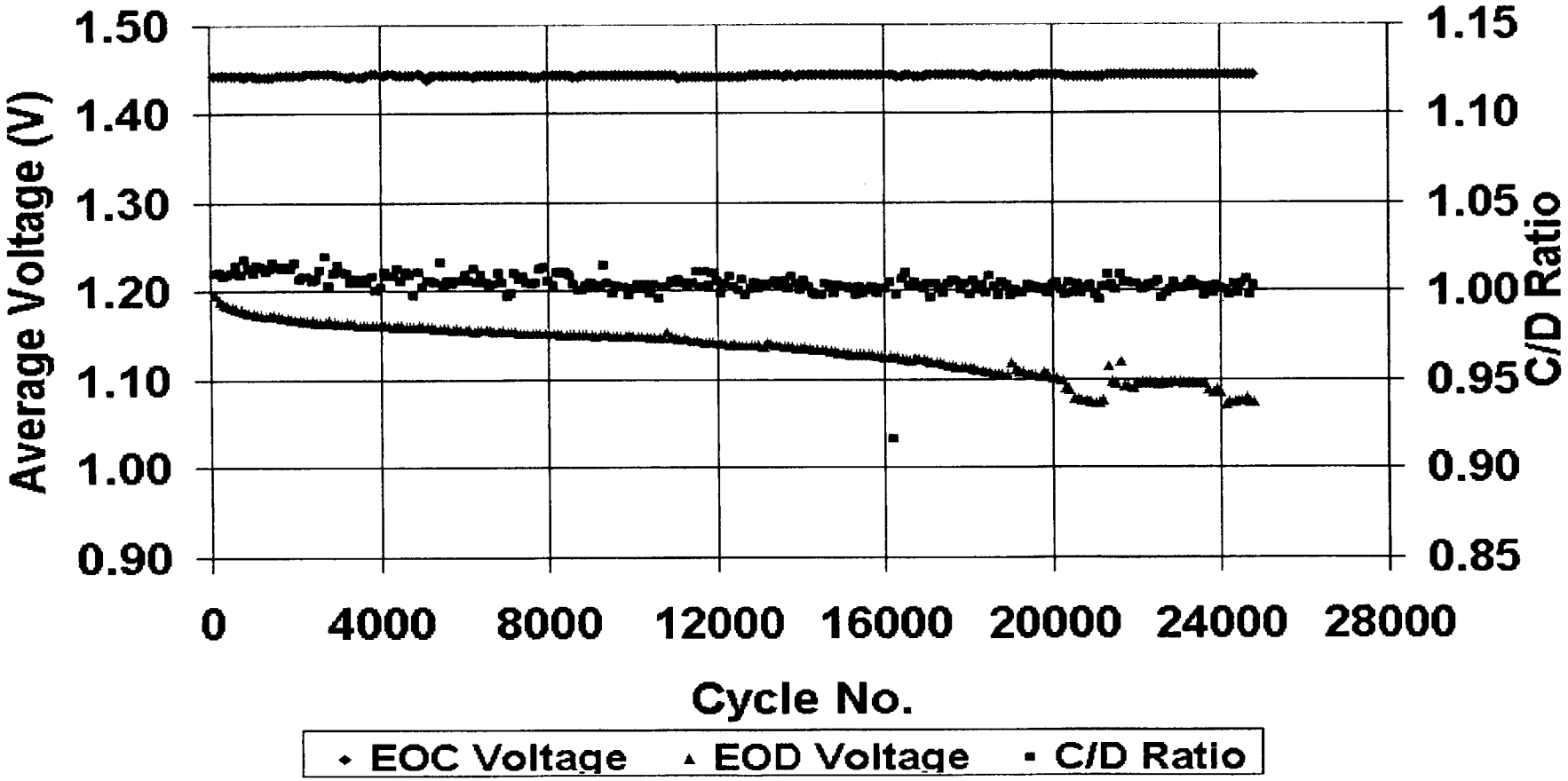
Post-Storage Accelerated LEO Life Tests (Cont'd)

- Pack 2 consists of five lot 3 cells
  - 0°C test started on 8/11/97
  - Initial V/T = 1.444 V/cell, which remains the current limit
  - As of 2/7/02, 24800 cycles have been completed.
    - Average EOCV = 1.443 V
    - EOC cell voltage differential = 2.0 mV
    - C/D = 1.003
    - Average EODV = 1.076 V
    - EOD cell voltage differential = 33.2 mV

Pack 2: Average Voltage and C/D (Pre-Life Storage @ 0°C: 1, 2, 3 Mos.)



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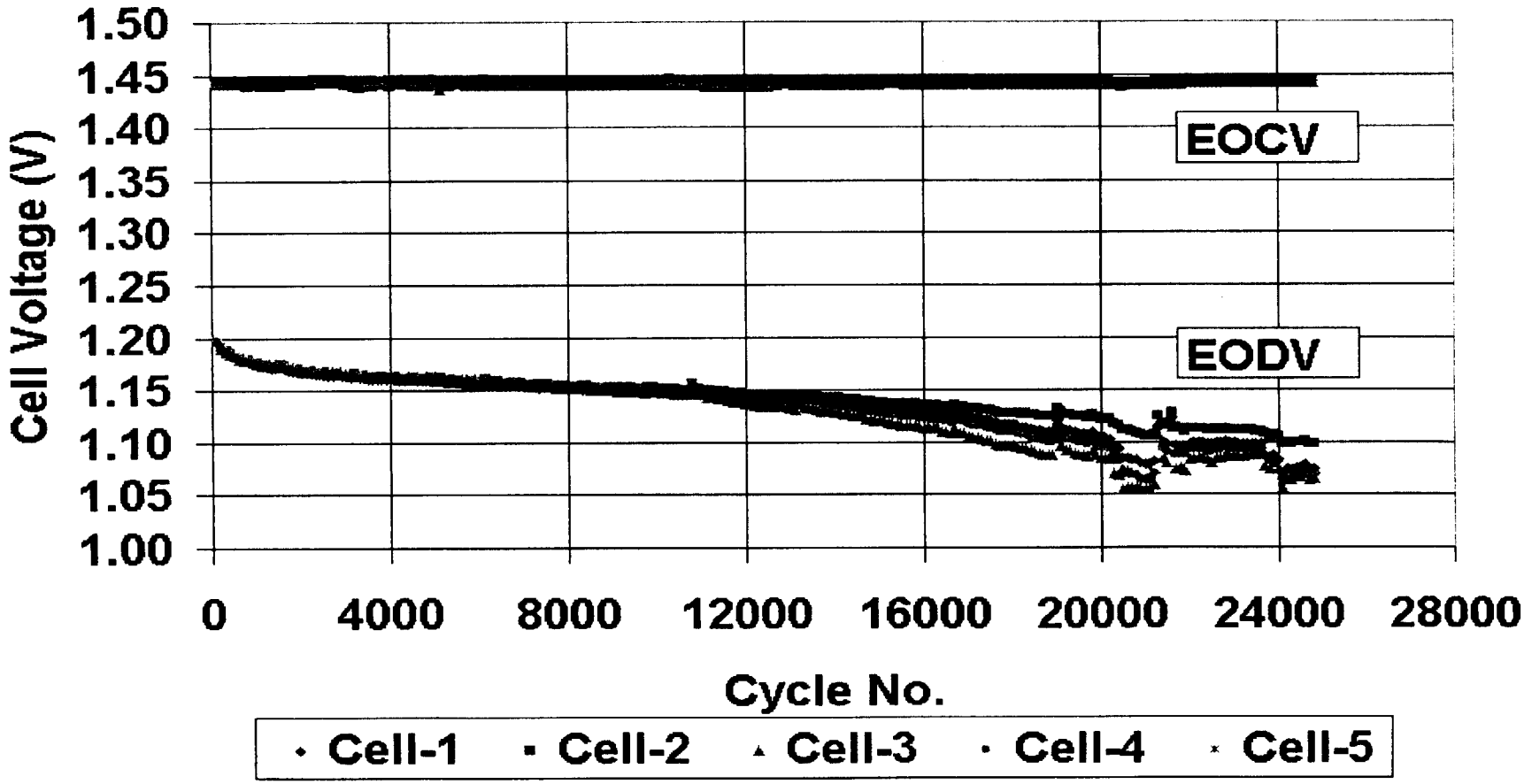
Pack 2: EOCV and EODV
(Pre-Life Storage @ 0°C: 1, 2, 3 Mos.)



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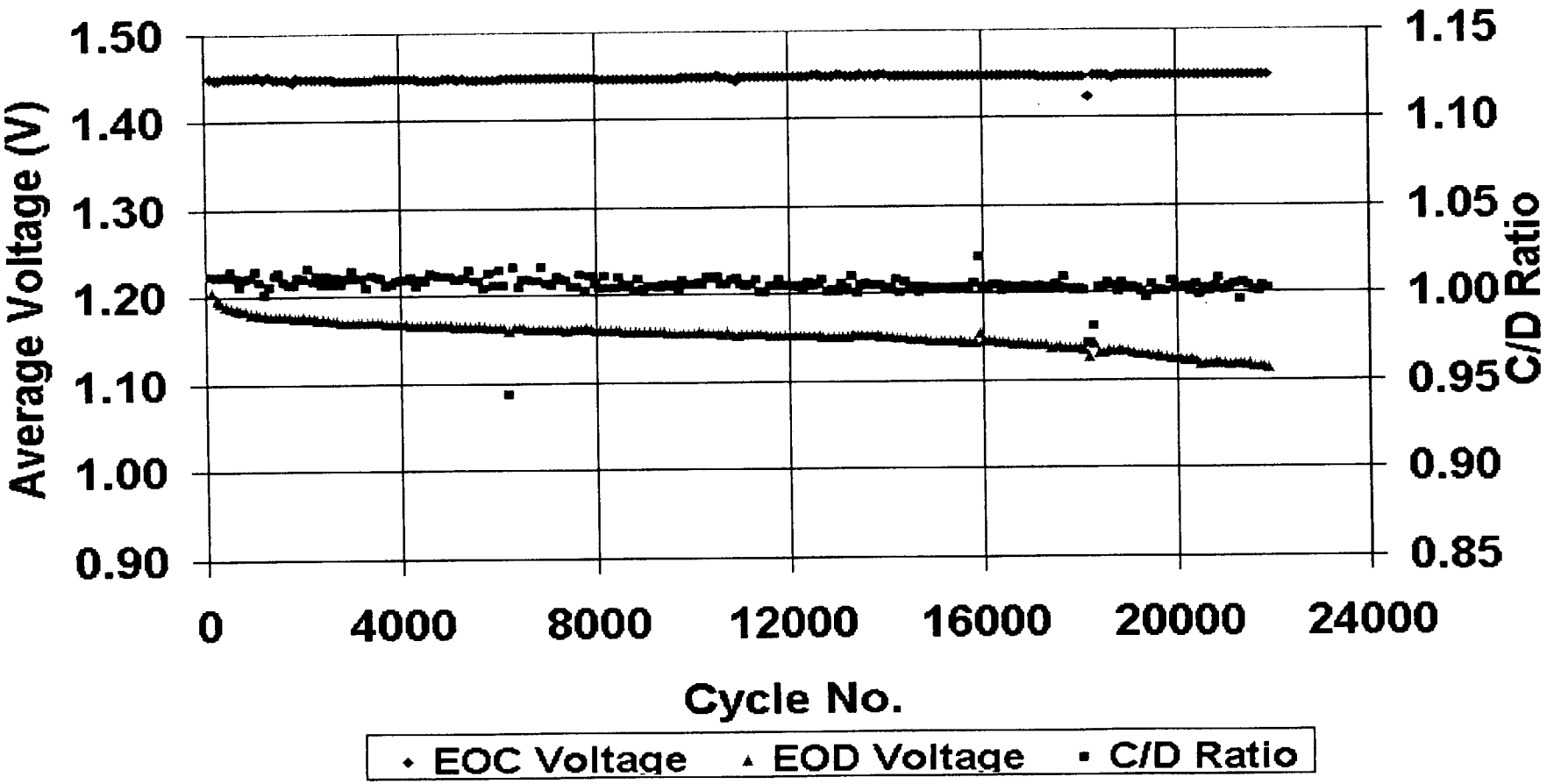
Post-Storage Accelerated LEO Life Tests (Cont'd)

- Pack 3 consists of five lot 2 cells
  - 0°C test started on 2/17/98
  - Initial V/T = 1.444 V/cell. Increased to present value of 1.450 V/cell during cycle 81
    - Recharge close to, but less than, 100%
  - As of 2/9/02, 21900 cycles have been completed.
    - Average EOCV = 1.449 V
    - EOC cell voltage differential = 3.2 mV
    - C/D = 1.002
    - Average EODV = 1.115 V
    - EOD cell voltage differential = 28.0 mV

Pack 3: Average Voltage and C/D (Pre-Life Storage @ 0°C: 1, 2, 3, 6 Mos.)



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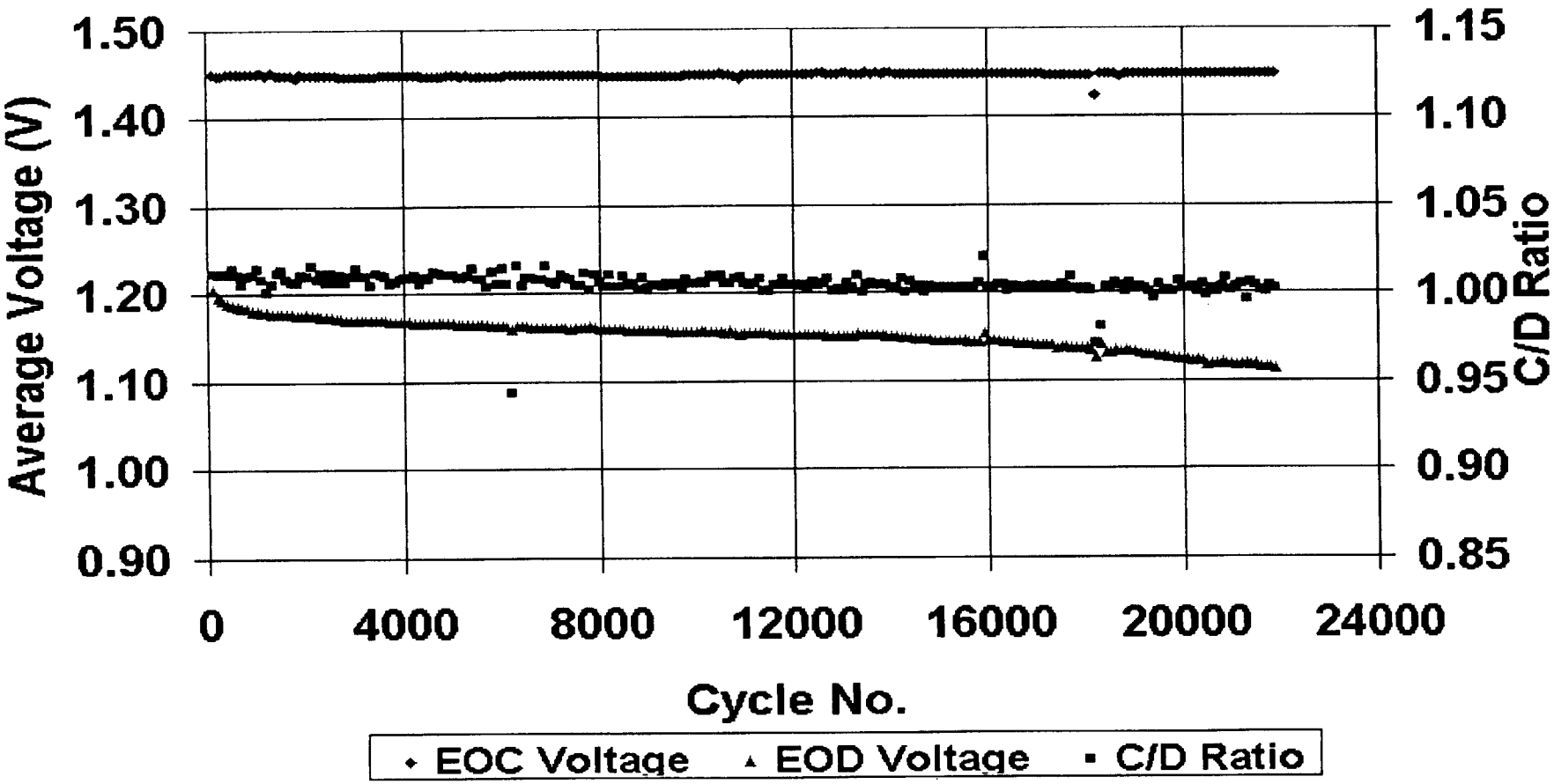
Pack 3: Average Voltage and C/D (Pre-Life Storage @ 0 Deg. C: 1, 2, 3, 6 Mos.)



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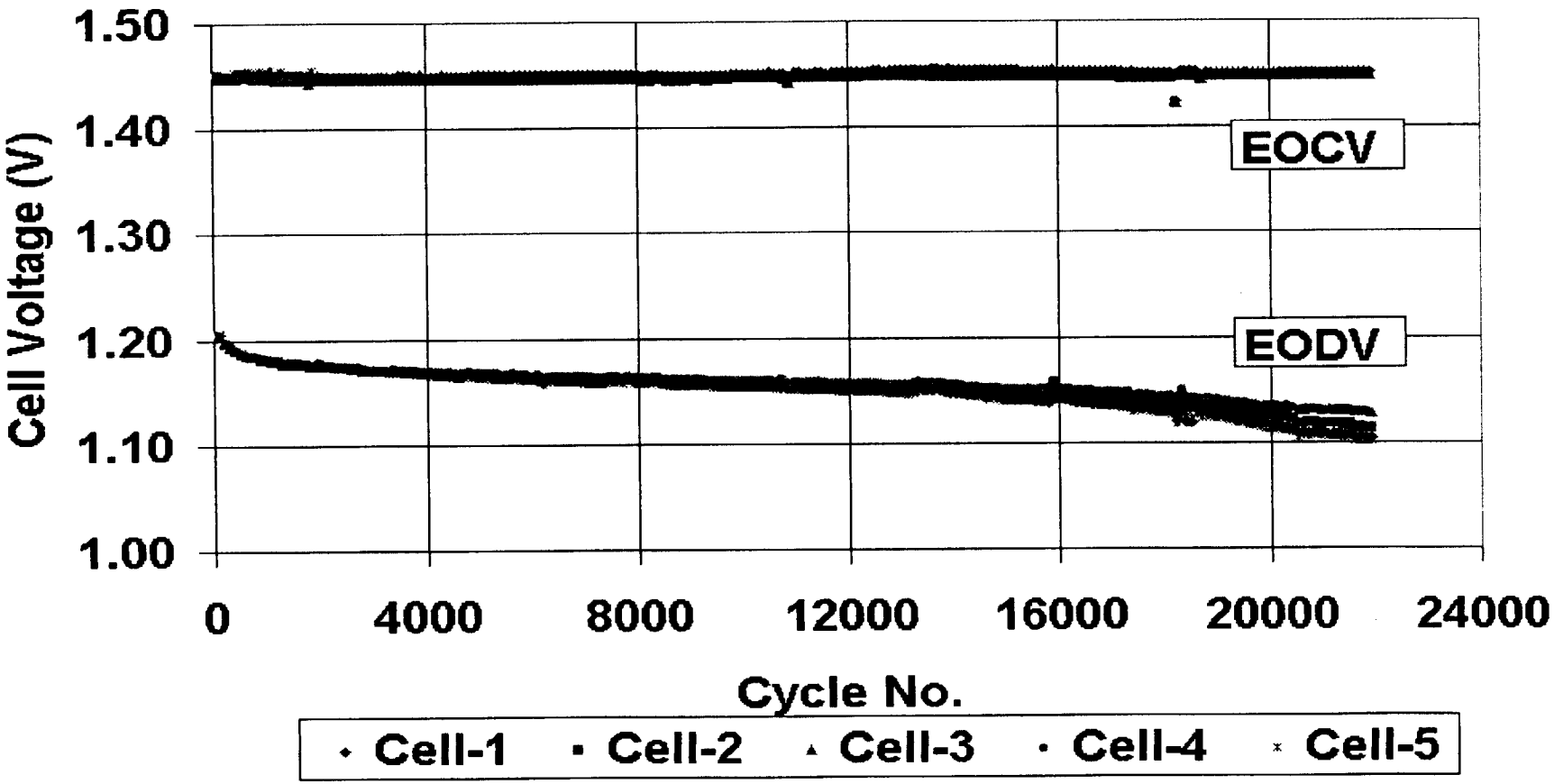
Pack 3: EOCV and EODV
(Pre-Life Storage @ 0 Deg. C: 1, 2, 3, 6 Mos.)



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Summary

- Cycle-life capability supports generic Air Force qualification
  - Conventional LEO mission goal up to 5-year duration
  - Conventional GEO mission goal up to 10-year duration
- Handling and storage may not require active charging
  - Cell manufacturer now provides option of up to 180 days of open-circuit storage with top-off charging every 14 days or less
  - Programs have more flexibility
- Launch site
  - Could eliminate requirement for continuous trickle charge
  - Can result in battery processing cost and time reduction