Is cell wet-life as important a consideration with Lithium-ion as other chemistries?

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Introduction

- **What is wet life?** The time from cell activation (manufacture) to present day
- 5 yr max *pre-launch* wet life requirements occasionally appear on specs for Li-ion batteries
- Are these numbers technically justified? This paper examines the utility of the requirement as applicable to Li-ion

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Motivation

- Improved Li-Ion specific wet life requirements could reduce risk for customers
- Longer wet life requirements can enable more flexible battery usage and procurement strategies for customers

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“Bottom-Up” Approach for NiCd

- Early NiCd life testing: cells stored for 3 to 6 years, then cycled
- Results showed that cycling performance began to suffer for storage periods >5 years.
- Degradation mechanism identified as interaction of Nylon separator and KOH electrolyte
- This drove a 5 year max wet life requirement for NiCd (and NiH_2 with similar electrolyte / separator combinations) batteries in many applications

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“Top-Down” or “Carry-Forward” for Li-Ion?

- The cited NiCd degradation mechanism does not apply to Li-Ion. However we do know that degradation occurs during storage due to other mechanisms, and thus need a number to use
- Similar store-then-cycle tests take time and are expensive, thus data is not yet available to empirically specify a Li-Ion max wet life
- “Carry-Forward”: NiCd’s degradation mechanism does not apply to Li-Ion, but the observed 5 yr NiCd max might have served as a conservative starting point
- “Top-Down”: Alternatively, working backwards through the entire spacecraft AIT process makes 5 years a reasonable and practical starting point for the requirement

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Refining Li-Ion Wet Life Req's

- In either case, the door to extend such wet life requirements is open if sufficient test data is available

- ABSL is currently well positioned to pursue such an endeavour thanks to its life test libraries, modelling/prediction capabilities, experience with past missions, and stock of old cells

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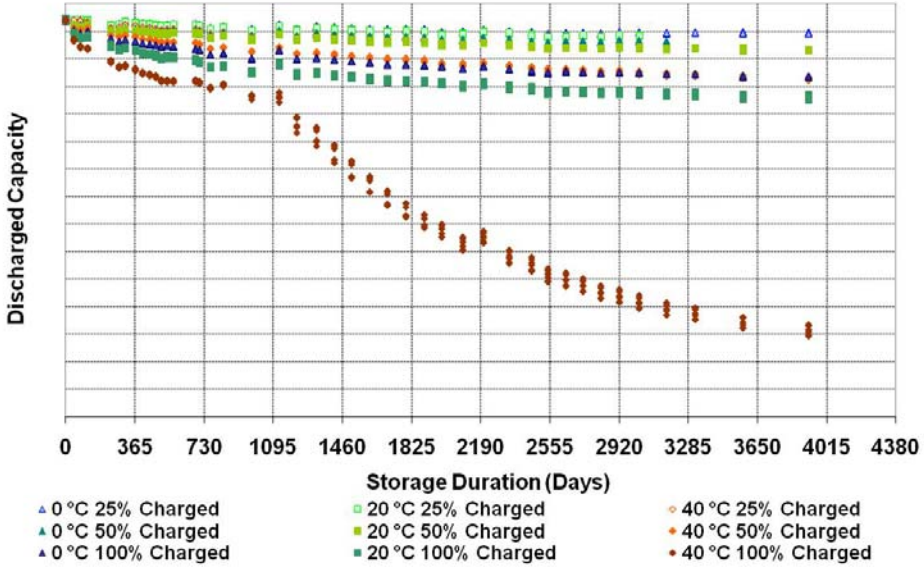
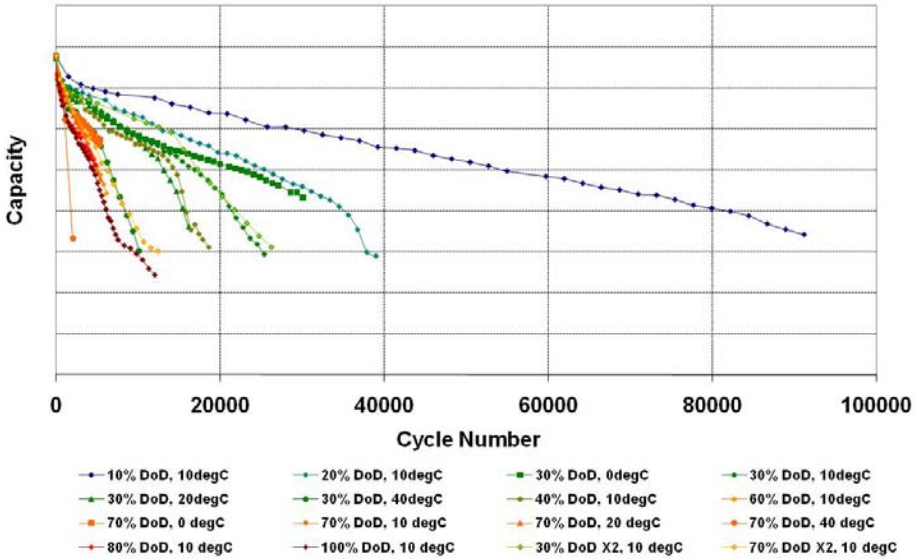
Li-Ion Endurance

- Li-Ion is known for its excellent storage characteristics
- ABSL has over 9 years of storage data at a broad range of temperatures and SOCs
- ABSL has over 9 years and as many as 90k+ cycles of operational endurance test data





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Modeling Tools

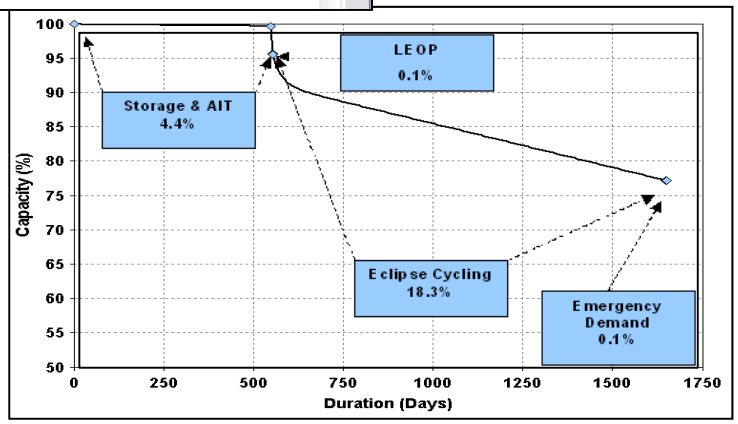
Electrical Design

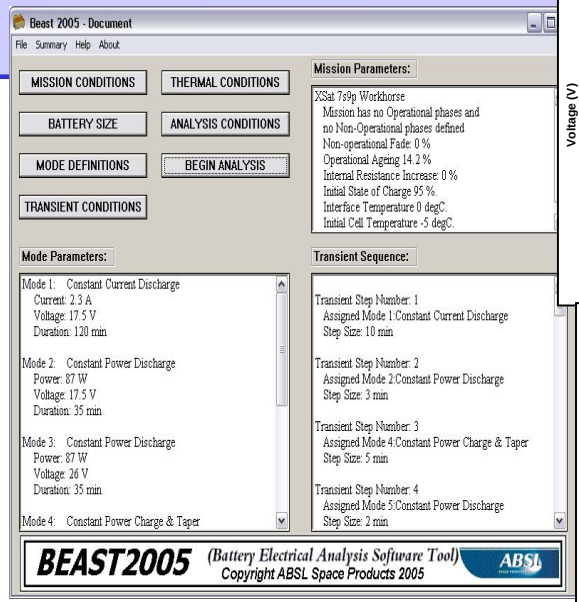
LIFE ⇄ BEAST

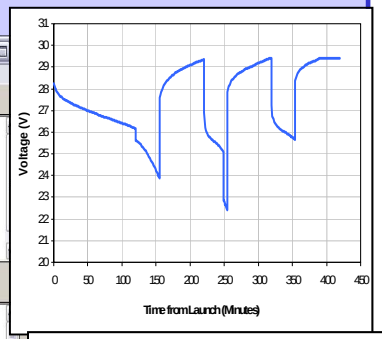
EOL Capacity & Resistance

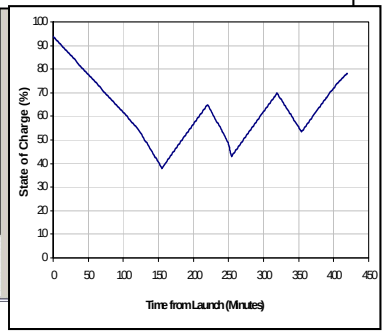
DOD

Phase Number	Duration (Days)	Capacity (%)	Phase Description
0	0	100.0	Initial Condition
1	547	99.6	Ground Storage
2	554	95.6	Ground Test
3	554	95.5	LEOP
4	1647	77.2	Eclipse Cycling
5	1648	77.2	Emergency (Nominal)
6	1649	77.1	Emergency (Peak)









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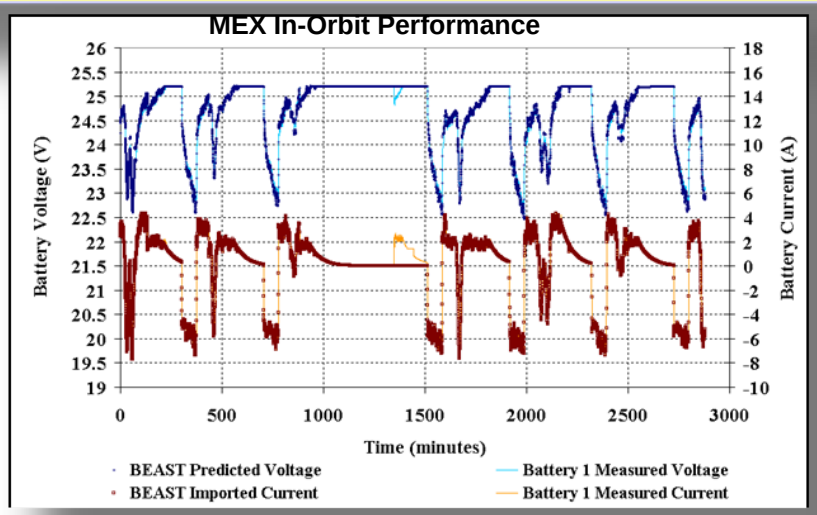
Modeling Tools

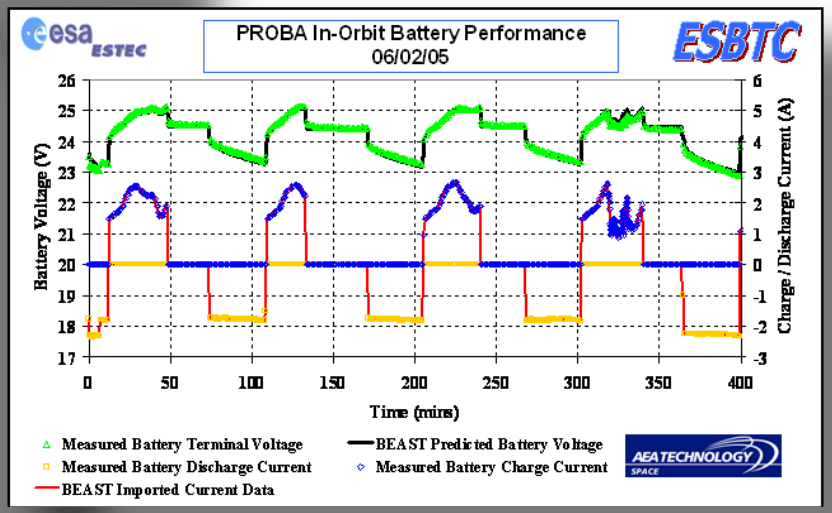
Electrical Design

LIFE → BEAST: *EOL Capacity & Resistance*

BEAST → LIFE: *DOD*

Comparison against in-orbit telemetry shows a high degree of accuracy for complex mission profiles and long mission durations.





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Historical Precedence

- Many successful flights with >3 year wet life, some with > 4 years and one with > 5 year wet life
- Proba and Mars Express on-orbit performance correlates very well with ABSL prediction

Project	Activation Date	Launch Date	Wet Life Storage
Proba	Jan 1999	Oct 2001	33 months
Rosetta	Jan 1999	March 2004	62 months
SDO Life test	Dec 2000	May 2003	29 months
Mars Express	Jan 1999	June 2003	53 months
MicroSat	Dec 2000	June 2004 Dec 2004	42 months 48 months
SaudiSat	Jan 2002	June 2004	29 months
NSat	Jan 2002	Dec 2004	35 months
Essaim	Dec 2000	Dec 2004	48 months

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ABSL's approach to date…

- All individual cells are screened before and after storage (prior to battery assembly), and outliers that exhibit anomalous storage degradation are rejected
- Battery assemblies stored for lengthy periods are cycled prior to use to assess storage effects on capacity and resistance
- EOL mission performance is forecasted using LIFE and BEAST to address impacts of extended storage periods

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Case Study: PROBA

- PROBA is the longest operating Li-Ion battery in Earth orbit at more than 8 years & 40k cycles
- On orbit data has been compared to BEAST/LIFE predictions and shown excellent correlation (*Neubauer, Space Power Workshop 2008*)
- PROBA cells were 'on the shelf' for ~2.5 years prior to launch. What if pre-launch wet life had been increased to 6 or even 10 years?

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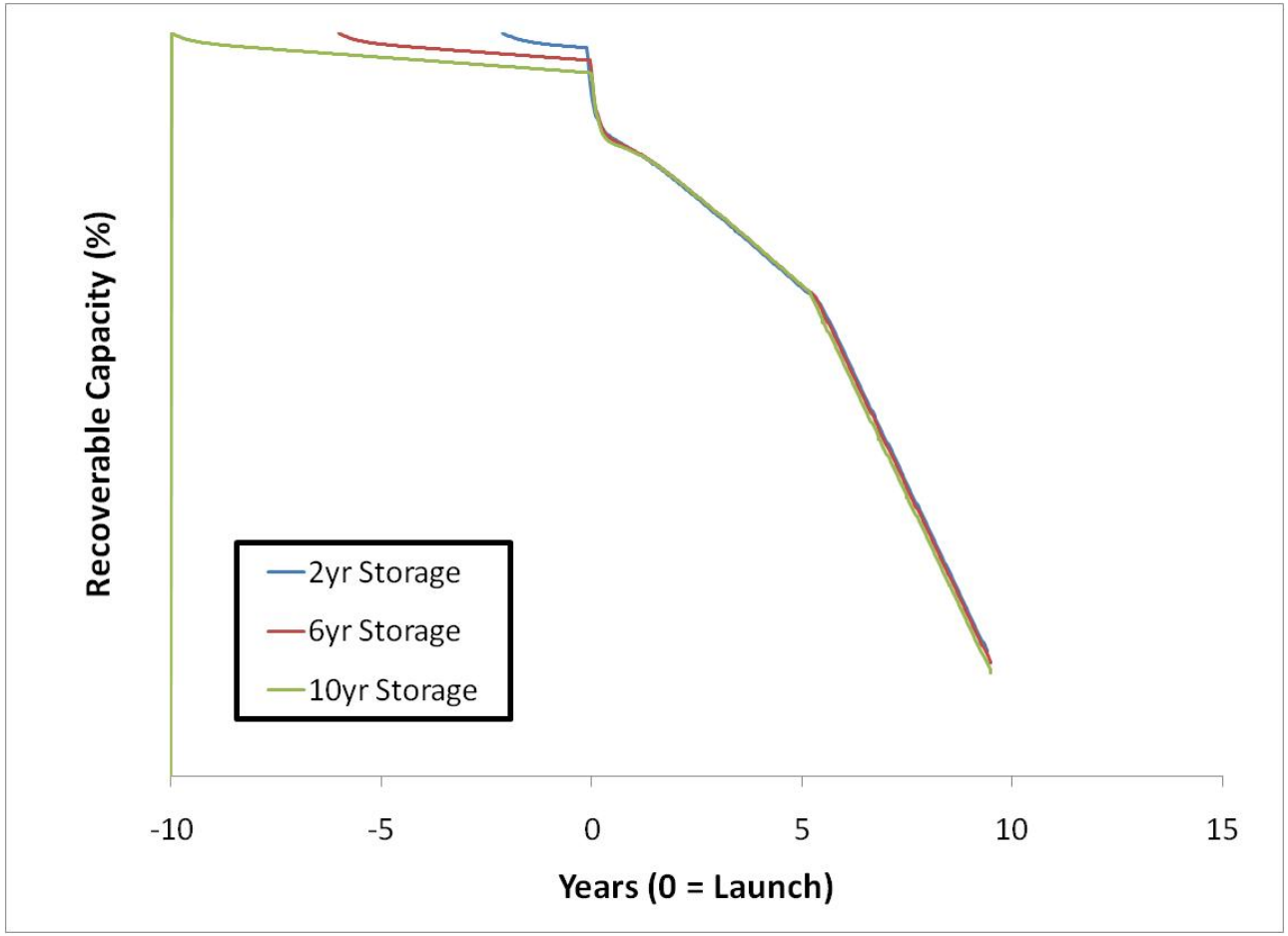
PROBA Battery Degradation

- Forecasted capacity fade shows minimal affect of storage extension on mission when treated properly.



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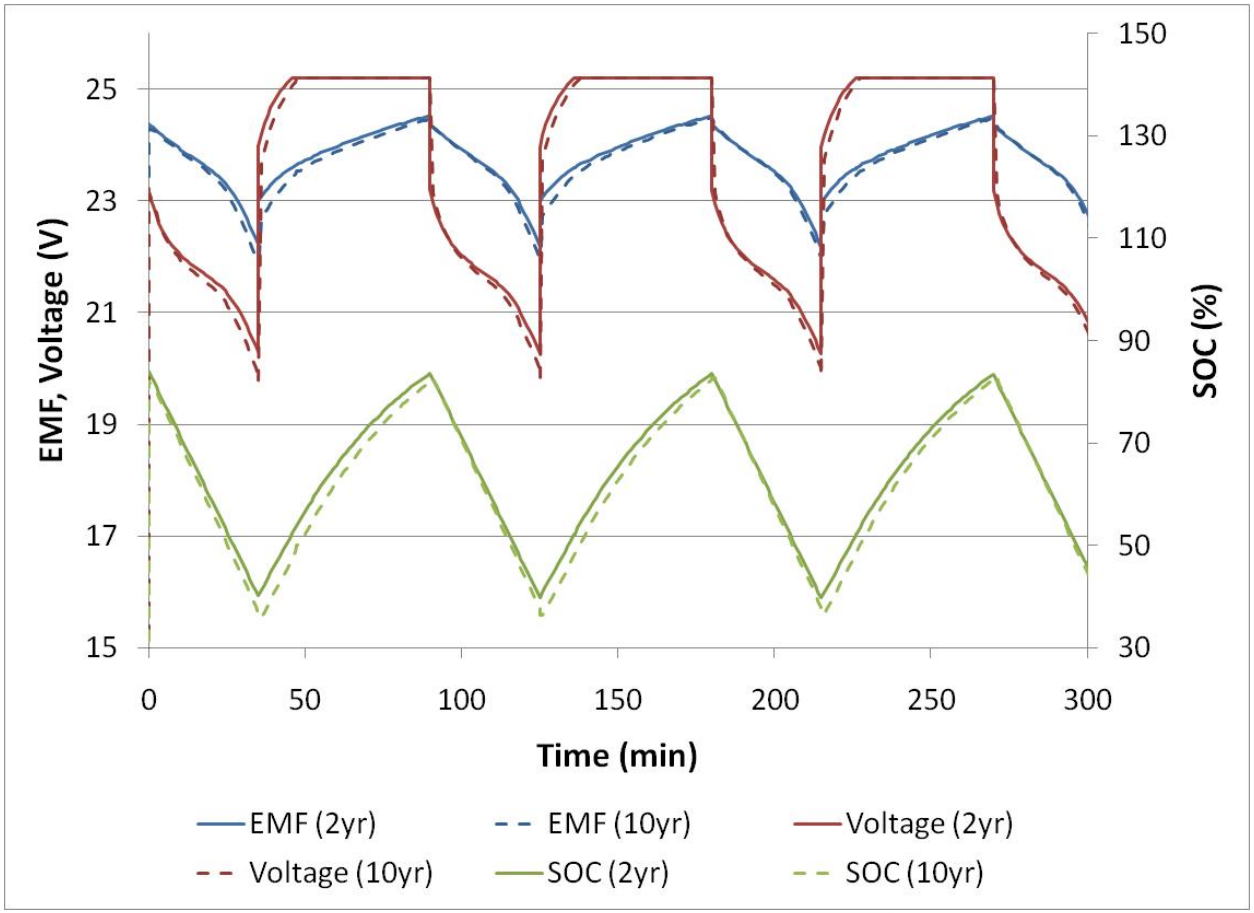
PROBA EOL Performance

- Representative cycle at EOL 8 years into mission for 2 and 10 yr storage cases shows <0.5 V difference



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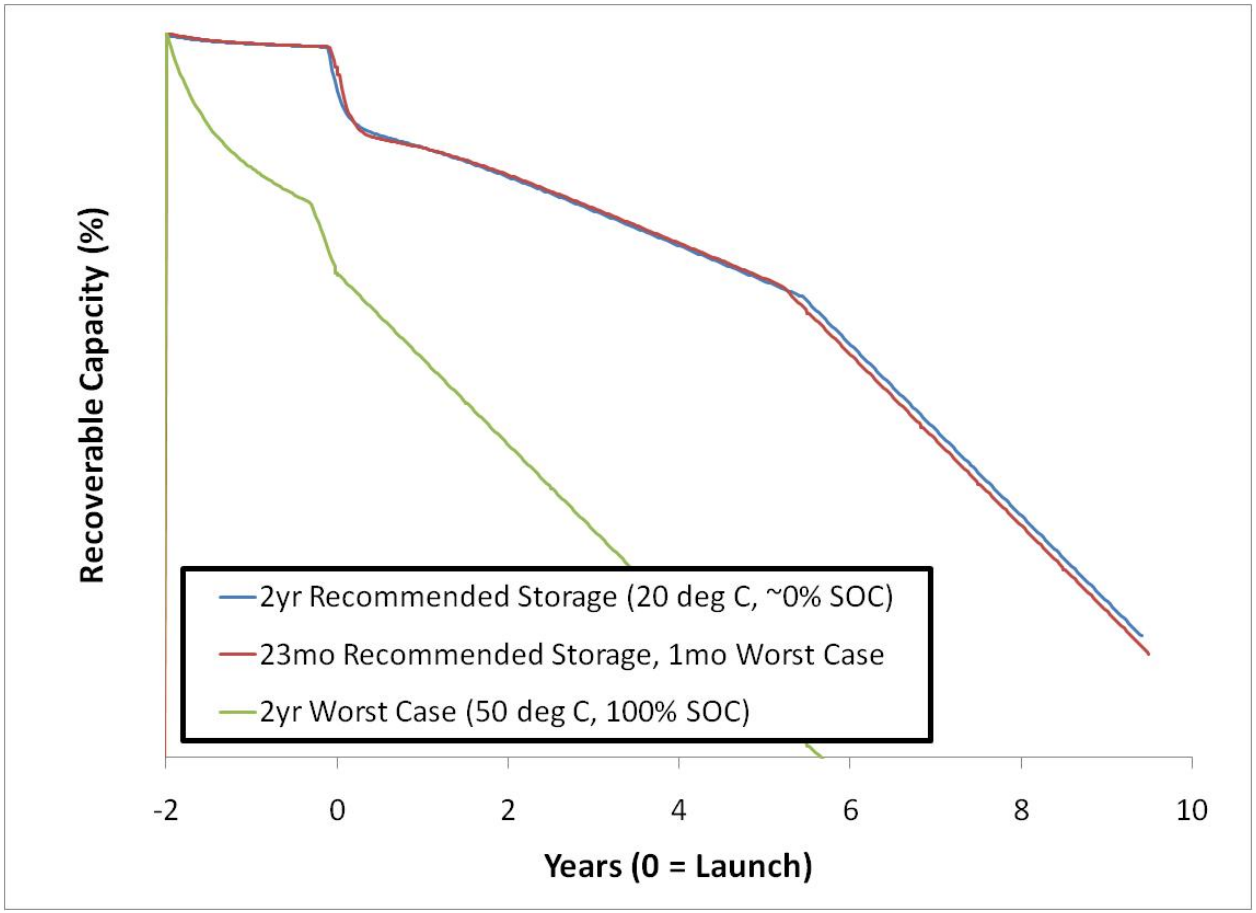
Importance of Storage Conditions

- Improper storage (high temperature and SOC), however, can dramatically degrade mission performance



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Exploratory Testing

- Objectives:
  - Further validate ABSL modeling tools for assessing impacts of long storage periods
  - Demonstrate that long storage periods are in many cases perfectly manageable

- Methods:
  - Retrieve ~9 yr old cells from storage
  - Conduct standard LAT accelerated life test and compare performance to original LAT data for batch
  - Conduct long term life tests and compare performance to standard library data & predictions

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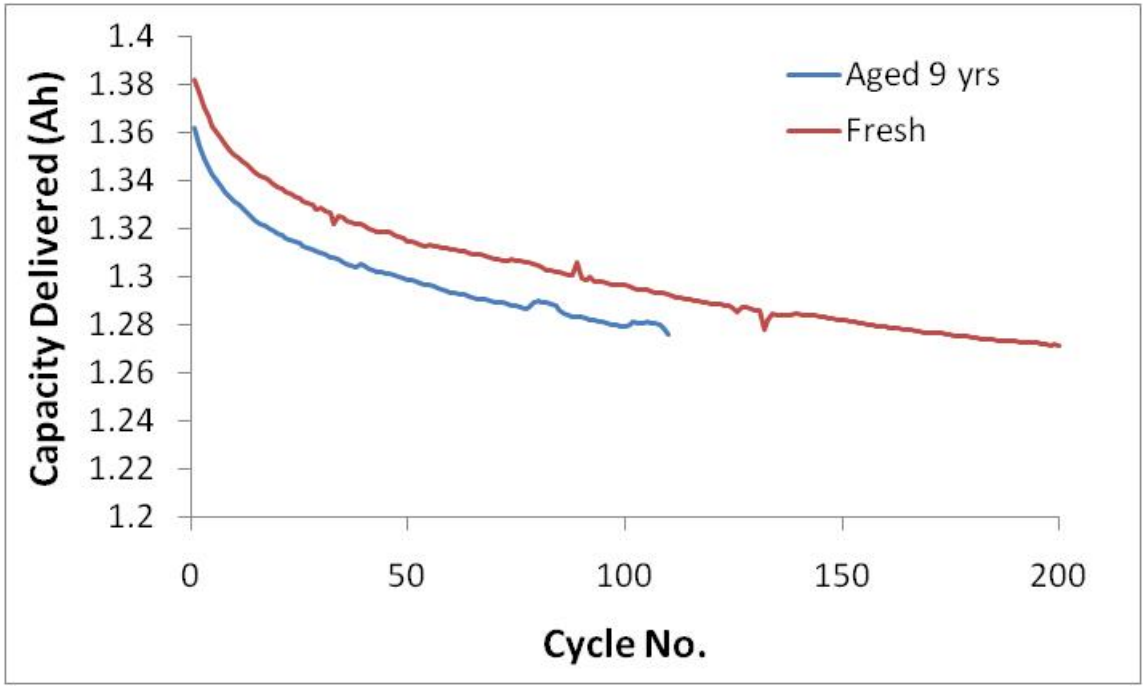
LAT Cycling

- **LAT Cycle:** accelerated cycling between voltage limits (nearly 100% DOD) at ambient temperature
- Results show identical trends and only ~1% difference between fresh and 9 year old cells.



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Long Term Life Tests

- Conditions will tentatively include…
  - 10% DOD, 10 deg C, C/2 rates
  - 30% DOD, 20 deg C, C/2 rates
  - 30% DOD, 40 deg C, C/2 rates
  - 70% DOD, 10 deg C, 1C rates
- 9 year old and 5 year old cells to be tested
- Looking for interested partners…

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Conclusions

- Testing of 9 year old ABSL cells shows minimal effect of storage on accelerated cycling performance
- Planned testing will further study the long term effects of 5 to 9 year storage periods prior to cycling
- ABSL's modeling tools predict the impact of shelf life extensions are negligible, hinting that 5 year wet life requirements may not always be necessary
- **But when stored improperly, the wet life allowance can be immaterial as performance can be dramatically degraded.**

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Better Use of Li-Ion Batteries

- Proving that Li-Ion batteries maintain performance after long shelf life periods enables…
  - Less restrictive wet life requirements
  - More flexible procurement / use strategies for battery customers
  - More cost effective procurement / build strategies for battery suppliers
  - Improved security of supply strategies
- BUT… *proper storage is critical to allowing these benefits!*

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