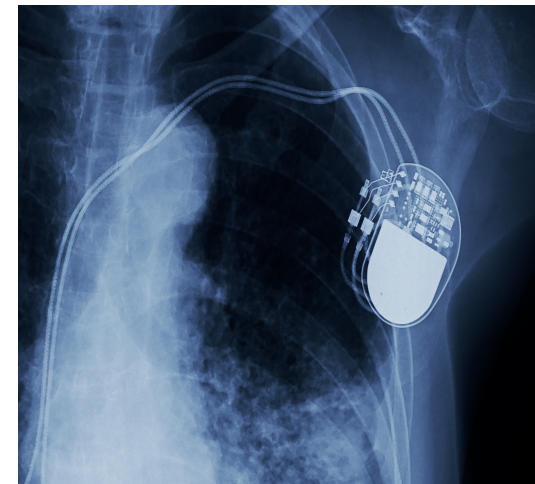


Updates of the Lithium-ion
Space Chemistry, and COTS
Testing

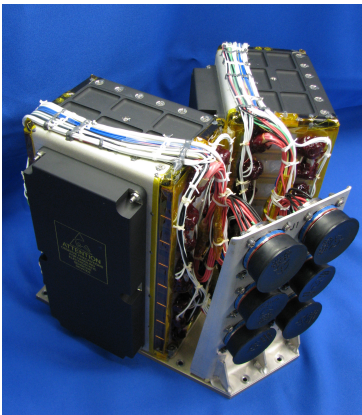
NASA Space Battery
Workshop
Huntsville, AL
November 27-29th, 2018

Chad Deroy

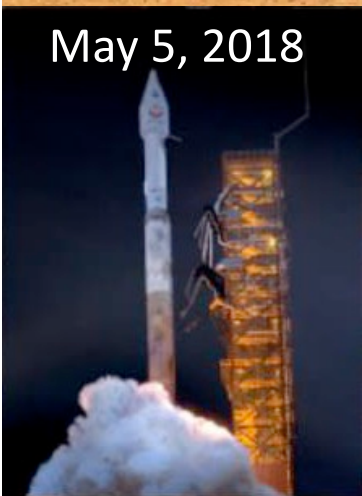


This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

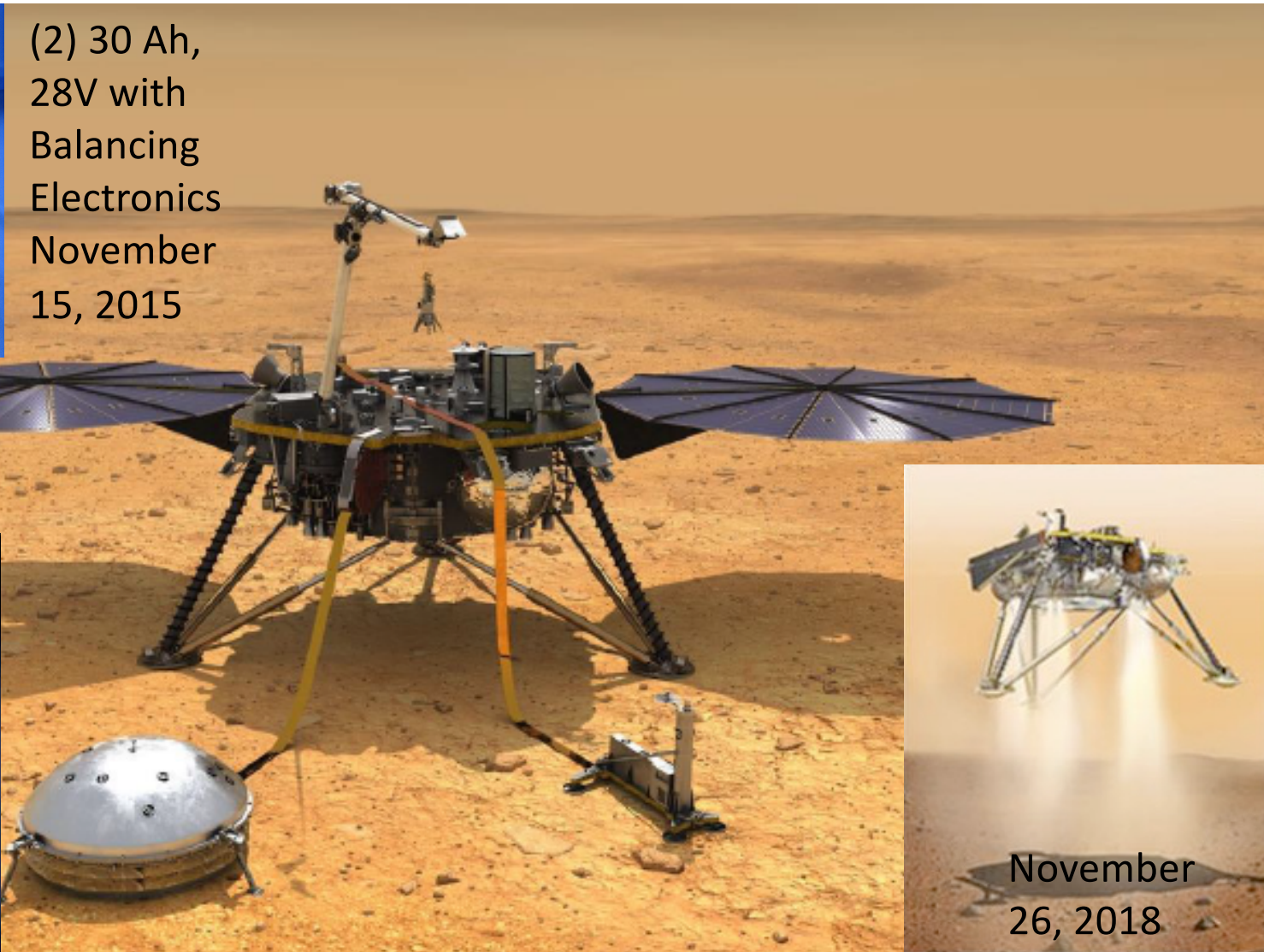
Congratulations InSight!!!!



(2) 30 Ah,
28V with
Balancing
Electronics
November
15, 2015



May 5, 2018



November
26, 2018

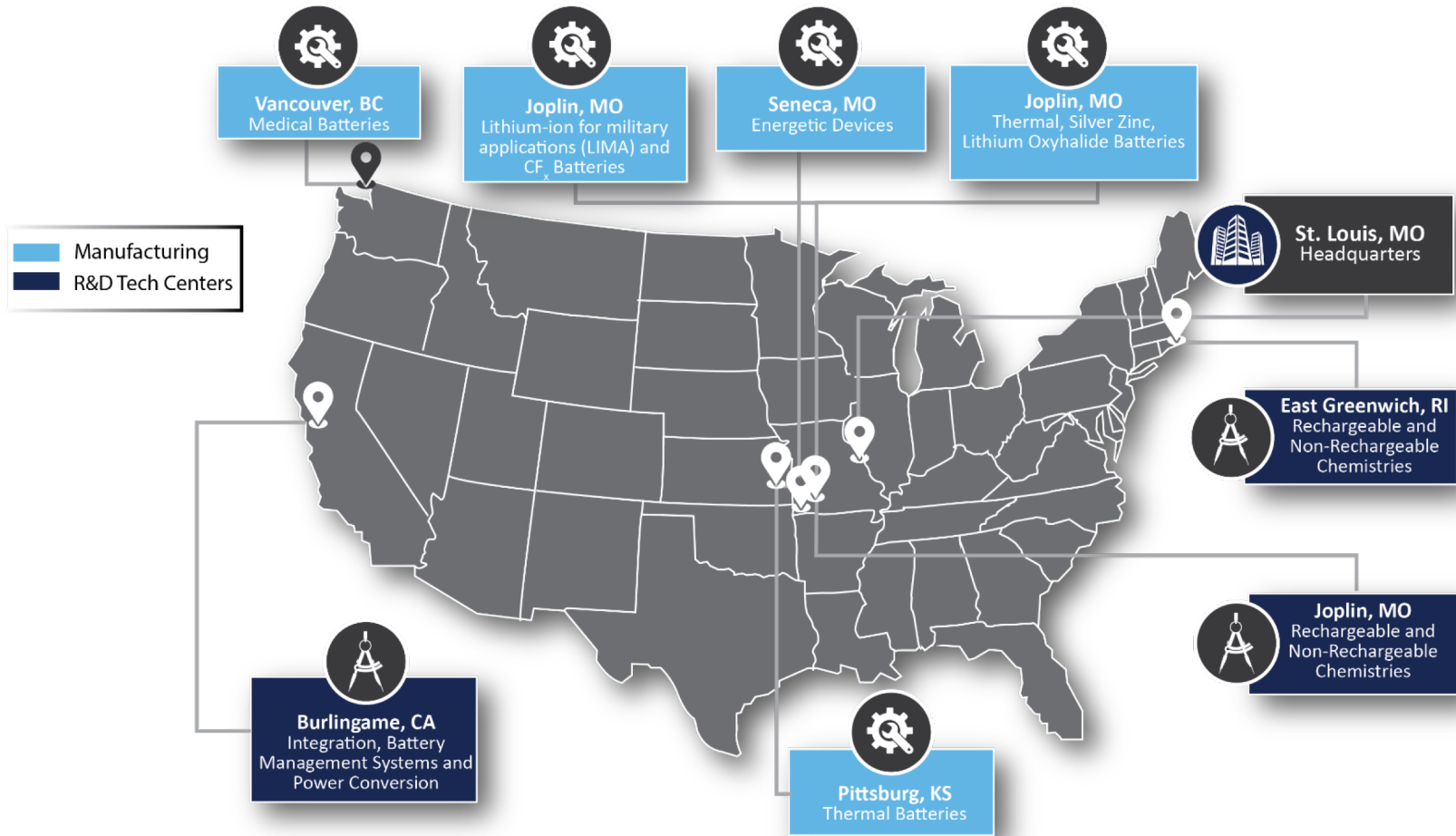
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

A dark blue fighter jet is shown in flight, banking to the right. The background consists of a vast, textured sea of white clouds under a deep blue sky. The overall image has a monochromatic blue color scheme.

EAGLEPICHER⁺
TECHNOLOGIES

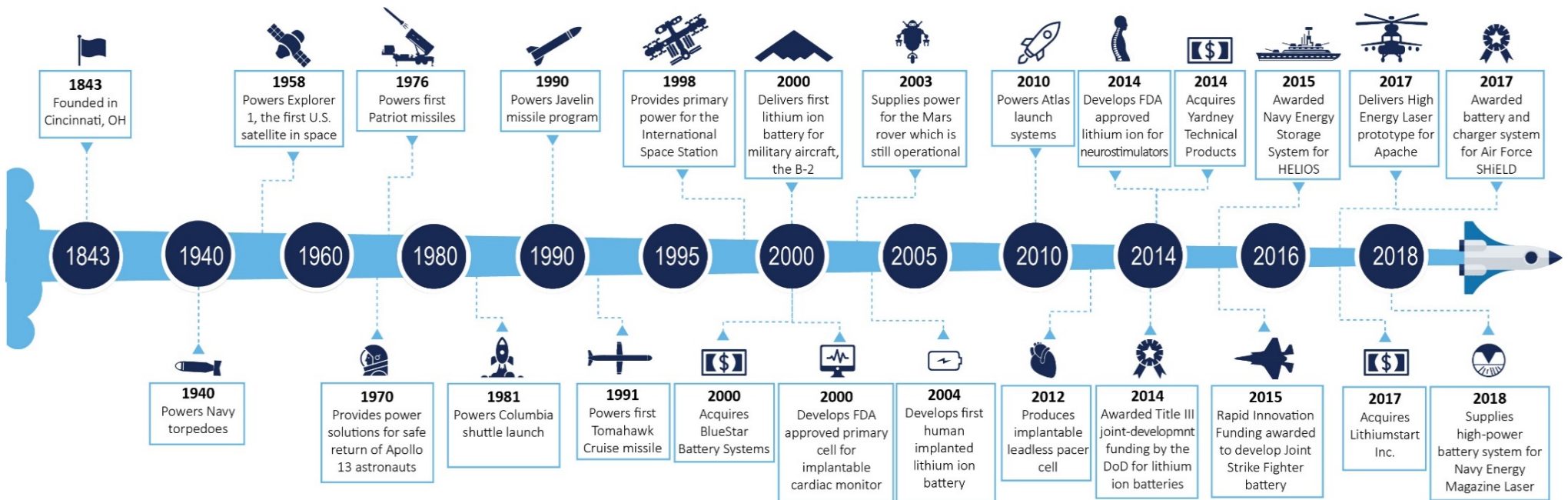
**EaglePicher Provides Reliable,
Flexible, Power and Energy Dense
Solutions for High Technology
Applications**

Innovating, Investing and Growing



This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

Heritage in Mission-Critical Applications



Serving Mission-Critical Aerospace, Defense, Aviation and Medical Battery Markets

This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

EAGLEPICHER⁺
TECHNOLOGIES

A satellite with large solar panels is shown in space, orbiting Earth. The satellite is white and gold, with several large, rectangular solar panels extending from its central body. The Earth is visible in the background, showing a blue sky and white clouds. The overall scene is set against a dark blue background.

Life Testing Updates

Updated Chemistries for Space application

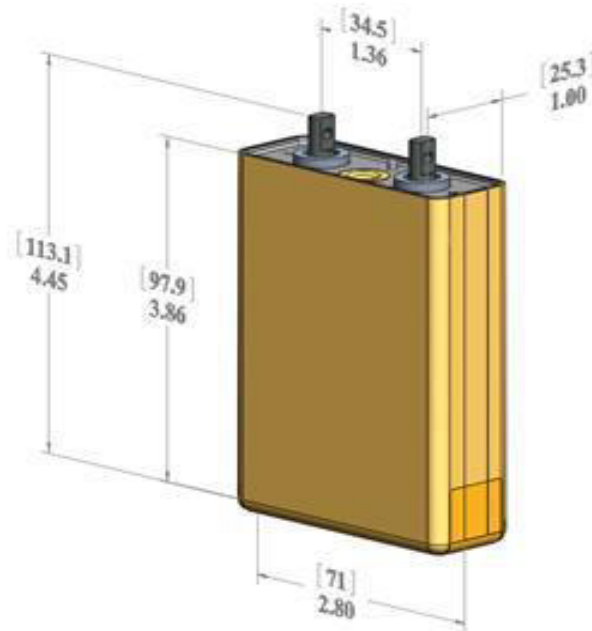
➤ NCP12-4 Design

- NCA/Synthetic Graphite
- 14.5 Ah BOL
- 12 Ah Nameplate

➤ Physical Properties:

- 456 grams
- 4.45" Tall x 2.8" Wide x 1.0" Thick

Currently
used for LEO
Applications



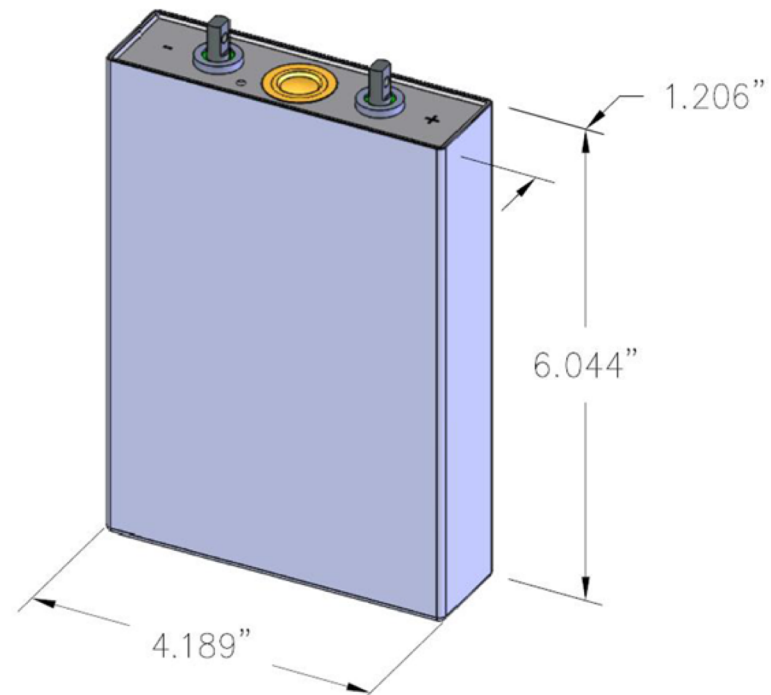
➤ NCP43-4 Design

- NCA/Synthetic Graphite
- 47 Ah BOL
- 43 Ah Nameplate

➤ Physical Properties:

- 1283 grams
- 6.0" Tall x 4.2" Wide x 1.2" Thick

Currently
used for LEO
Applications



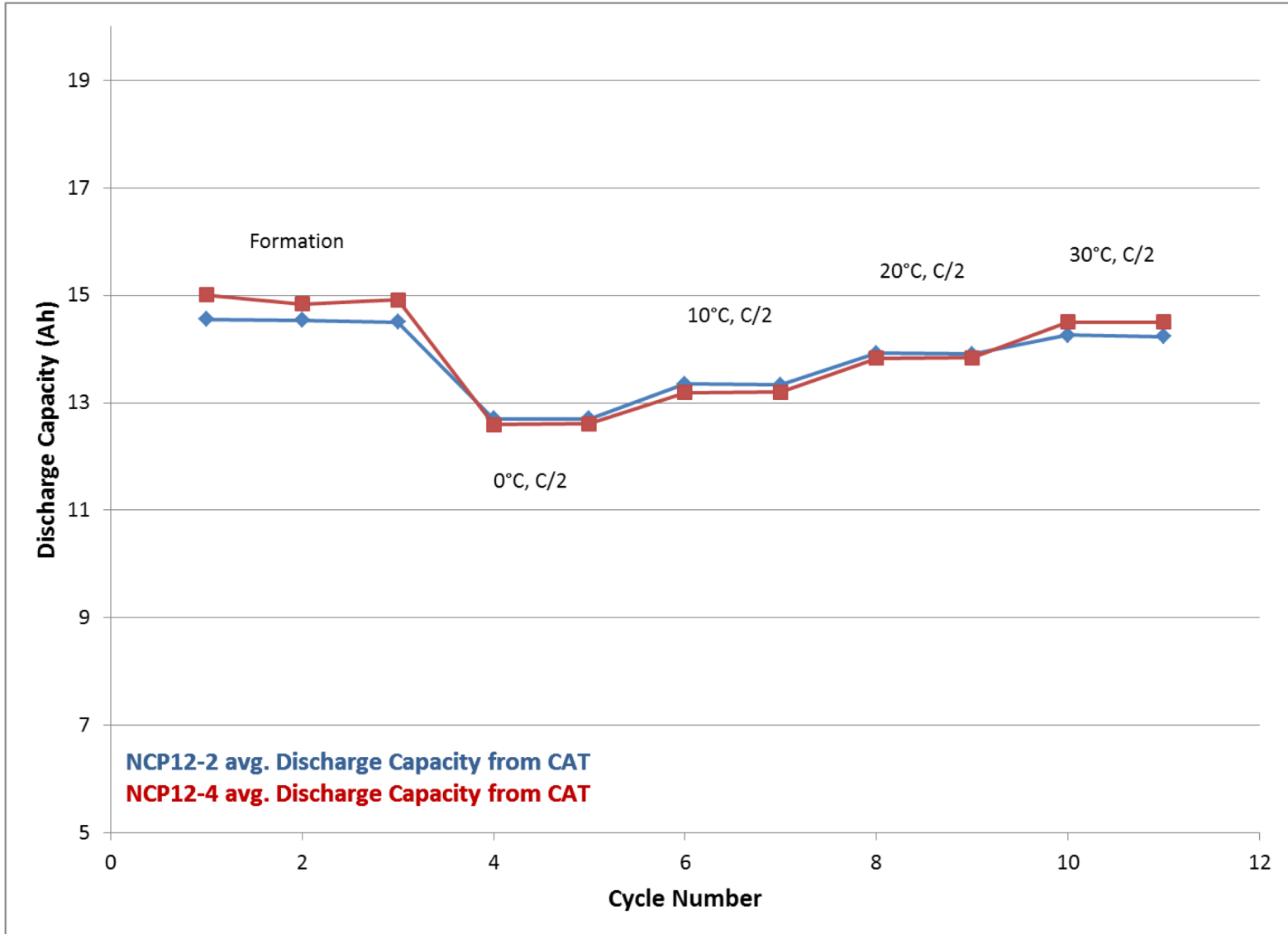
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

EAGLEPICHER⁺
TECHNOLOGIES

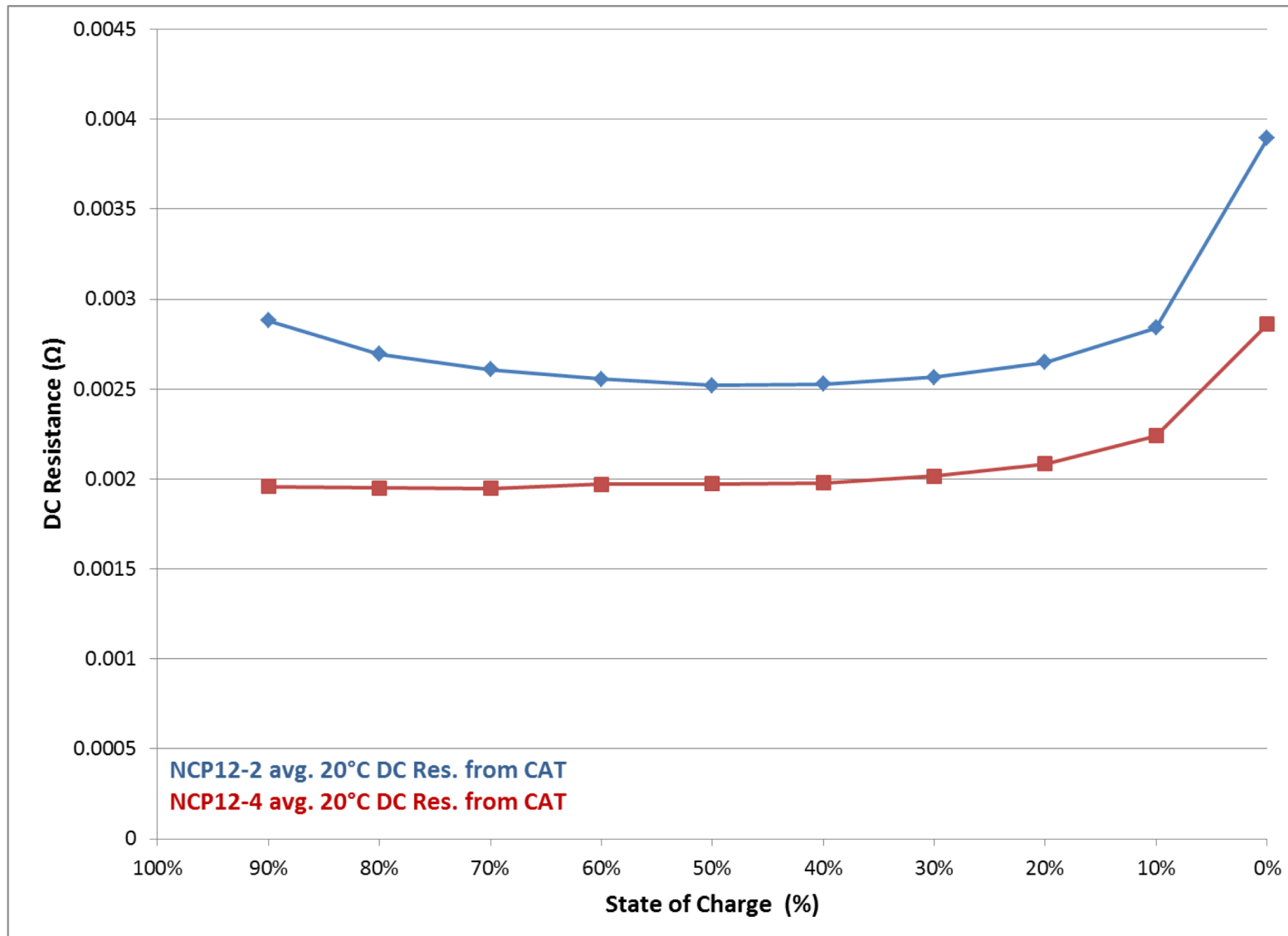


NCP12-4

BOL Test; Discharge Capacity



BOL Test; 20°C DC Resistance



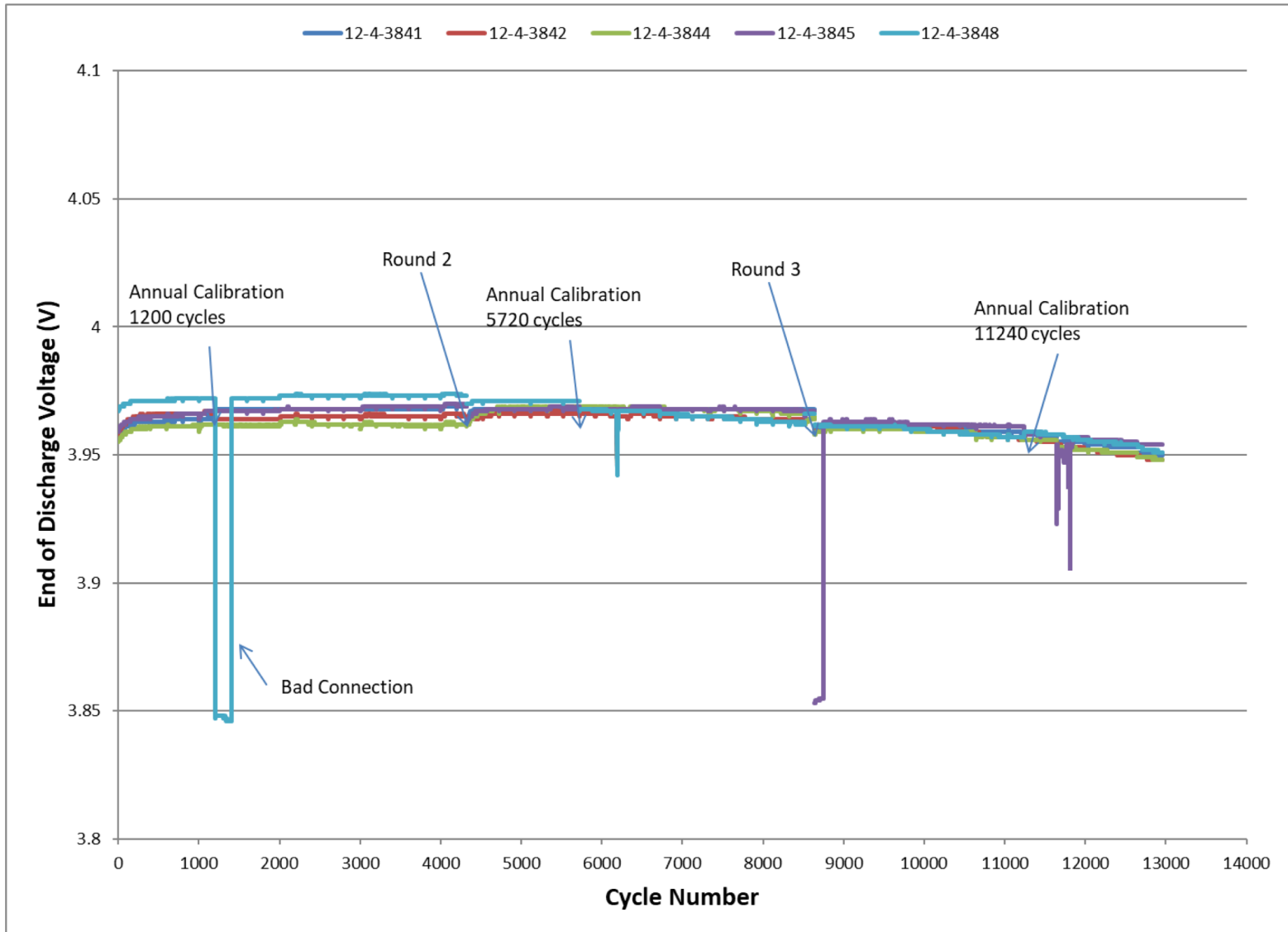
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

12AH LIFE CYCLING @30°C

- + The NCA chemistry NCP12-4 cells were placed on life cycling per LiTP-6245 that was previously run on the NCP12-2 NCO chemistry cells.
 - Per para. 5.1 Real-time life cycling at 30°C
 - 4320 cycles per round
 - 2.4 amp charge to 4.1Vdc, tapering for a total time of 55 min
 - 13 amp discharge for 4.5 min
 - Open Circuit rest for 30.5 min
 - Capacity and DC Resistance
 - Every 1000 Cycles

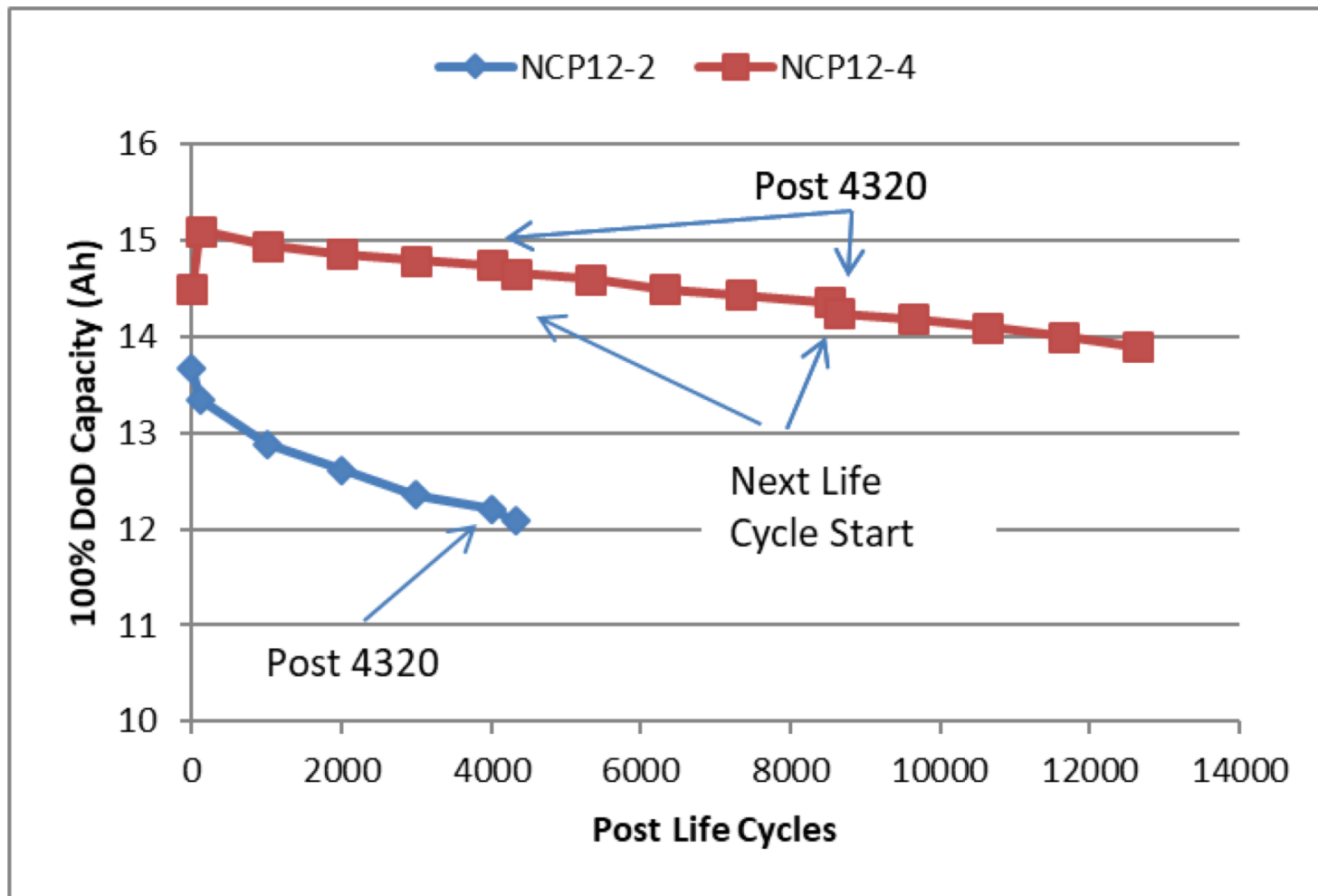
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

END-OF-DISCHARGE VOLTAGE



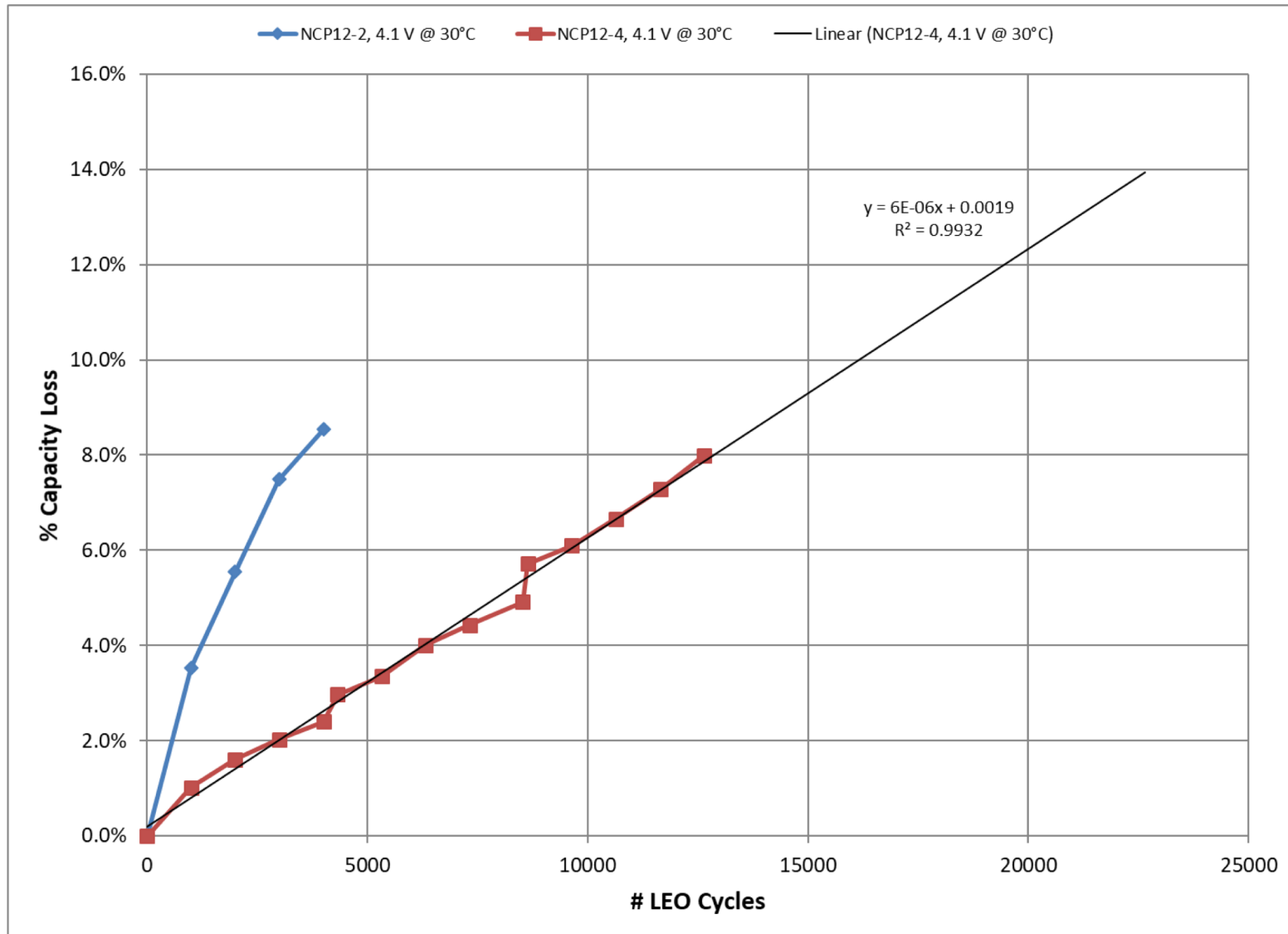
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP12 Life Cycle Capacity Checks @30°C



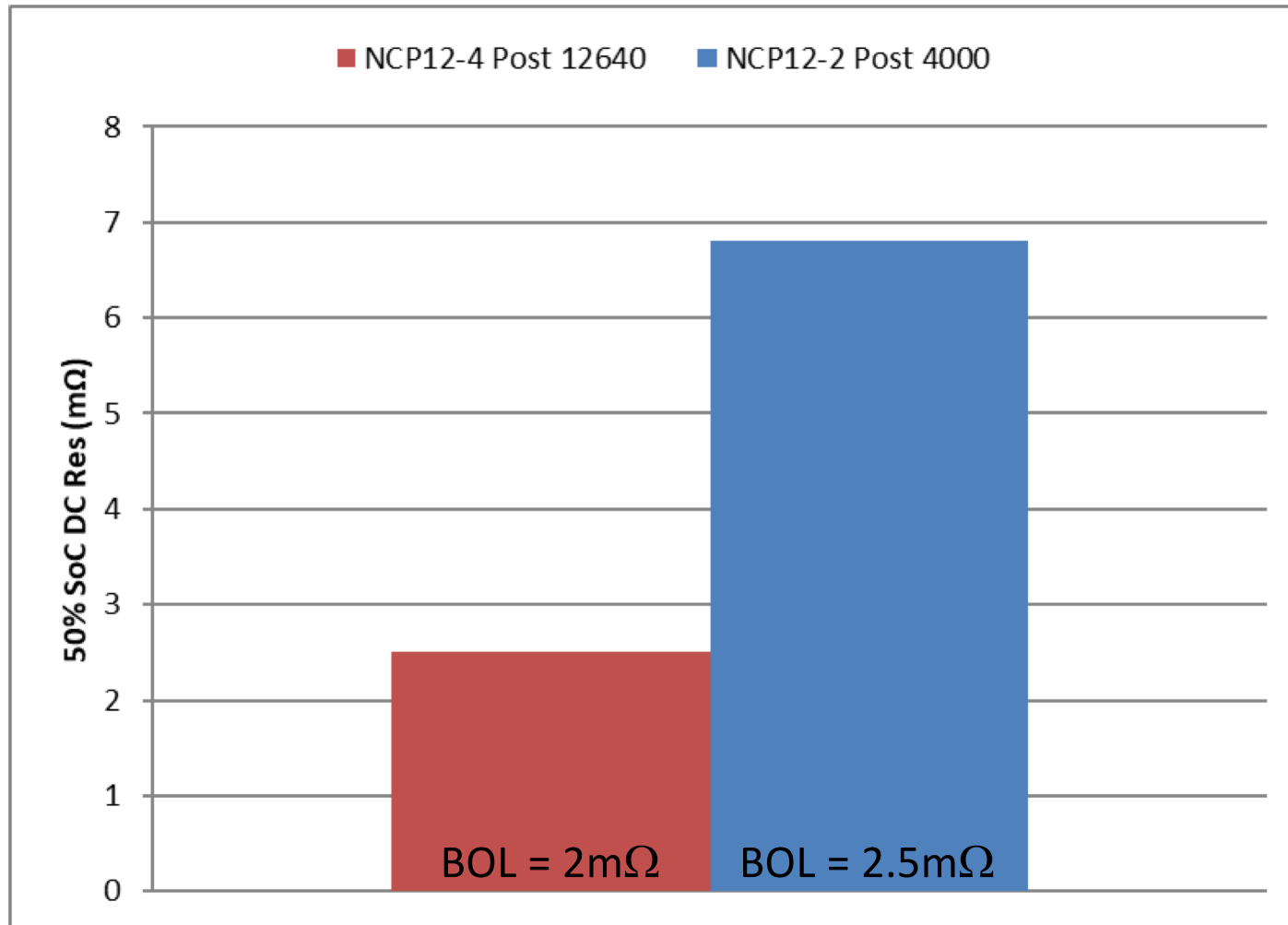
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP12 Capacity Loss Comparison



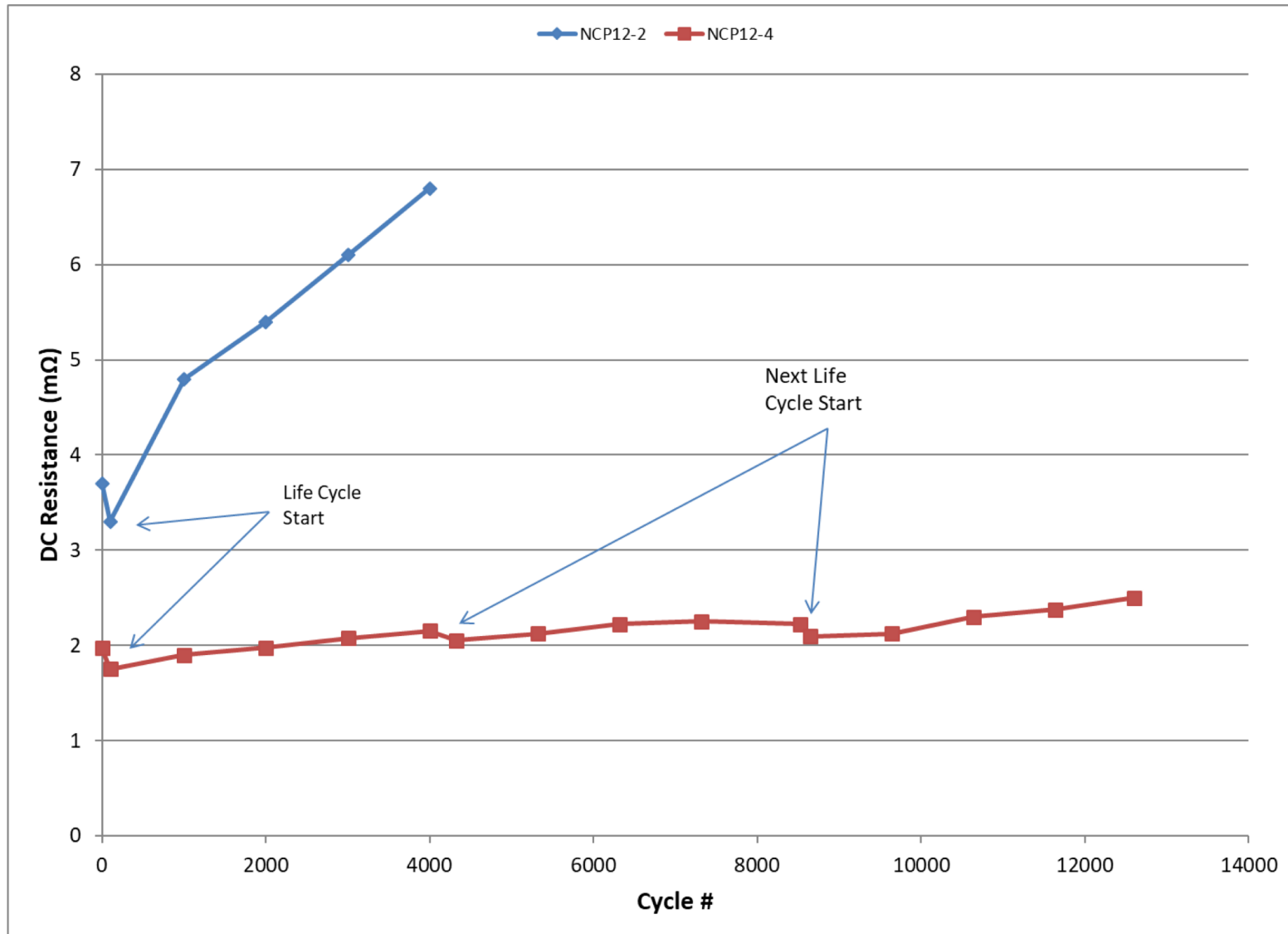
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

Life Cycle 50% SoC DC Res. @30°C



This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP12 DC Resistance Comparison



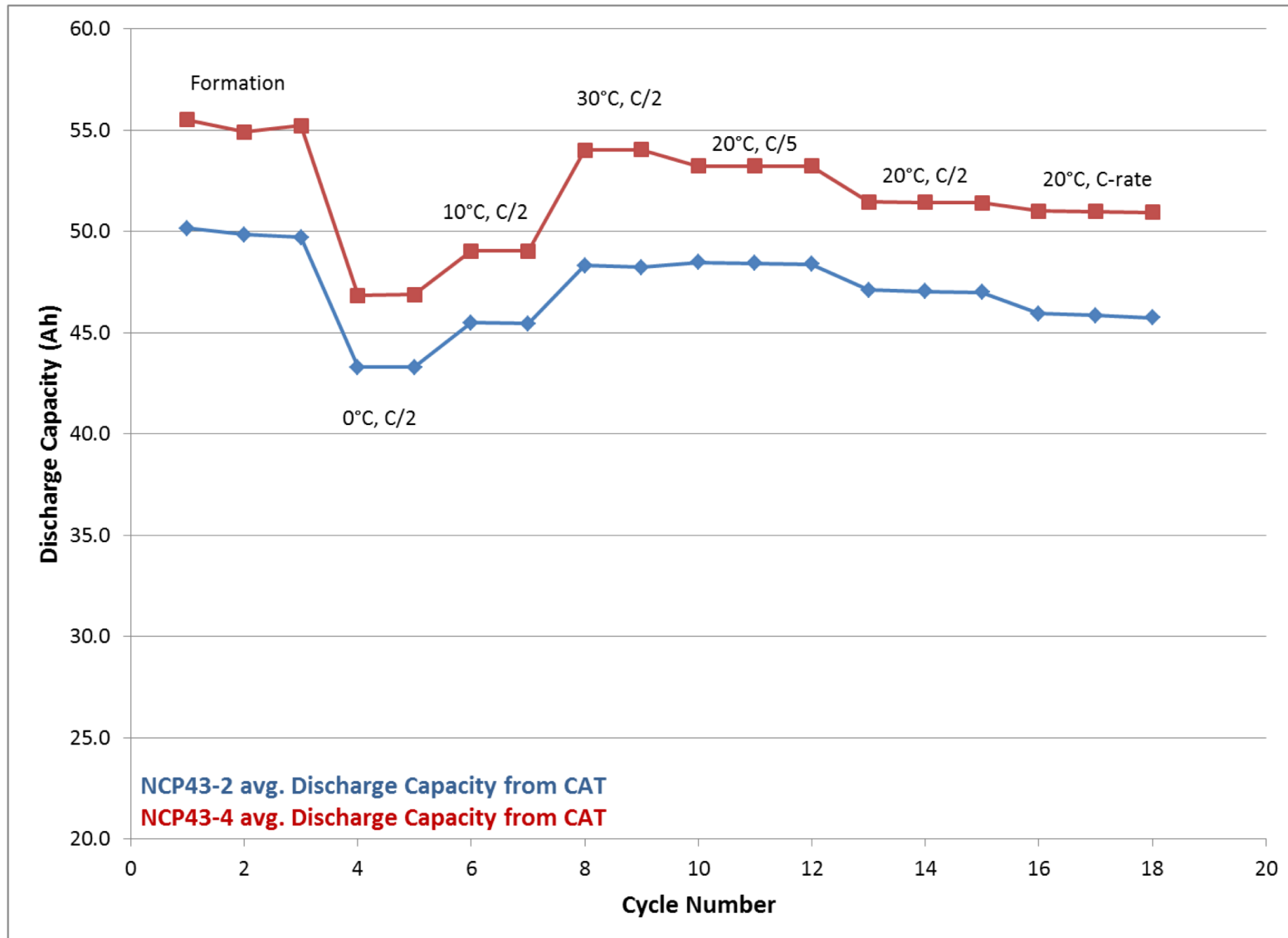
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

EAGLEPICHER⁺
TECHNOLOGIES



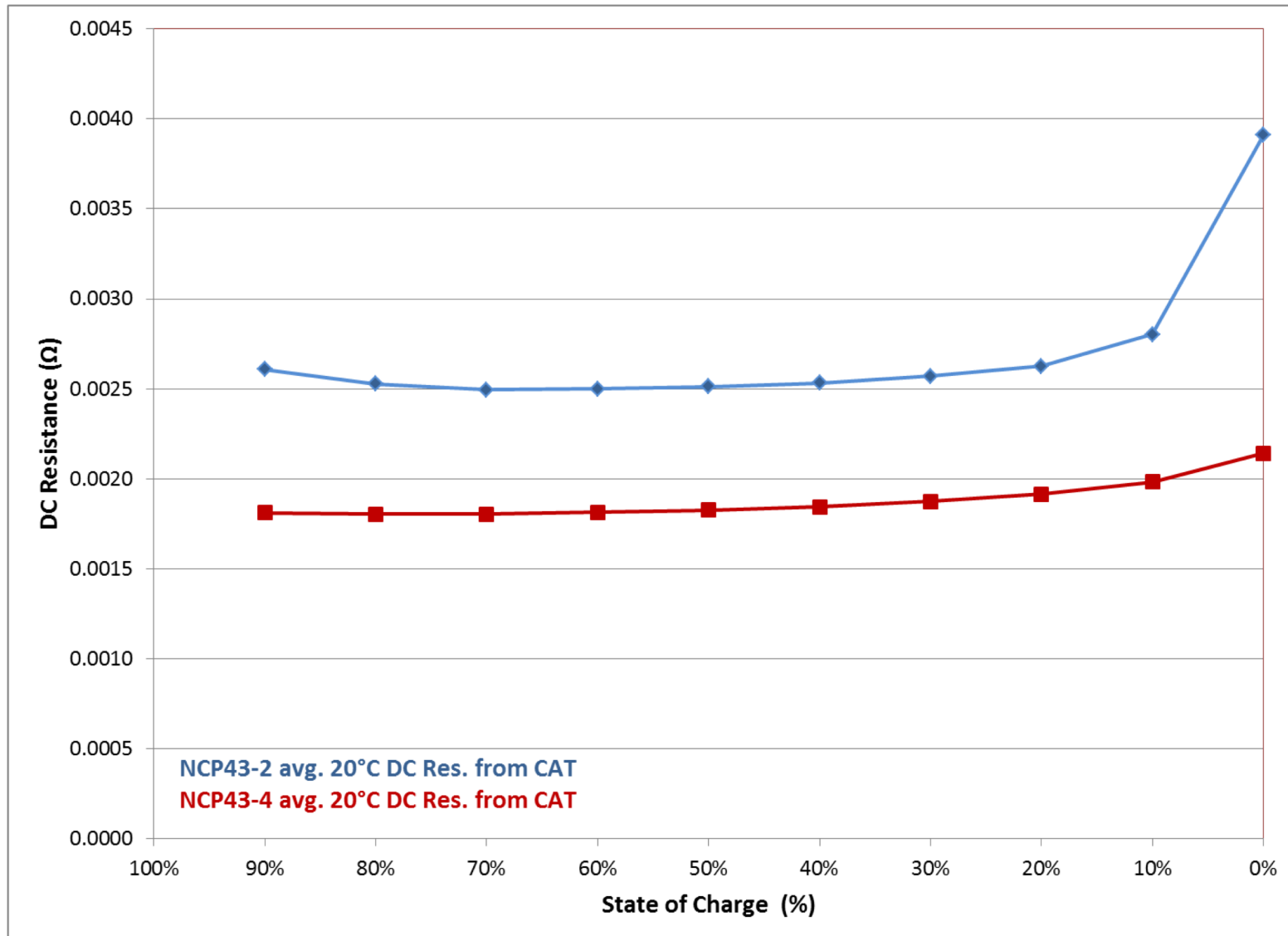
NCP43-4

BOL Test; Discharge Capacity



This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

BOL Test; 20°C DC Resistance

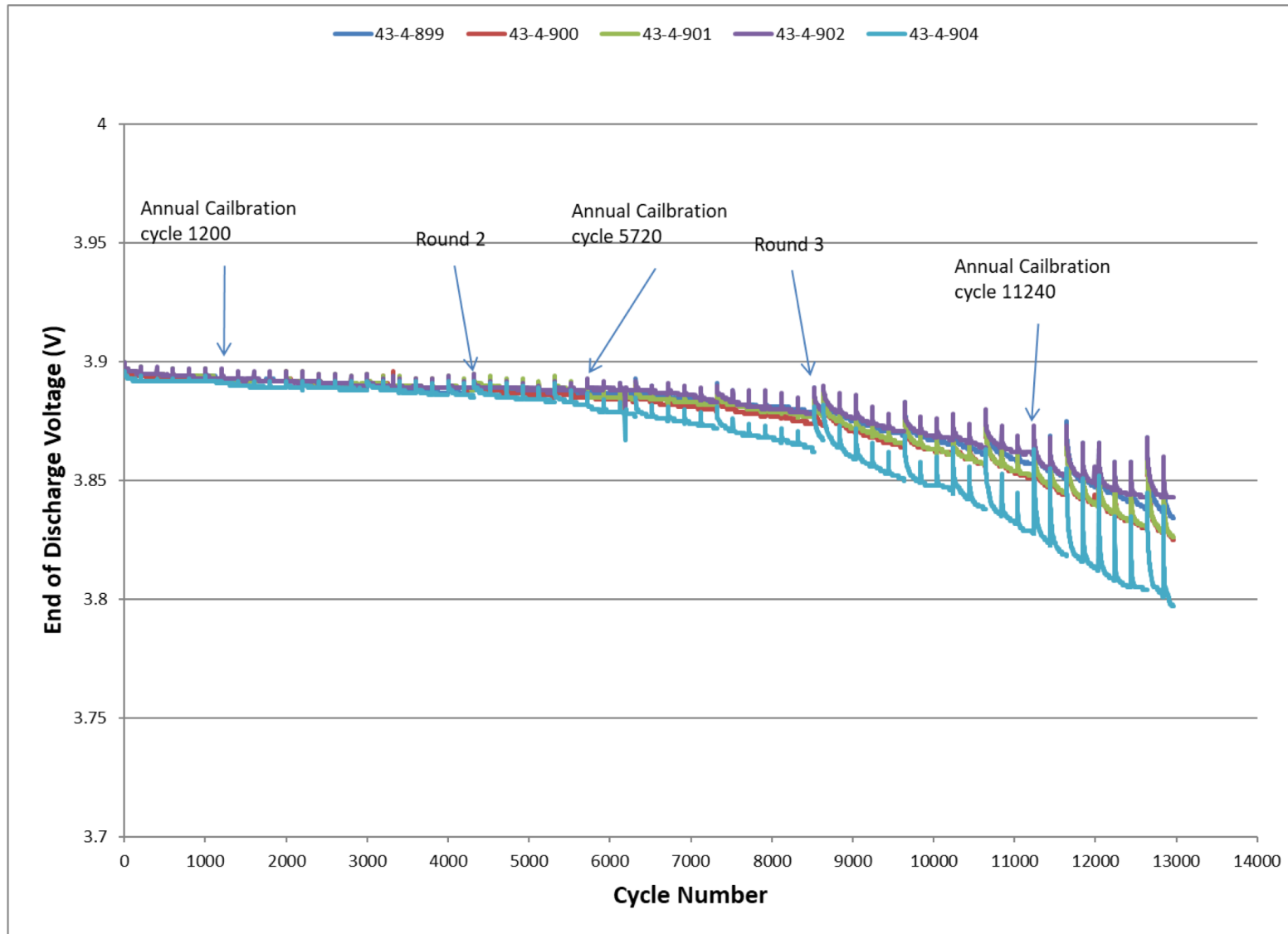


This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

43AH LIFE CYCLING @30°C

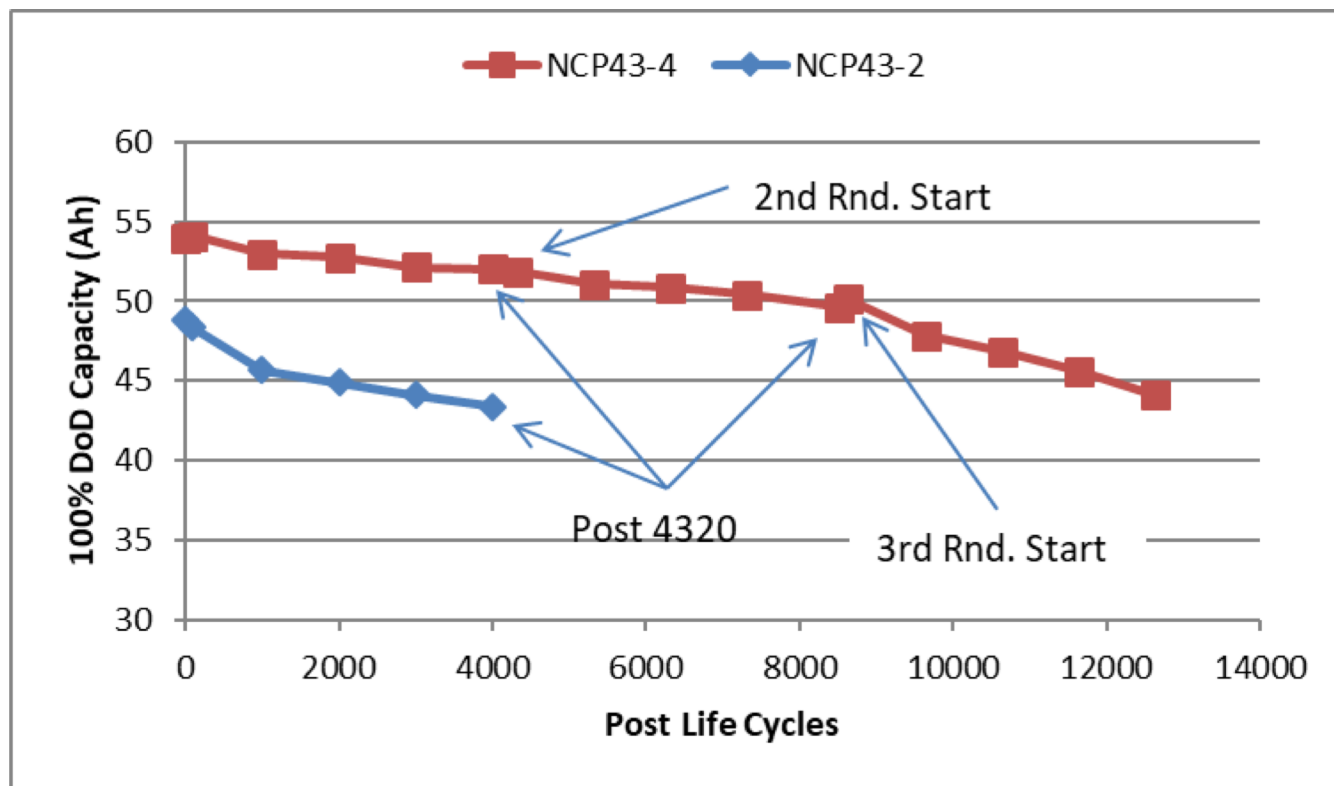
- + The NCA chemistry NCP43-4 cells were placed on life cycling per LiTP-6245 that was previously run on the NCP43-2 NCO chemistry cells.
 - Per para. 5.3 Real-time life cycling at 30°C
 - 4320 cycles per round
 - 11.0 amp charge to 4.1Vdc, tapering for a total time of 53.3 min
 - 14.0 amp discharge for 36.7 min
 - Capacity and DC Resistance
 - Every 1000 Cycles

NCP43-4 End-of-Discharge Voltage



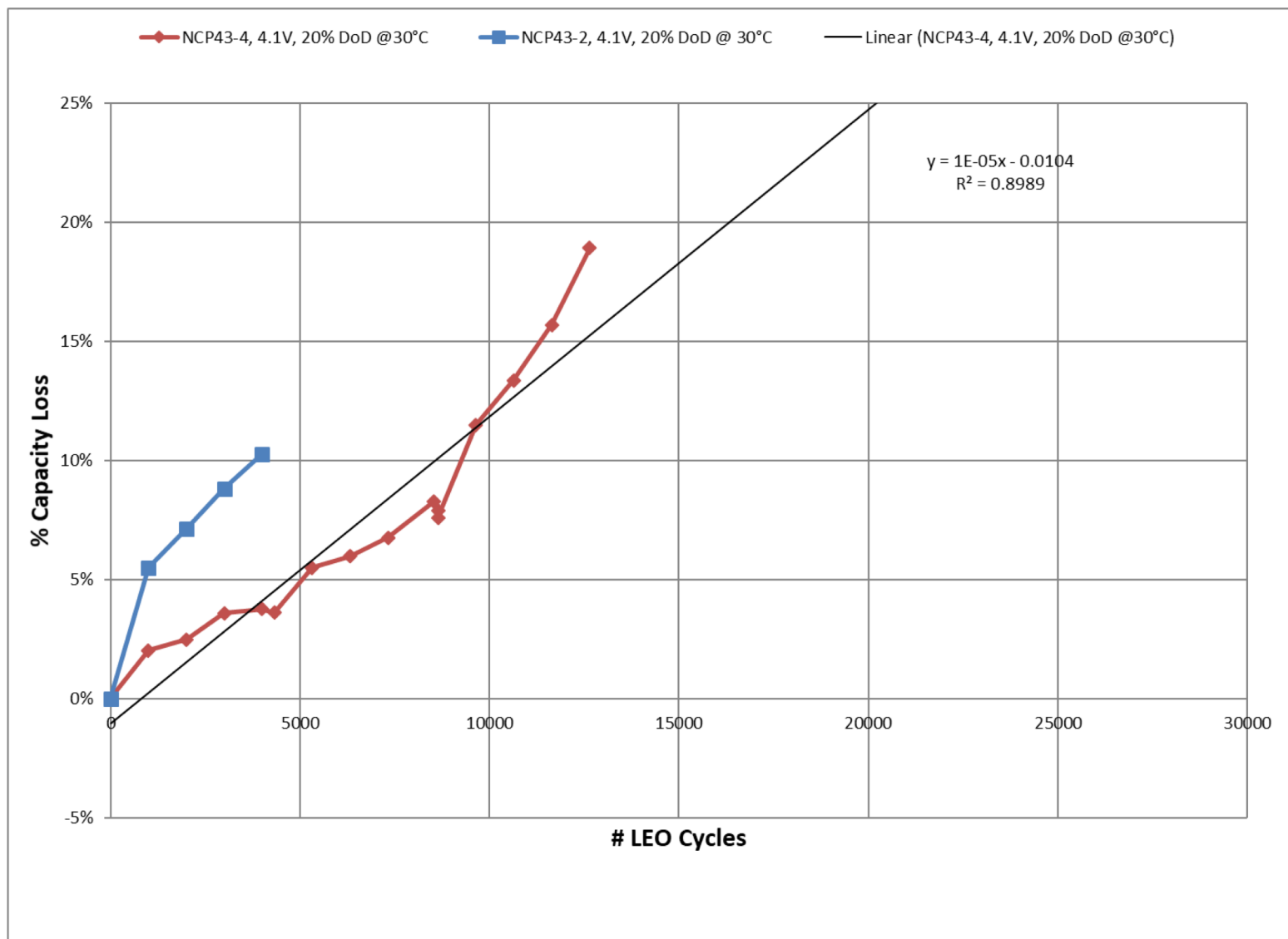
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP43 Life Cycle Capacity Checks @30°C



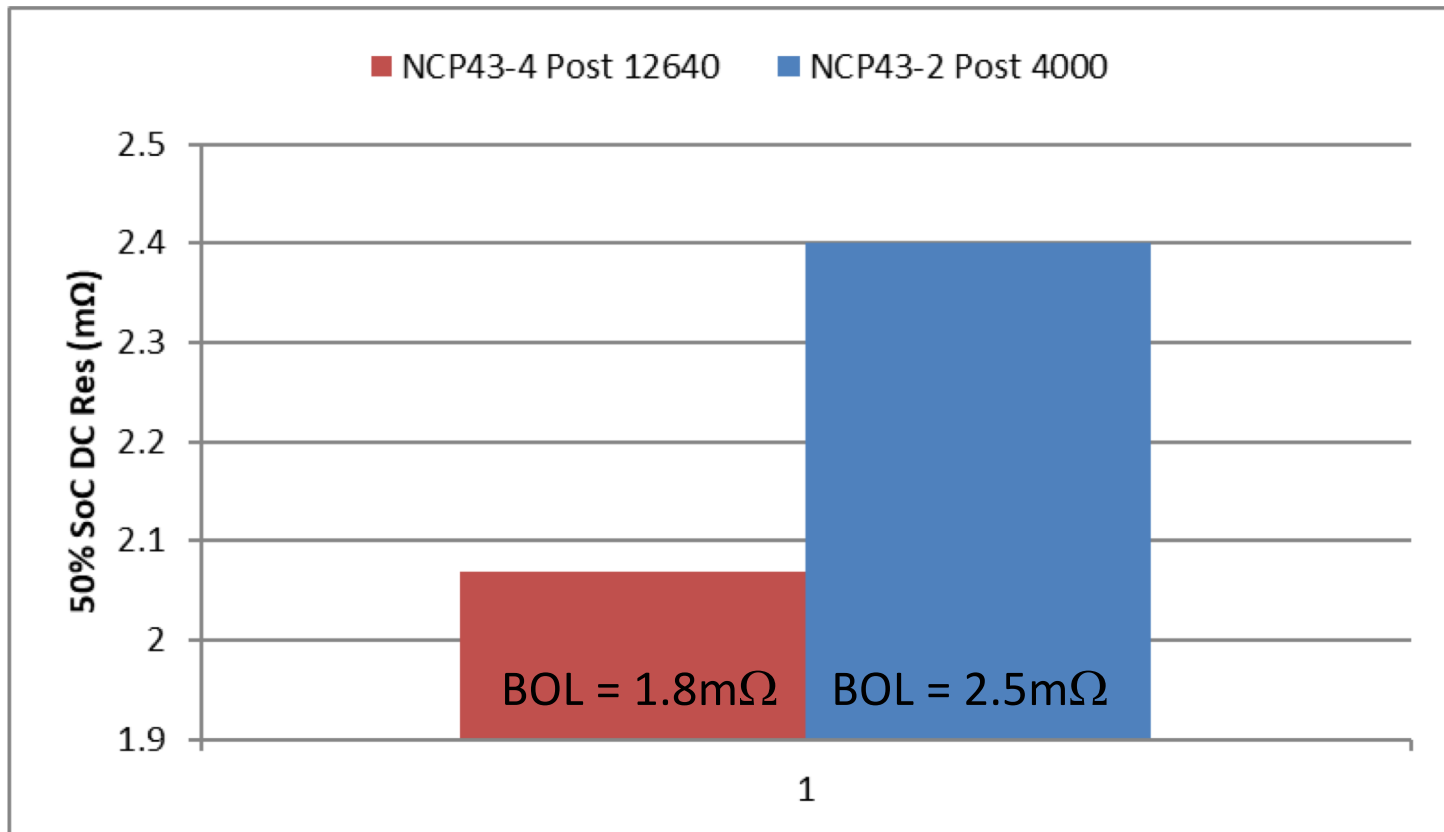
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP43 Capacity Loss Comparison



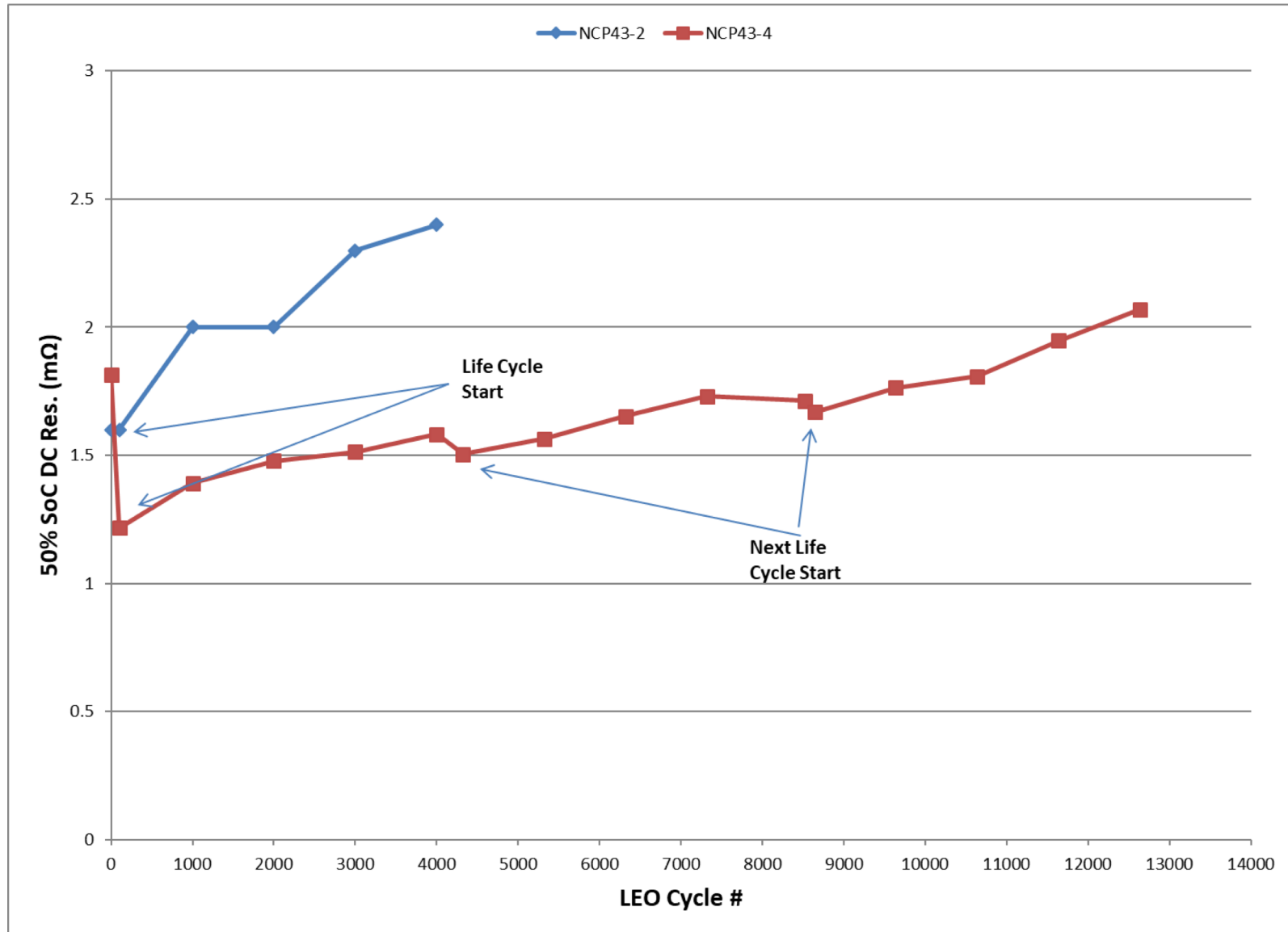
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

Life Cycle 50% SoC DC Res. @30°C



This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

NCP43-4 DC Resistance Comparison



This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

A detailed illustration of a satellite in space. The satellite has a central body with various instruments and a large rectangular panel extending from it. Two large solar panel arrays are deployed, each consisting of multiple rectangular panels with a grid pattern. The background shows the Earth's surface with clouds and the horizon, with the Moon visible in the distance. The entire scene is set against a dark blue sky.

COTS Cell Evaluations

COTS EVALUATION- TEST PLAN

— CAT Tests (All Cells)

- Use (or determine) the 1C rated capacity for C rate calculation
 - * 50% SOC should be half of the rated capacity at 1C/25°C
- Use datasheet to select operating voltage range
- Low Rate Continuous
 - Continuous 25°C
 - » C/5 Charge, C/5 Discharge 3 cycles, 72hr stand
 - » C/5 Charge, C/2 Discharge with DCR at 100% and ~50% SOC* (at 1hr)
 - » C/5 Charge, 1C Discharge
 - » C/5 Charge, 5C Discharge
 - » C/5 Charge, ~20A Discharge
 - Continuous 0°C
 - » C/5 Charge, C/5 Discharge 3 cycles
 - » C/5 Charge, C/2 Discharge with DCR at 100% and ~50% SOC* (at 1hr)
 - » C/5 Charge, 1C Discharge
 - » C/5 Charge, 5C Discharge
 - » C/5 Charge, ~20A Discharge
 - Continuous -20°C
 - » C/5 Charge, C/5 Discharge 3 cycles
 - » C/5 Charge, C/2 Discharge with DCR at 100% and ~50% SOC* (at 1hr)
 - » C/5 Charge, 1C Discharge
 - » C/5 Charge, 5C Discharge.
 - » C/5 Charge, ~20A Discharge

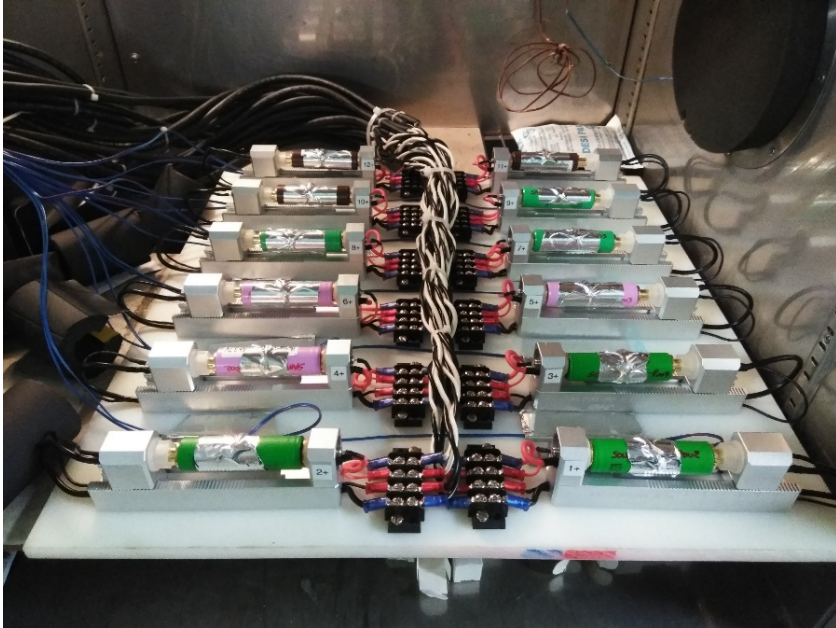
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

COTS EVALUATION- TEST PLAN CONT.

- *40% DoD LEO Life Cycling @ 20°C*
 - » *Characterization Cycles @20°C (4.1 V to 3.0V)*
 - » C/5 Charge, C/5 Discharge (3 cycles)
 - » C/5 Charge, C/2 Discharge with DCR at 10% increments until 0% SoC
 - Start LEO Cycle
 - » C/5 to 4.0V tapered to C/10
 - LEO Cycles
 - » 0.8C Discharge for 30 minutes
 - » C/2 Charge for 60 minutes tapering current to 4.0V
 - » Repeat the LEO discharge/charge cycling in 200 cycles have completed
 - » Once 1000 LEO cycles have completed repeat *Characterization Cycles*
 - » Continue LEO cycling and *Characterization Cycles until...?*
- *HOLD cells here until any mission specific testing is considered.*
- Cell DPA, Document Construction

This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

SETUP FOR COTS EVALUATION



12-cell test
fixture

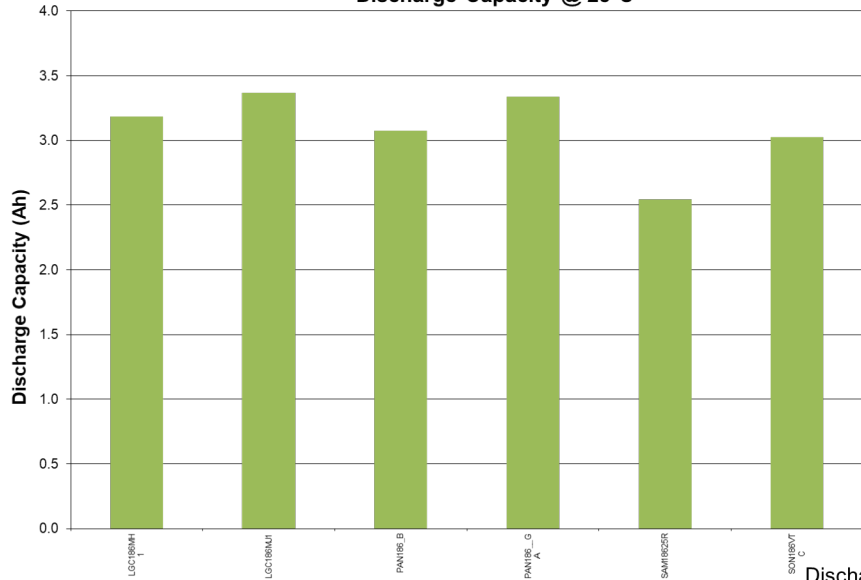


Foam Insulation

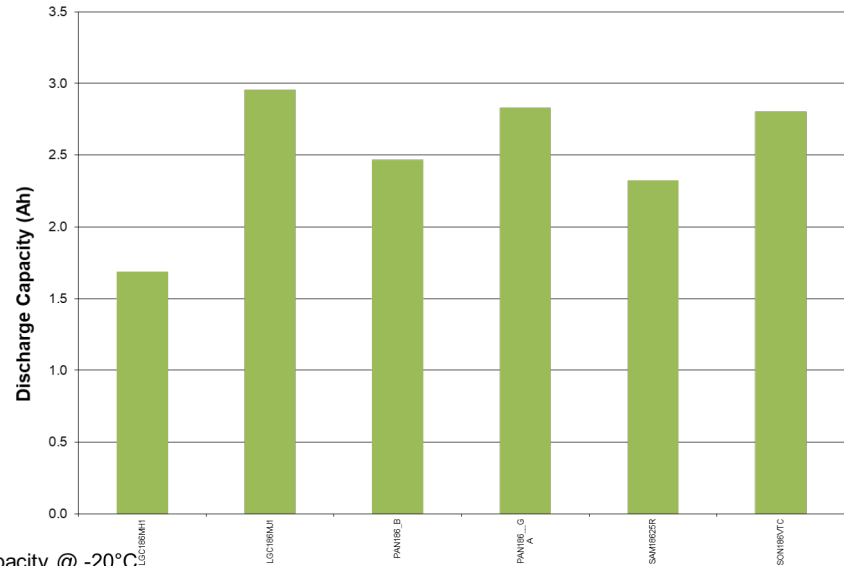
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

CAPACITIES @ VARIOUS °C

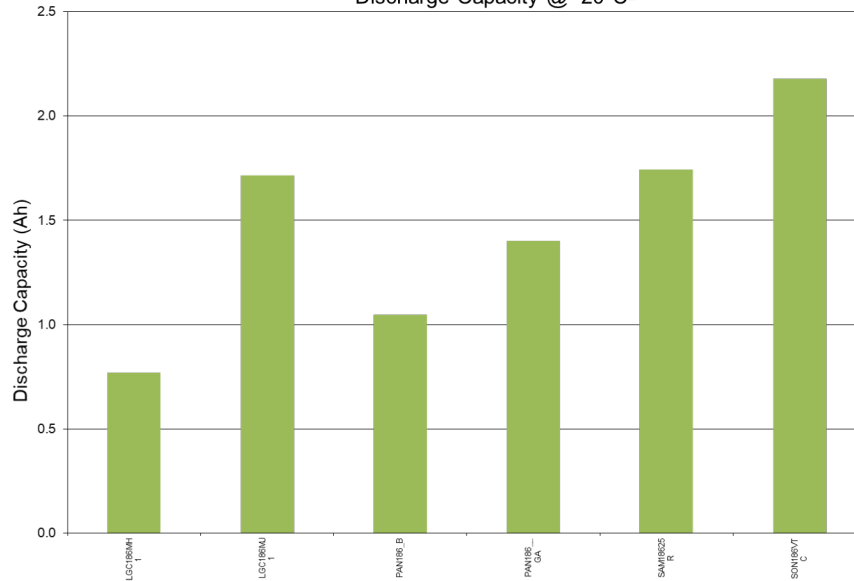
Discharge Capacity @ 25°C



Discharge Capacity @ 0°C



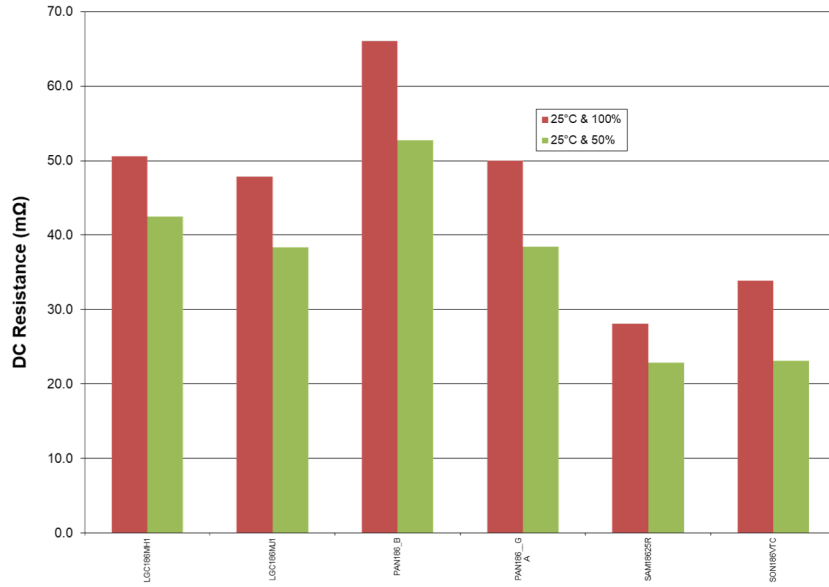
Discharge Capacity @ -20°C



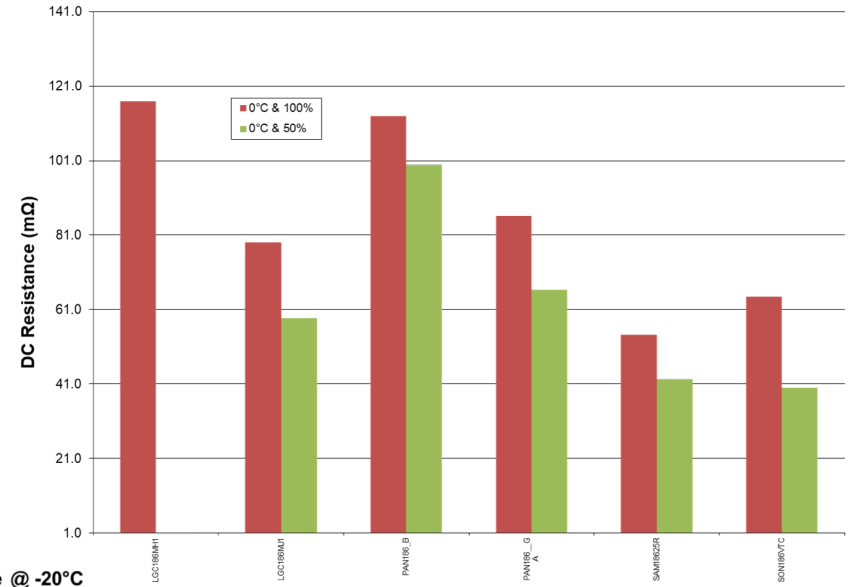
This document does NOT contain technology or technical data controlled under either the International Traffic in Arms Regulations (ITAR) or the Export Administration regulations (EAR)

DC RESISTANCE @ VARIOUS °C

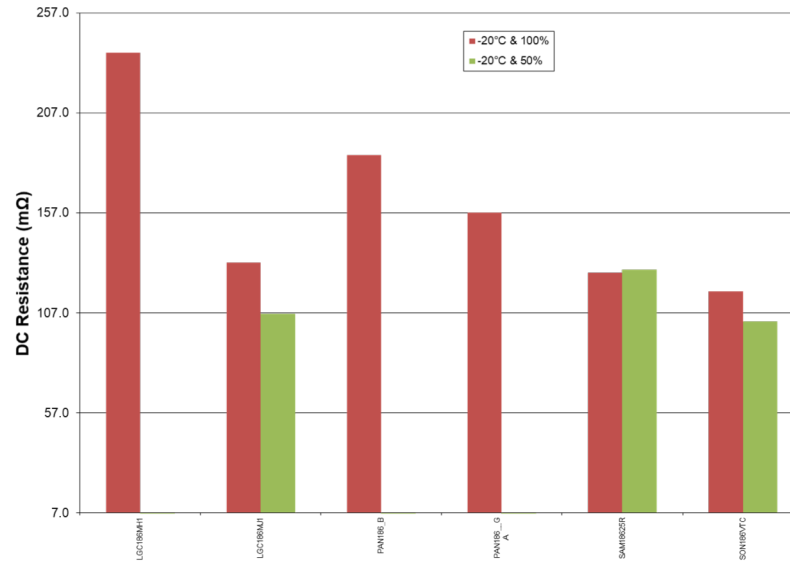
DC Resistance @ 25°C



DC Resistance @ 0°C



DC Resistance @ -20°C



ONGOING AND FUTURE WORK

- + Next Generation of Lithium-ion Space Chemistry for these prismatic cell designs yields improvements
 - Increased BOL capacity
 - Decreased capacity loss over life
 - Reduction of 3-times in impedance growth, following LEO cycling
 - Physical dimensions allow for Off-the-shelf designs, utilizing this chemistry, gaining improvements for the next generation of space vehicle.
- + COTS solutions are being developed for certain applications.

Thank You

Thanks to all the employees at EaglePicher

