Long Life, High Energy Silver/Zinc Batteries

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Presentation Outline

- Introduction to RBC Technologies
- Rechargeable Zinc Alkaline (**RZA™**) Systems

  MnO_2/Zn Ni/Zn Ag/Zn Zn/Air
- RZA Silver/Zinc Battery Developments
  - NASA Phase I and Phase II SBIR goals and results
  - Other silver/zinc opportunities

RBC Background

- Founded in 1989 to commercialize battery technology based on Ford discovery of rechargeable form of manganese-dioxide
- In 1999, RBC was awarded $3.8 million Advanced Technology Program by US Dept. of Commerce, NIST to accelerate RZA development
- Core competencies, rechargeable zinc, stable ion-blocking separator and cathode active materials
- In 2000, expanded RZA technology family to include nickel-zinc and silver-zinc
- RBC commercializes technologies through licensing and joint-venture agreements

Facilities and Staff

- College Station, Texas facility encompasses 10,000 square feet
  - full development capabilities to support the design and processing of batteries and materials
  - 400 channels of computer controlled electrical testing stations

- Battery Industry Depth - Over 110 years of professional battery industry experience: R&D, Engineering, Applications, Manufacturing, Marketing
- Extensive Corporate relationships: Electronics OEMs, battery manufacturers, materials suppliers, universities, National laboratories, agencies

Commercialization Activity Focused on Two RZA Systems

RZA System	Mn/Zn Manganese/Zinc	Ni/Zn Nickel/Zinc	
Positive electrode (cathode)	Bismuth-modified manganese-dioxide (BMD)	Nickel hydroxide	
Specific energy (wh/kg)	70-90	50-75	
Product Formats	Cylindrical AAA, AA, C and D, small (0.5 – 3 Ah) prismatic cells	15 Ah+ Ah prismatic cells and 12-volt batteries	Cylindrical sub C and D cells
Applications	Portable electronics, cameras, toys and games, radios and CD players, PDA's	42-volt hybrid and electric vehicles, standby power.	Power tools, lawn & garden tools., electric bike and electric scooter.

Spiral Wound RZA Ni/Zn Battery

- Being developed with manufacturing partner
- Wide range of potential applications with performance/cost attributes intermediate between nickel-metal hydride and lead-acid batteries
- Higher cell voltage means fewer cells in series for a given battery voltage, (eg. 12 Volt battery uses 7 Ni/Zn cells vs 10 cells for either NiCd or NiMH)

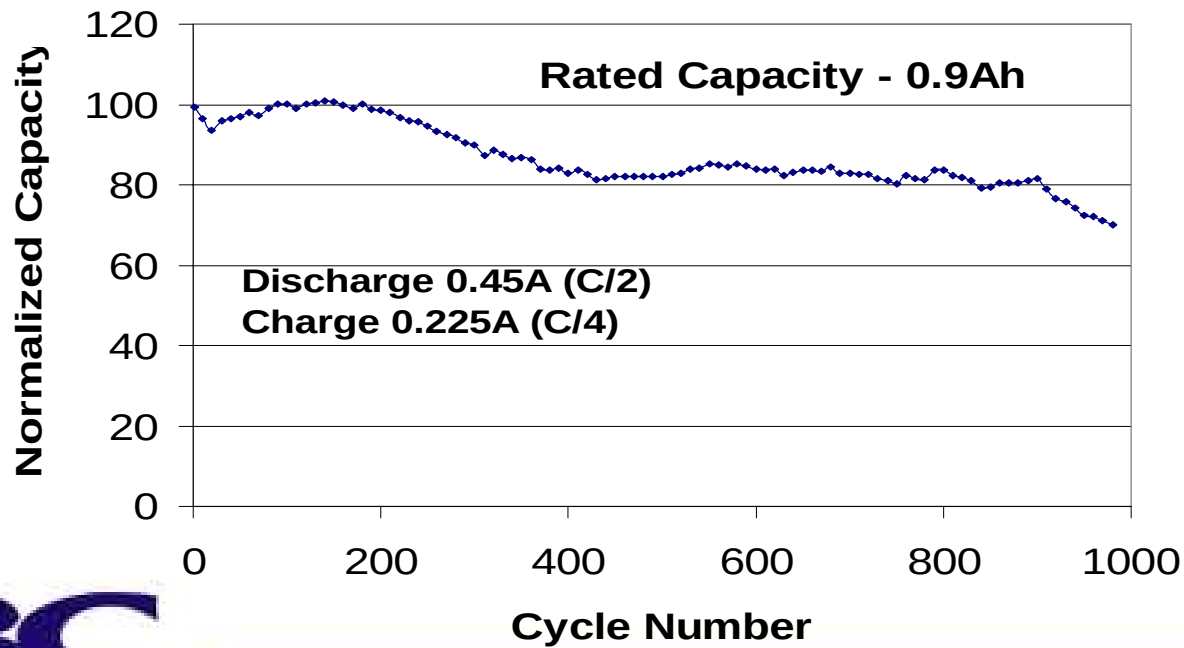
TABLE: COMPARISON OF D SIZE CELLS in 3 NICKEL ELECTROCHEMISTRIES

	NiCd	***RZA NiZn***	***NiMH***
Capacity (ampere-hours)	4.6	5.0	6.5
Operating Voltage (Volts)	1.2	1.65	1.2
Weight (g)	139	139	170
Watt-hours per kg	40	59	46
Watt-hours per liter	106	158	150

- For a given energy content an RZA Ni/Zn battery can be lighter, smaller and lower cost than the other nickel chemistries.

RBC-Ni/Zn Technical Innovation

- Anode formulation for minimal shape change, no dendrites, 1,000 cycles.
- Advanced low cost separator designs for dendrite prevention
- Charging algorithms to facilitate maintenance-free operation
- Developed innovative processes for continuous, uniform electrode manufacture



RZA Systems - Specific Energy

System	Specific Energy (Wh/kg)
Ni/Zn	55-80
$Mn0_2$/Zn	70-90
Ag/Zn	100-200

Silver-Zinc Electrochemistry

$$2AgO + H_2O + 2e \underset{\text{charge}}{\overset{\text{discharge}}{\longleftrightarrow}} Ag_2O + 2OH^-$$

$$Ag_2O + H_2O + 2e \longleftrightarrow 2Ag + 2OH^-$$

$$Zn + 2OH^- \longleftrightarrow Zn(OH)_2 + 2e$$

$$Zn(OH)_2 + 2OH^- \longleftrightarrow Zn(OH)_4^{2-}$$

Overall Reaction

$$AgO + Zn + H_2O \longleftrightarrow Ag + Zn(OH)_2$$

Silver-Zinc Applications

(primary as well as secondary)

Space	Launch-vehicle guidance and control, telemetry, NASA vehicles Lunar Rover and Mars Rover, space shuttle payload launch and power for the life-support equipment used by the astronauts during EVA's.
Military	Missle systems, Navy: mines, buoys, deep submergence and rescue vehicles, torpedo propulsion, drones and submarines.

Silver/Zinc Problems and Opportunities

- Highest specific energy and energy density
- High discharge rate capability
- Good charge retention
- Flat discharge voltage curve

BUT

- **Relatively low cycle life**
- **Limited wet life (3-18 months, fill/activate prior to use)**
- Sensitivity to overcharge

Technical Issues

- Zincate migration from electrode following discharge, non uniform charging leading to shape change
- Zinc dendrite formation which can penetrate the separator causing shorting
- Cellophane separators chemically attacked by colloidal silver and KOH
- Silver goes into solution and can pass through the separator

Note:

- RBC has developed separator system which inhibits cross over of selective ions in alkaline electrolyte (U.S. 5,952,124)

NASA SBIR Phase I, Technical Objectives

- Collaborate with Eagle-Picher Technologies, an established supplier of mission-critical silver/zinc batteries to:
  - construct silver/zinc cells using RBC's advanced anode and separator components
  - evaluate the ability of these components to render improvements in: specific energy, cycle life and wet-life of rechargeable silver/zinc batteries

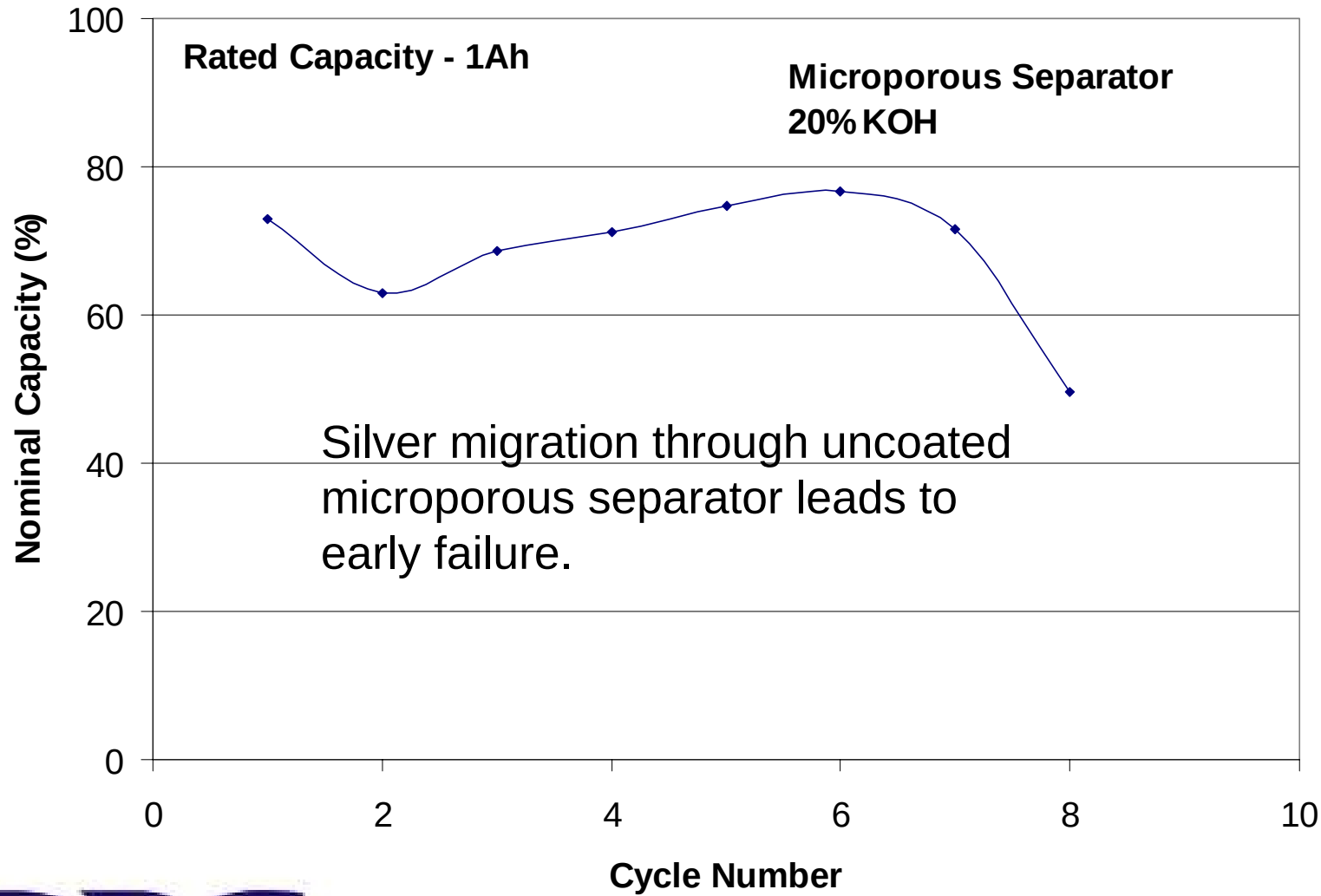
Design Variables

– ***Separators Evaluated:***

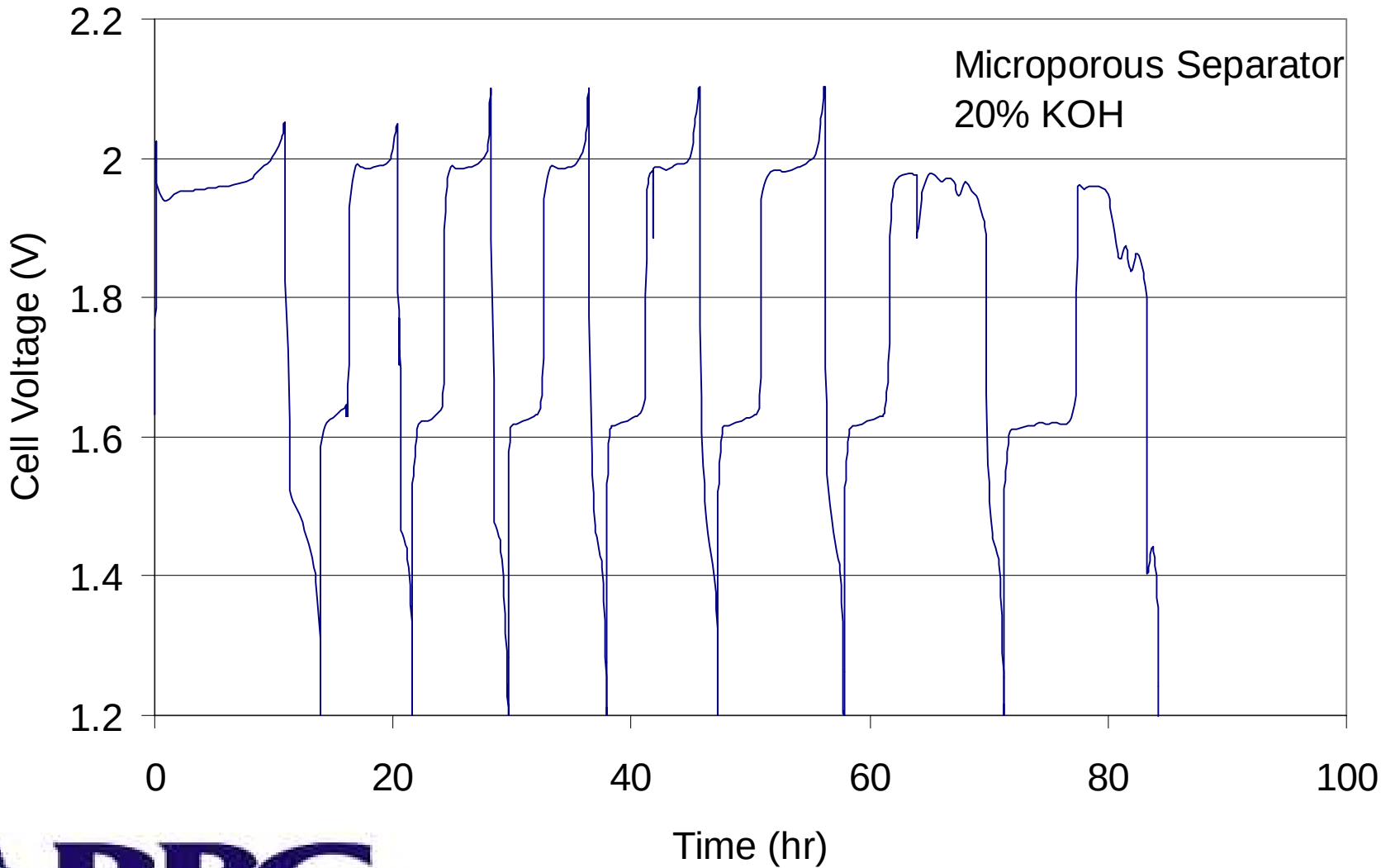
Separator Type	***Description***
Microporous polyolefin separator	Continuous polyolefin membrane, approximately 1 mil thick, with carboxylic surface functionality
SPPO coated microporous polyolefin separator	As above, but dip-coated with sulphonated polyphenylene oxide per U.S. 5,952,124
Cellophane laminate	Cellophane laminated to a non-woven polyamide, approximately 6 mils thick
AMS	A mineral filled polyolefin supplied by Advanced Membrane Systems.

- ***Electrolyte compositions evaluated:***
  – 20%KOH 45%KOH

1Ah Cell - Standard RZA Separator & Electrolyte



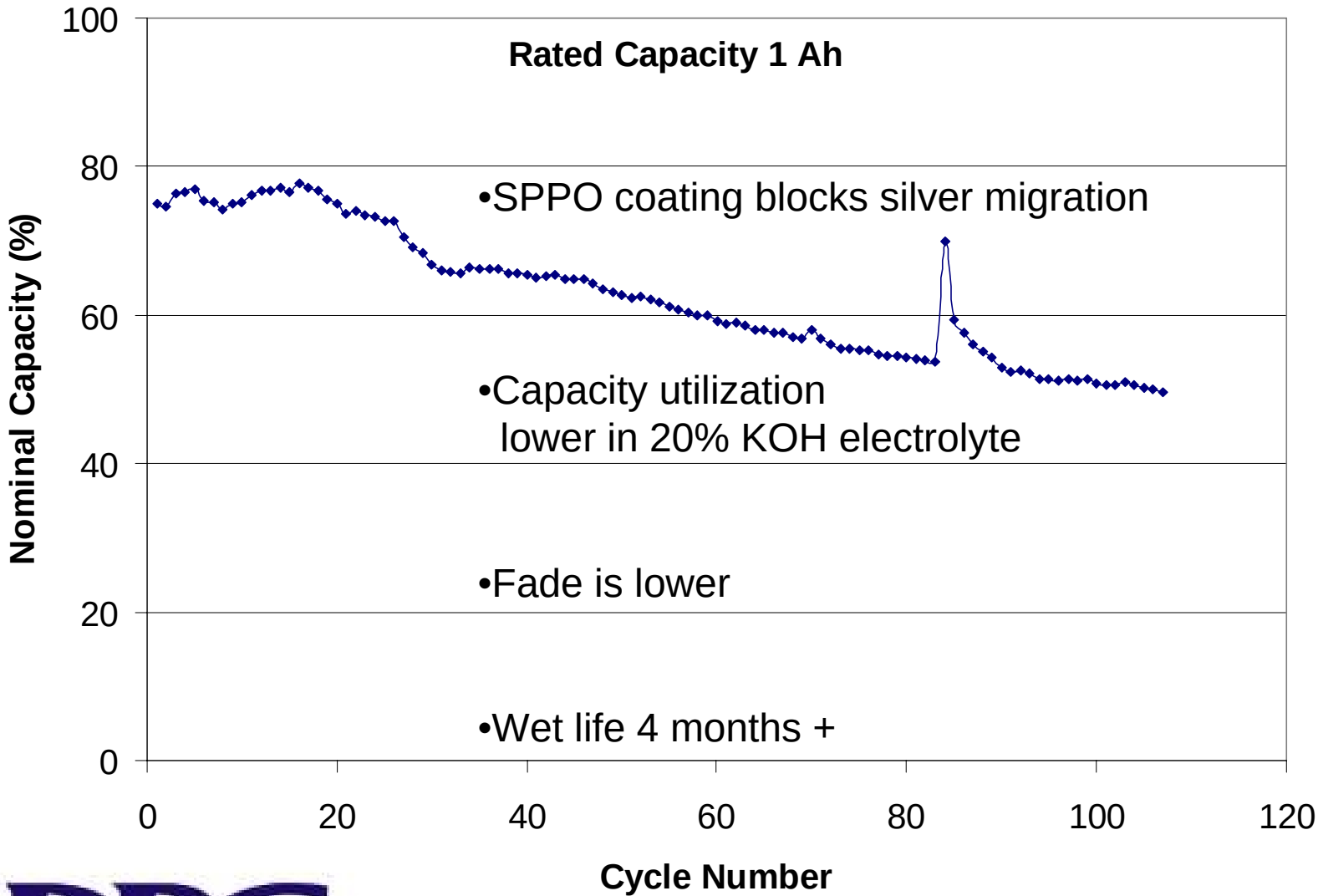
1Ah Cell - Standard RZA Separator & Electrolyte



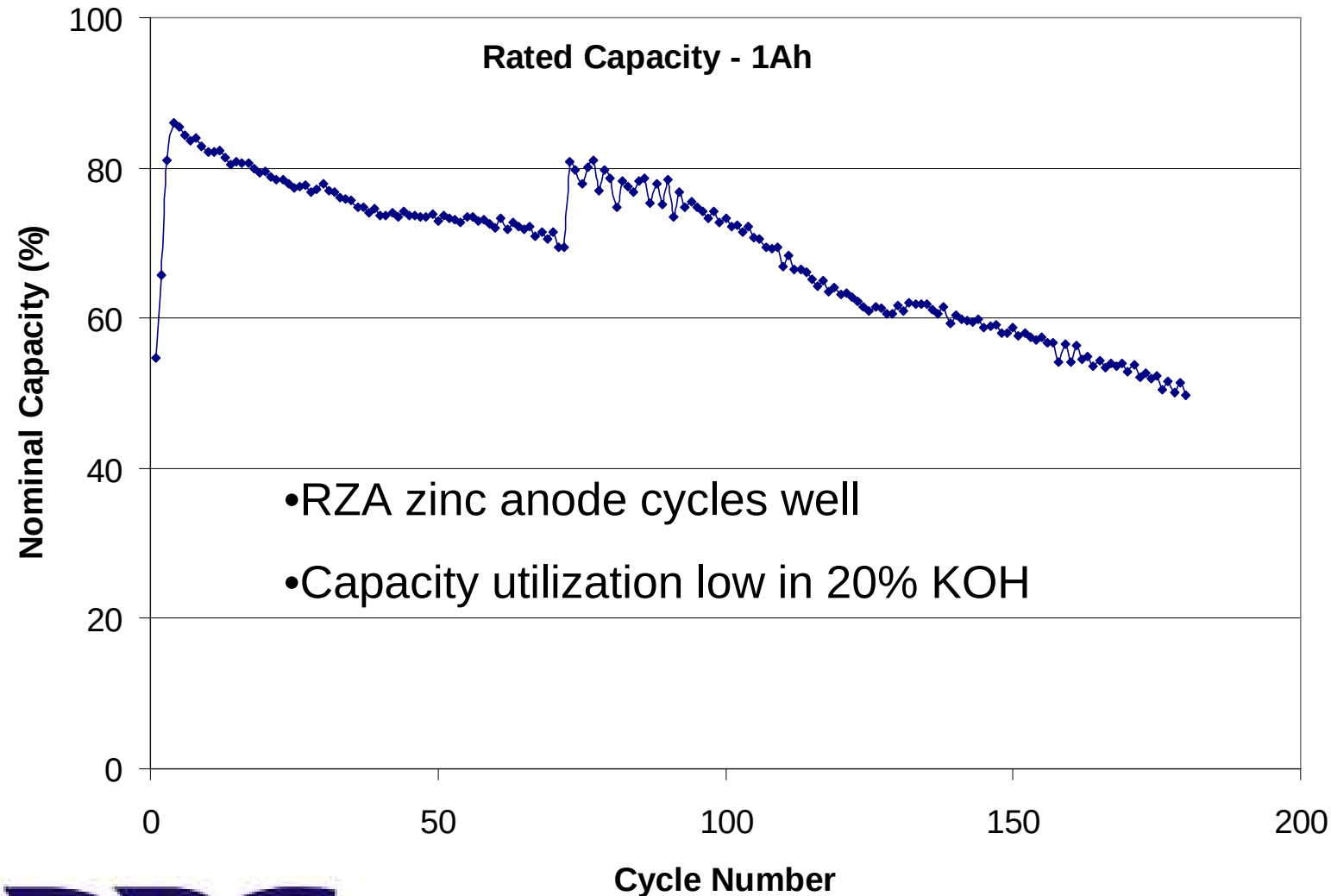
RBC TECHNOLOGIES

Quality Battery Solutions

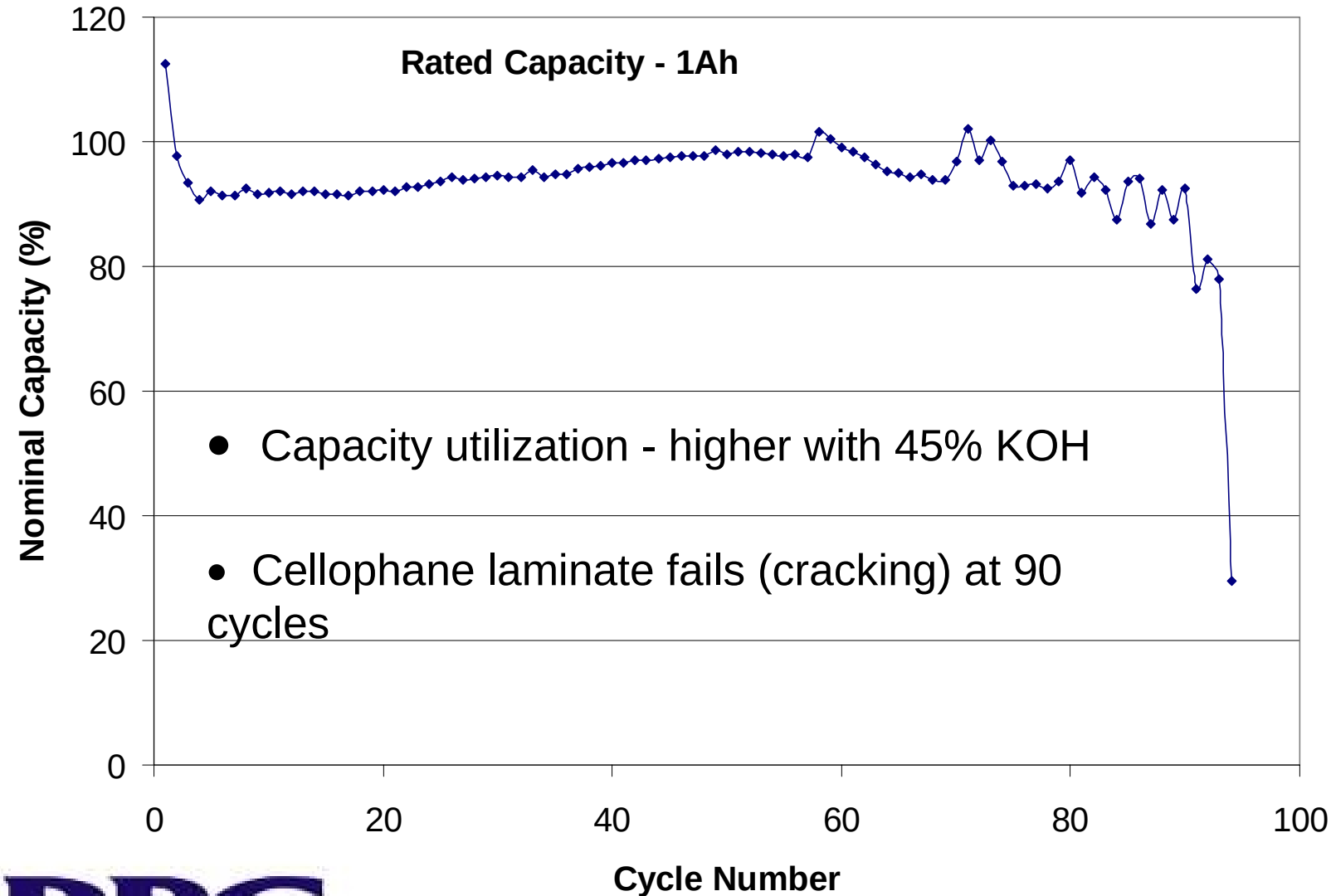
1 Ah Cell - SPPO Coated Separator 20% KOH



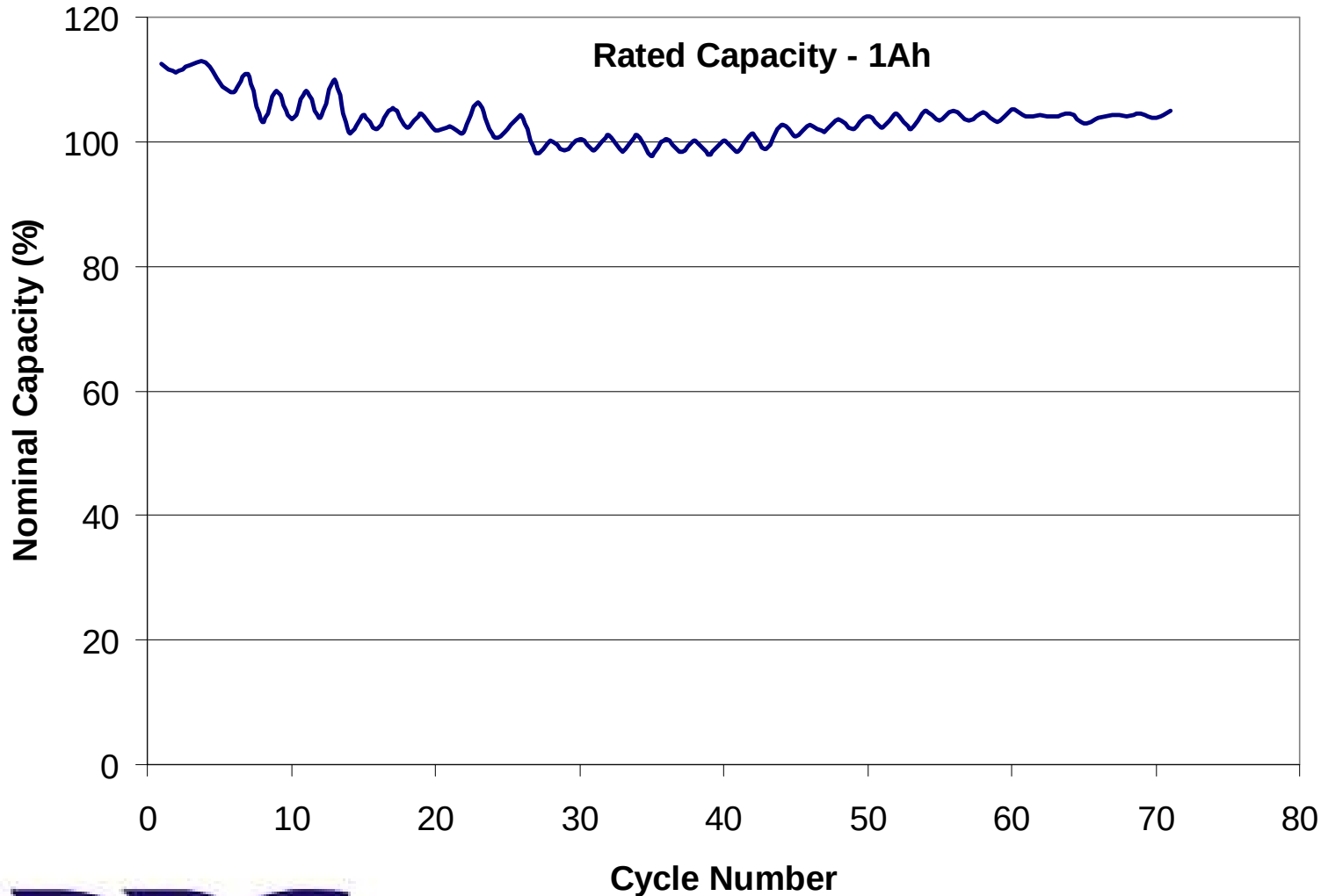
1 Ah-Cellophane Laminate Separator, 20% KOH



1 Ah Cell - Cellophane Laminates, 45% KOH



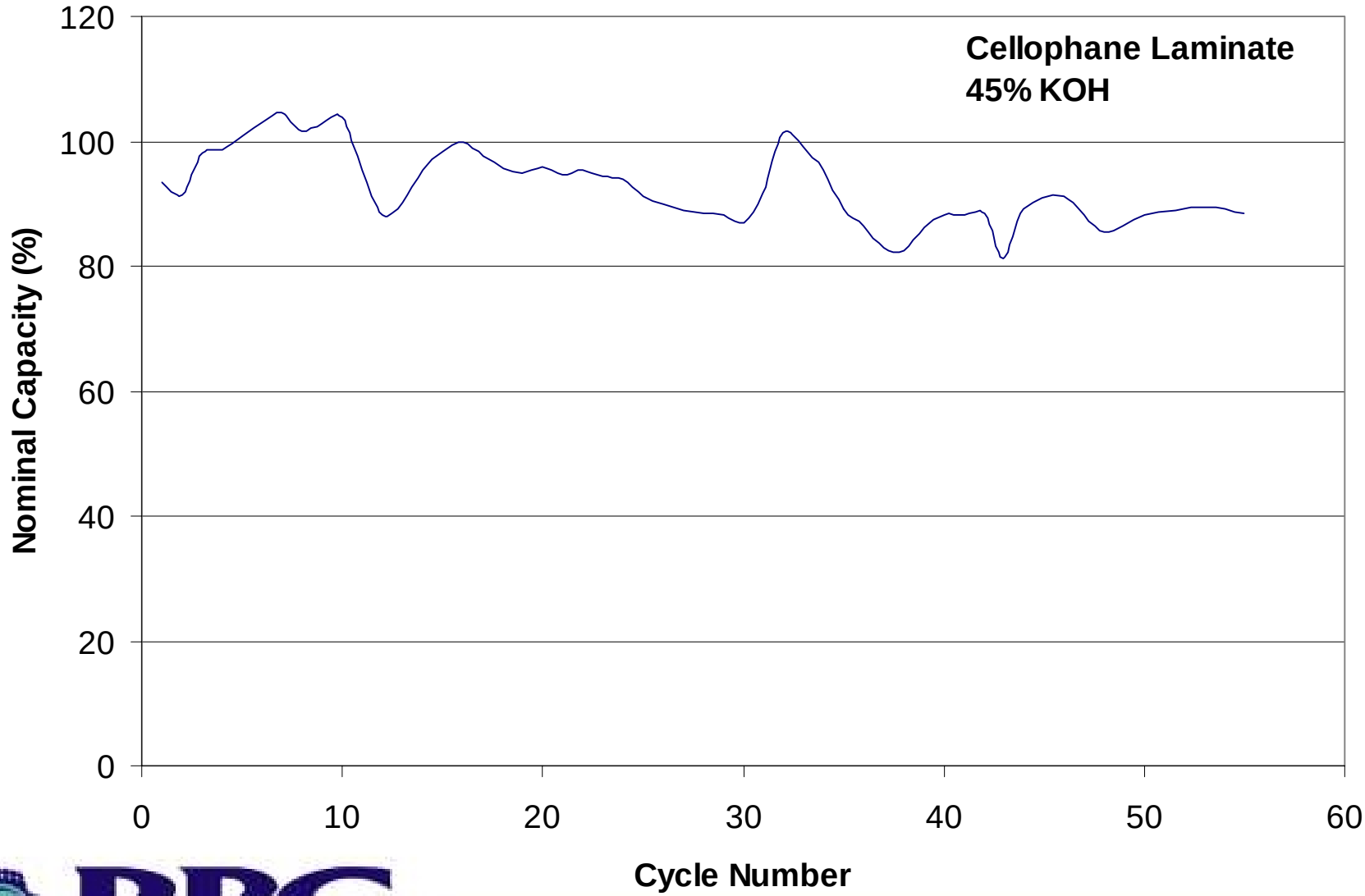
1Ah Cell - AMS Separator, 45% KOH



RBC TECHNOLOGIES

Quality Battery Solutions

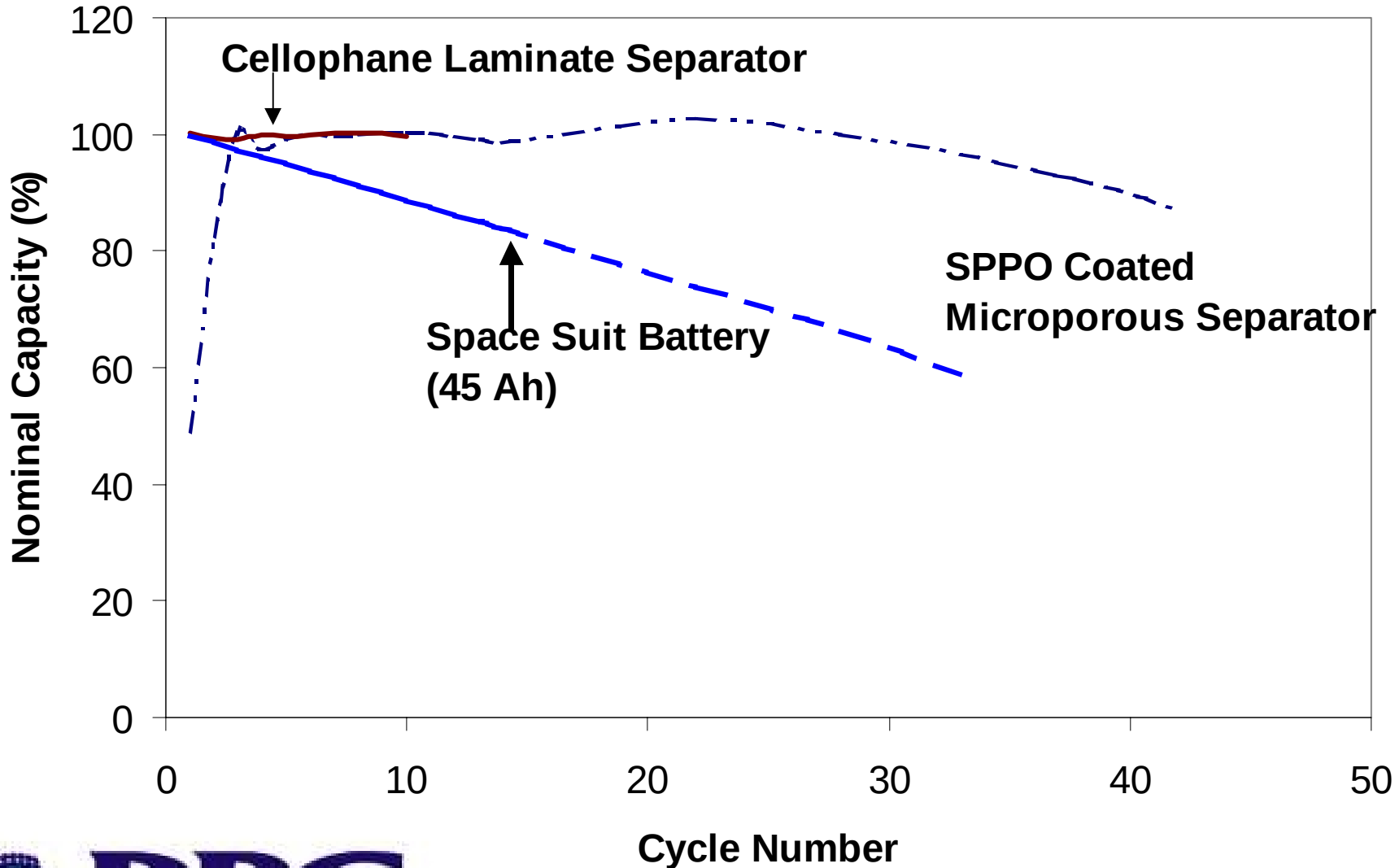
Silver-Zinc 10 Ah Cell



RBC TECHNOLOGIES

Quality Battery Solutions

5 Ah Silver-Zinc Cells, 45% KOH



Phase I Conclusions

- Use of RBC anode in Silver-Zinc cells enhanced cycle life substantially.
- Within the limited time period of the project, wet life exceeding 4 months was demonstrated with the cell still operating satisfactorily.
- Coated microporous separators inhibit silver migration. Coated and filled polyolefin separators allow for greater wet-life stability then cellulose and cellulose laminates.
- All the cells were assembled in the charged state and did not need formation.
- KOH concentration must be optimized for cycle life, capacity and wet life.

NASA SBIR PHASE II
Technical Objectives

Application Demonstration: EMU-PLSS Battery

- Optimize separator and electrolyte for wet life/cycle life
- Scale to 5Ah, 17V battery (11 cells in series)
- Scale to 40Ah cells and a 17V battery
- Deliver two (2) 17V, 40Ah equivalent batteries to NASA, which will exceed the performance of current batteries.

Phase II SBIR Goals

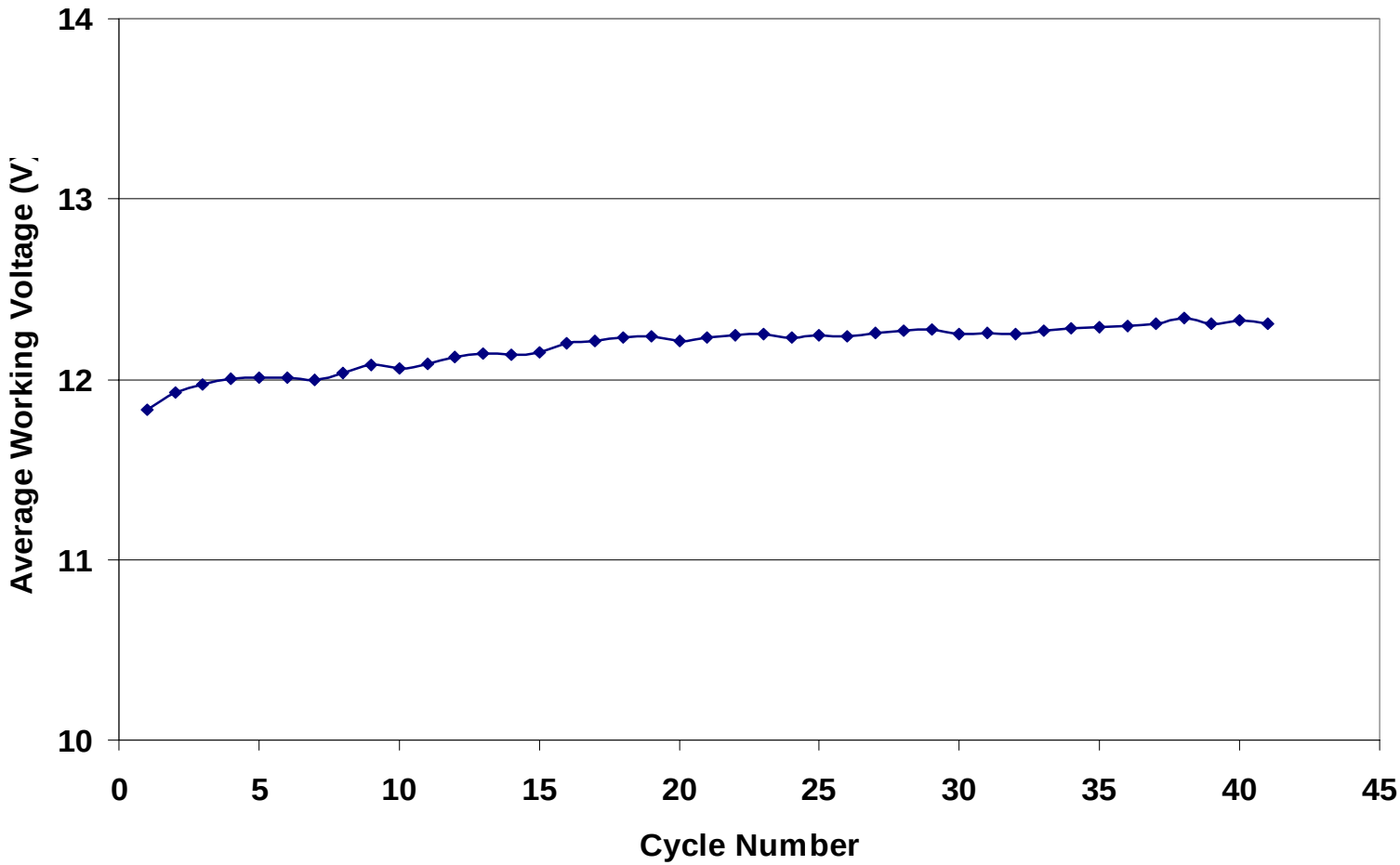
Application Demonstration: EMU-PLSS Battery

Item	***Existing***	***Phase II Goal***
Conditioning	Fill and electrically charge	Fill and go
Volume (L)	2.27	2.12
Weight (Kg)	4.4-6.4	5.2
Capacity	26.6 Ah minimum @3.8A	26.6 Ah minimum @3.8A
Number of cycles to 26.6 Ah cut-off	7-32	50 minimum
Operation	Rugged, Vented maintenance free	Rugged, vented maintenance free
Charging	With existing charger	Ability to interface with existing charging systems
Wet-life	170-420 days	450 days minimum
Electrical	16.5 volts	16.5 volts

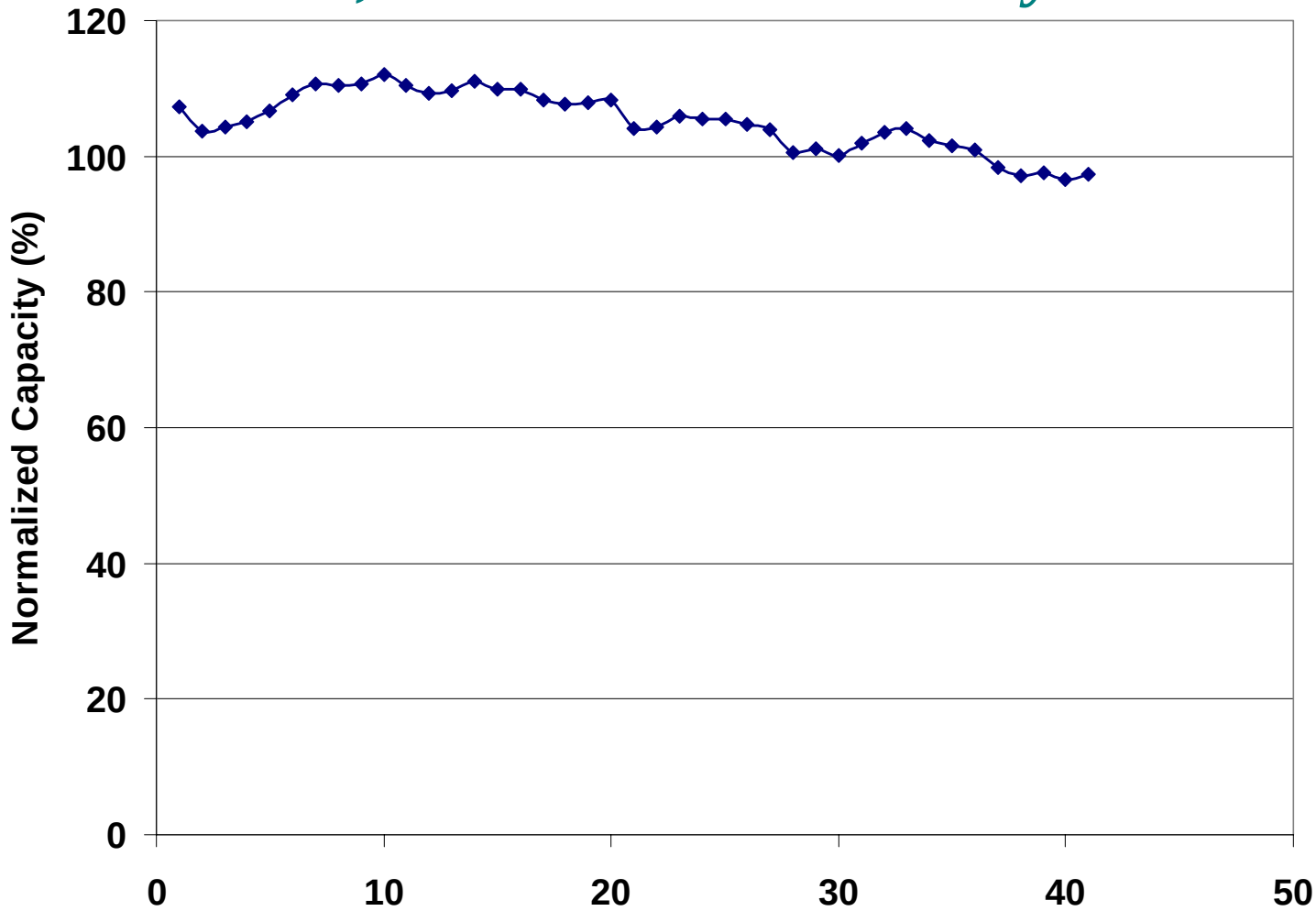
Phase II -Current Status

- Program started Sept. 2002
- Evaluating separators,absorbers and electrolytes to optimize wet/cycle life
- 12V batteries have been assembled and are being tested
- More than 40 cycles and at least two months wet life demonstrated

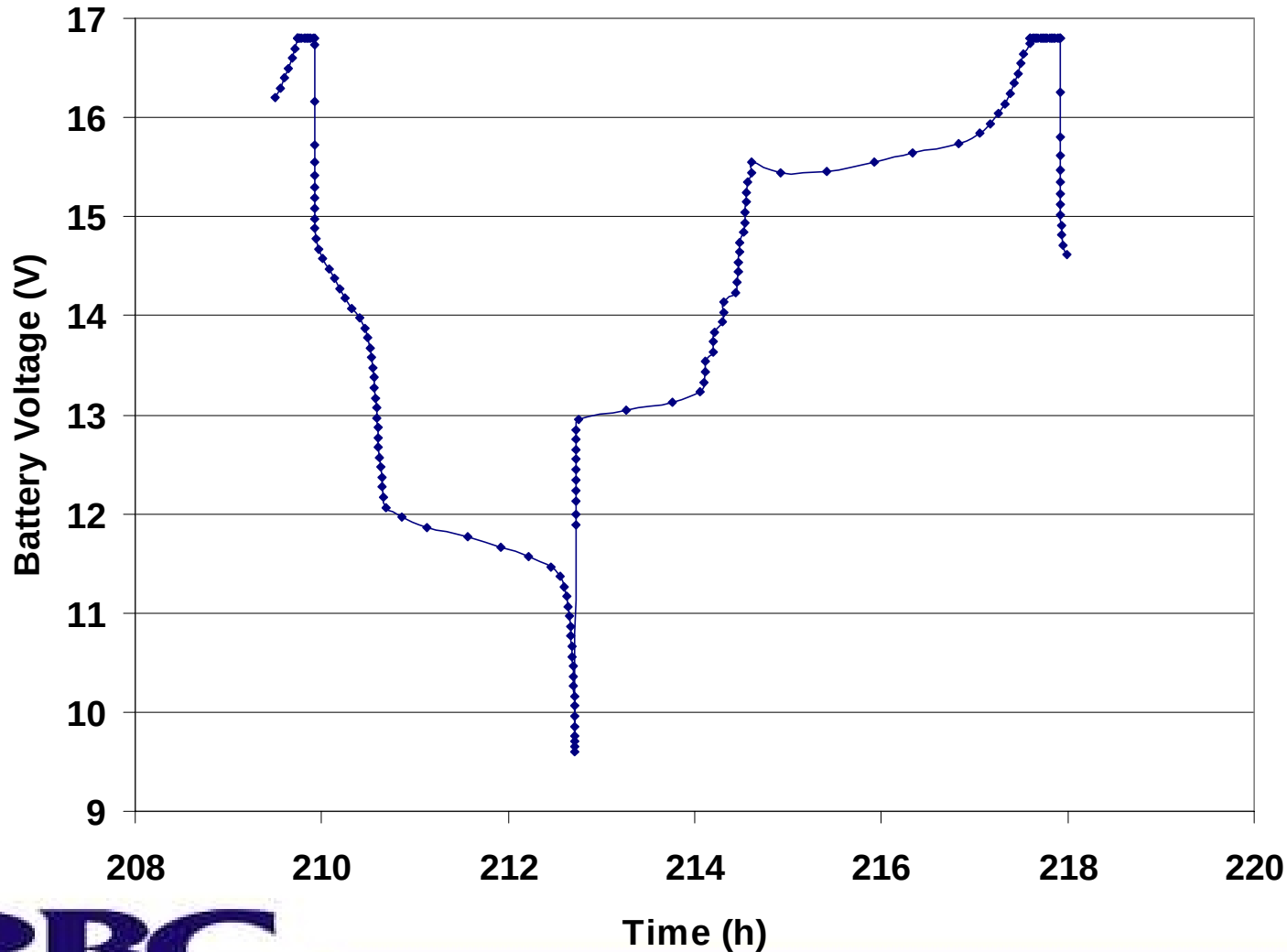
Average Working Voltage vs Cycle number for 1 Ah, 12V Silver/Zinc Battery



Capacity vs Cycle number for 1 Ah, 12V Silver/Zinc Battery



Discharge/Charge Profile for 1 Ah, 12V Silver/Zinc Battery



Opportunity- Spiral Wound RZA Silver/Zinc Battery

TABLE: Comparison of Cylindrical Cells in Various Rechargeable Electrochemistries

Chemistry	Cell config.	Capacity (Ah)	Cell voltage	Wh/kg	Wh/l
NiCd	D	4.6	1.2	40	106
RZA-NiZn	D	5.0	1.65	59	158
NiMH	D	6.5	1.2	46	150
Li-ion	18650	2.0	3.7	130	410
RZA-Ag/Zn	D	10.2	1.5	110	300

Conclusions

- Issues with long term wet life and cycle life of the silver/zinc battery system are being overcome through the use of new anode formulations and separator designs

- Performance may exceed 200 cycles to 80% of initial capacity and ultimate wet-life of > 36 months

- Rechargeable silver/zinc batteries available in prismatic and cylindrical formats may provide a high energy, high power alternative to lithium-ion in military/aerospace applications

Acknowledgements

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Advanced Technology Program

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