

Development of New Battery Chemistries for Ocean Worlds Exploration

Keith J. Billings, Ratnakumar Bugga, Keith B. Chin, John-Paul Jones,
Simon C. Jones, Charlie Krause, Adam Lawrence, Raymond
Ontiveros, Jasmina Pasalic, Marshall C. Smart, and William C. West,
Erik J. Brandon

Electrochemical Technologies Group

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109
*John-Paul.Jones@jpl.nasa.gov

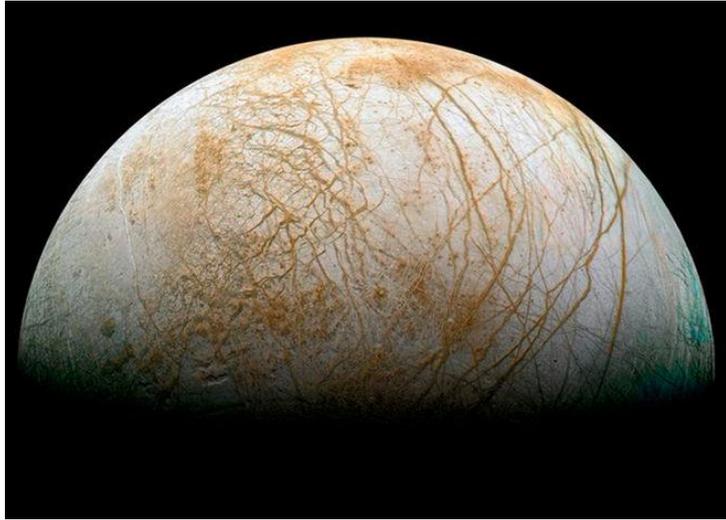
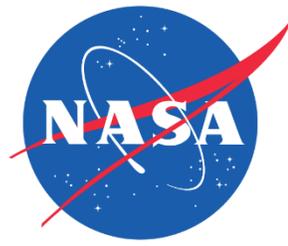
Space Power Workshop

Manhattan Beach, CA
Thursday, April 27, 2017

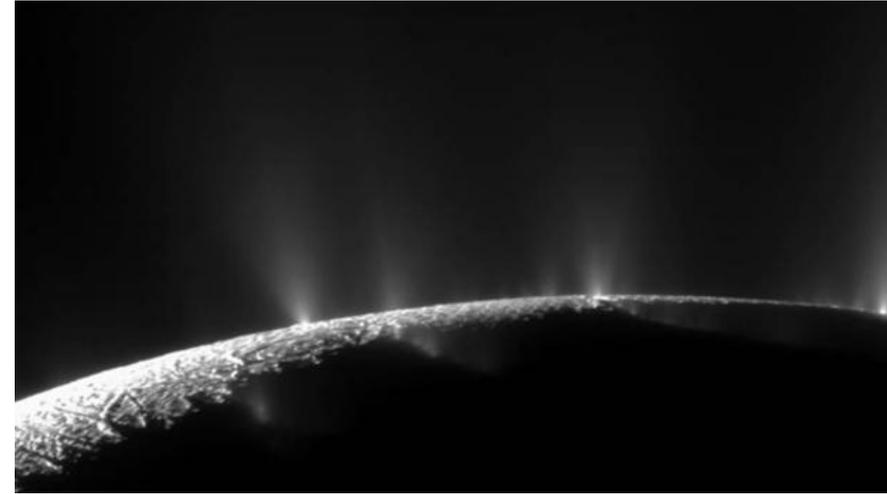
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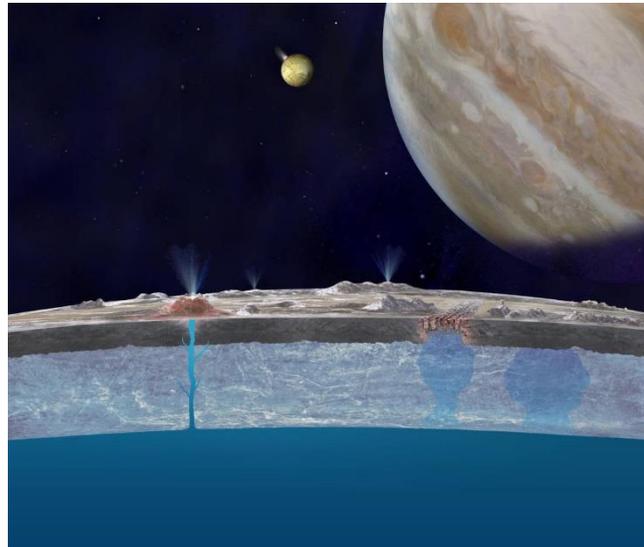
Increasing Interest in “Ocean Worlds”



Europa

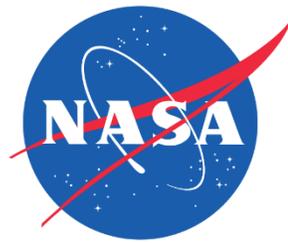


Enceladus Plumes

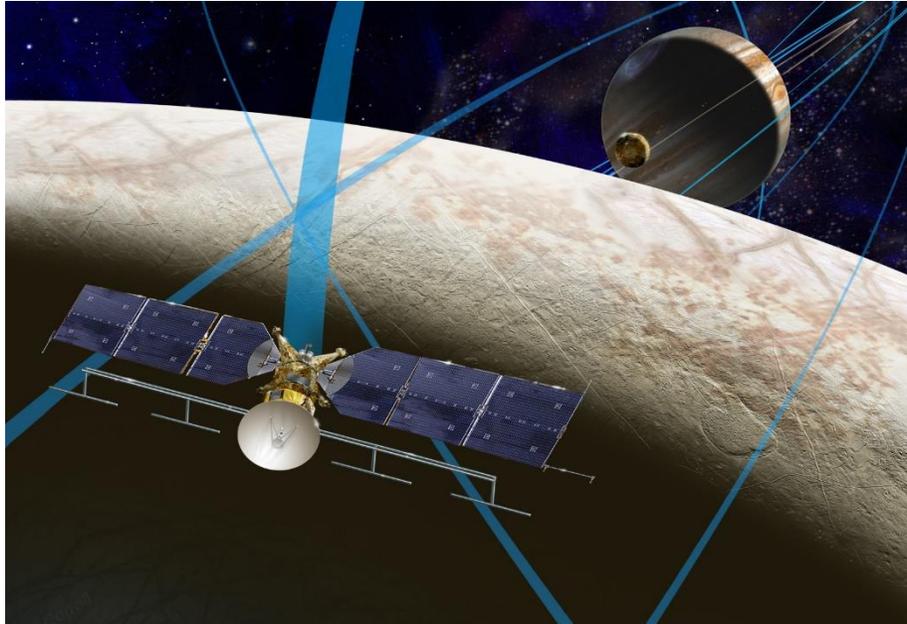


Depiction of cross-section of Europa

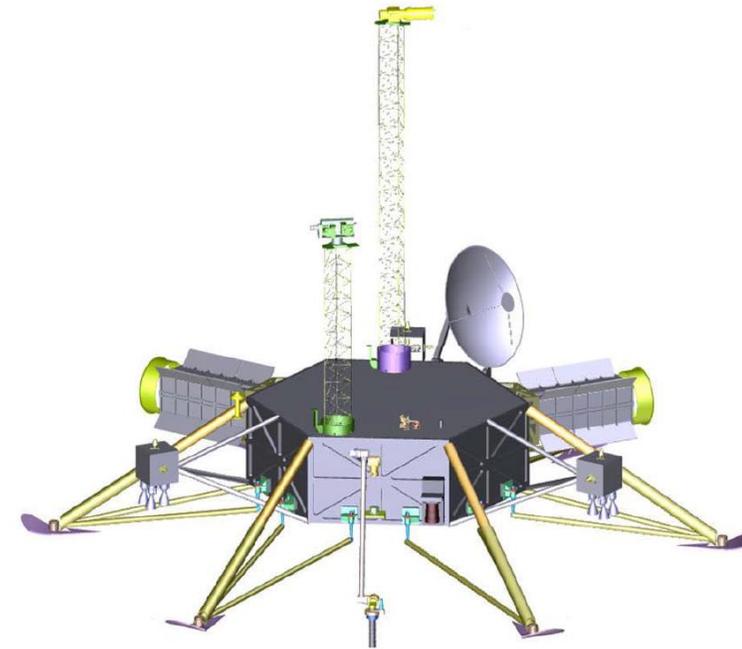
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Power Challenges



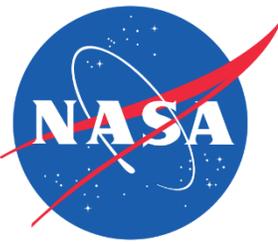
Solar arrays are the baseline power system for the planned multiple flyby Europa Mission



A potential Europa Lander could use primary batteries operating for weeks vs. hours

Artist's Concepts

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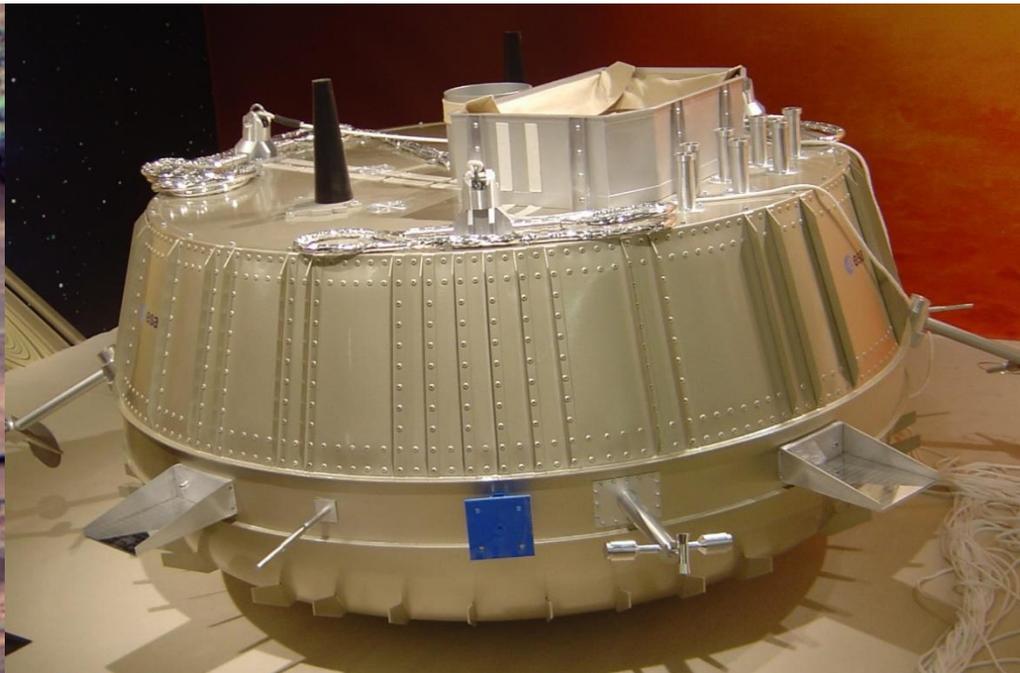
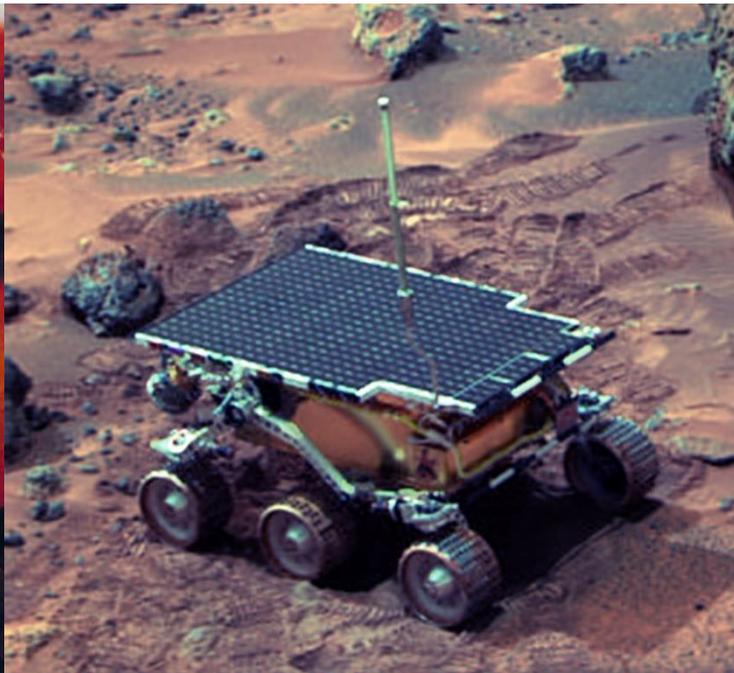


Three Examples of Primary Batteries for Space

Galileo Probe 1989: Li/SO₂
~580 Wh
58 minutes

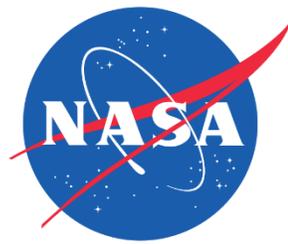
Sojourner Rover 1996: Li/SOCl₂
432 Wh
56 days (PV + battery)

Huygens Probe 2004: Li/SO₂
~2700 Wh
153 minutes



A Europa Lander could require at least 480 hours of operation on battery power alone, therefore, high specific energy is critical to achieving mission objectives

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Evaluation of Cell Options

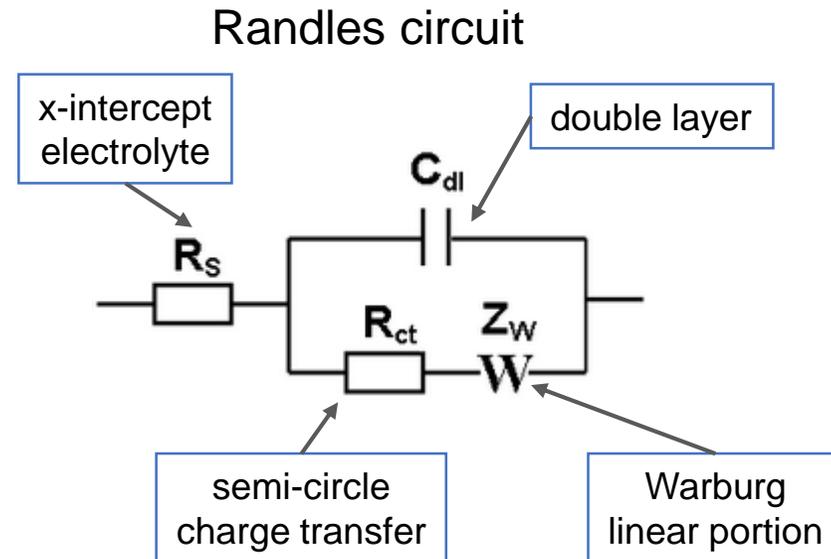
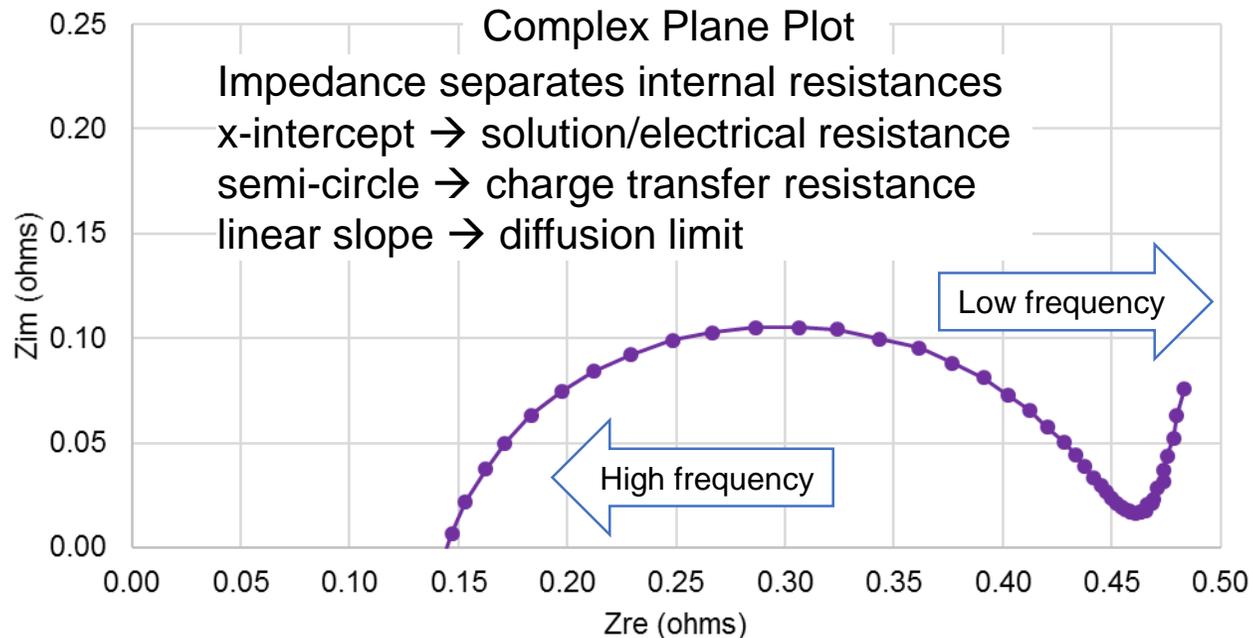
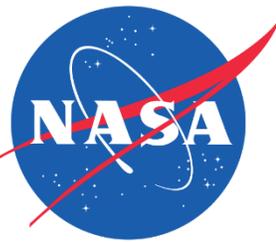
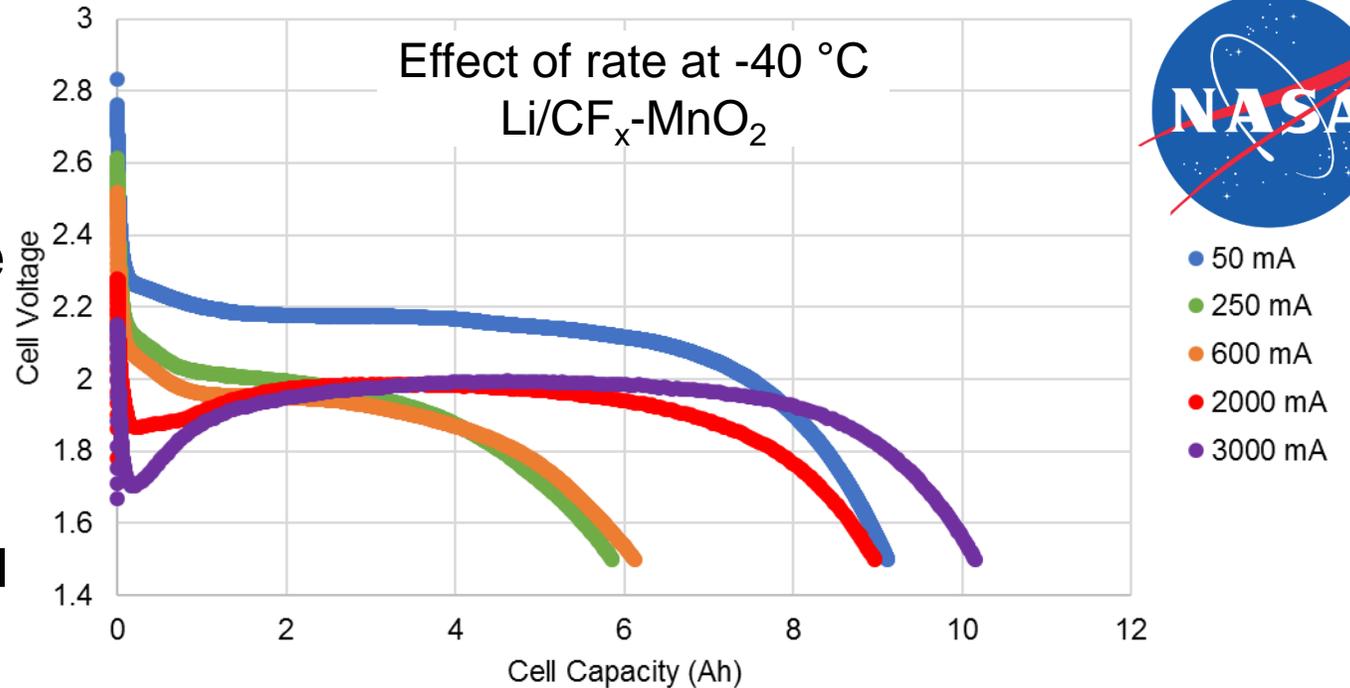
Cell Chemistry	Vendor	Part Number	Format
Li/SO ₂	Saft	LO 26 SXC	D cell
Li/SOCl ₂	Saft	LSH 20	D cell
Li/MnO ₂	Ultralife	CR15270	D cell
Li-FeS ₂	Energizer	L91	AA cell
Li/CF _x -MnO ₂	Eagle-Picher	LCF-133 (COTS and modified)	D cell
Li/CF _x	Ray-O-Vac	DP-BR-20AI	D cell

Targeting high specific energy at moderate rates (50-600 mA) and temperature of -40 to +30°C (baseline temperature is 0°C)

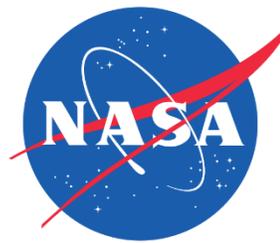
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Testing methods

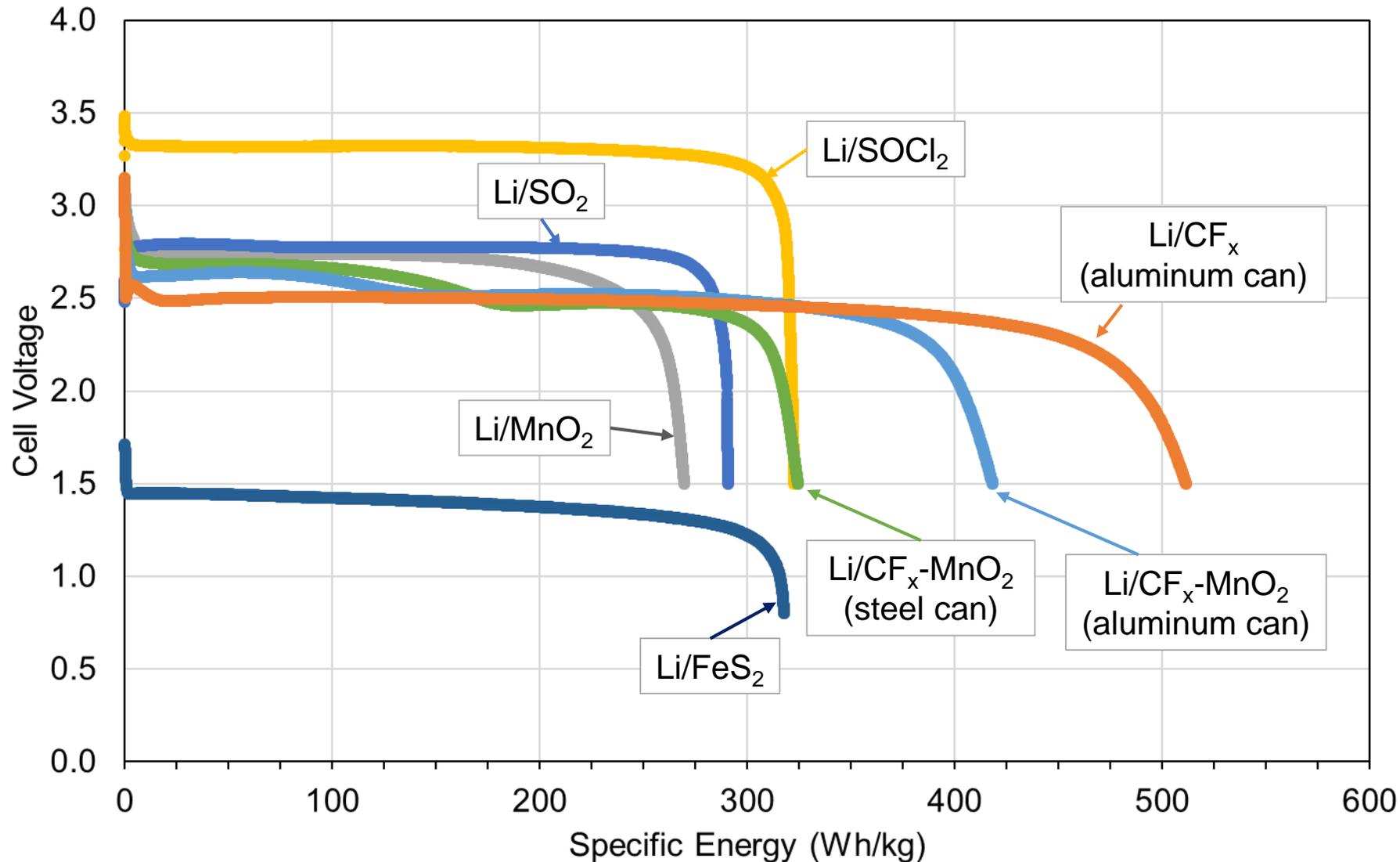
- Discharge/cycling performance
 - Rate (50, 250 and 600 mA)
 - Temperature (-40 to +21 °C)
- Impedance analysis
 - Apply range of frequencies to cell
 - “static” conditions



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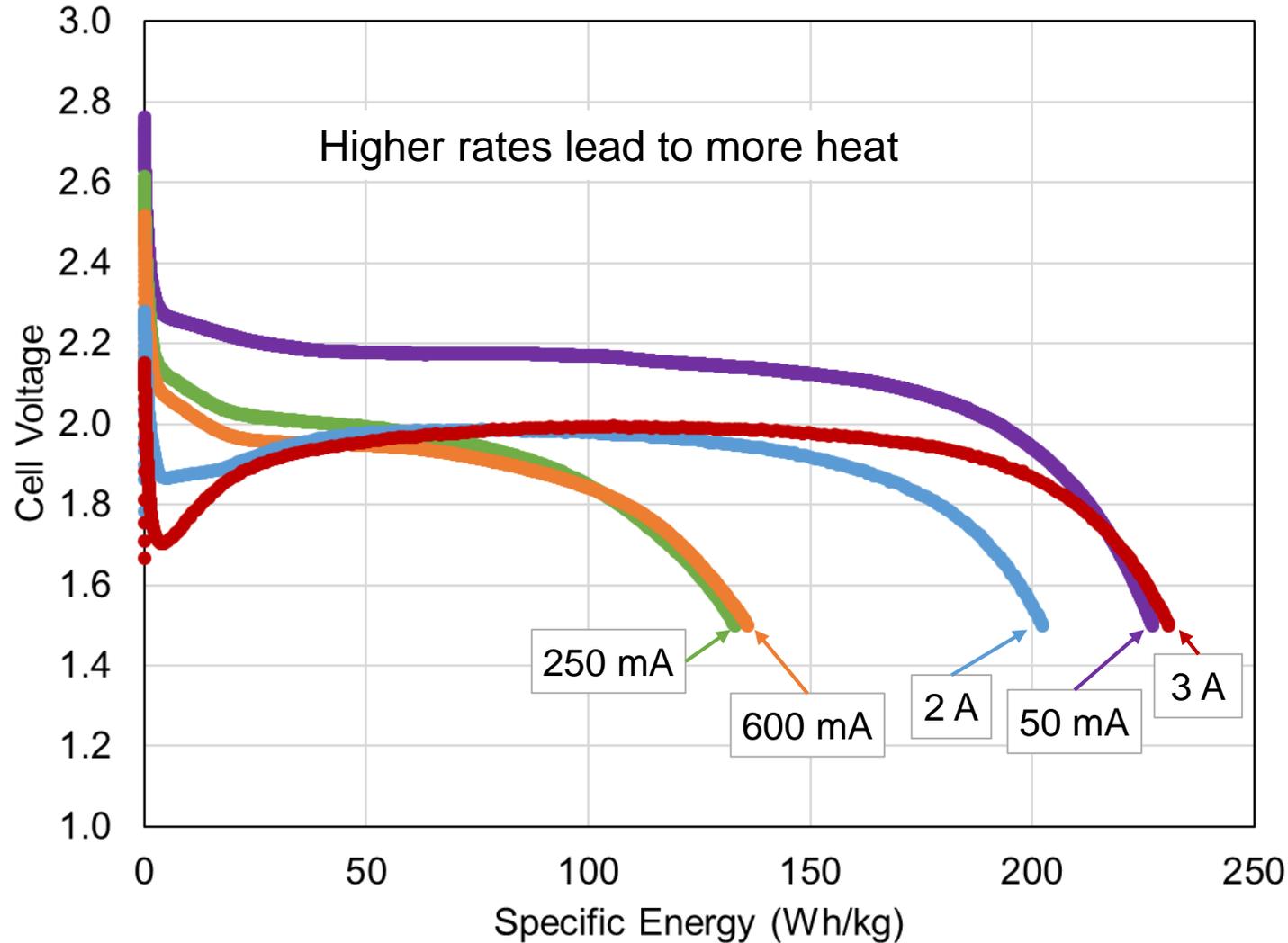
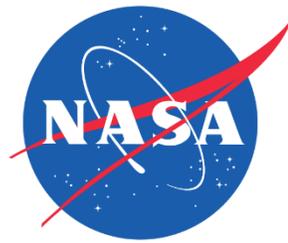


Screening Capacity of Primary Cells

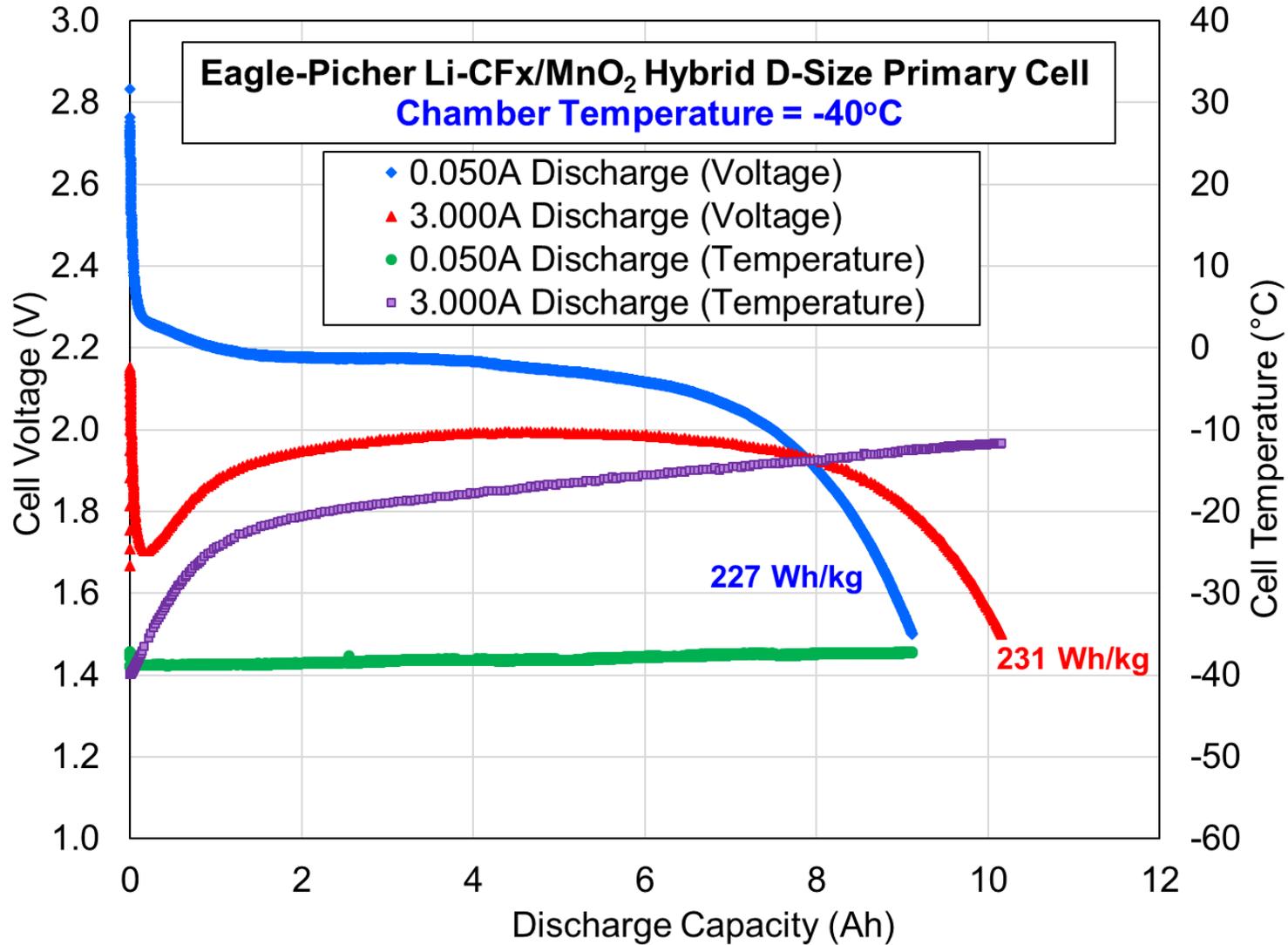
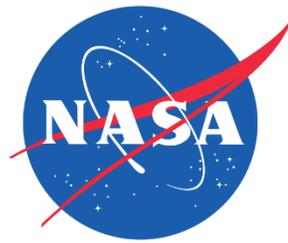


- Discharged at the same condition
- 0 °C, 250 mA
- Li/FeS₂ discharged at 100 mA due to size (AA instead of D)
- 2 Li/FeS₂ cells could be connected in series to provide comparable voltage

Li/CF_x-MnO₂ Discharge Rate at -40 °C



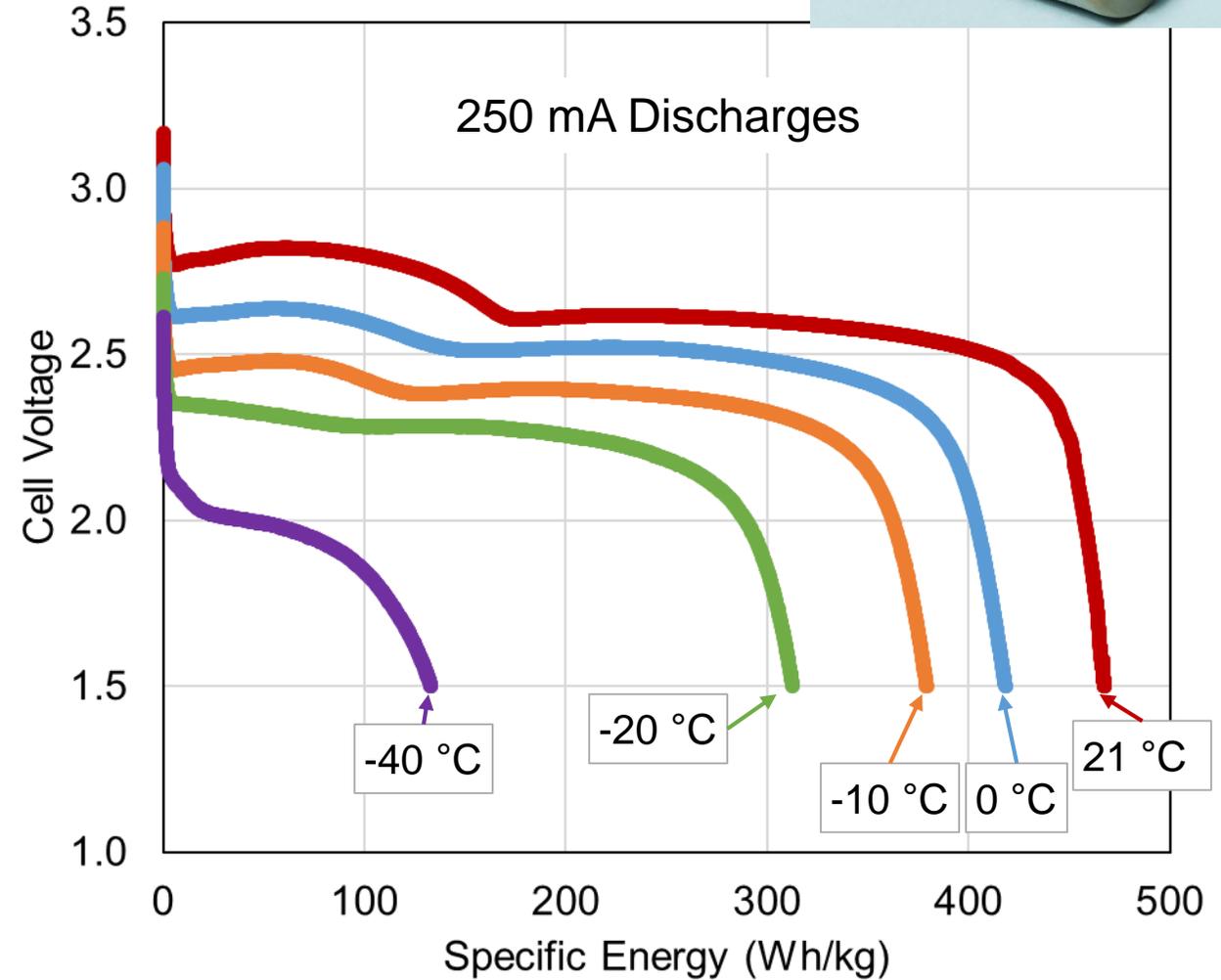
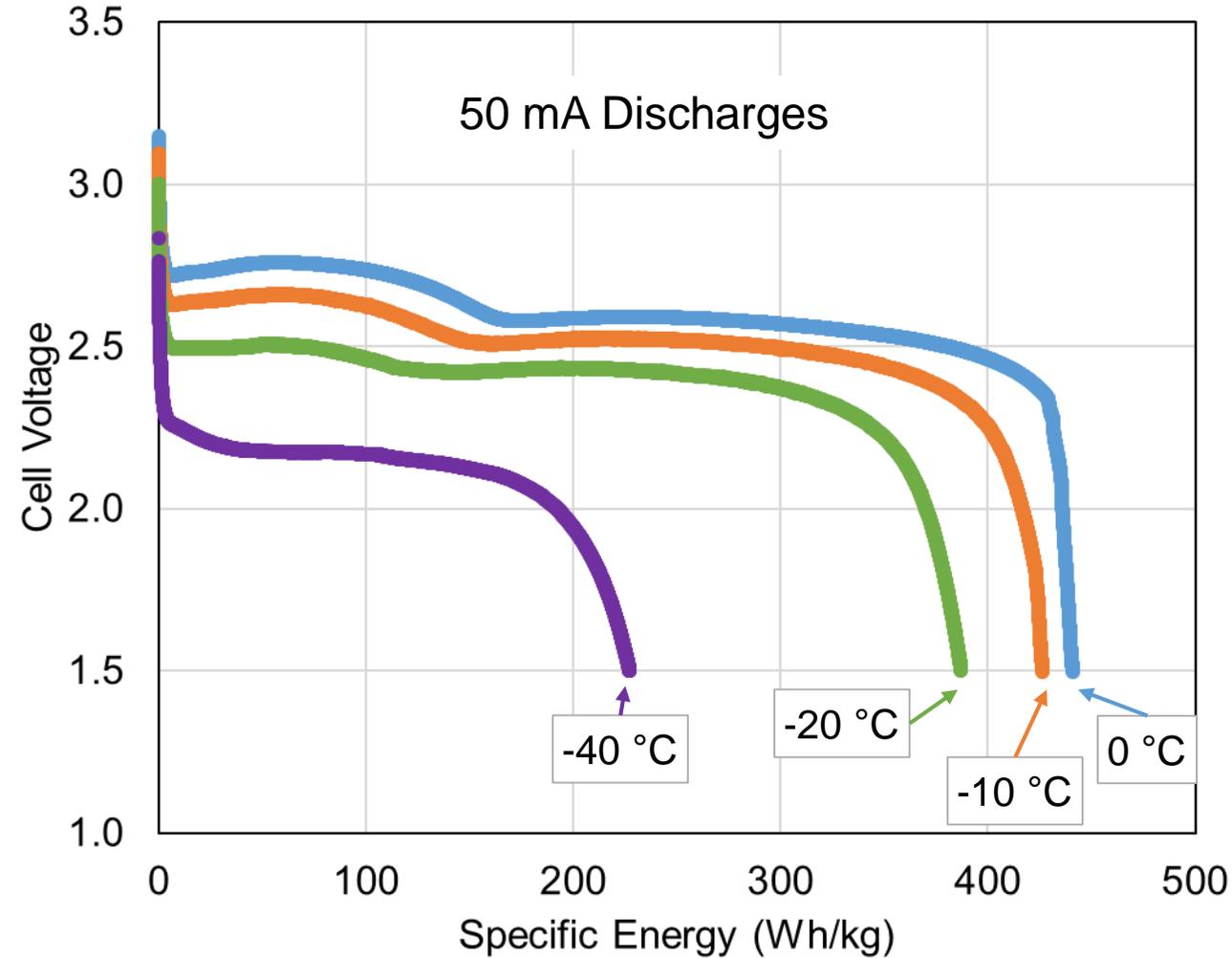
Li/CF_x-MnO₂ Discharge Rate at -40 °C



Hybrid cells perform well at low temperature and high rates

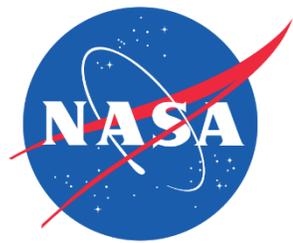
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Li/CF_x-MnO₂ Temperature Dependence



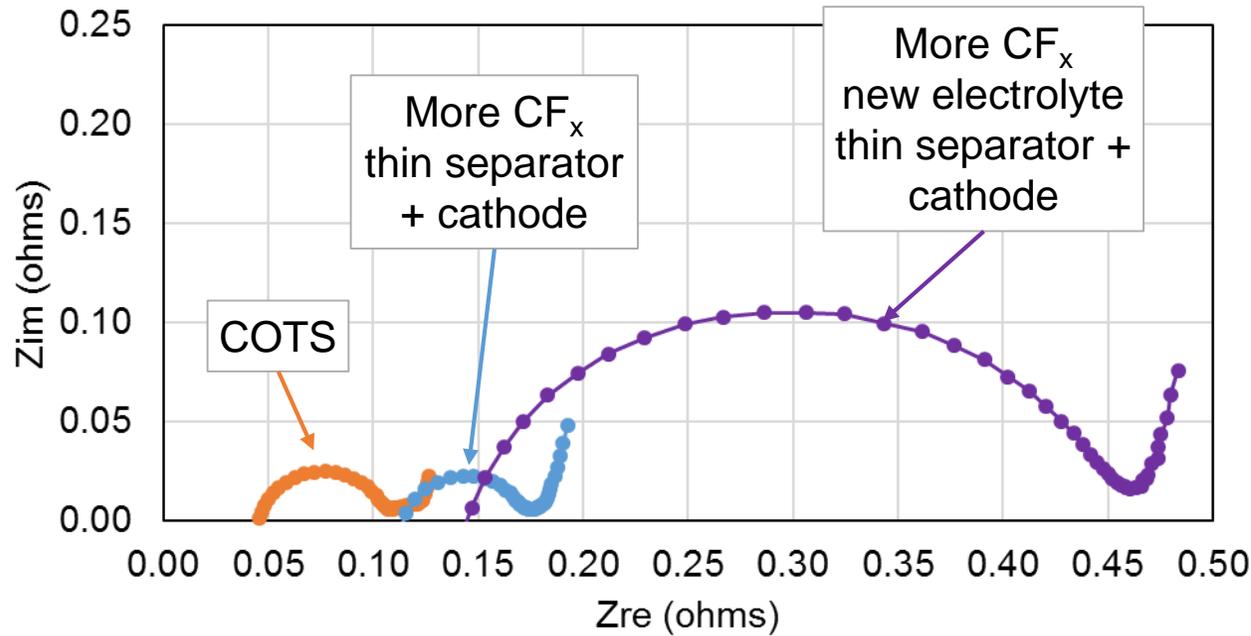
Delivered capacity reduced at low temperatures and moderate rates

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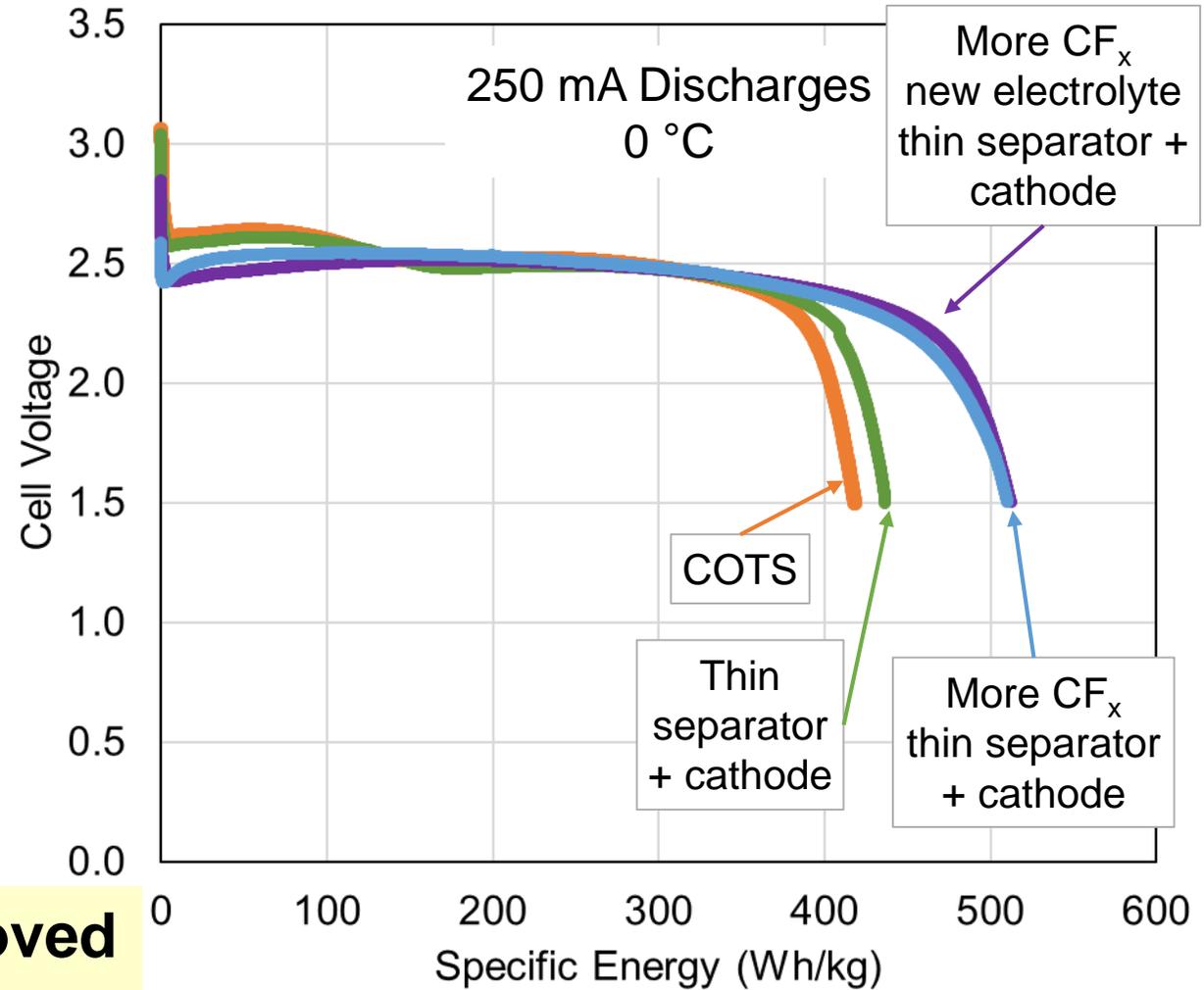


Improved Hybrid Cells

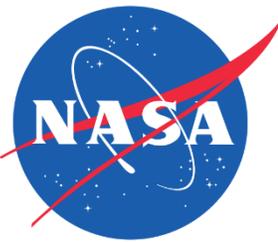
low temperature, low rate targeted



More CF_x → increased cell resistance
New electrolyte → increased cell resistance

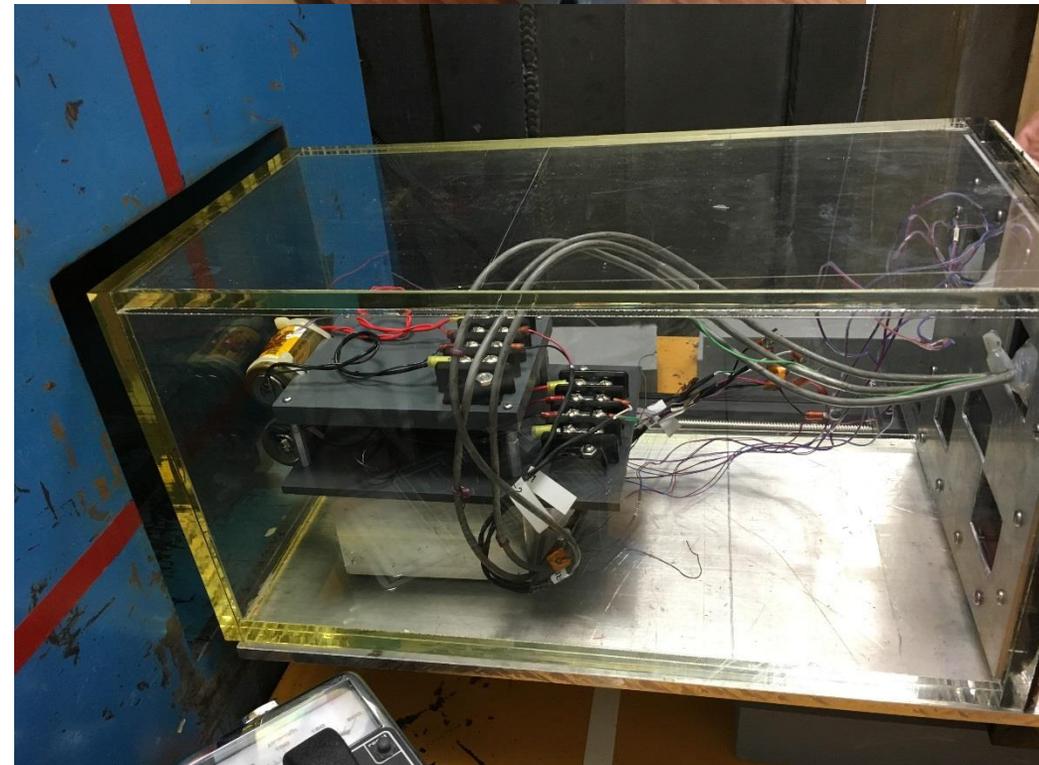
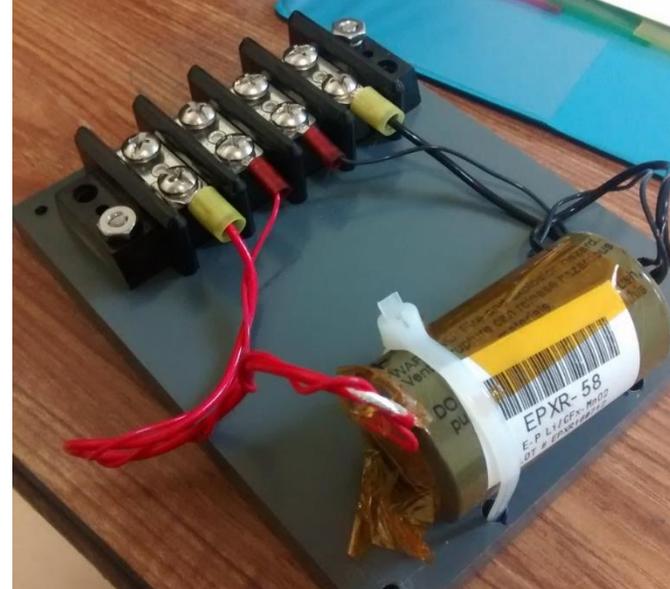


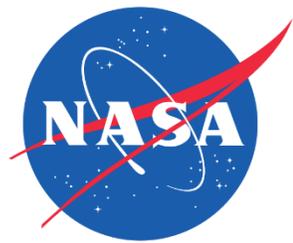
Cell modification by vendor lead to improved low temperature, moderate rate performance



Radiation Testing

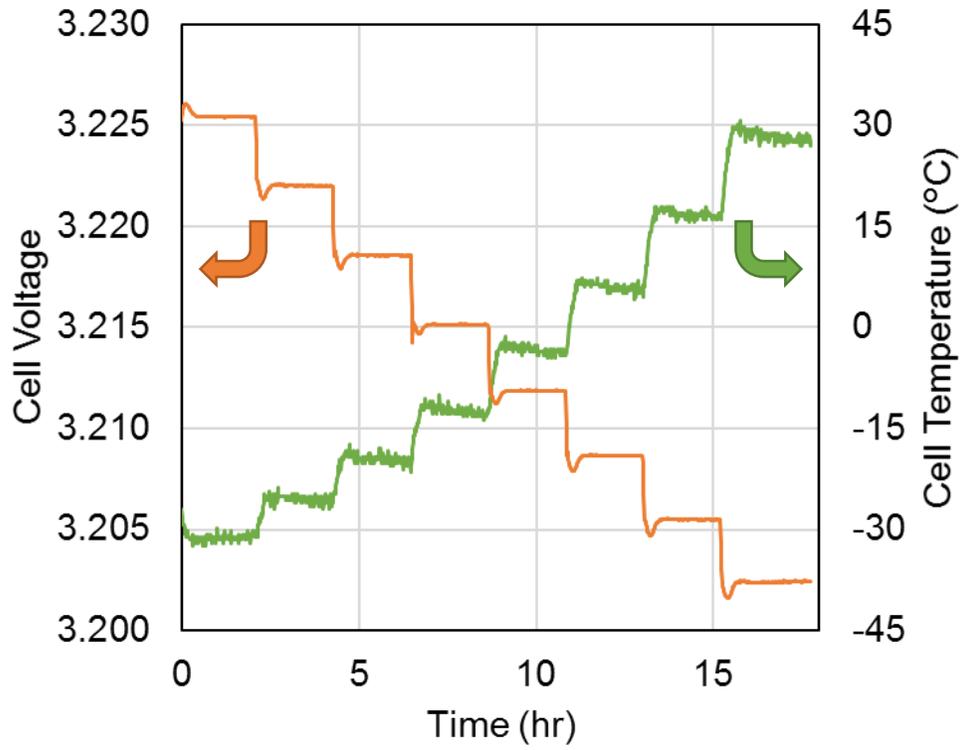
- Europa is a high radiation environment
- Possible planetary protection protocol
- Eagle-Picher Li/CF_x-MnO₂ hybrid COTS cells
- JPL high dose rate ⁶⁰Co source
 - 1.3 MeV gamma rays
 - ~200 rad/s
 - 1 MRad up to 15 MRad



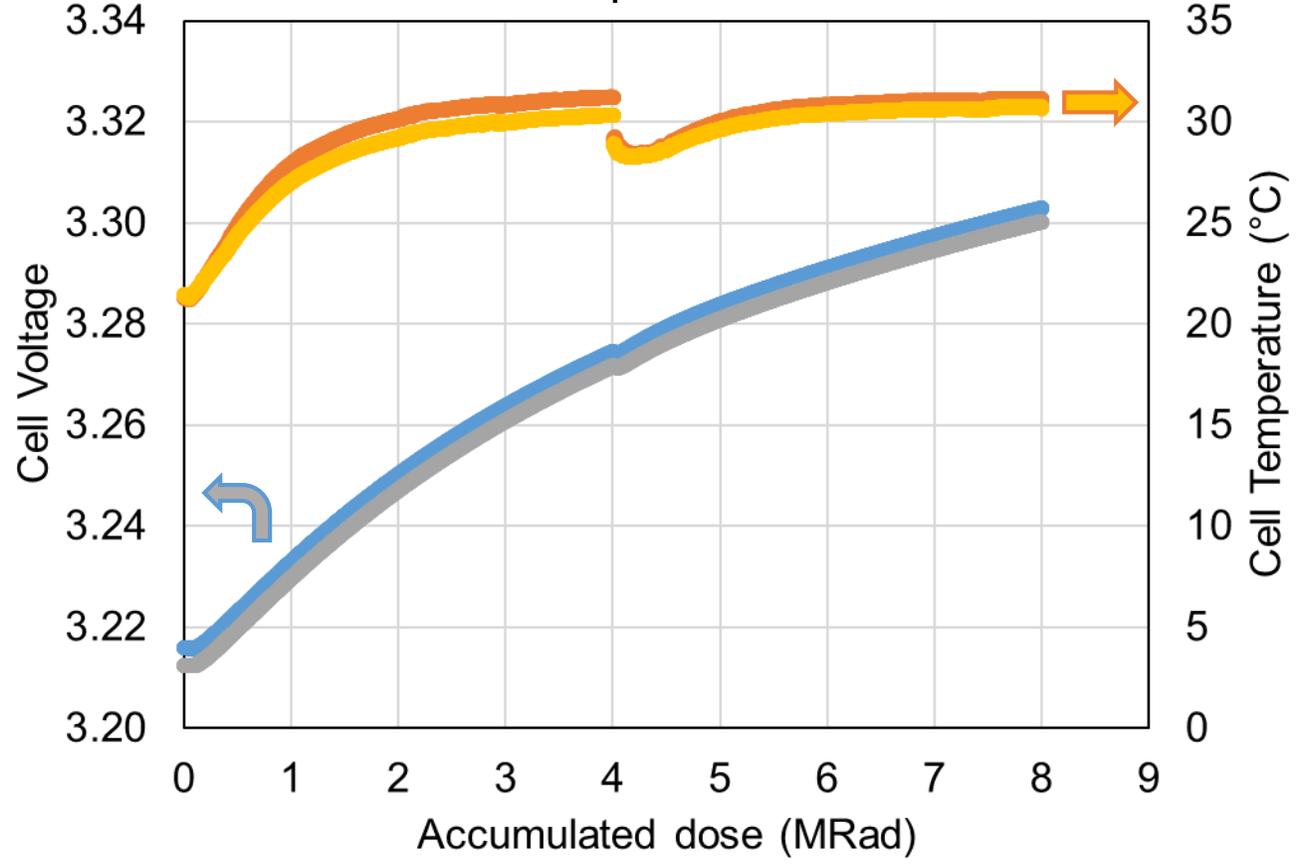


Li/CF_x-MnO₂ cell voltages increase during radiation exposure

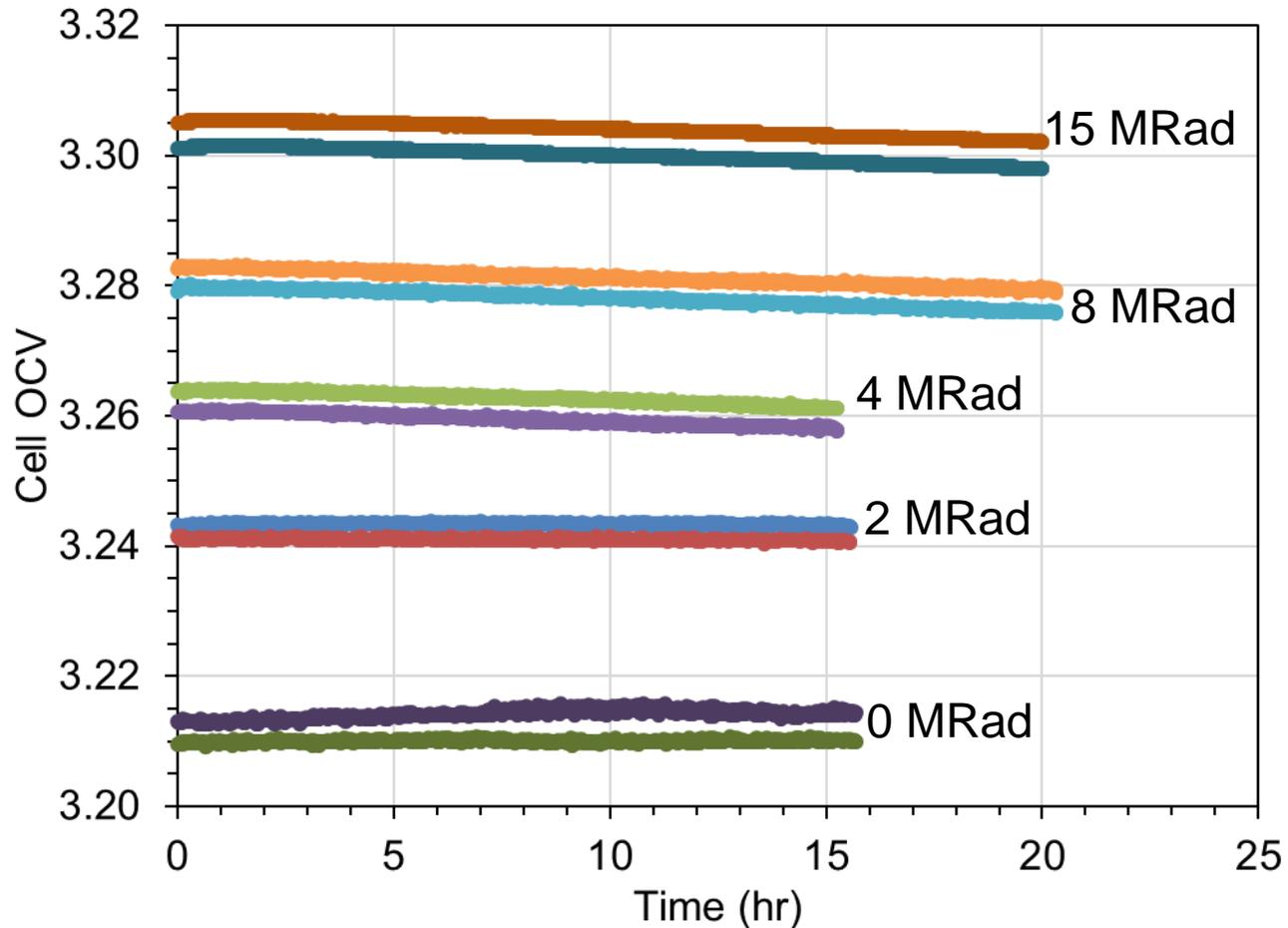
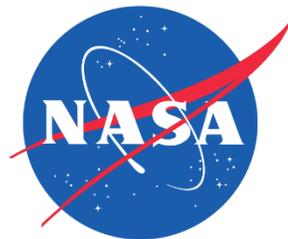
Temperature rise does not correlate with voltage increase in the absence of radiation



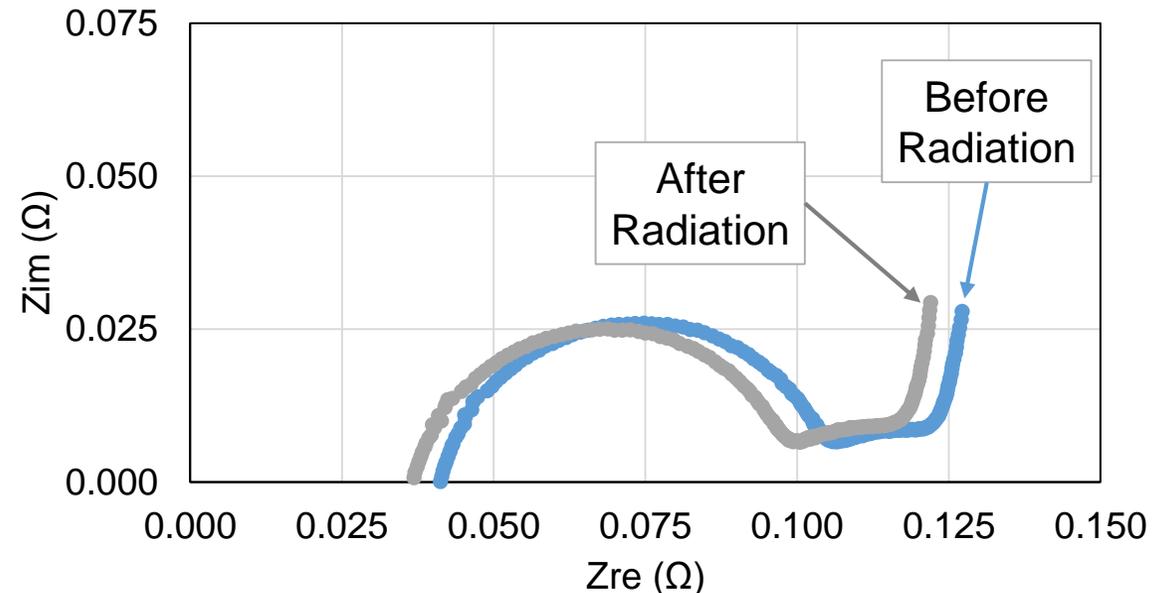
Cells increase by 100 mV and 9 °C over the course of 8 MRad exposure

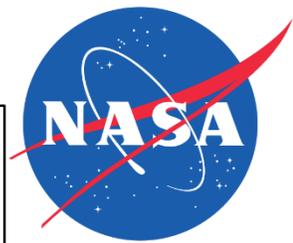


Rest OCV and Impedance Analysis of $\text{Li}/\text{CF}_x\text{-MnO}_2$ Cells



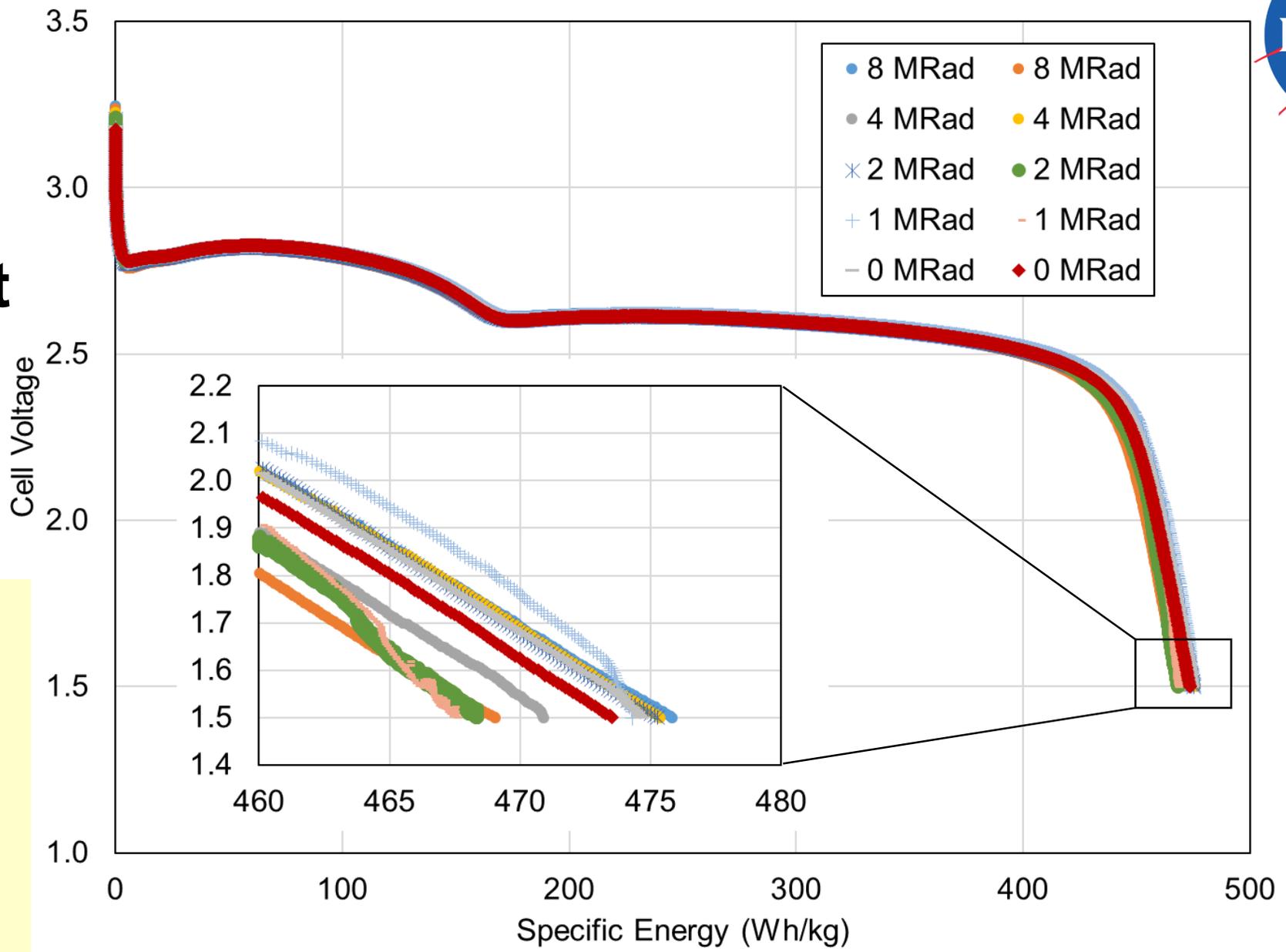
- OCV monitored for >15 hours
- Linear regression analysis shows a slight voltage drop (**0.18 to 0.2 mV/hr**) for higher dose cells (4, 8, 15 MRad)
- No change in impedance after radiation
 - Slight change in x-intercept likely due to connections

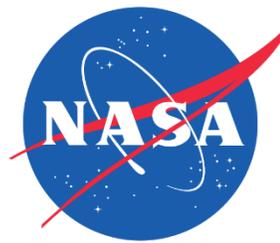




Li/CF_x-MnO₂ Radiation cell discharge performance at 250 mA, 21 °C

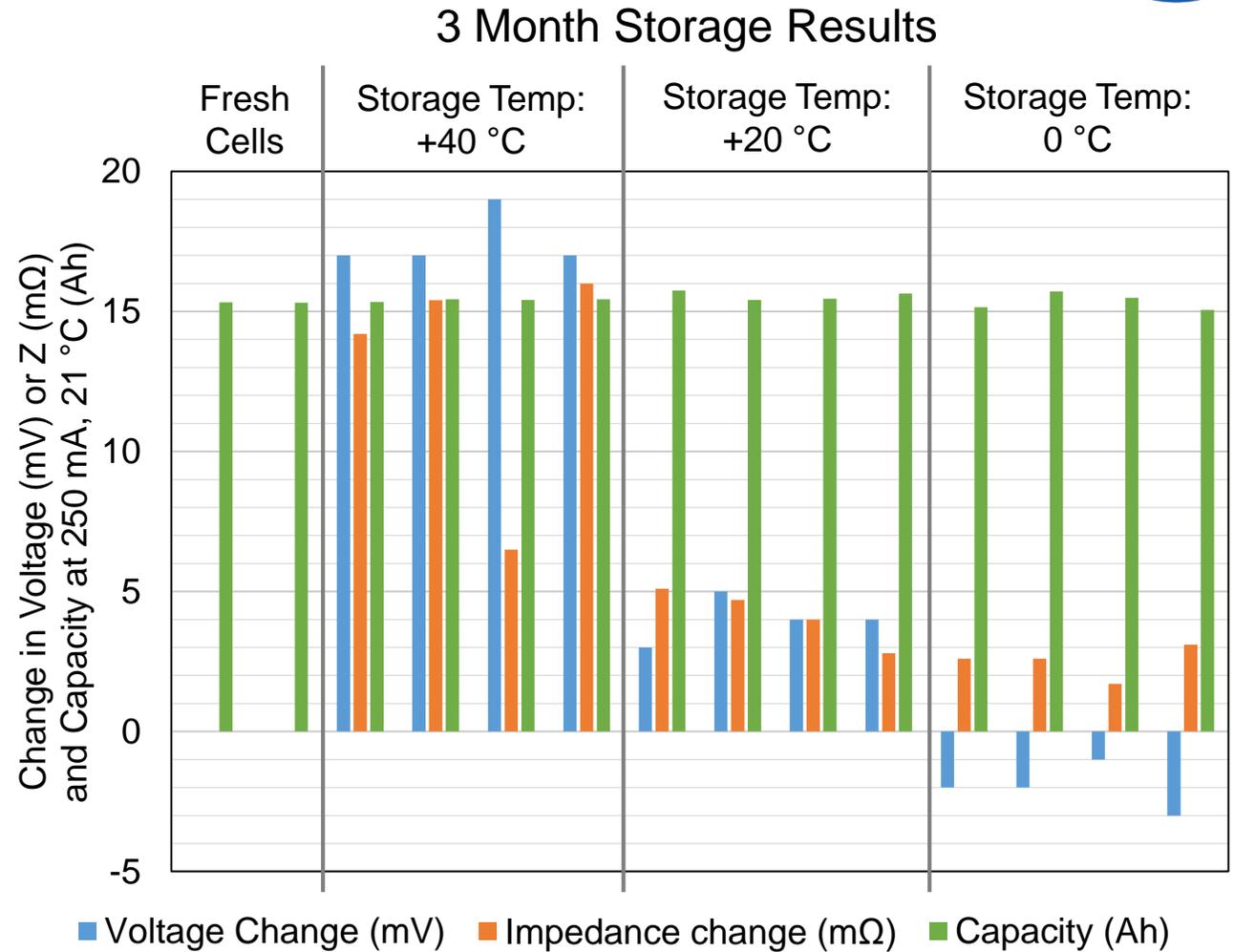
Radiation does not appear to impact beginning of life delivered capacity, but currently assessing impacts on self-discharge



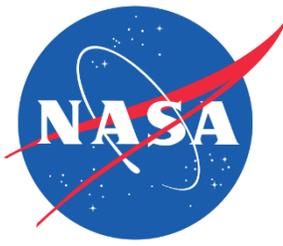


Storage testing Li/CF_x-MnO₂

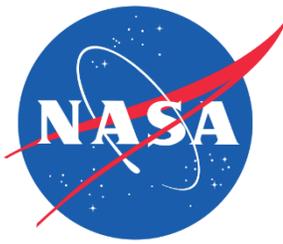
- Storage at 3 temperatures
 - 40 °C
 - 20 °C
 - 0 °C
- Pull cells out after 3 months, then every 6 months for 3 years
- Check impedance and voltage change and discharge cell
- No impact on capacity after 3 months



Summary and Plans



- Moderate specific energy (550 Wh/kg) available from improved Li/CF_x-MnO₂ cells
 - ~50 % higher than heritage Li/SOCl₂ cells
 - Still function at low temperature/high rate
- High dose radiation (up to 10 MRad) does not appear to significantly affect delivered capacity
 - Cell voltage is impacted
 - Impedance is not impacted
 - Evaluating impacts on self-discharge
 - May be useful for planetary protection
- Currently assessing pure Li/CF_x options for improved specific energy



Acknowledgements

The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA), and was supported by the Planetary Science Division.

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