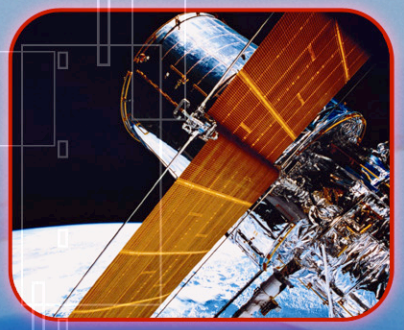
QUALLION



Characteristics of Quallion's Battery for Aerospace Application

Hiroshi Nakahara, PhD
Quallion LLC

2009 NASA Aerospace Battery Workshop, 11/17-19/2009

Powering Life.

Contents

- **Program overview**
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  - LEO cycle (@ 4.1V, R.T.)
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  - LEO cycle @ 20% DOD, R.T. or 30°C)
    - Electrical characteristics
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Powering Life.

QUALLION

Program Overview

Development 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					→	→	→	- - →

Quallion's Chemistry

- Cycle Performance
- ZeroVolt™ Technology

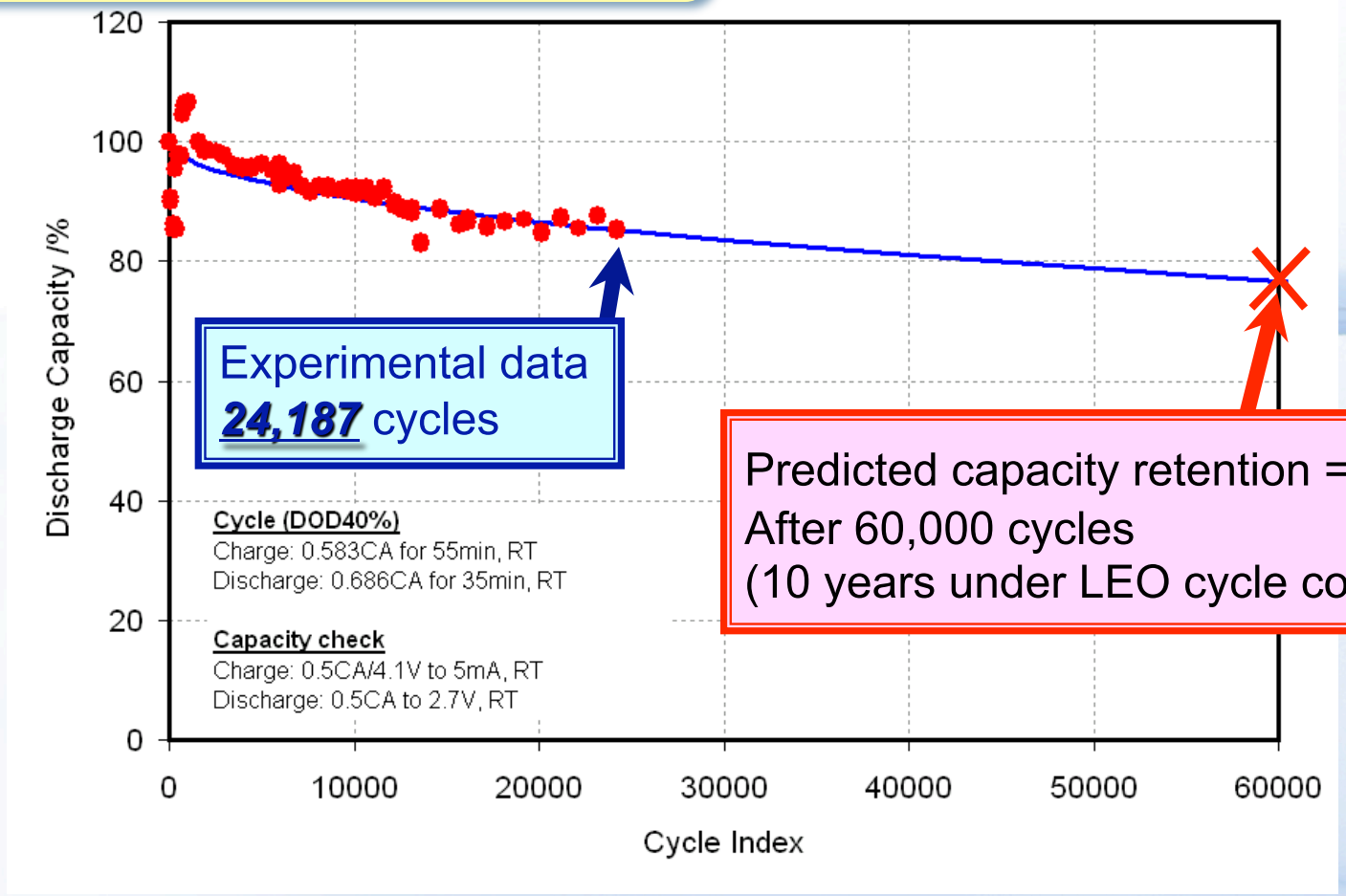
Powering Life.

LEO Cycle : Discharge Capacity (170mAh model cell)

Capacity retention equation *)

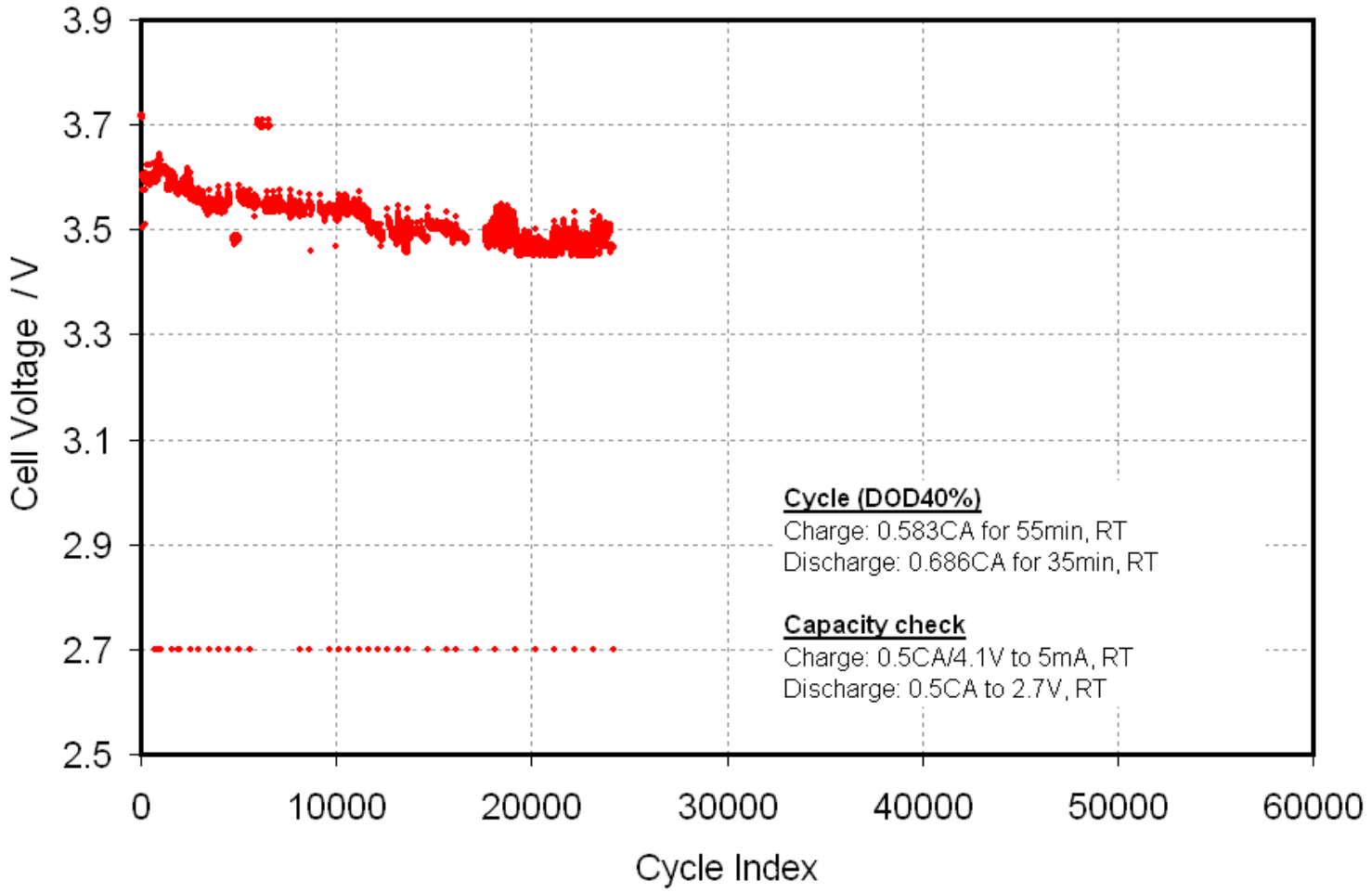
(Discharge capacity retention) = 100 - $k \times \sqrt{N_{cycle}}$

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



Powering Life.

LEO Cycle : Cell Voltage
(170mAh model cell)



Powering Life.

Zero Volt™ Capability

Cycle Performance after 0V Storage (17 months)
(200mAh model cell)

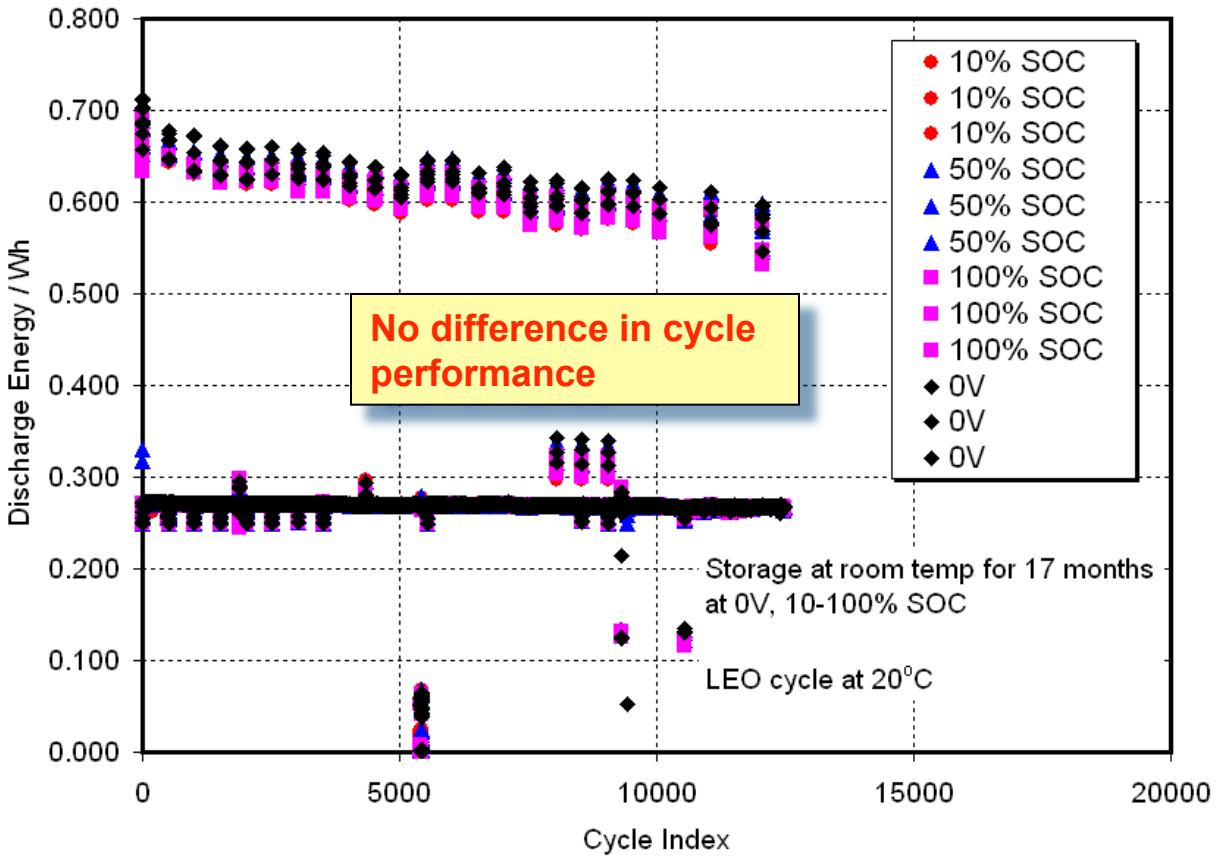
Storage Condition
For 17 months,
- 100% SOC (3 cells)
- 50% SOC (3 cells)
- 10% SOC (3 cells)
- 0V (3 cells)

(at room temperature)

Cycle condition
- LEO cycle (4.1V, 40% DOD)

Capacity check
- 100% DOD
  at every 500 cycles

(at 20°C)

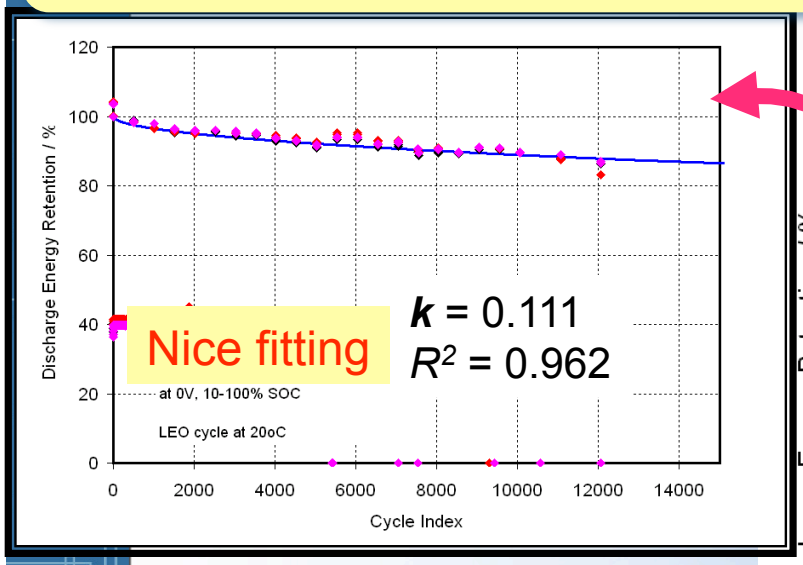


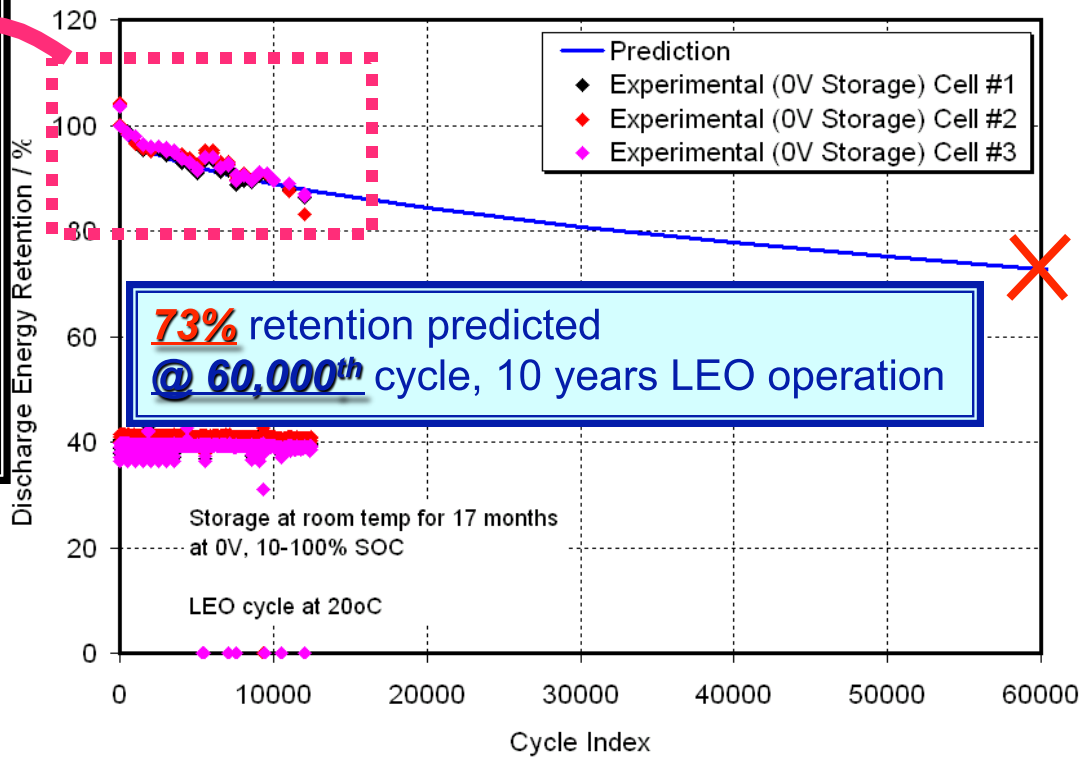
Cycle Life Prediction after 0 Volt Storage
(200mAh model cell)

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





Powering Life.

Quallion's SAT Cell Performance QL015KA / QL075KA

- Cycle Performance
- Calendar life

Powering Life.

Cell characteristics
QL015KA

	QL015KA
Height / mm	89.0
Width / mm	54.5
Thickness / mm	37.5
Weight / g	445
Operating voltage / V	2.7 – 4.1
Discharge capacity / Ah	14.5*
Weight energy density / Wh/kg	117
Volumetric energy density / Wh/l	287
Zero-Volt™ technology	Applicable

* Discharge at C/2

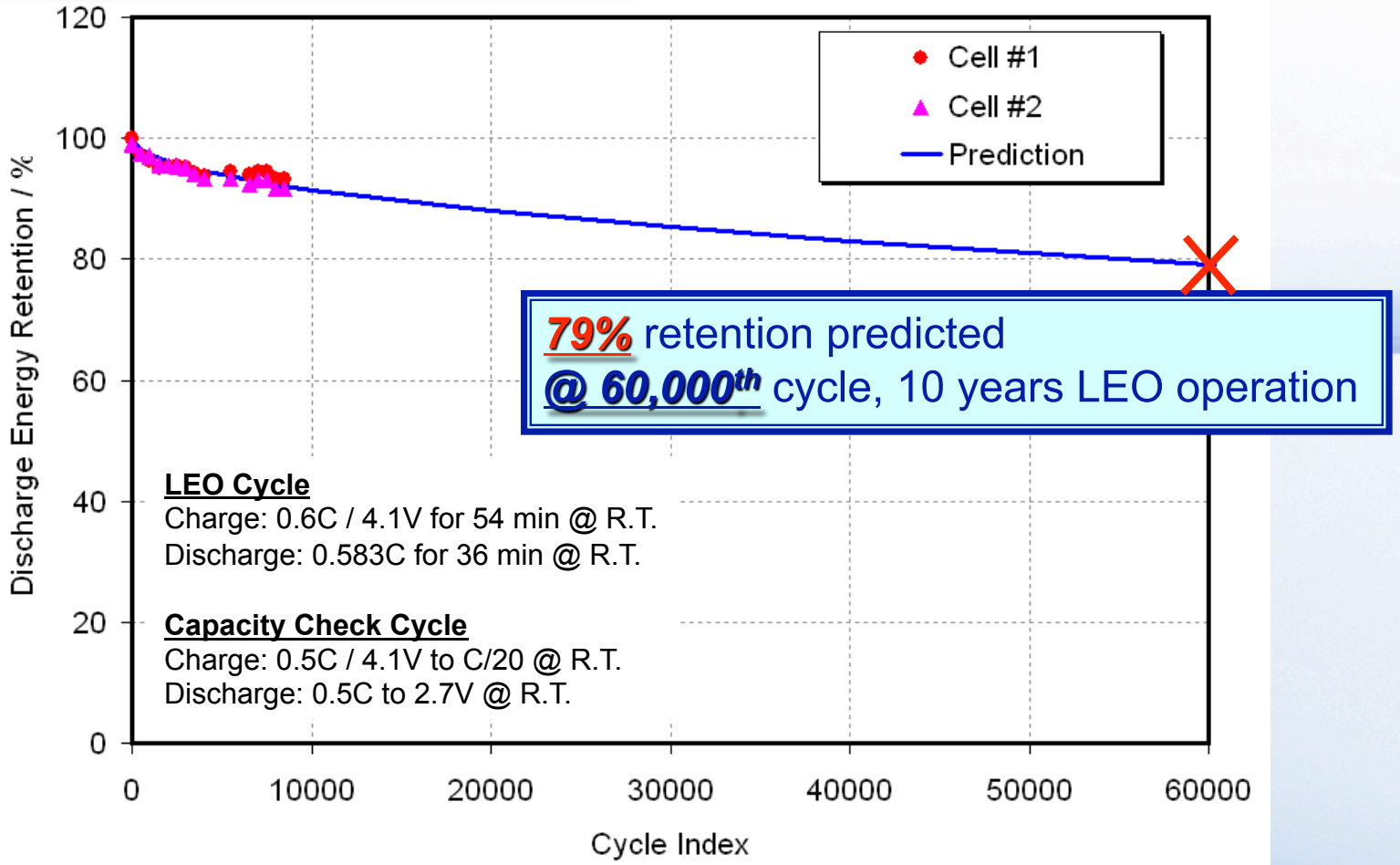
Powering Life.

QL015KA
LEO Cycle Performance: 40% DOD, 4.1V, R.T.

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



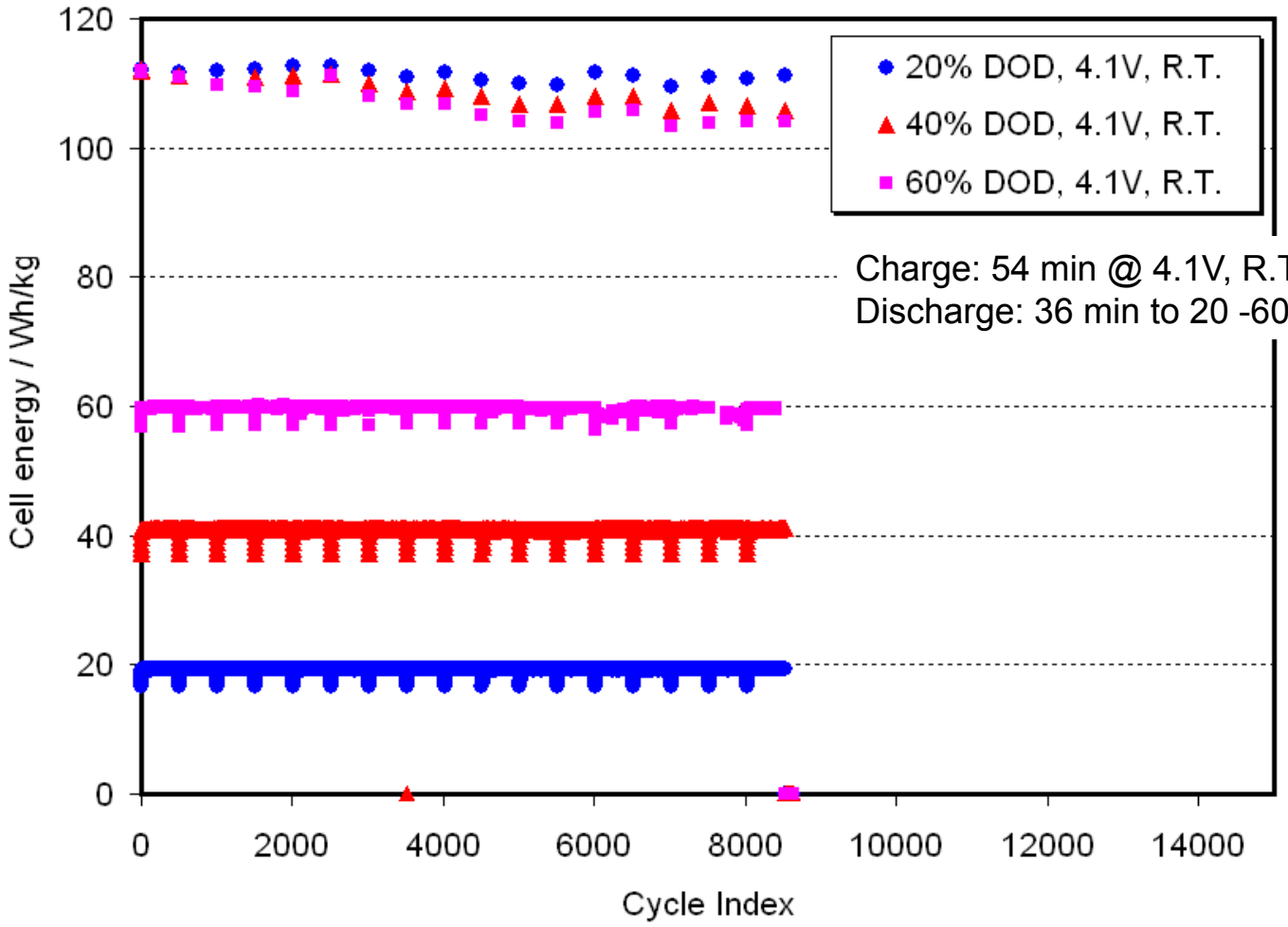
79% retention predicted
@ 60,000th cycle, 10 years LEO operation

LEO Cycle
Charge: 0.6C / 4.1V for 54 min @ R.T.
Discharge: 0.583C for 36 min @ R.T.

Capacity Check Cycle
Charge: 0.5C / 4.1V to C/20 @ R.T.
Discharge: 0.5C to 2.7V @ R.T.

Powering Life.

QL015KA
Effect of DOD on LEO Cycle Performance: 4.1V, R.T.

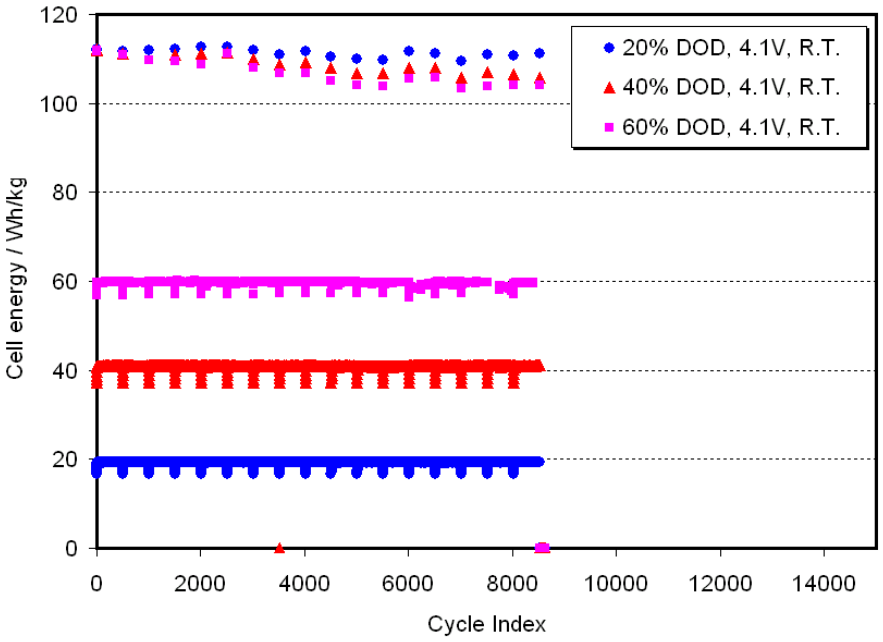


Charge: 54 min @ 4.1V, R.T.
Discharge: 36 min to 20 -60 % DOD @ R.T.

Powering Life.

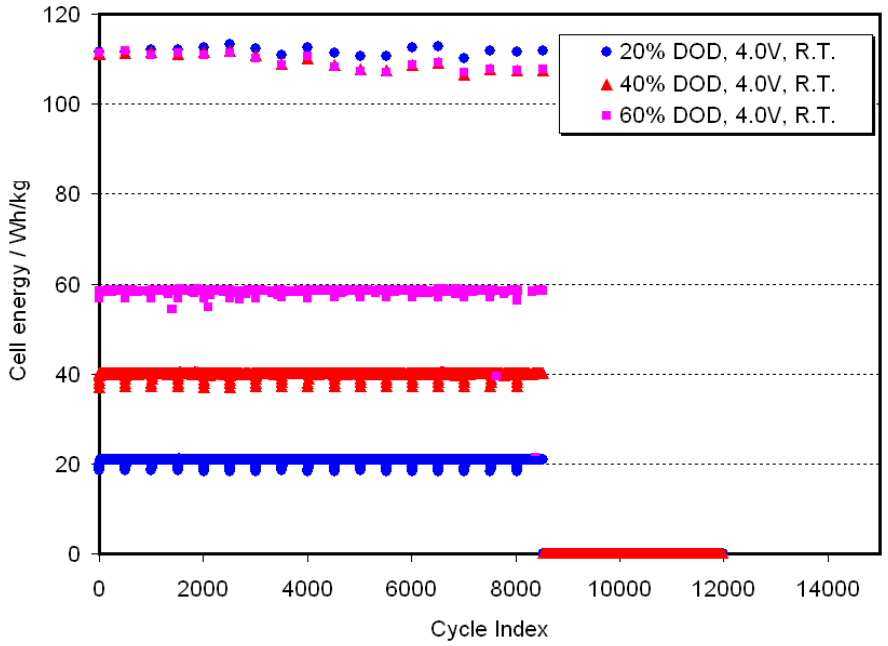
QL015KA
Effect of Charge Voltage and DOD on LEO Cycle Performance

4.1V Charge



Charge: 54 min @ 4.1V, R.T.
Discharge: 36 min to 20 -60 % DOD @ R.T.

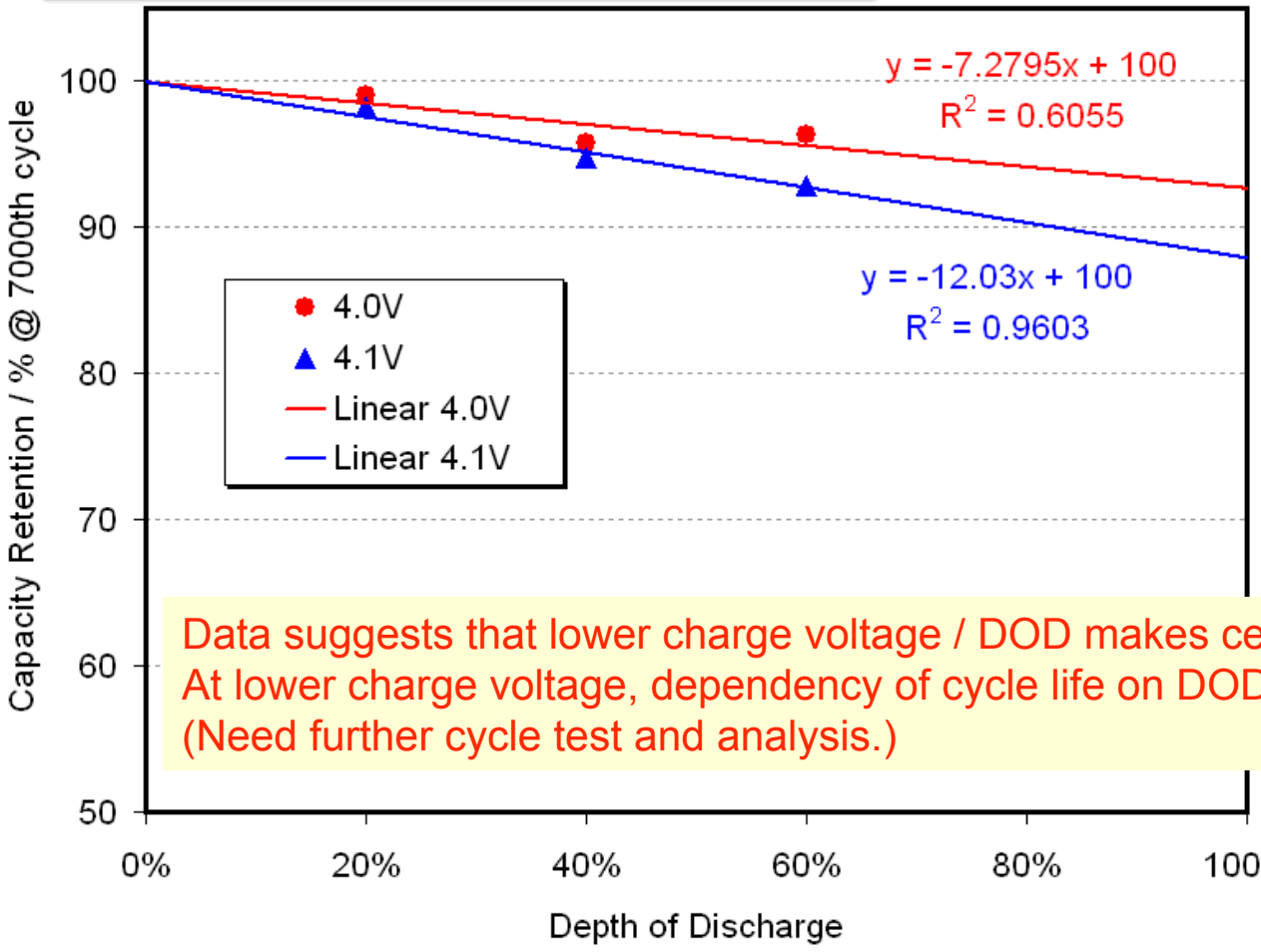
4.0V Charge



Charge: 54 min @ 4.0V, R.T.
Discharge: 36 min to 20 -60 % DOD @ R.T.

QL015KA
Effect of Charge Voltage and DOD on Capacity Retention (LEO Cycle Performance)

Capacity Retention after 7000 cycles



Data suggests that lower charge voltage / DOD makes cell life longer.
At lower charge voltage, dependency of cycle life on DOD is less.
(Need further cycle test and analysis.)

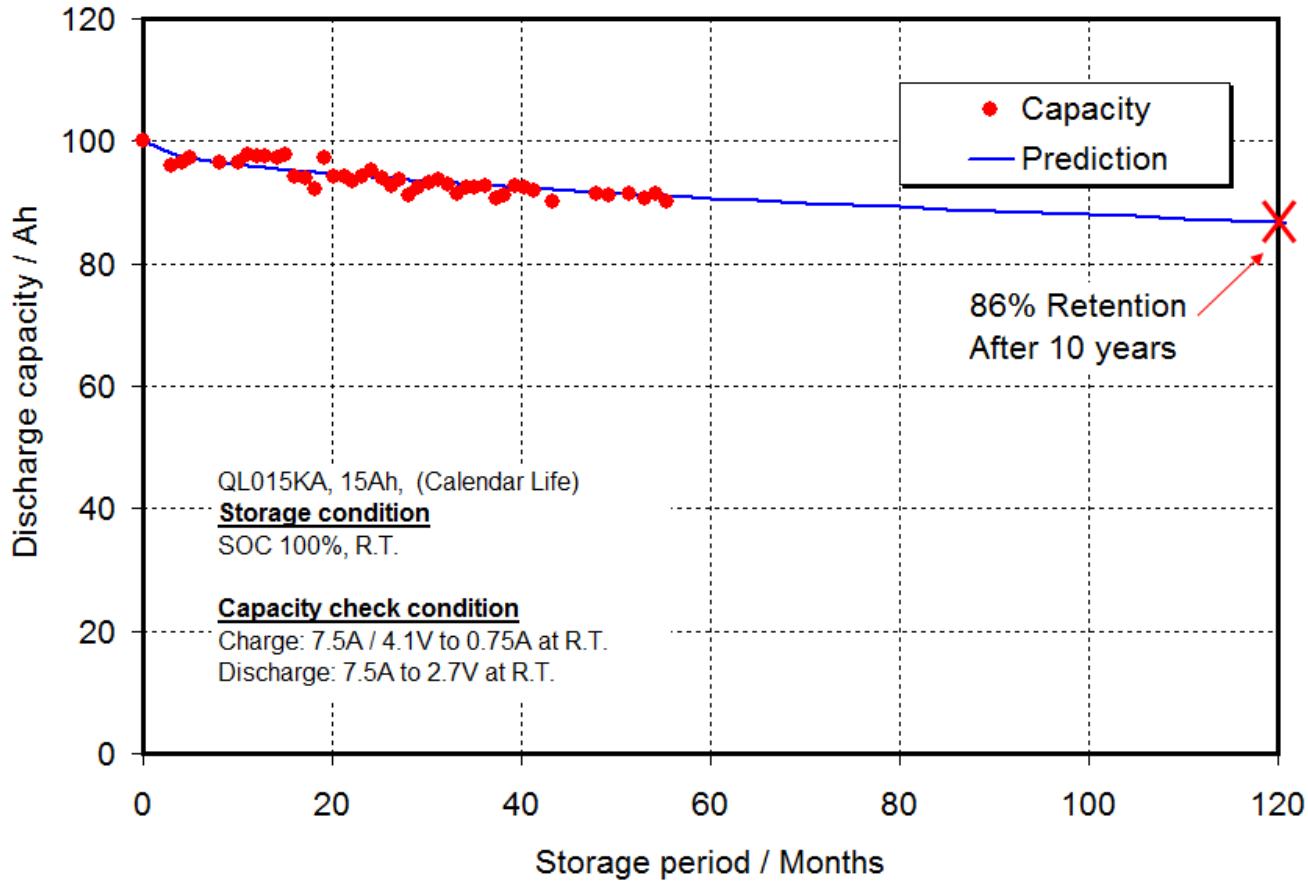
Powering Life.

QL015KA
Calendar Life: 100% SOC, 4.1V, R.T. Storage

Capacity retention equation *)

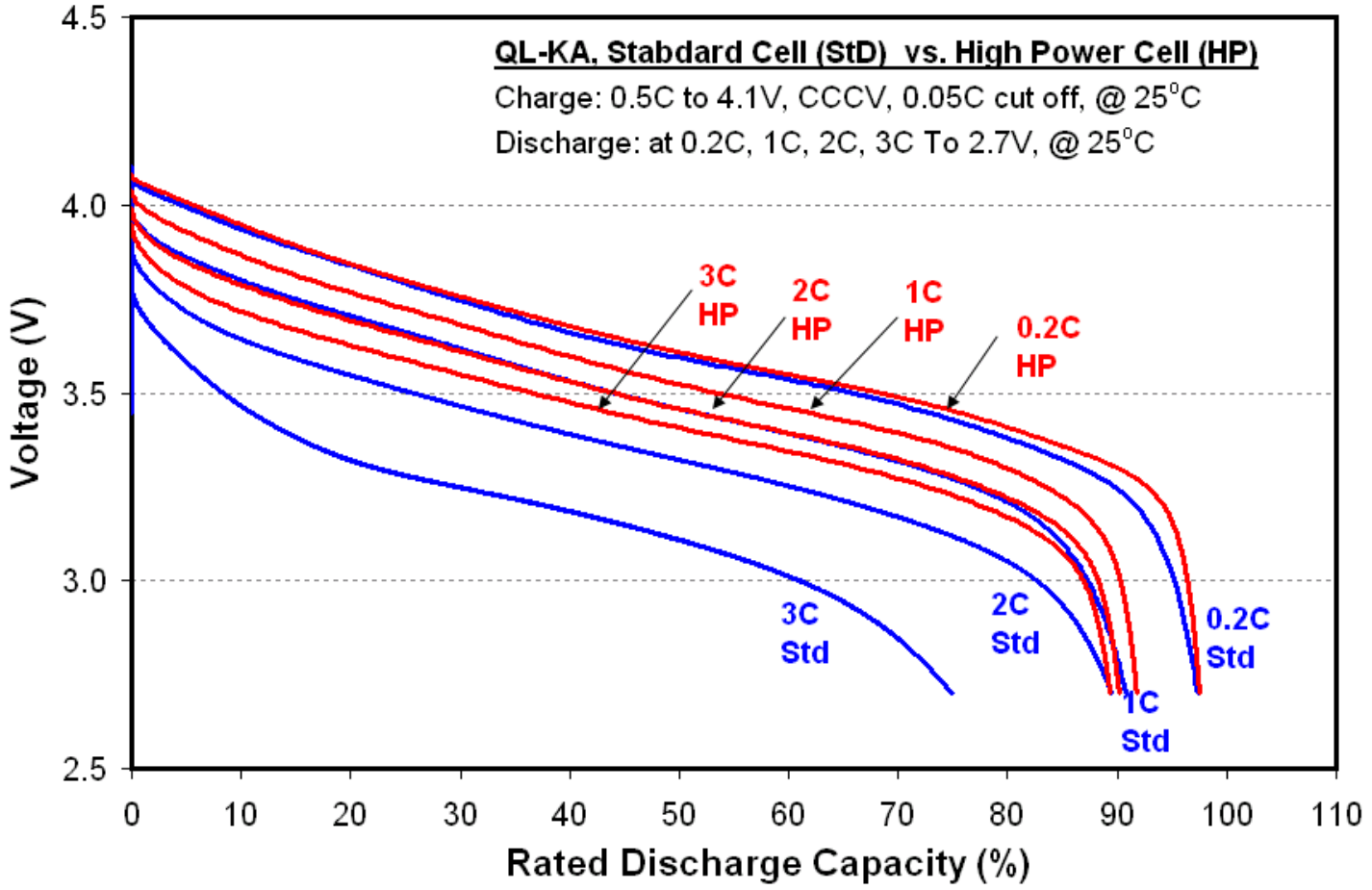
(Discharge capacity retention) = 100 - $k \times \sqrt{Time}$

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



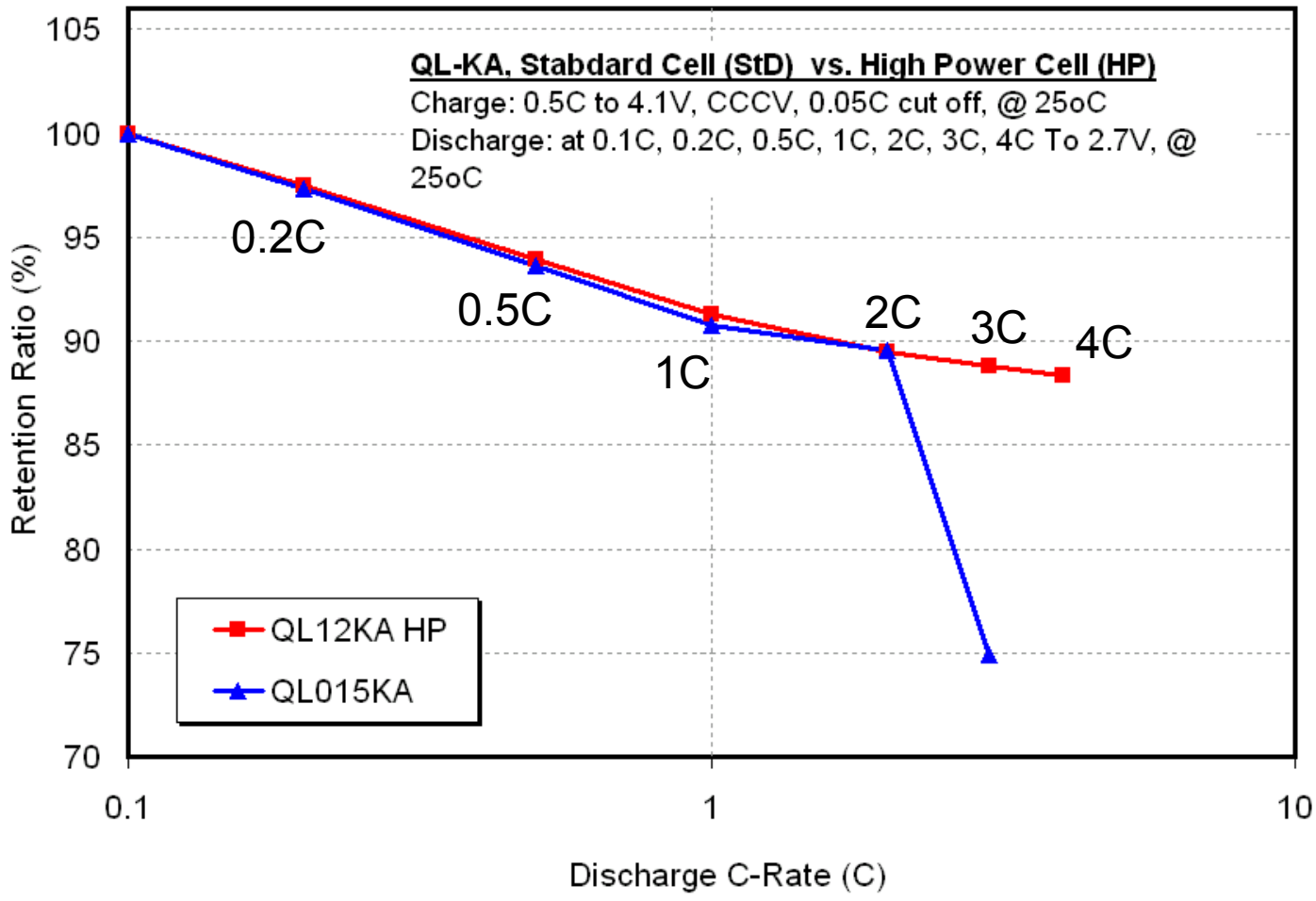
Powering Life.

QL-KA HP Cell Series
High Power Cell (QL12KA HP): Discharge Curves

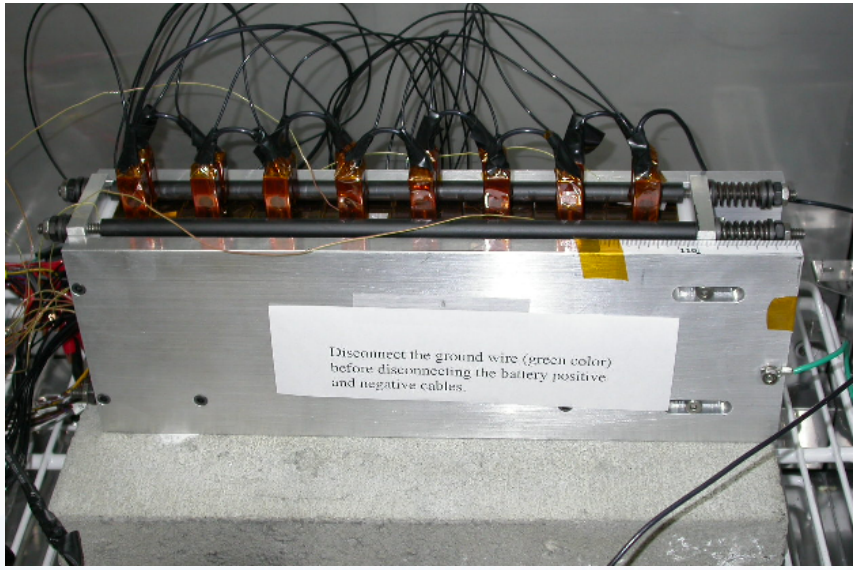


Powering Life.

QL-KA HP Cell Series
High Power Cell (QL12KA HP): Discharge Capacity



Powering Life.



8S QL015KA Pack

Voltage / Temperature Profiles in LEO 20% DOD Cycling

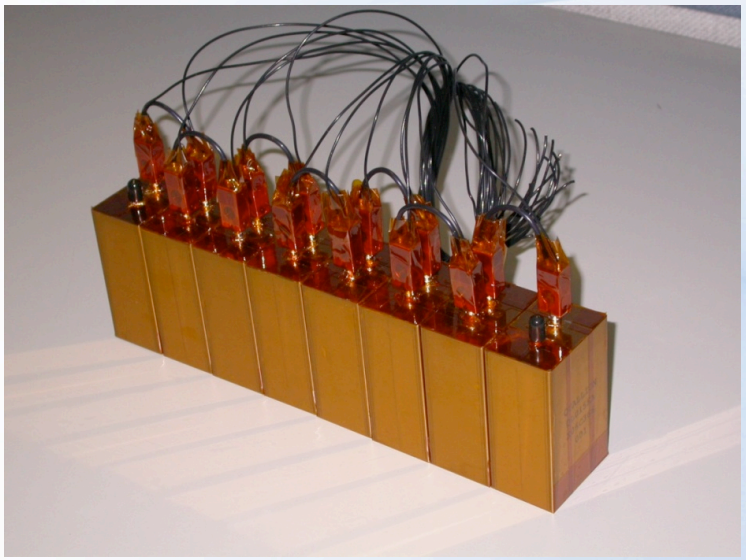
(Status up to 29,318 cycles; 36 months)

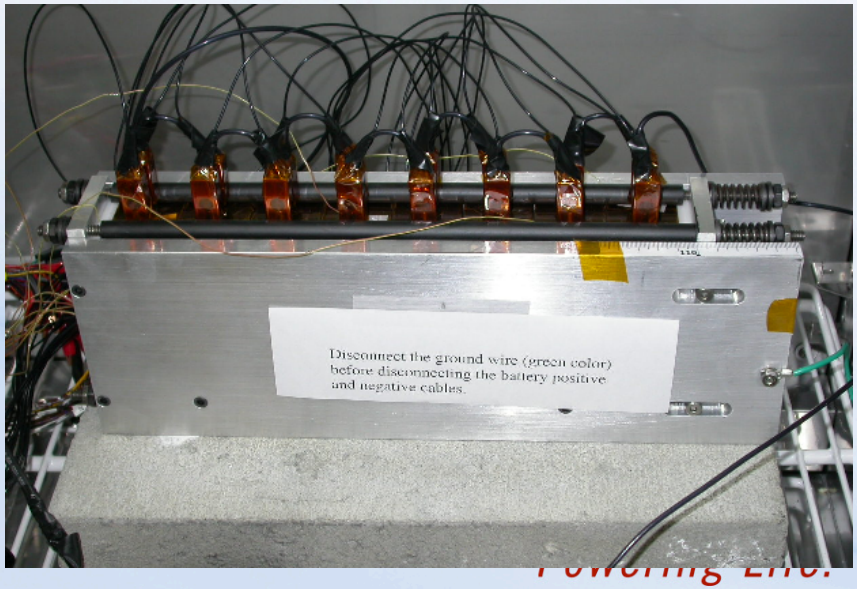
Powering Life.

8S QL015KA Pack

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

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





8S QL015KA Pack
Cycle Test Protocol

Charge:

CC Charge: Constant current at 9A until one individual cell reaches 4.1V

CV Charge: Constant voltage charge at the last battery voltage recorded when first individual cell hit 4.1V.

Total charge time of 27.5 minutes

Discharge:

CC discharge: Constant current at 10.3 A for 17.5 min (3 Ah = 20% DOD)

Total discharge time of 17.5 min

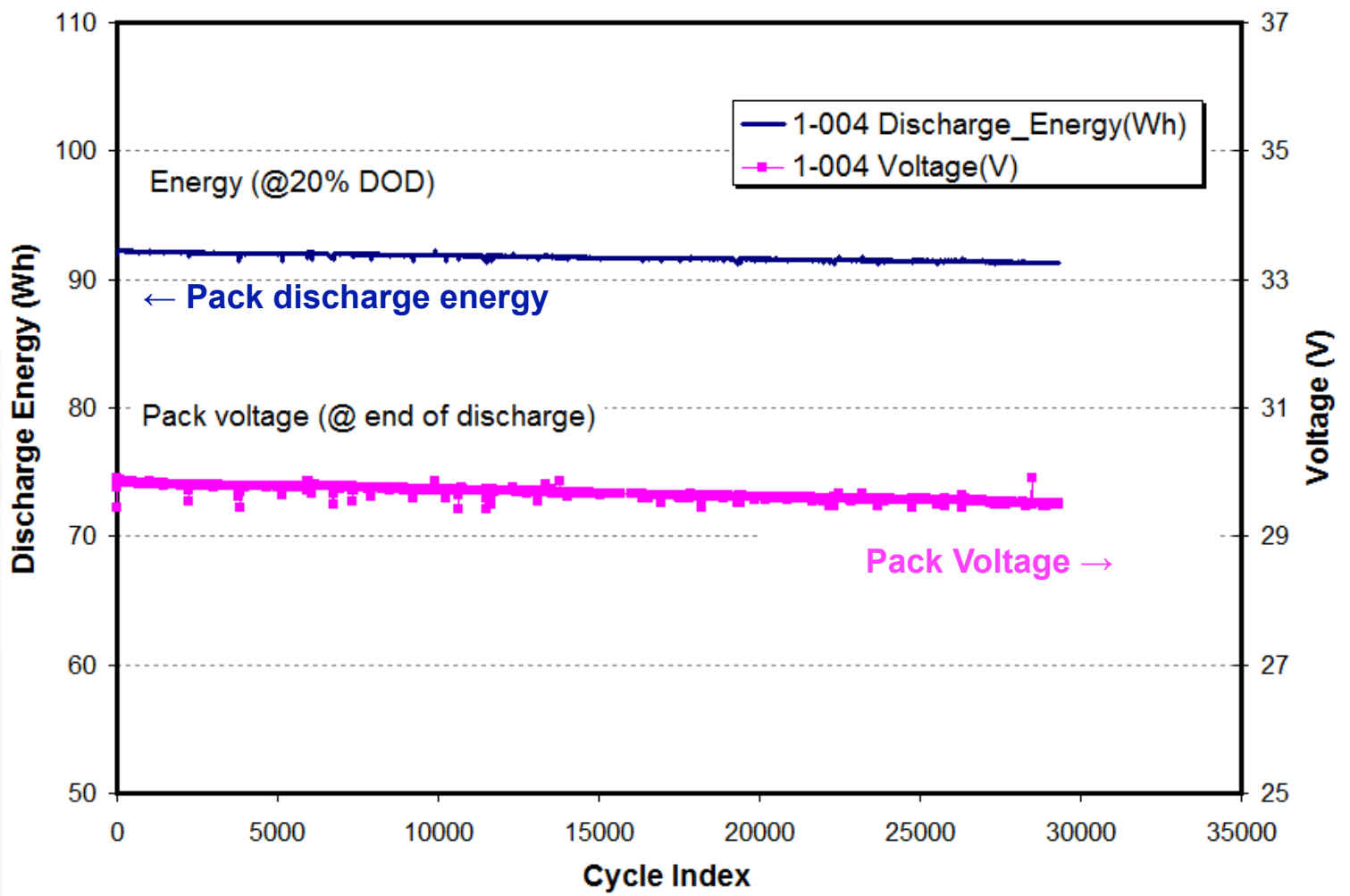
Temperature: 30°C

- No rest between charge and discharge steps

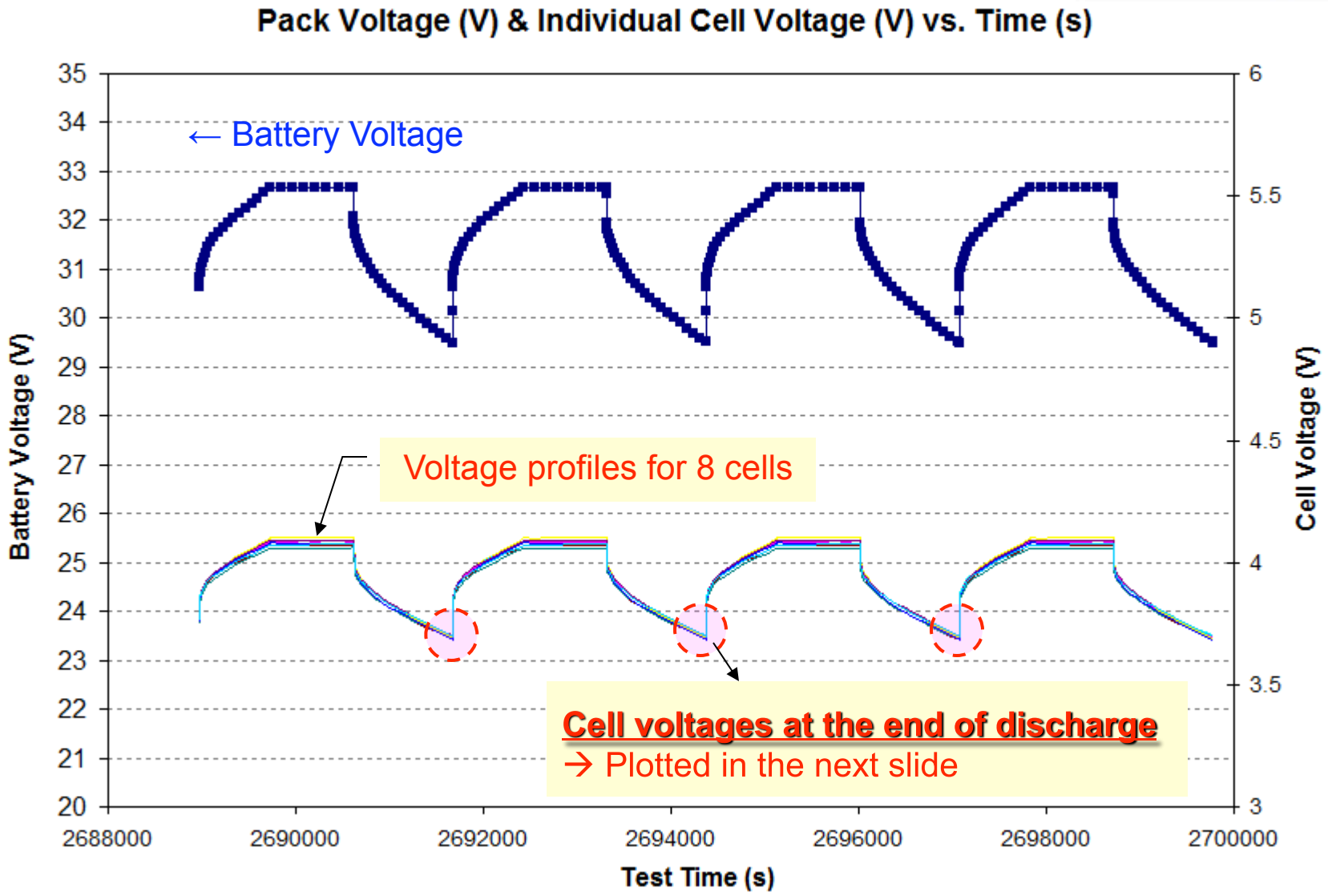
- No cell balancing circuit

Pack voltage at the End of Discharge (20% DOD) and Discharge Energy

Pack voltage and discharge energy through ***29,318*** cycles (***36*** months duration)

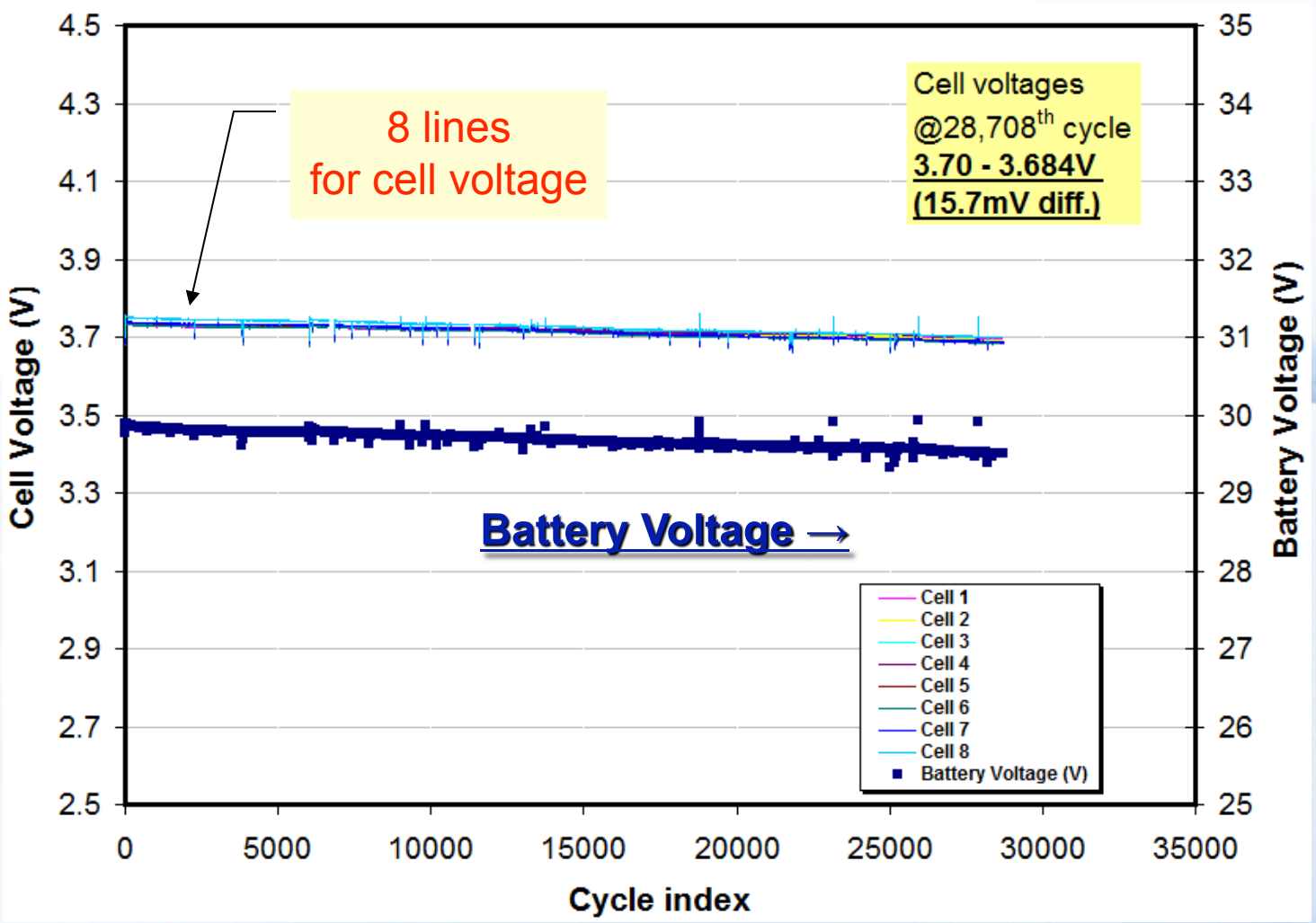


Pack / Cell Voltage vs. Time (in Cycling) @ 29,318th cycle



Cell Voltages @ End of Discharge

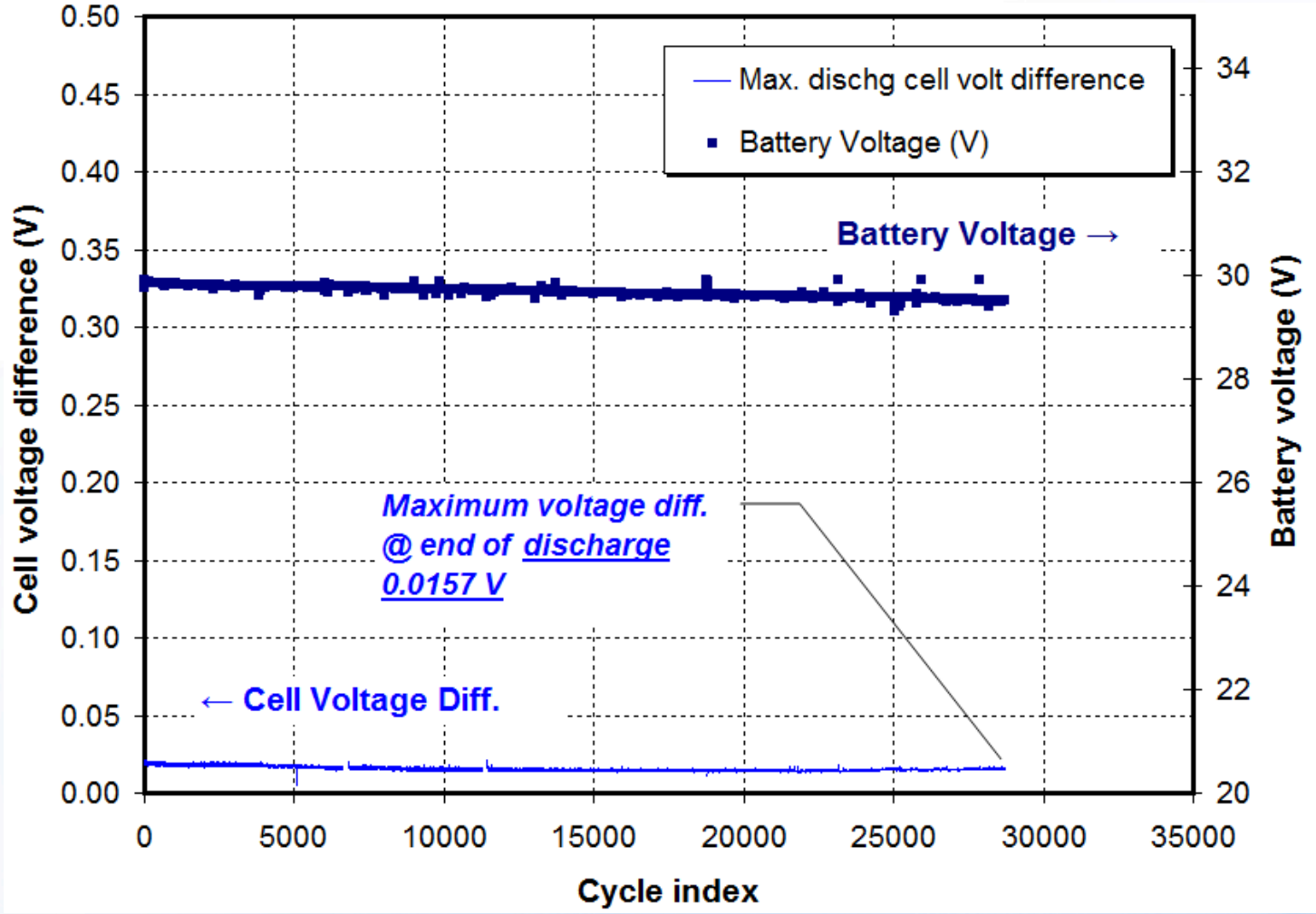
Constant cell voltage through ***28,708*** cycles (for ***36 months*** duration)

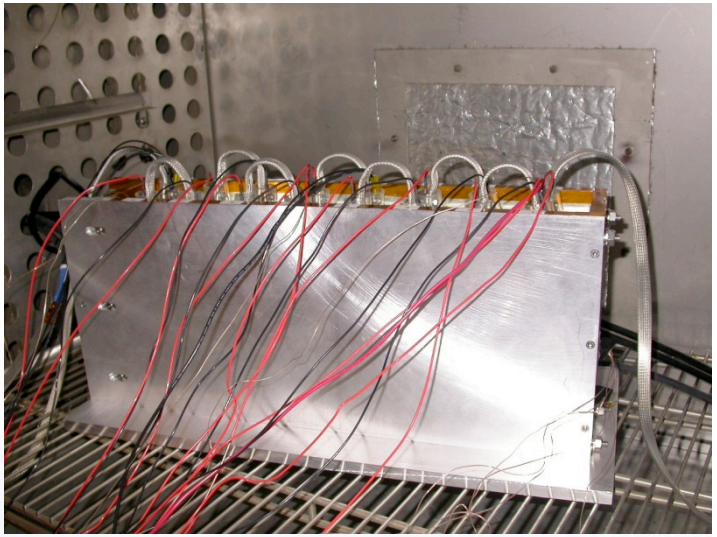


Powering Life.

Cell Voltage Difference (End of Discharge) & Battery Voltage (End of Discharge)

Cell voltage difference (@ the end of discharge) after ***28,708*** cycles





Battery Pack
8 QL075KA cells in Series

Voltage Profiles
in LEO 20% DOD Cycling

(11,891 cycles; 13 months)

Powering Life.

8S-QL075KA Pack
Cycle Test Protocol

Charge:

- CC Charge: Constant current at 43.2A until one individual cell reaches 4.1V
- CV Charge: Constant voltage charge at the last battery voltage recorded when first individual cell hit 4.1V.
- Total charge time of 26.6 minutes

Discharge:

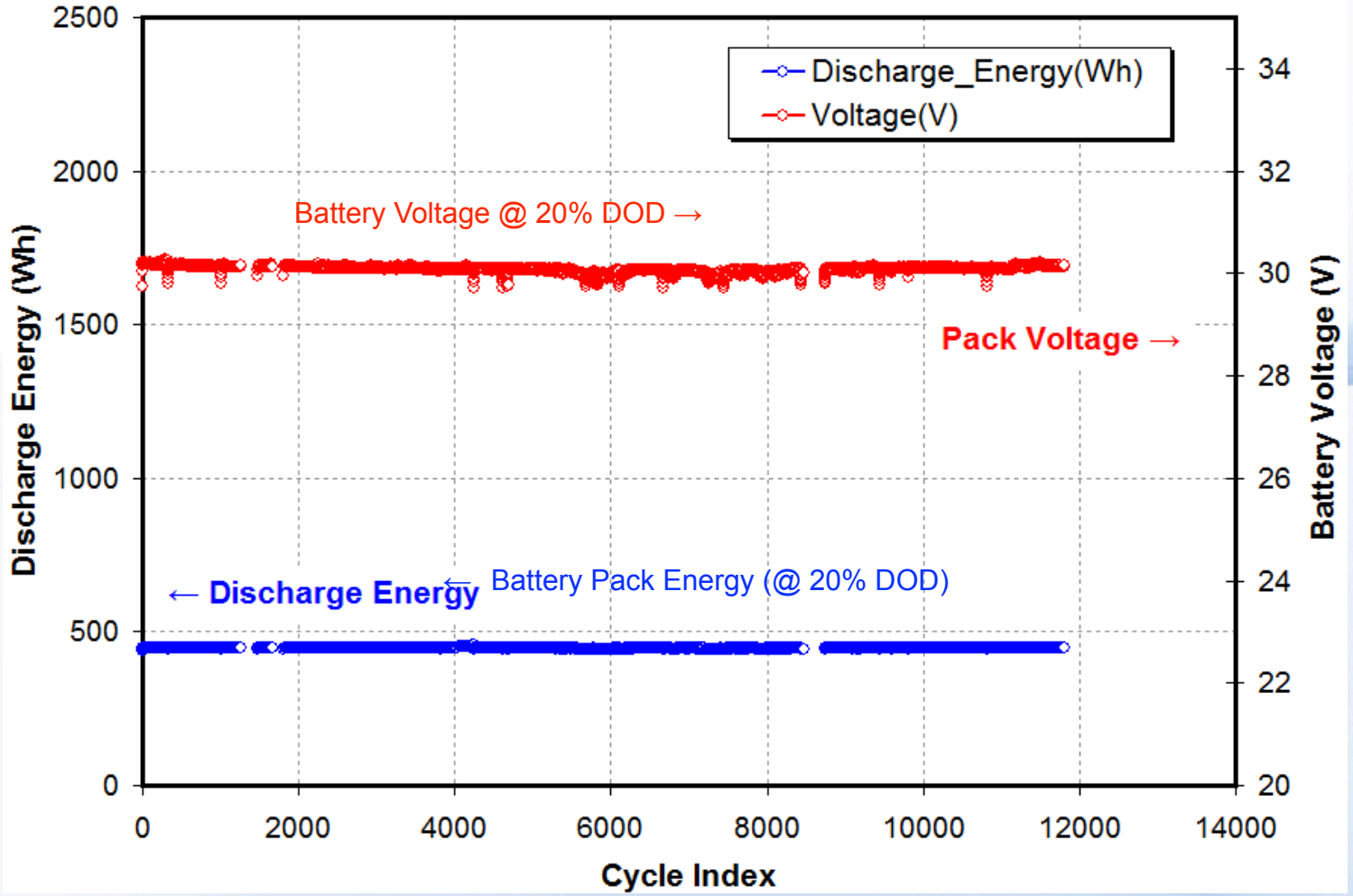
- CC discharge: Constant current at 47 A for 18.4 min (14 Ah = 20% DOD)
- Total discharge time of 18.4 min

No rest between charge and discharge steps

No cell balancing circuit

QL075KA 8 Cells Pack
Pack Voltage at End of Discharge (20% DOD) and Discharge Energy

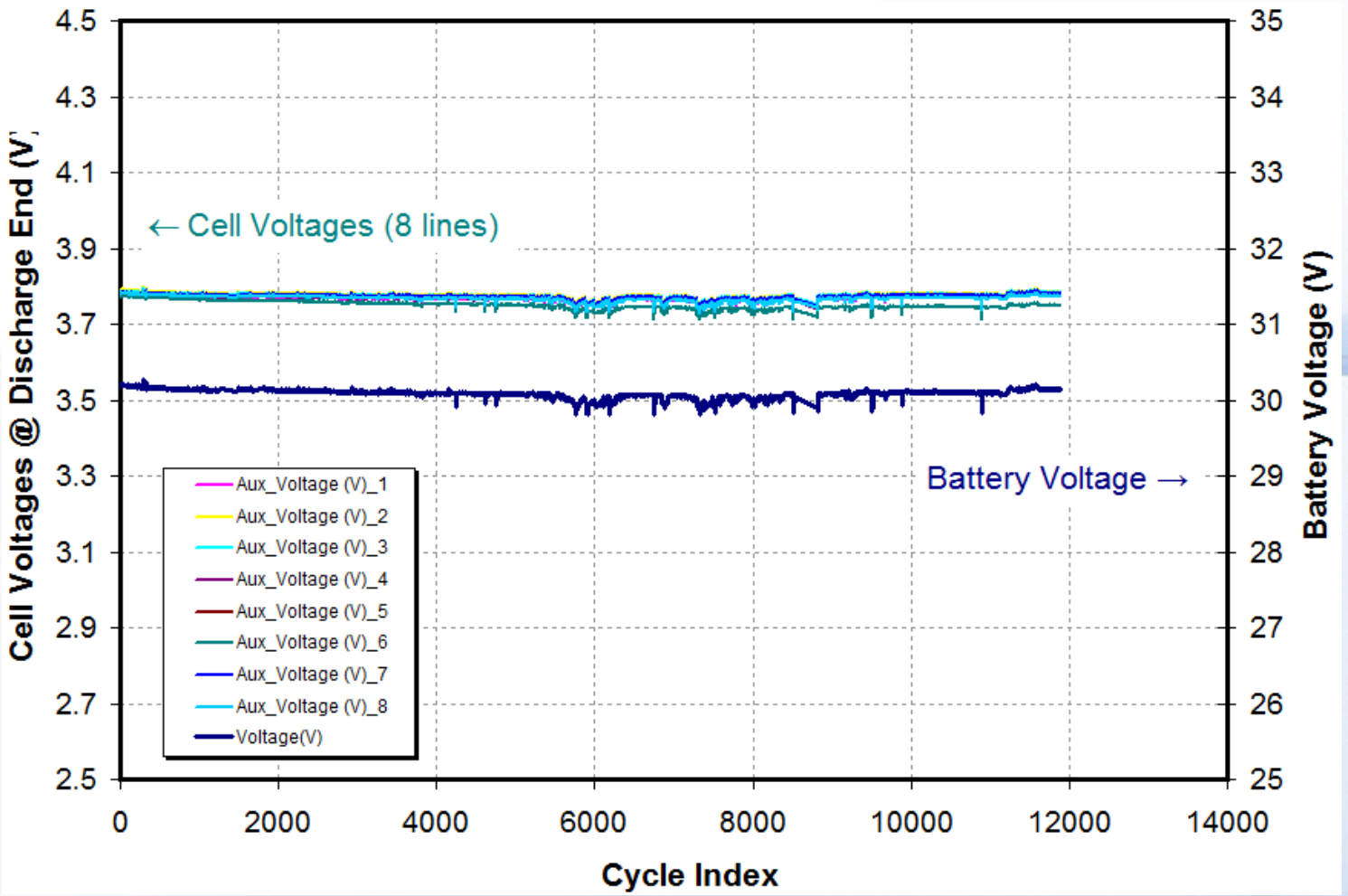
Constant battery voltage through ***11,891*** cycles (for ***13 months*** duration)



Powering Life.

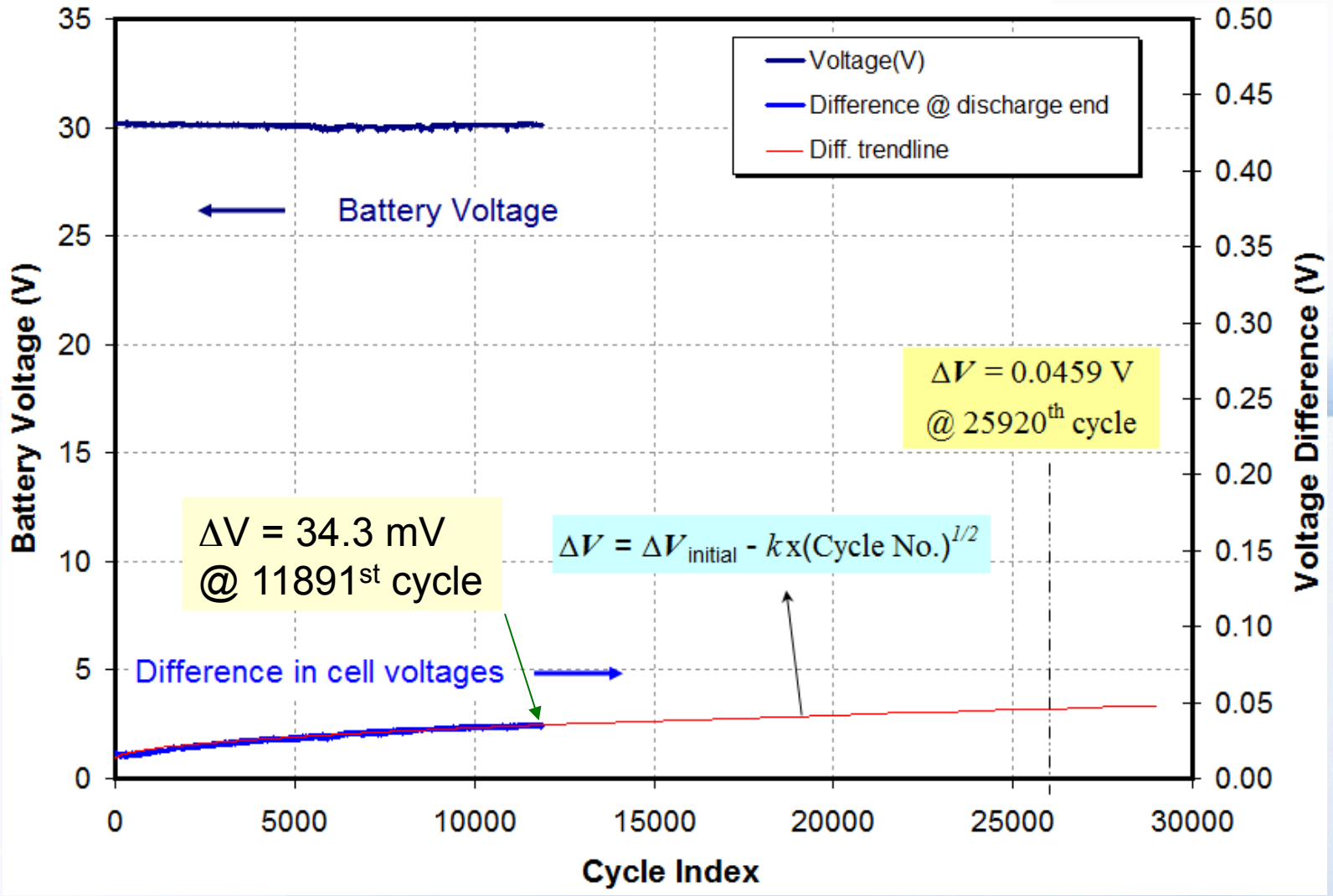
QL075KA 8-cell-pack Battery and Cell Voltages

Constant cell voltage through ***11,891*** cycles (for ***13 months*** duration)



Powering Life.

QL075KA 8-cell-pack
Cell Voltage Difference & Prediction



Powering Life.

QUALLION

Summary

➢ Chemistry

- ➢ By using semi-empirical requisition,
  - ➢ 5A-2™ Chemistry was expected to maintain **75 – 80% capacity under LEO cycle at 40% DOD, R.T**. after 10 years
  - ➢ 5A-2™ Chemistry was expected to maintain **86% capacity under 100% SOC storage** at R.T.
  - ➢ After 1.5 – 2.5 year-storage at 0V at R.T., ZeroVolt™ Technology was expected to maintain **73% capacity** under LEO cycle at 40% DOD, R.T. after 10 years.

→ After 10-year LEO cycle, ~15% loss of capacity due to calendar life and ~ 10% of capacity loss due to charge / discharge cycle was considered.

➢ Both DoD and charge voltage affected the capacity retention after LEO cycling. (The further test / analysis is awaited.)

➢ Battery Pack Performance

- ➢ 8 QL015KA cells in series
  - ➢ **15 mV** difference in cell voltages **after 28,708 cycles**
  - ➢8 QL075KA cells in series
  - ➢ **32 mV** difference in cell voltages **after 11,891 cycles**

Powering Life.