Electrical and Thermal Characterizations of the QL015KA Pack in 8 Series

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11/27/2007, NASA Aerospace Battery Workshop 2007

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    - Cycle life test result
- Battery Pack (QL015KA, 8 cells in series)
    - Cell voltage and cell temperature
    - Temperature gradient in pack

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Program Overview

Program Goal

- Cycle life: 60,000 cycles (40% DOD LEO cycle)
- Type: Prismatic
- Energy density: 150Wh/kg, 350Wh/l

	2002	2003	2004	2005	2006	2007	2008	2009
Chemistry evaluation (Small model cells, 170mAh or 200mAh)								
15Ah SS case cell								
15Ah Al case cell								
75Ah SS case cell								
Set up facility (70 cells/week)								

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Chemistry Evaluation & Prediction for Long Life (Quallion 5A-2™)

- Long cycle life
- Zero Volt™

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Quallion's chemistry for long life

- **Cathode material:** $LiNi_xCo_yAl_zO_2$ (LNCAO)
- **Anode material:** Graphite mixture
- **Electrolyte:** High purity carbonate system electrolyte with $LiPF_6$
- **Separator:** Polyolefin porous membrane

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Cycle Performance (170mAh model cell)

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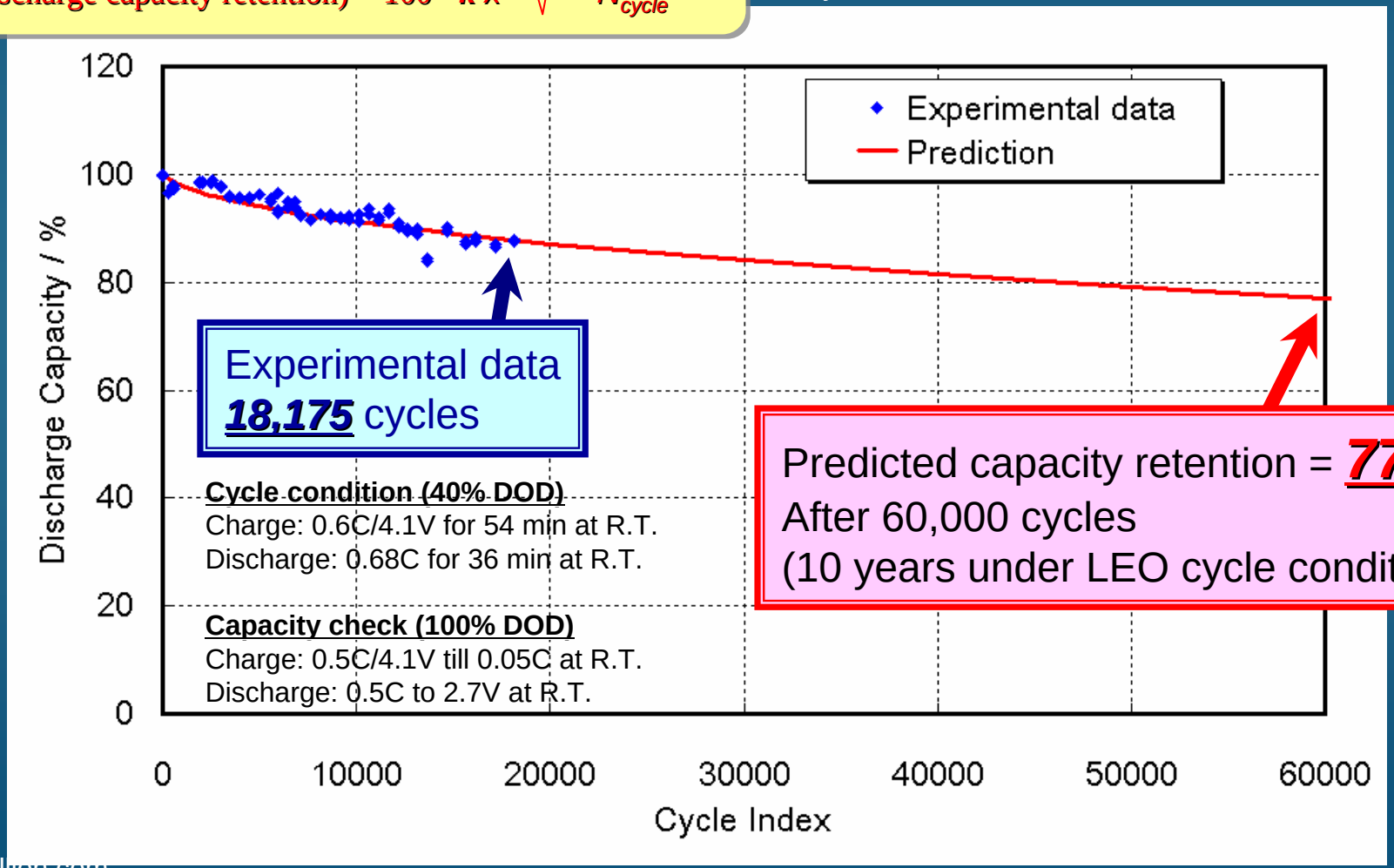
Capacity retention equation *)

(Discharge capacity retention) = $100 - k \times \sqrt{N_{cycle}}$

*) k: constant to determine capacity fading rate
N_{cycle}: charge and discharge cycle index



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Zero Volt™ Capability
Cycle Performance after 0V Storage (200mAh model cell)

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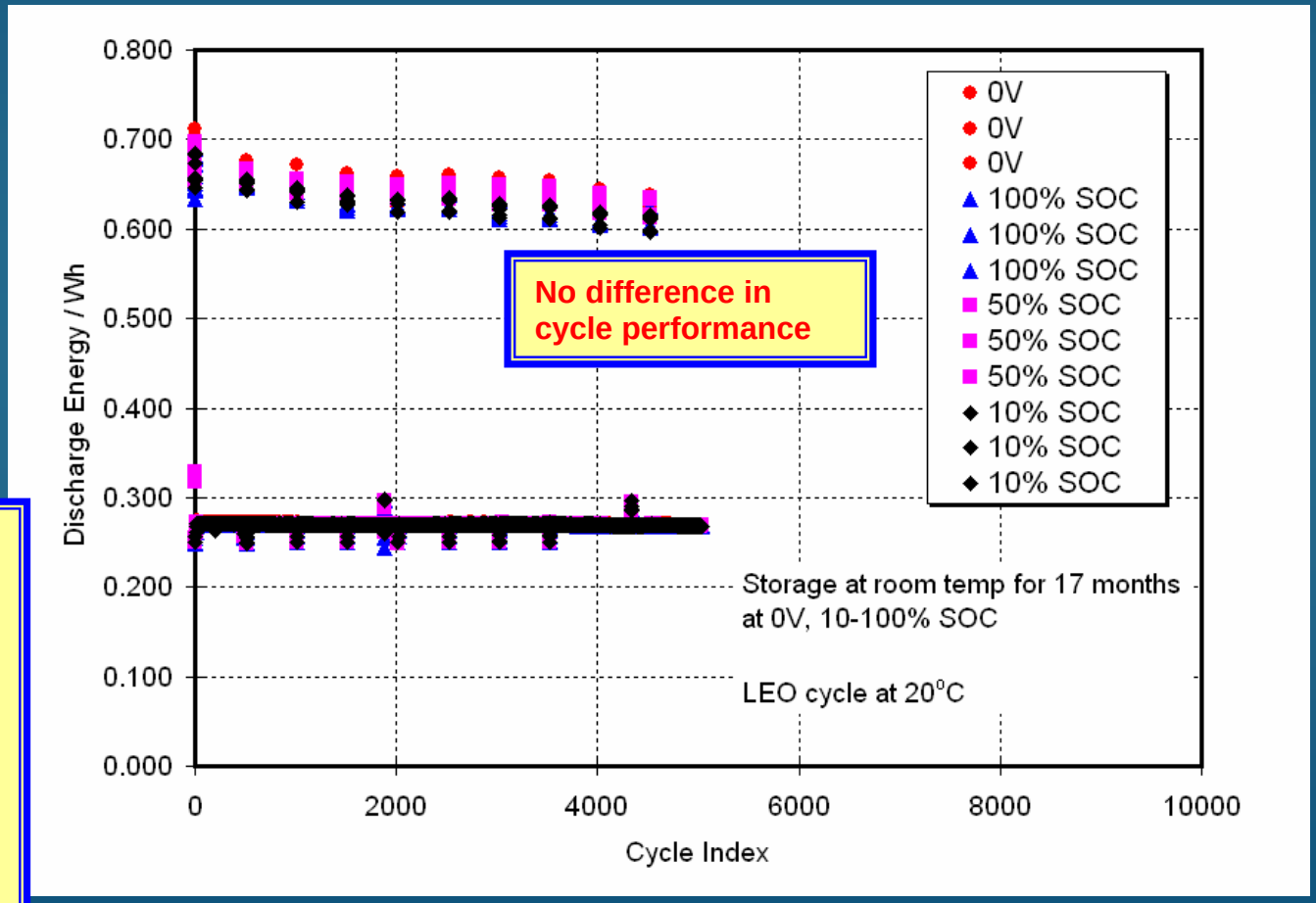
Storage Condition
For 17 months,
- 100% SOC (3 cells)
- 50% SOC (3 cells)
- 10% SOC (3 cells)
- 0V (3 cells)

(at room temperature)

Cycle condition
- LEO cycle (40% DOD)

Capacity check
- 100% DOD
  at every 500 cycles

(at 20°C)



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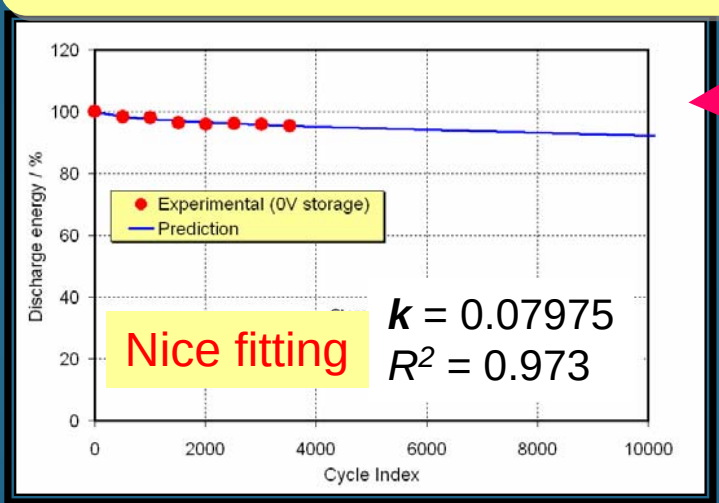
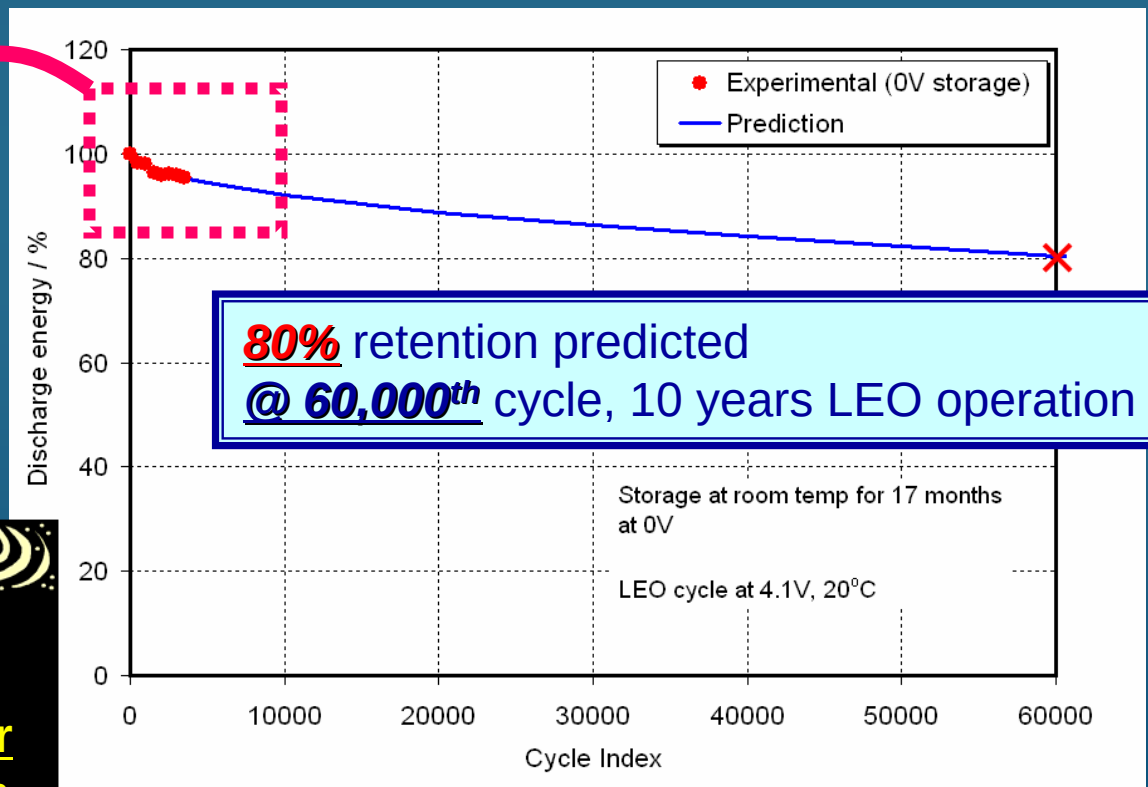
Cycle Life Prediction after 0 Volt Storage (200mAh model cell)

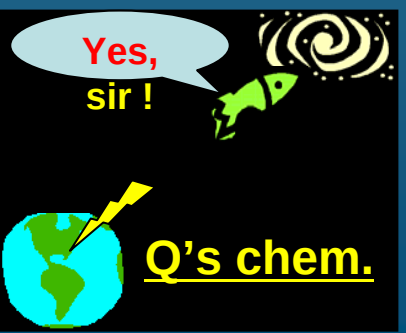
Capacity retention equation *)

$$(\text{Discharge capacity retention}) = 100 - k \times \sqrt{N_{cycle}}$$

*) k: constant to determine capacity fading rate
N_{cycle}: charge and discharge cycle index







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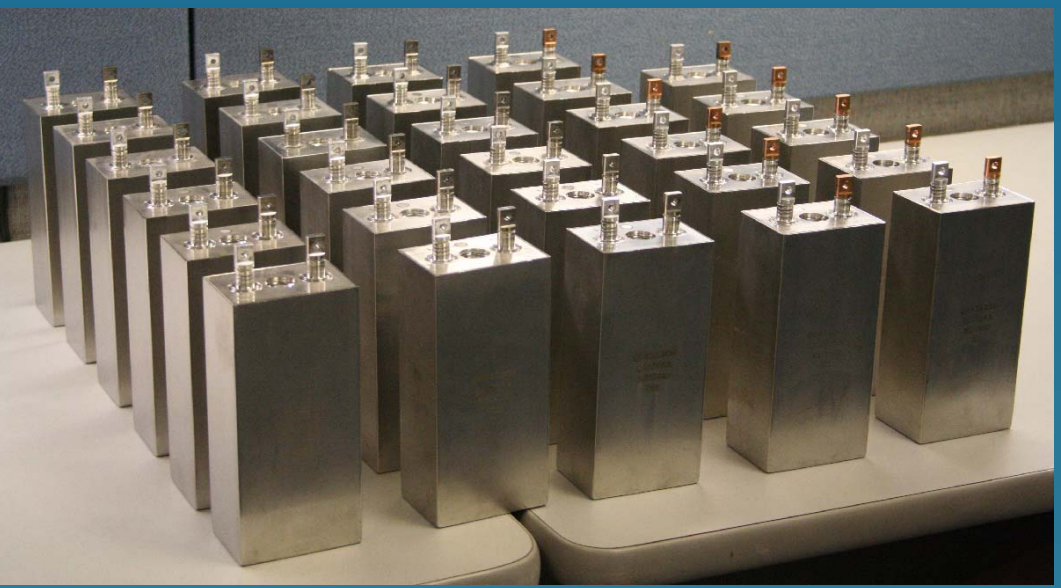
72 Ah Cell (QL075KA)



- 5A-2™ chemistry
- Zero-Volt™ enabled
- SS case

QL075KA Characteristics

- Chemistry: 5A-2™
- Zero Volt™ enabled
- SS case

Case/cover material	SS
Width	80.9 (mm)
Thickness	56.2 (mm)
Height	173.7 (mm)
Weight	1820 g
Discharge capacity	72 Ah
Weight energy density	148 Wh/kg

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QL075KA Cell Cycle Life

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- Cell nameplate: 60Ah (5/6 of 72Ah)

40% DOD cycle

- Discharge for 36 minutes at 40A to **40% of depth of discharge** (DOD).
- 24Ah taken out at the end of discharge (about **94Wh (52Wh/kg)** in each cycle)
- Charge for 54 minutes at 36A, to maximum cell voltage of **4.1V**

Capacity check at every 500 cycles

- Charged at C/2 (30 A) to 4.1 V, and I_{taper} of C/20 (0.3 A).
- Discharged to 2.7V at C/2 rate (30 A), **100% of DOD**.

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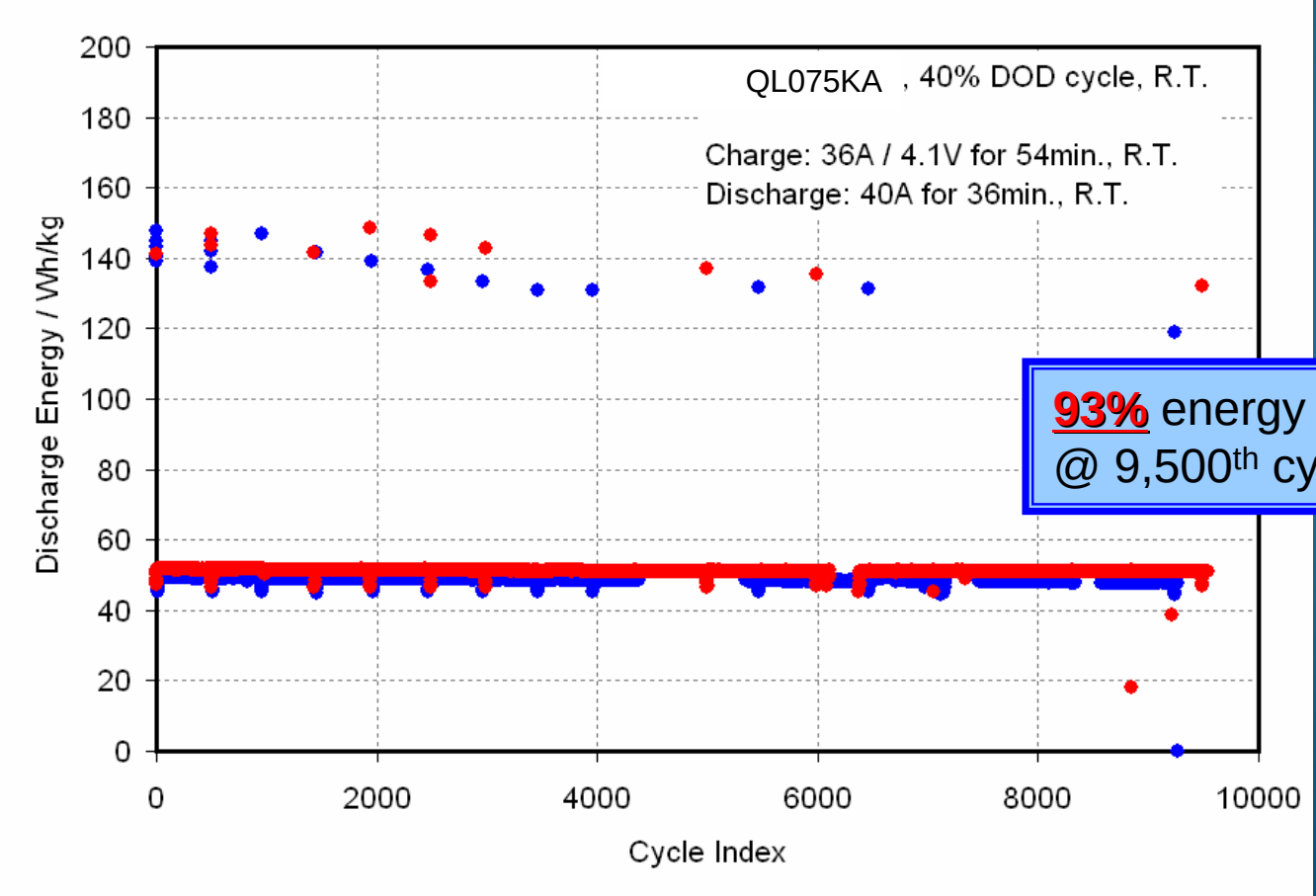
QL075KA Cell
40% DOD Cycle @ R.T.

Discharge energy



93% energy retention @ 9,500th cycle

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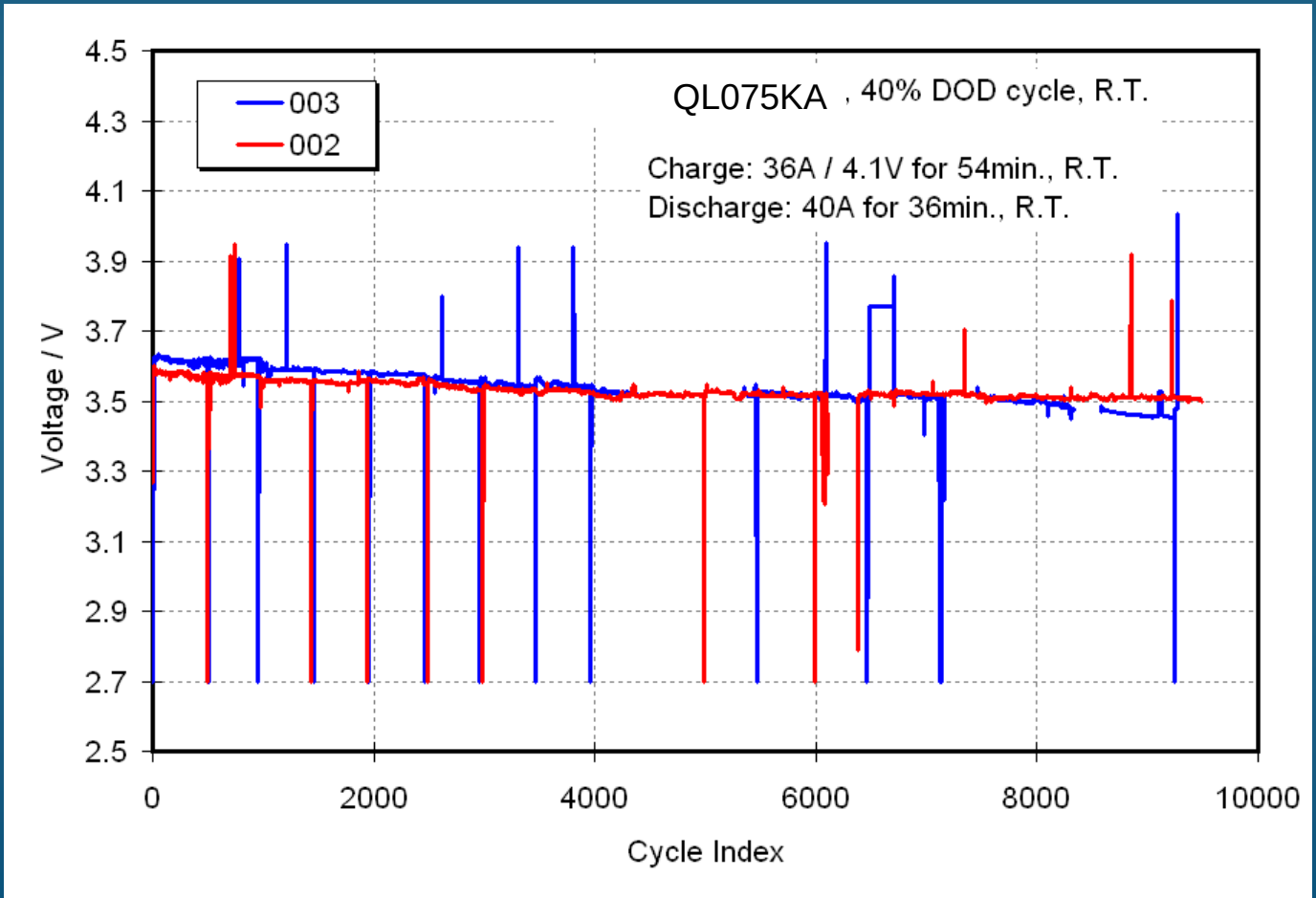
QL075KA Cell
40% DOD Cycle Performance @ R.T.

Cell voltage @ end of discharge



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QL075KA Cell
40 % DOD Cycle Prediction @ R.T.

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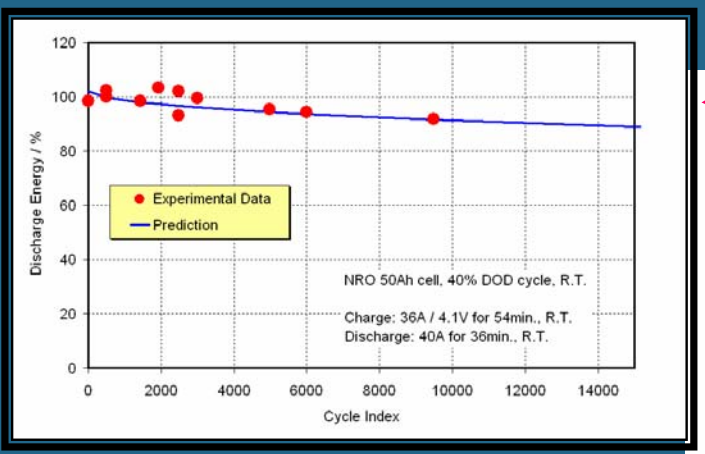
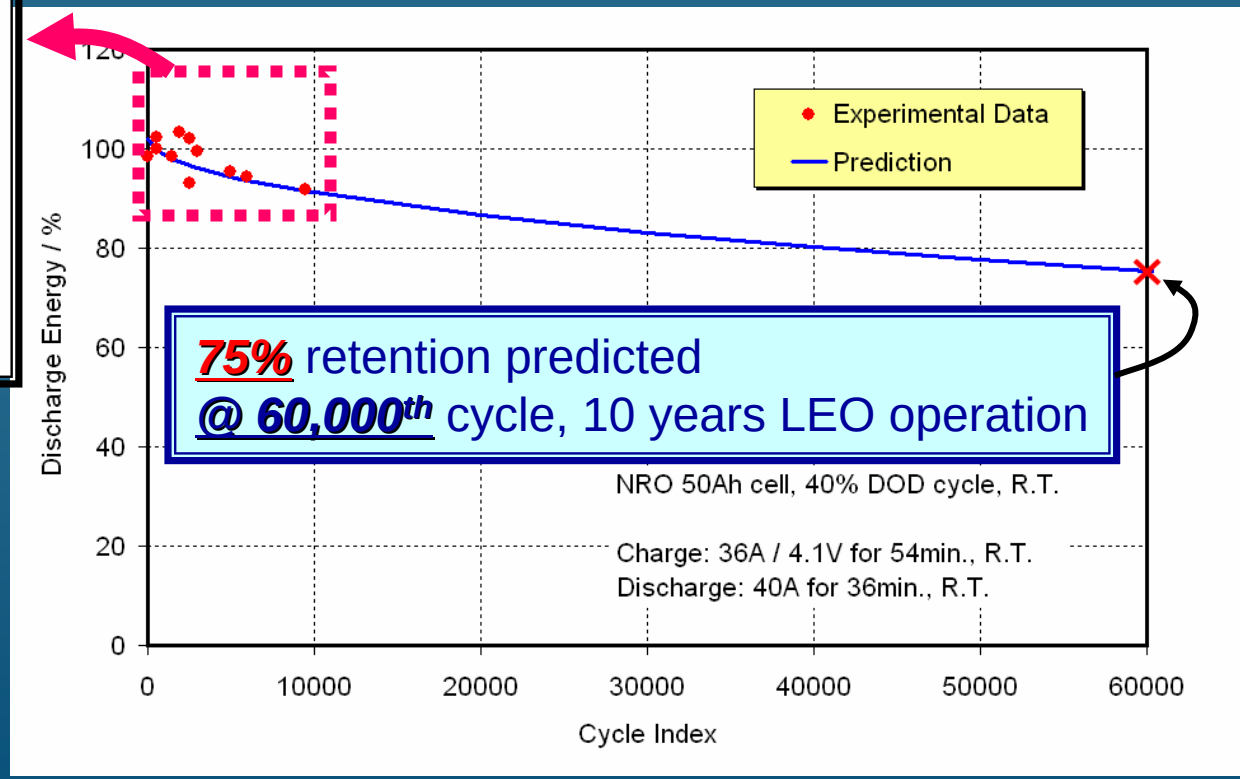
Capacity retention equation *)

$$(\text{Discharge capacity retention}) = 100 - k \times \sqrt{N_{cycle}}$$

*) k: constant to determine capacity fading rate
N_{cycle}: charge and discharge cycle index



Discharge energy



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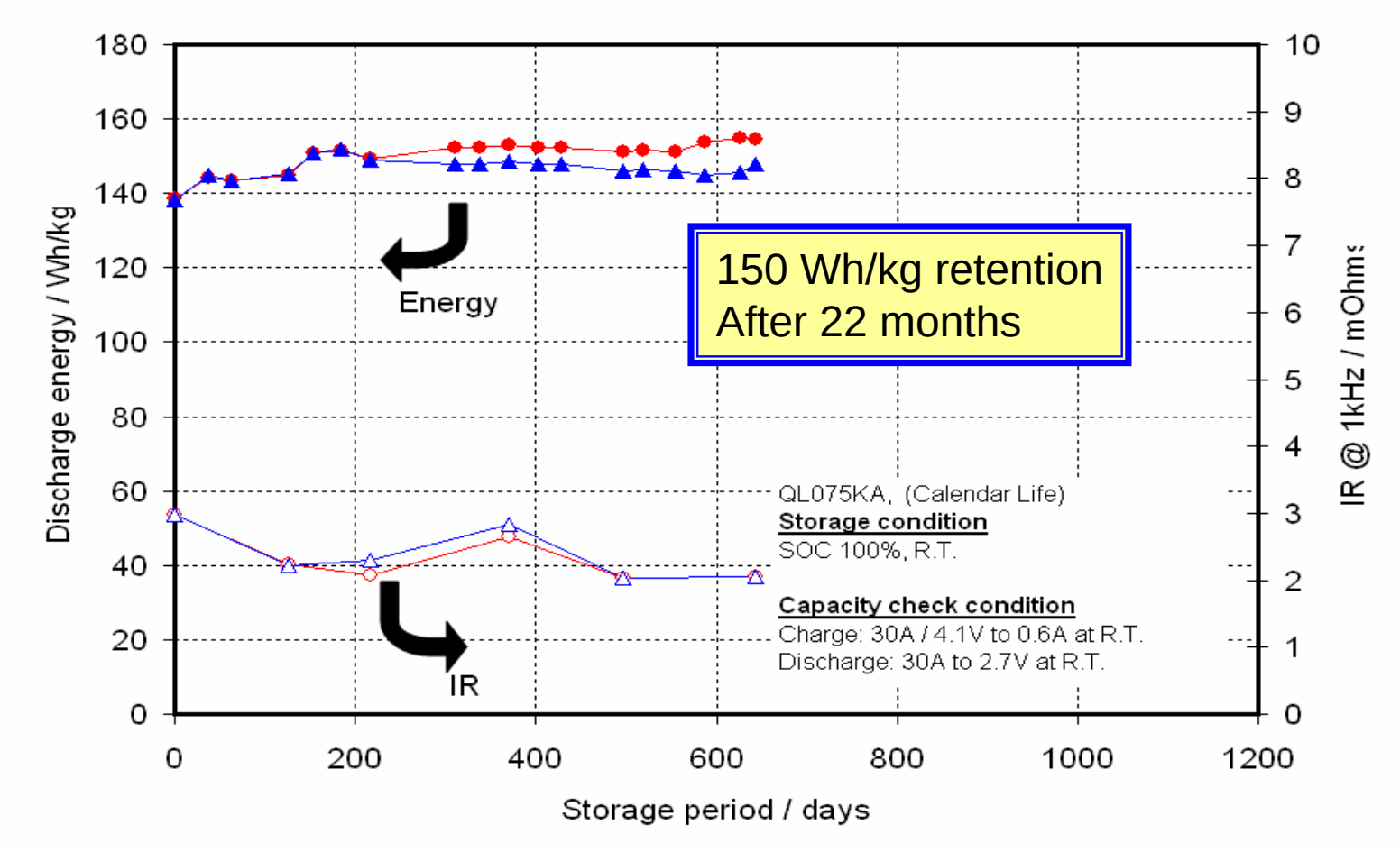
QL075KA Energy Density / IR Calendar Life (100% SOC @ R.T.)



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15 Ah Cell (QL015KA)

- 5A-2™ chemistry
- Zero-Volt™ enabled
- Al case

Al / SS Clad Cover

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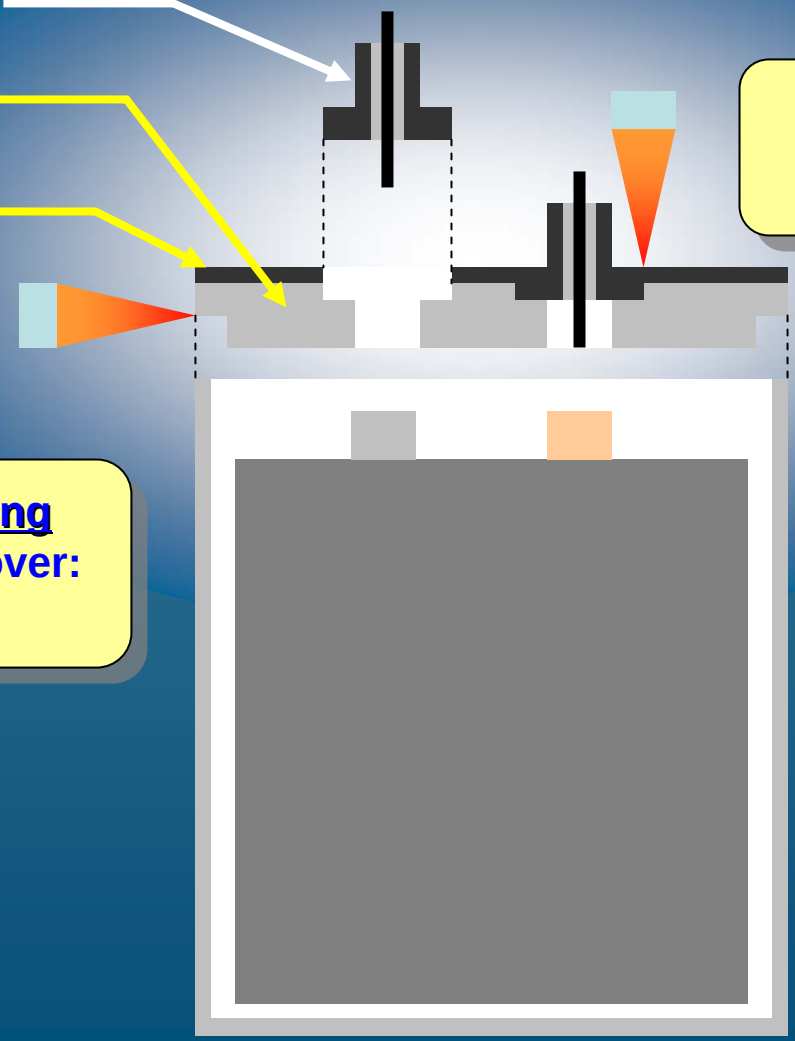
USP 6,554,178
USP 6,716,554



Laser welding
(Cover- FT, FP, Burst valve:
SS – SS)

Laser welding
(Case to Cover:
Al – Al)

SS case 121 Wh/kg

↓

Al case 150 Wh/kg

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15Ah Al Case Cell Characteristics

	QL015KA
Appearance	SS cover Al case
Cover material	Al-SS clad metal
Case material	Al
Dimension	89 mm^{h} × 53 mm^{w} × 36 mm^{D}
Weight	***360 g***
IR (@ 1kHz)	5 mOhm
Discharge capacity	15 Ah
Energy density	***150 Wh/kg***

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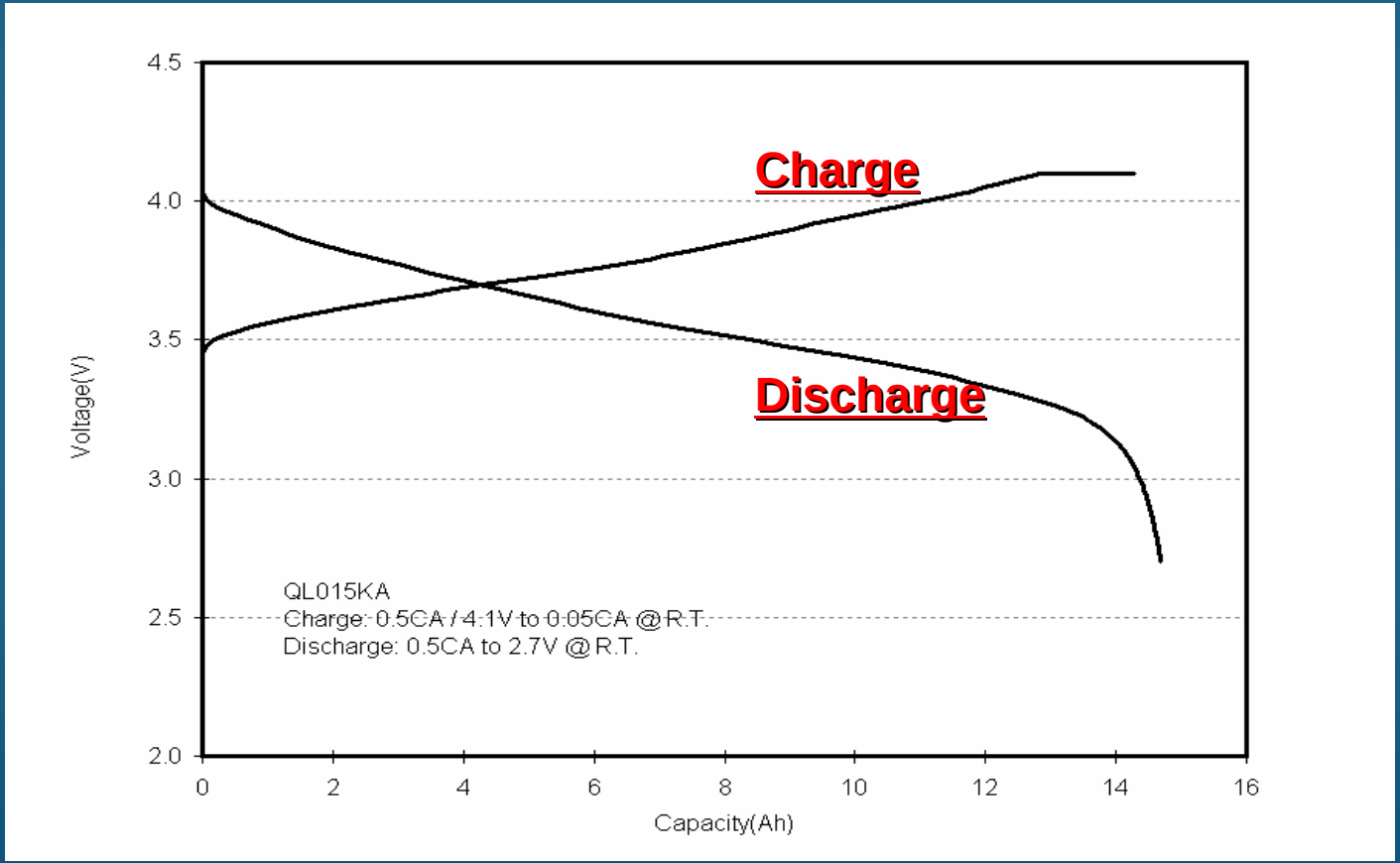
QL015KA: Charge and Discharge Curve



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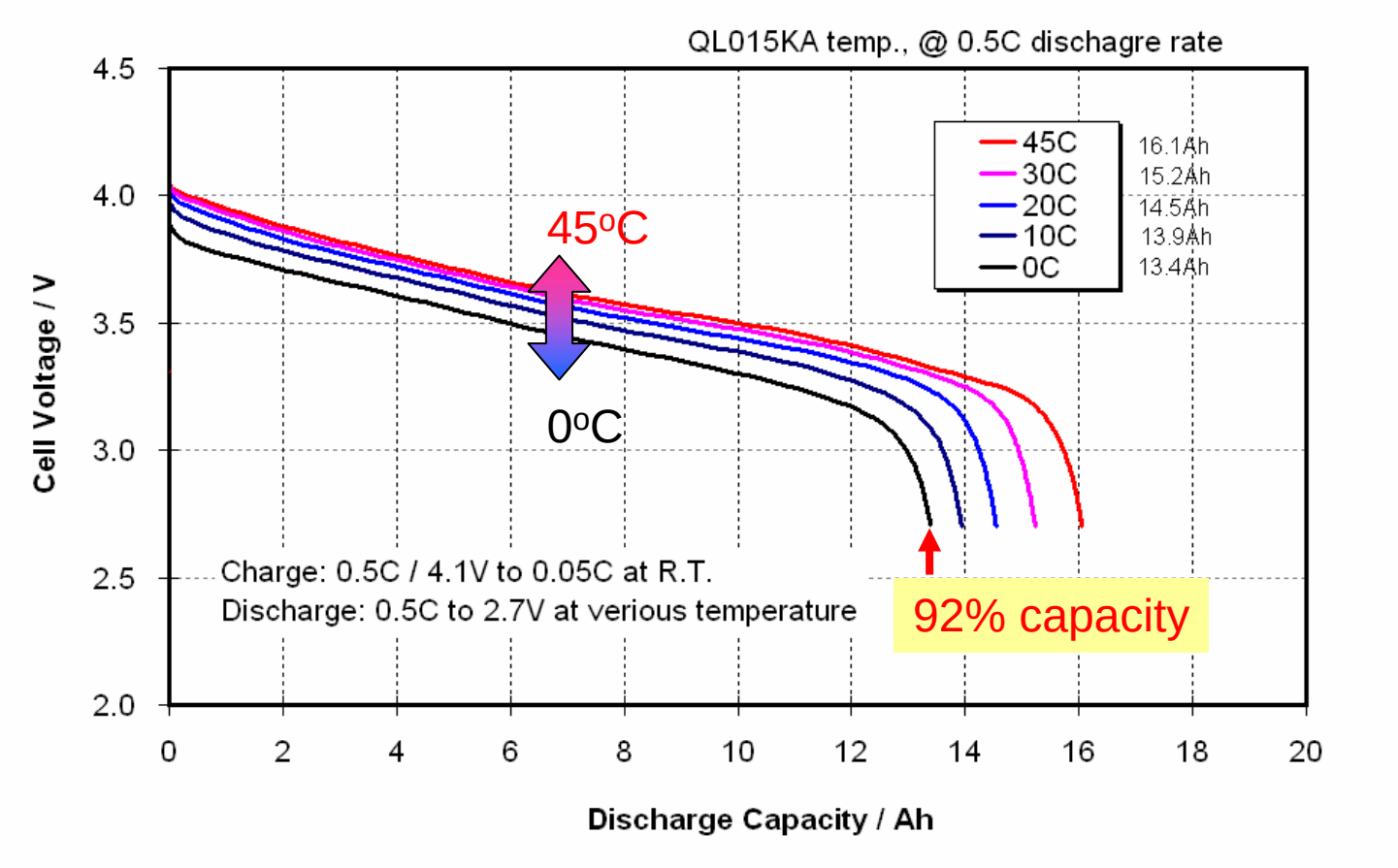
QL015KA: Discharge Curves @ 0 – 45ºC



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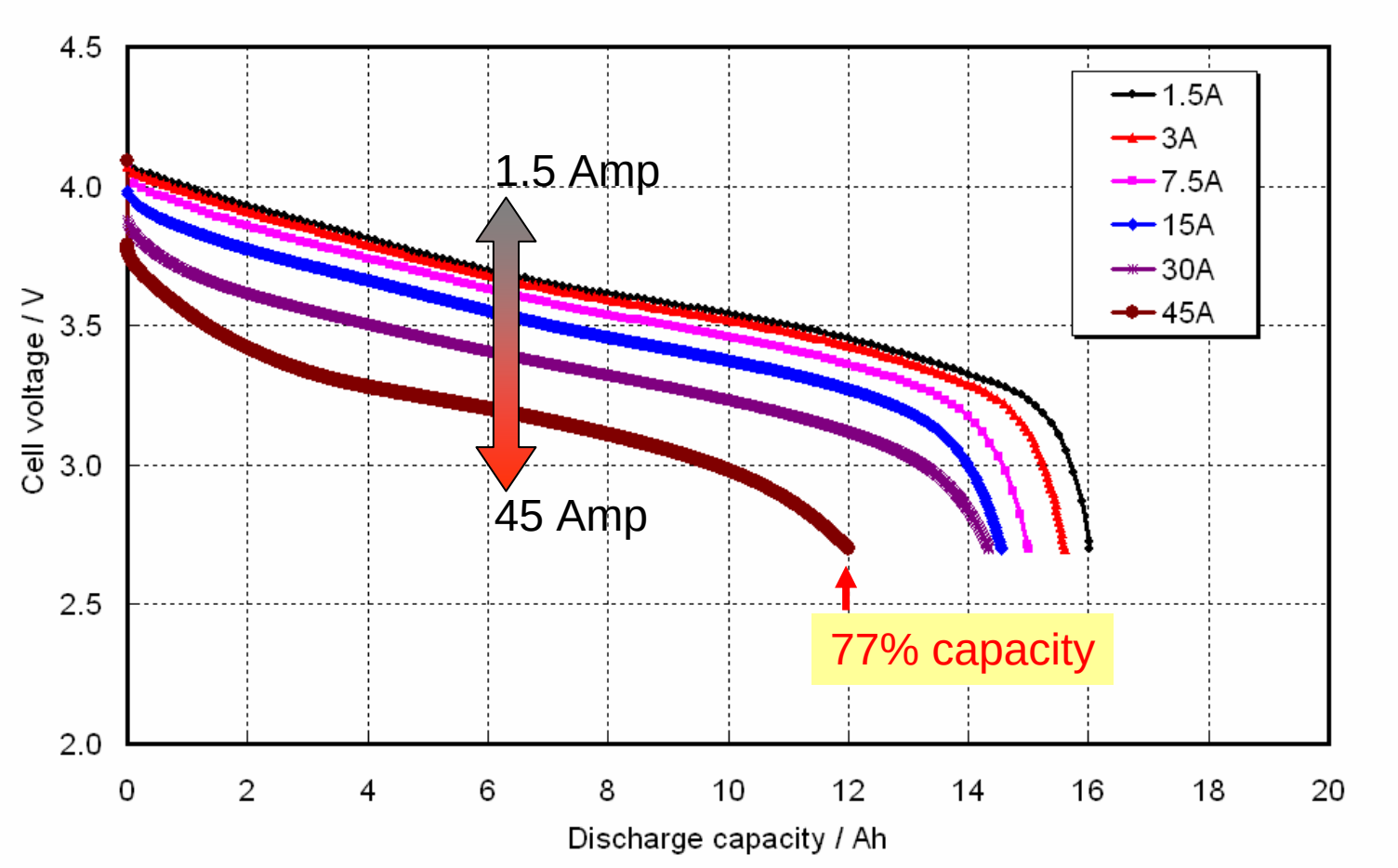
QL015KA: Discharge Rate Capability @ 1.5 – 45A (0.1 – 3C)



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15Ah Cell Cycle Life Test

- Cell nameplate: 12.5Ah (5/6 of 15Ah)

48% DOD cycle

- Discharge for 36 minutes at 9A to **48% of depth of discharge** (DOD).
- 6Ah taken out at the end of discharge (about **22Wh (49Wh/kg)**) in each cycle
- Charge for 54 minutes at 10A,
  to maximum cell voltage of **4.1V**

Capacity check / AC impedance check at every 500 cycles

- Charged at 7.5A to **4.1 V**, and I_{taper} of 0.75A.
- Rest for 10 minutes.
- Discharged to 2.7V at 7.5A.

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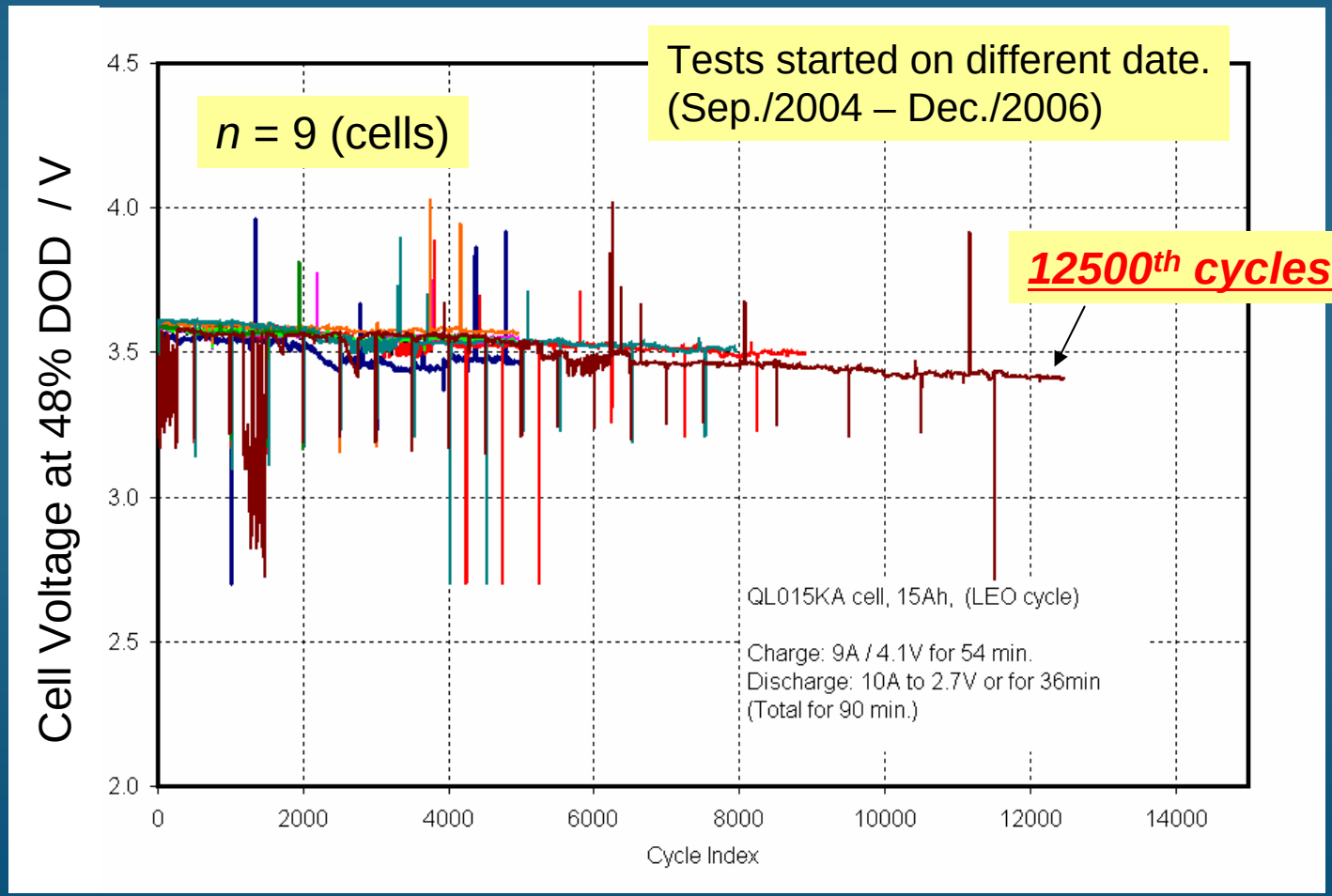
15Ah Cell Performance (*SS case*)

48% DOD cycle (49Wh/kg cycle)*

*Nameplate 12.5Ah (5/6 of 15Ah)



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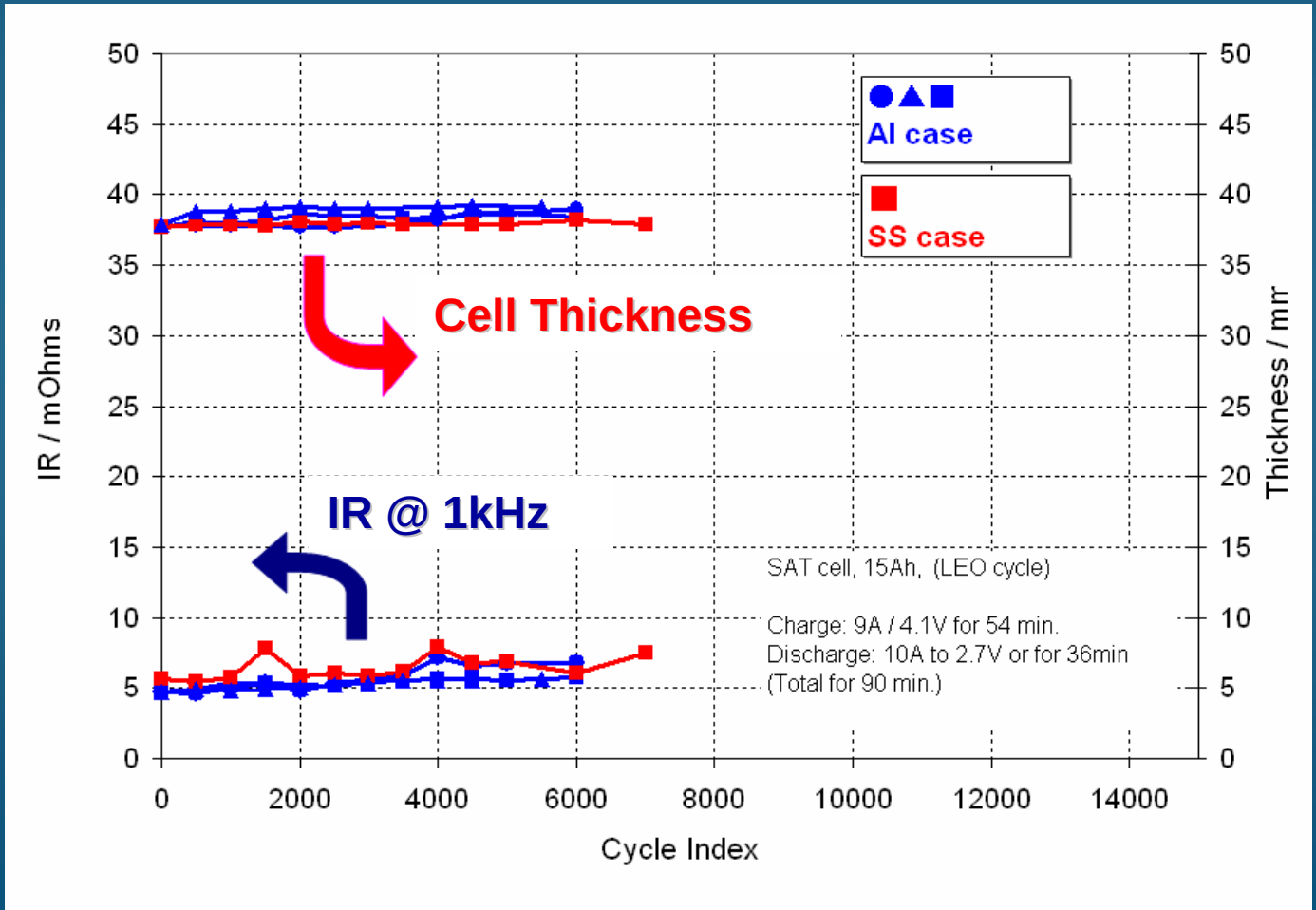
QL015KA Swelling Data

No Swelling after 6,000 Cycle



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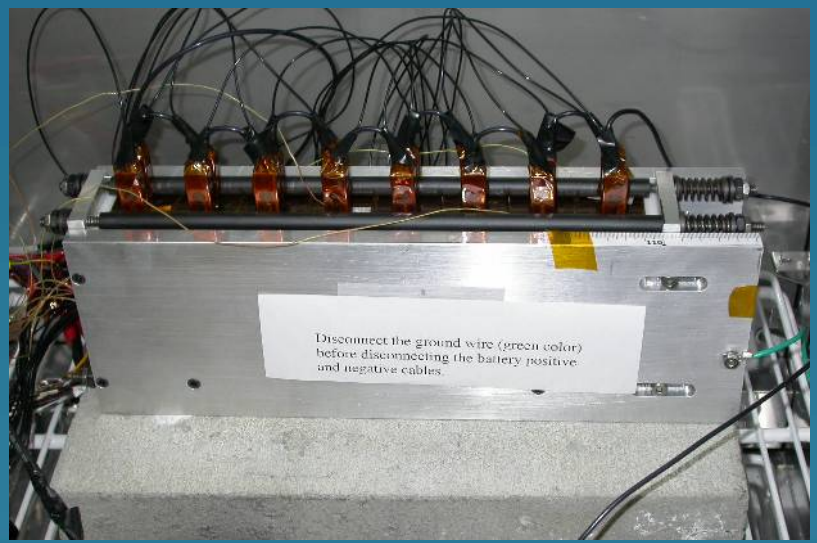
QL015KA in 8S Battery Pack Cycle Performance



Characteristics of QL015KA pack in 8 series connection under 20% DOD cycling at 30°C

- **Electrical characterization**
  - Capacity retention after 11,000th cycle
  - Cell / battery voltage transition
  - Difference in cell voltages
- **Thermal characterization**
  - Temperature profile in cycling
  - Hot / cold point in battery pack
  - Maximum temperature difference during cycling

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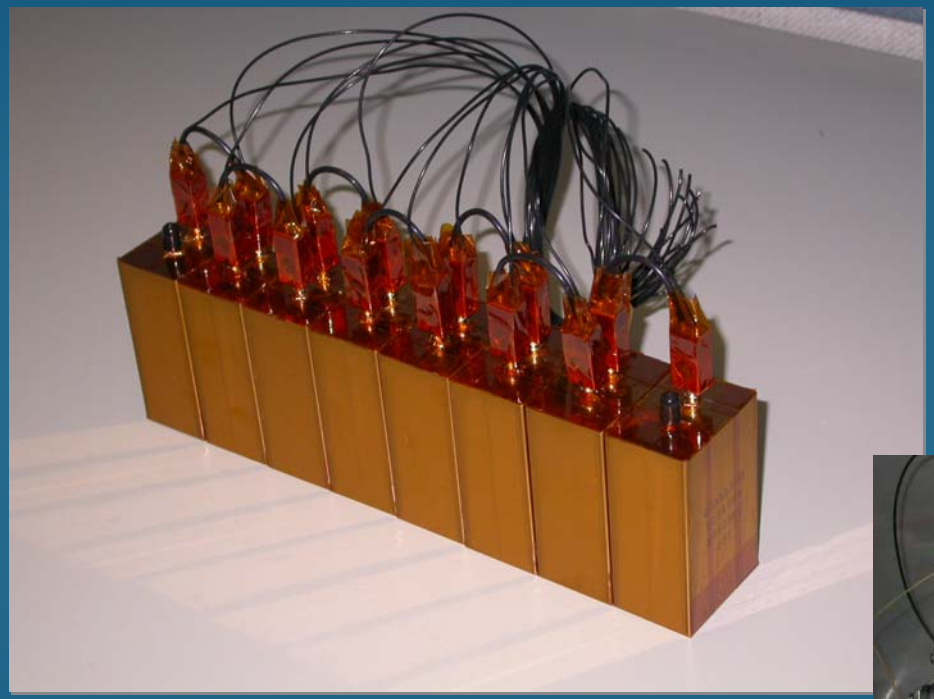
8-Cell Series Battery Pack



Cell type	QL015KA
Configuration	8 cells in series
Capacity	15 Ah
Voltage	21.6 – 32.8 V
Dimension	89 x 54.5 x 304 mm

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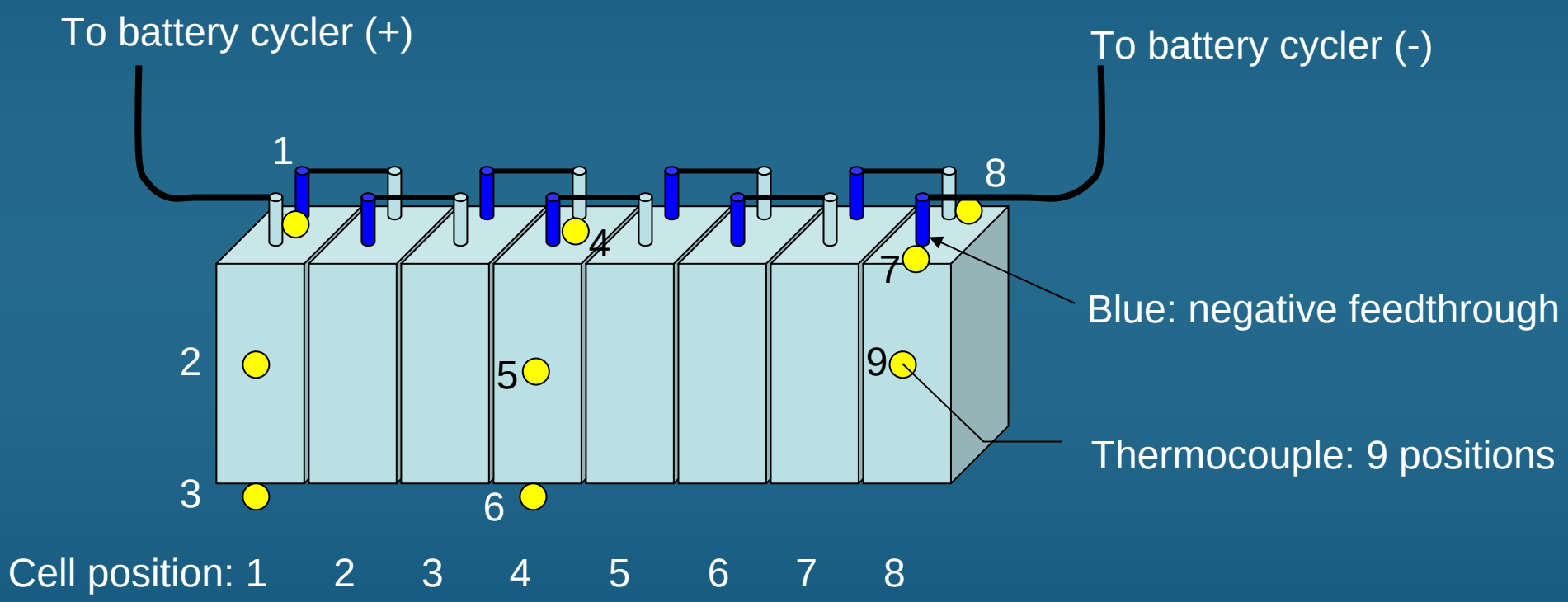
Thermocouple Location in 8 QL015KA Cells Battery



No cell balancing system is used.

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Cycle Test Protocol

- Cell nameplate: 12.5Ah (5/6 of 15Ah)

Charge:

CC Charge: Constant current at 9A (0.72C)
CV Charge: Constant voltage charge at 4.1V.
Total charge time of 27.5 minutes

Discharge:

CC discharge: Constant current at 10.3 A (0.82C) for 17.5 min (3 Ah = 24% DOD)
Total discharge time of 17.5 min

No rest between charge and discharge steps

Monitoring:

Battery voltage
Individual cell voltages
Cell temperatures (9 points)
Environmental temperature

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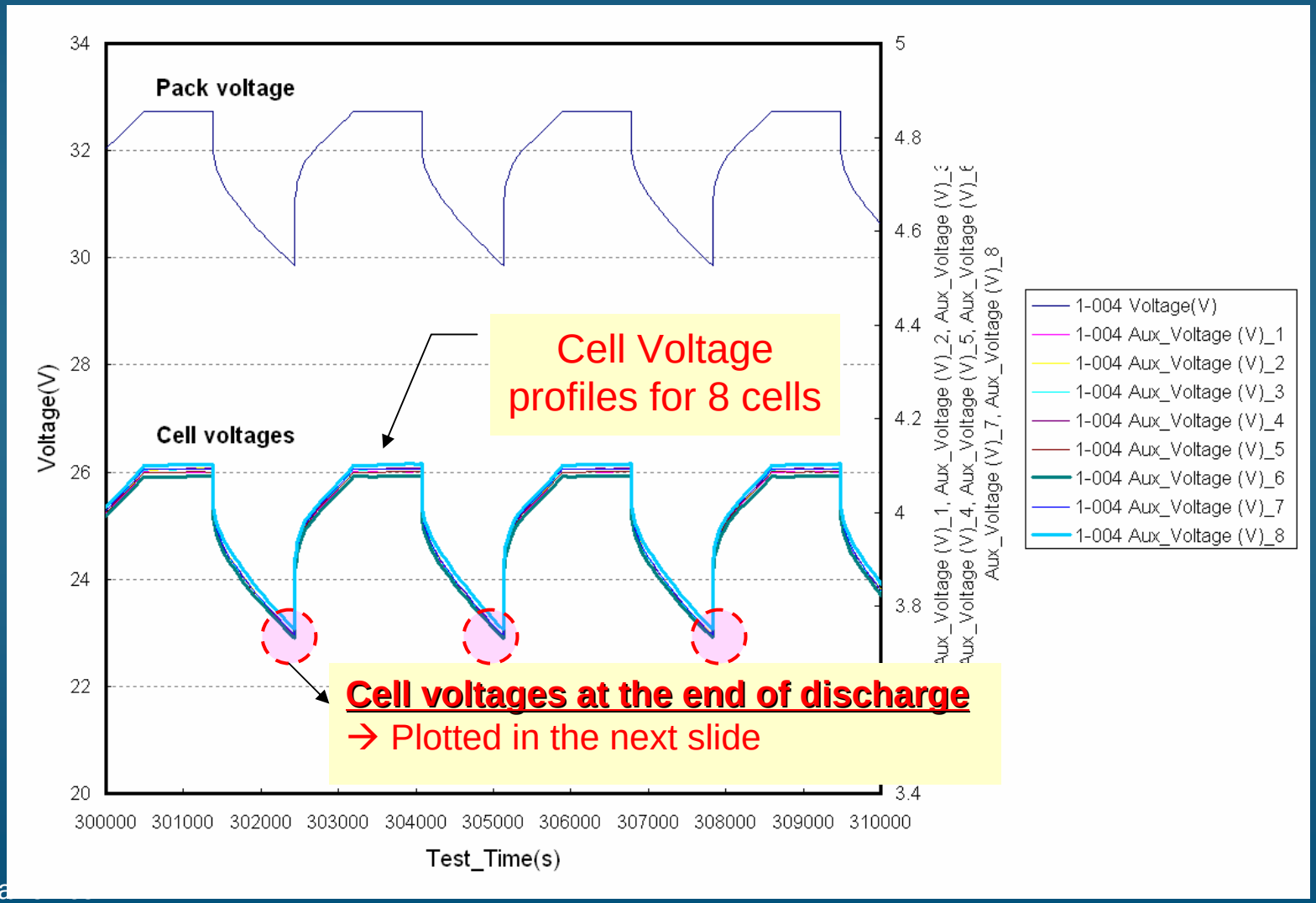
Battery / Cell Voltage Profile during Cycling



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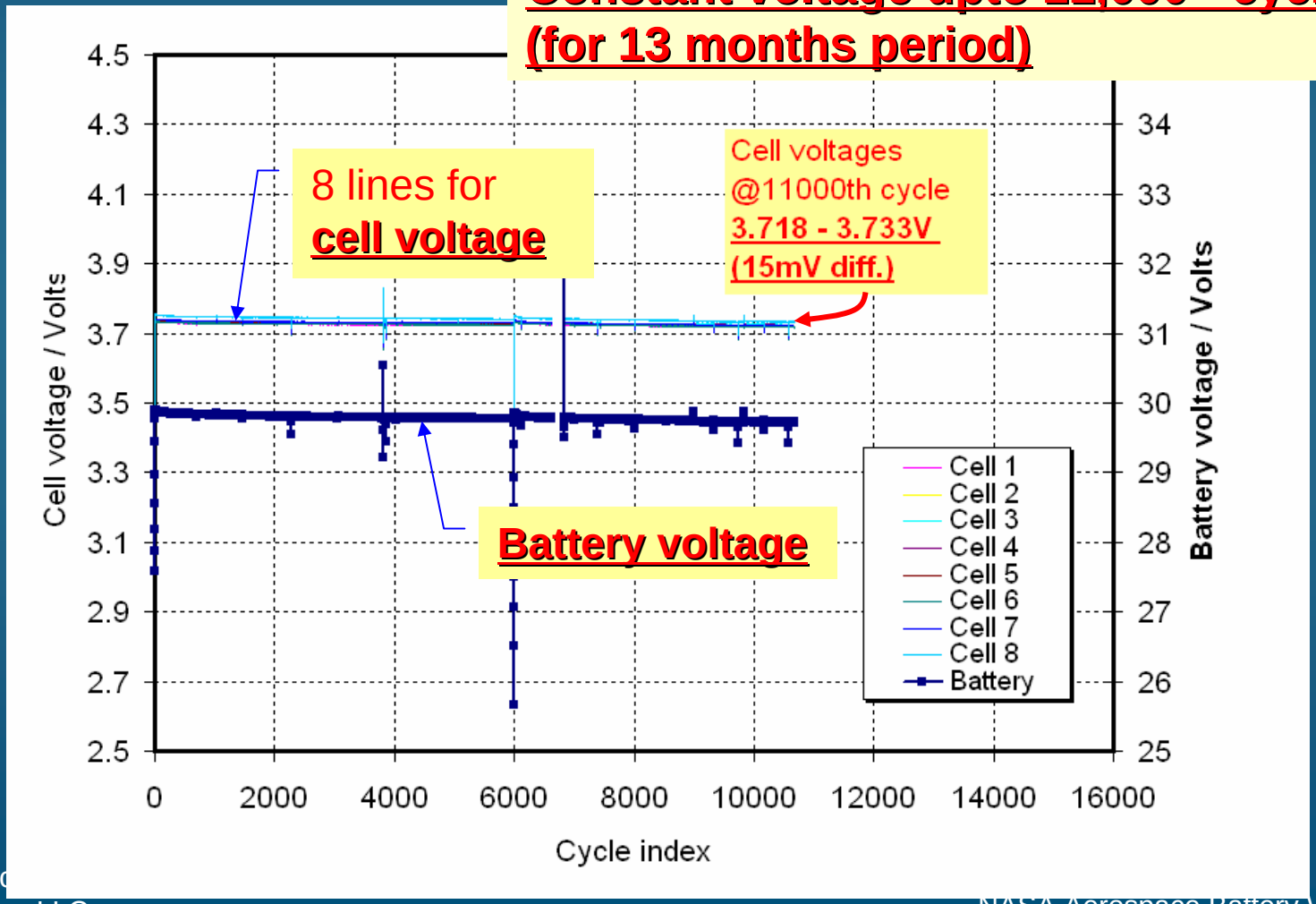
Battery Voltage and Cell Voltages at End of Discharge (24% DOD)

Constant voltage upto 11,000th cycle (for 13 months period)



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Temperature / Voltage Profile

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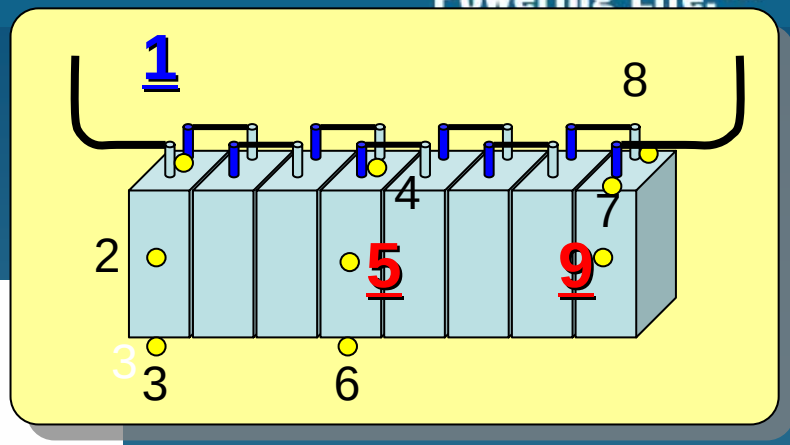

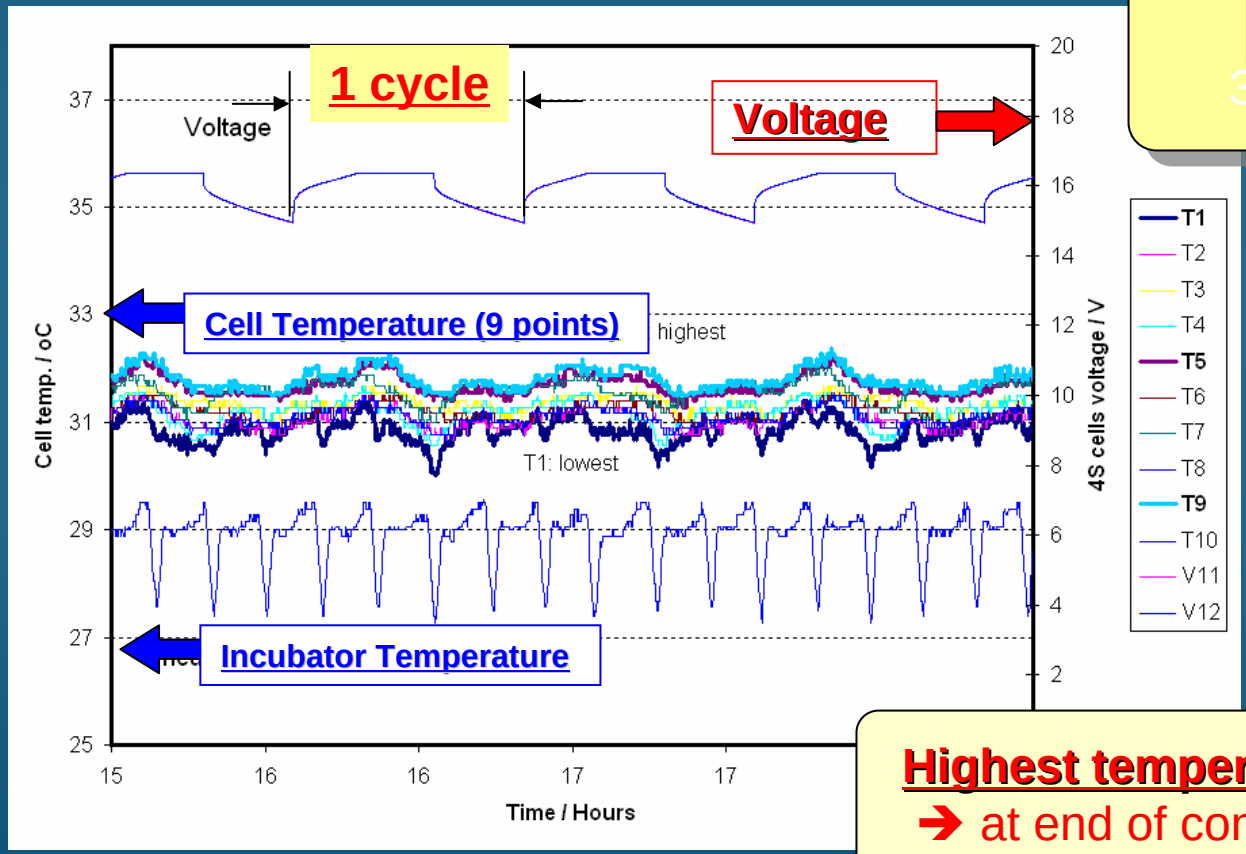

Lowest: near the positive terminal connected to Arbin tester

Highest: Negative side wall

Highest: Negative side wall

Highest temperature in time scale
➔ at end of constant current charge

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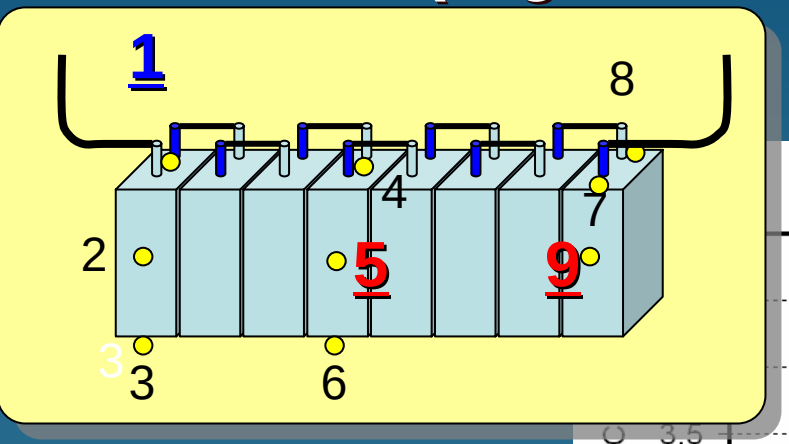
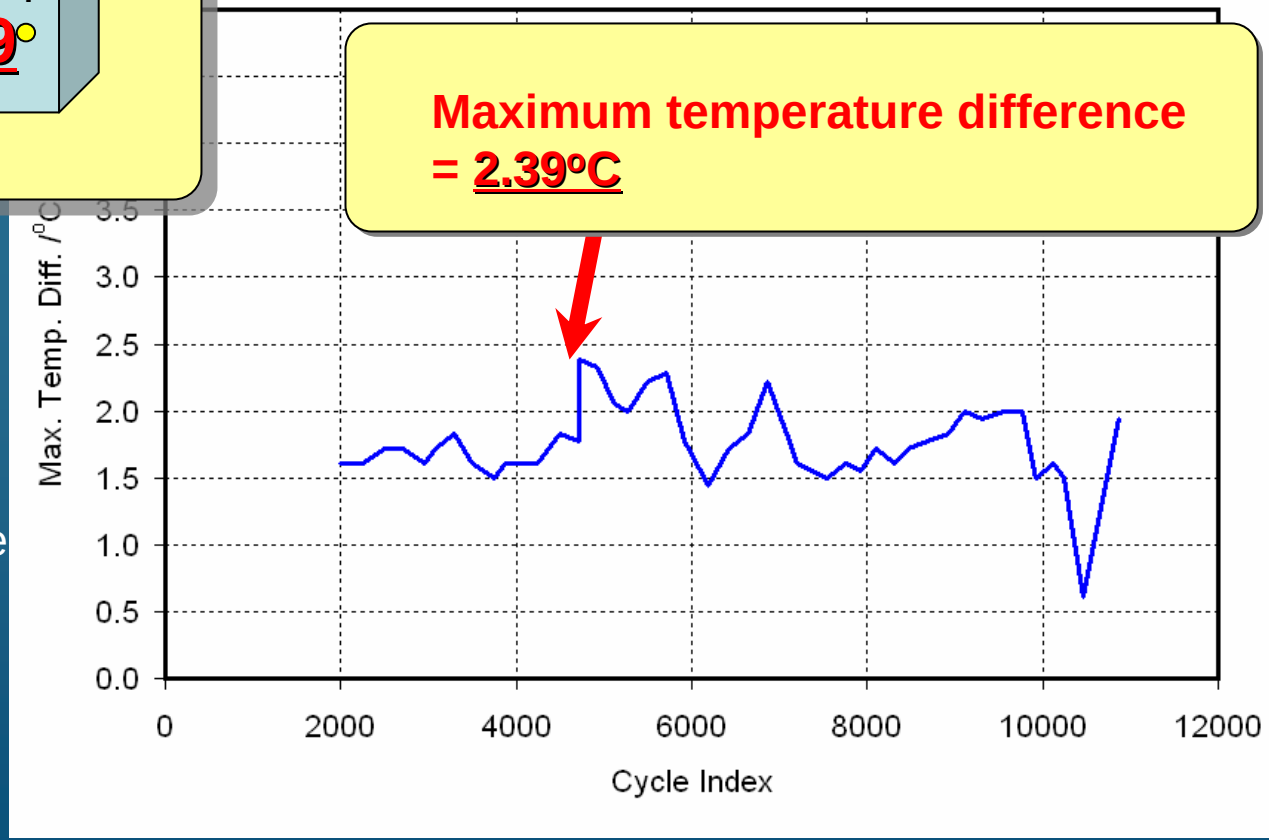
Temperature Difference in Battery Pack
(Highest temp.) – (Lowest temp.)



Lowest: Near positive (1)
Highest: Negative side wall (5) or (9)

Calculate the temp difference In battery pack



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Findings of Battery Pack Testing (QL015KA 8 cells in series)

- Pack voltage / discharge capacity were stable after 11,000 cycles.
- Difference in cell voltages after 11,000 cycles < 0.02V
- Maximum temperature gradient (between hottest and coldest point) = 2.39°C
- 1.6 % capacity loss after 7,000 cycles (14.8Ah → 14.6Ah)

(Not equipped with cell balancing circuit)

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Quallion Technology Applied to QL-KA cells

- Aluminum case with hermetic seal
  - USP 6,554,178 and 6,716,554
- 5A-2™ long life chemistry (LNCAO/Graphite Mix)
  - USP 6,852,449 and 6,998,192
  - Expected cycle life: > 60,000 cycle at DOD 40% (Nameplate base - 5/6 of total capacity)
- Zero-Volt™ storage capability
  - USP 6,596,439
- Life Modeling of Cell and Battery
  - First principles/semi-empirical model offered with cells
- 8-cell-series battery pack
  - 15 mV difference in cell voltages after 11,000 cycles
  - Max. 2.39°C temperature difference in 9 measurement points

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