HUBBLE SPACE TELESCOPE PROJECT

HST Dry-Wet Life Studies

Roger Hollandsworth, Jon Armantrout

Lockheed Martin Space Systems Company

Hari Vaidyanathan

Lockheed Martin IS & GS Mission Services

Gopal Rao

NASA-Goddard Space Flight Center

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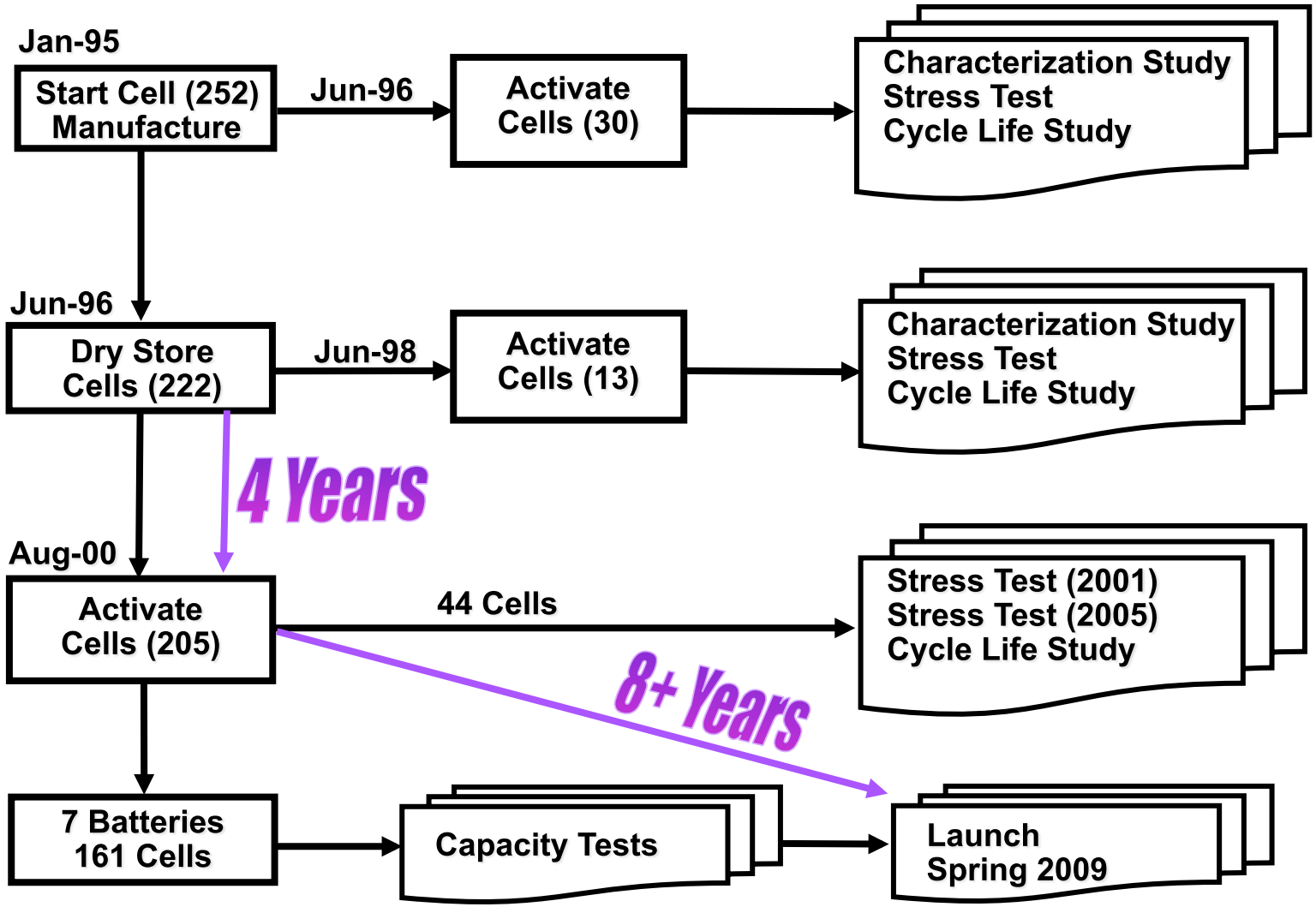
HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

HST SM4 Cell Shelf Life Studies



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Dry Cell

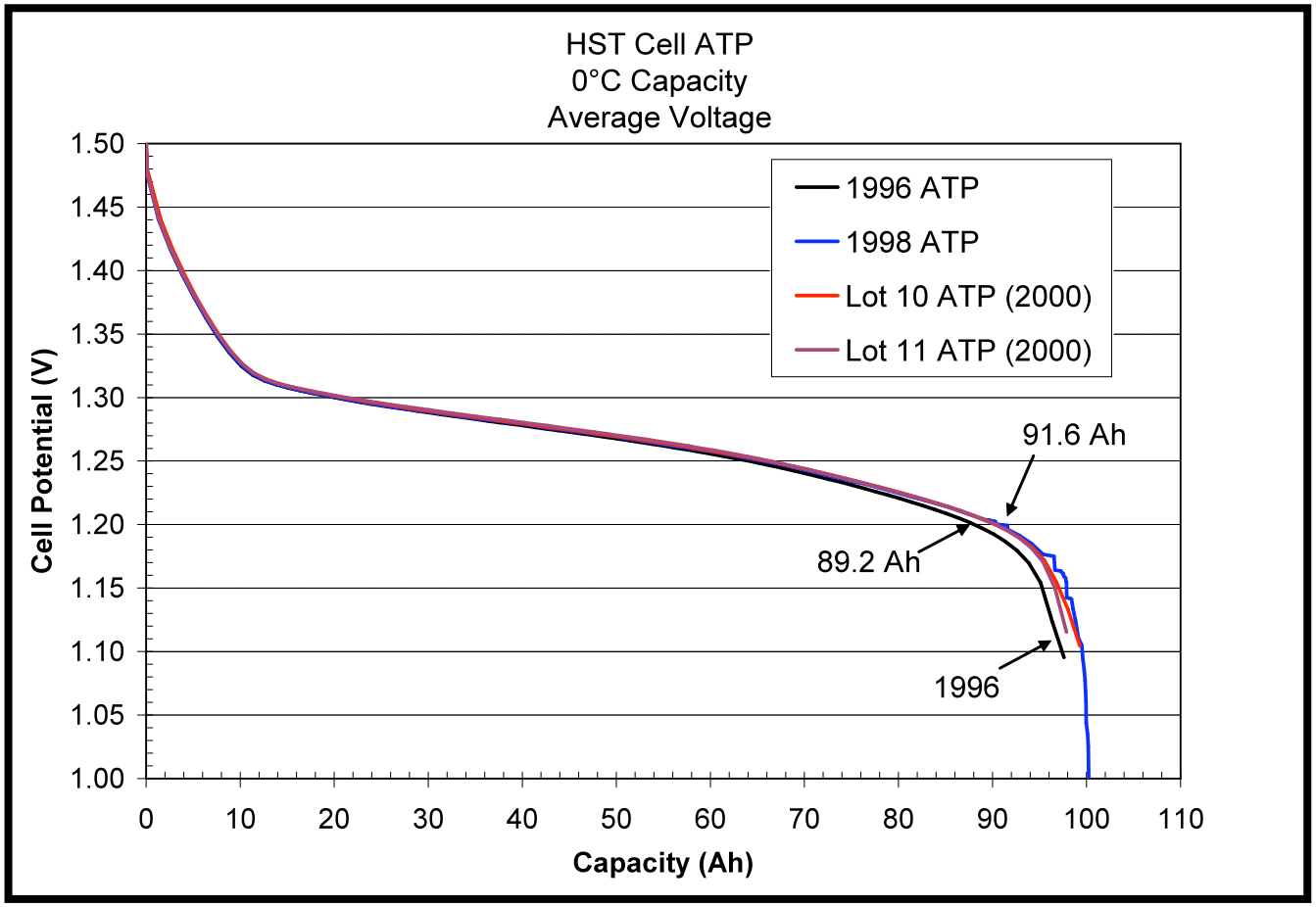
Shelf Life Study

"Effects Of Wet And Dry Storage On Ni-H2 Slurry Electrode Cells", J.D. Armantrout, R.A. Brown, D.V. Gordon and G.M. Rao, IECEC-1999, 1999

"Effects Of Dry Storage On Ni-H2 Slurry Electrode Cells", J. Armantrout & D. Gordon, NASA Aerospace Battery Workshop, Nov. 2000

HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Impact upon Cell ATP Capacity Due To Dry Storage Life



No Serious Impact To Flight Cell Capacity Attributable To 4 Year Dry Storage Observed

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Cell Capacity Characterization Study

Dry Sinter vs. Wet Slurry

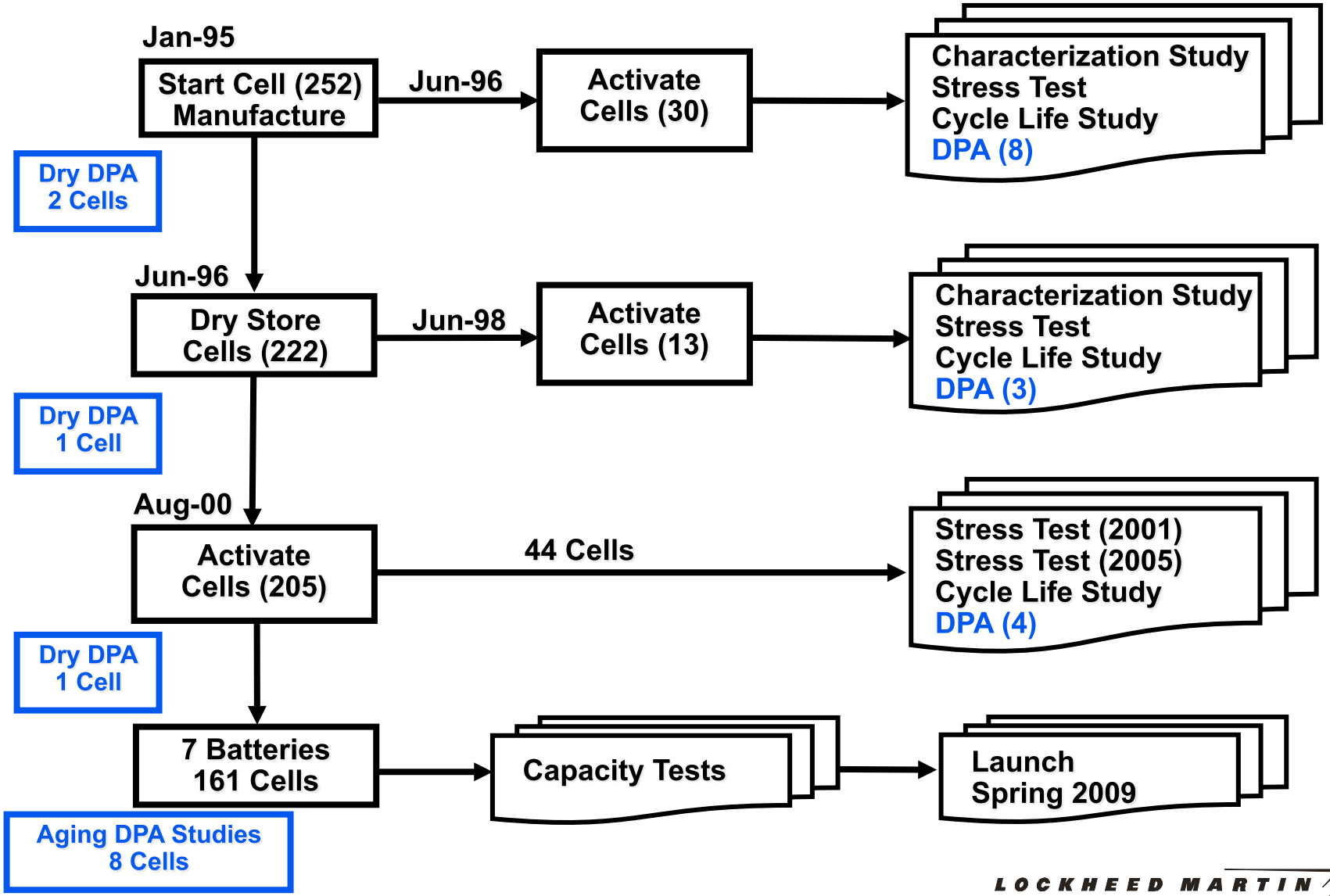
”Voltage *vs.* Temperature Characterization Of Standard 80 Ah Eagle-Picher Ni-H2 Cells”, G.M. Rao, J.D. Armantrout, D.P Hafen, and R.A. Brown, 1990 IECEC

“Performance Characterization of An 80 Ah Nickel-Hydrogen Cell”, D.P Hafen and J.D. Armantrout, 1993 IECEC, Paper 93117

“Performance Comparison Between Ni-H2 Dry Sinter And Slurry Electrode Cells”, J.D. Armantrout, NASA Aerospace Battery Workshop, Nov. 1997

HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

HST SM4 Cell Shelf Life Studies



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HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Wet DPA Electrochemical Capacity Results

CELL ID	History	Act. Date	DPA Date	Dry Store Life (Yrs)	Wet Store Life (Yrs)	CELL CAPACITY Actual 10 °C Ah to 1.0V	CELL CAPACITY 2nd Plateau Ah	CELL CAPACITY 2nd Plateau %	CELL CAPACITY Theoretical* Ah	CELL CAPACITY Actual 20 °C Ah to 1.0 V
10-537	Stress-Verif	Jun-96	Aug-97	0	1.17	90.8	0.8	0.9		
10-538	Stress-Verif	Jun-96	Aug-97	0	1.17	90.3				
10-564	Cell ATP	Jun-96	Aug-97	0	1.17	92.5	1.0	1.1		
10-572	Cell ATP	Jun-96	Aug-97	0	1.17	90.8	0.3	0.3		
10-599	Cell ATP	Jun-96	Aug-97	0	1.17	89.8	0.5	0.6	74.5	79.6
11-625	Cell ATP	Jun-96	Aug-97	0	1.17	90.8	0.6	0.7		
11-692	Cell ATP	Jun-96	Aug-97	0	1.17	92.1	0.8	0.9		
11-749	Cell ATP	Jun-96	Aug-97	0	1.17	92.9	0.6	0.6		
11-755	Cell ATP	Jun-96	Aug-97	0	1.17	92.1	0.8	0.9		
11-757	Cell ATP	Jun-96	Aug-97	0	1.17	91.6	0.4	0.4	74.9	81.5
10-515	Cell ATP	May-98	Jan-99	2	0.67	84.2	4.5	5.3	76.4	75.3
10-516	Stress	May-98	Jan-99	2	0.67	91.6	0.8	0.9		
11-744	Cell ATP	May-98	Jan-99	2	0.67	93.5	0.6	0.6		
11-754	Cell ATP	May-98	Jan-99	2	0.67	84.5	3.9	4.6		
10-511	Cell ATP	May-98	Jun-00	2	2.09	93.4	4.9	5.2	70.1	81.0
10-512	Stress -500 Cycles	May-98	Jun-00	2	2.09	93.0	6.3	6.8		
10-621	Cell ATP	Aug-00	May-01	4	0.77	85.0	0.8	0.9	75.0	73.2
11-740	Cell ATP	Aug-00	May-01	4	0.77	89.3	3.1	3.5	73.2	83.1
10-583	Cell ATP	Aug-00	Oct-05	4	5.22	92.3	7.7	8.3	77.2	76.8
11-643	Cell ATP	Aug-00	Oct-05	4	5.22	91.6	7.3	8.0	79.6	75.9
10-605	Cell ATP	Aug-00	Oct-07	4	7.2	94.7	5.8	6.1	74.6	82.4
11-718	Cell ATP	Aug-00	Oct-07	4	7.2	95.1	6.0	6.3		82.5
RNH 90-9 Lot 3										
3-142	S/N 1042	Mar-97	Aug-06	0	9.42	102.5	2.3	2.2	77.5	92.3
3-172	S/N 1042	Mar-97	Aug-06	0	9.42	98.8	0.7	0.7	77.6	87.0
3-102	S/N 1042	Mar-97	Oct-07	0	10.6	103.3	1.2	1.2	86.9	91.5
3-165	S/N 1042	Mar-97	Oct-07	0	10.6	102	1.1	1.1		90.3

Large Number of DPA Cells Spanning 1997 to 2007

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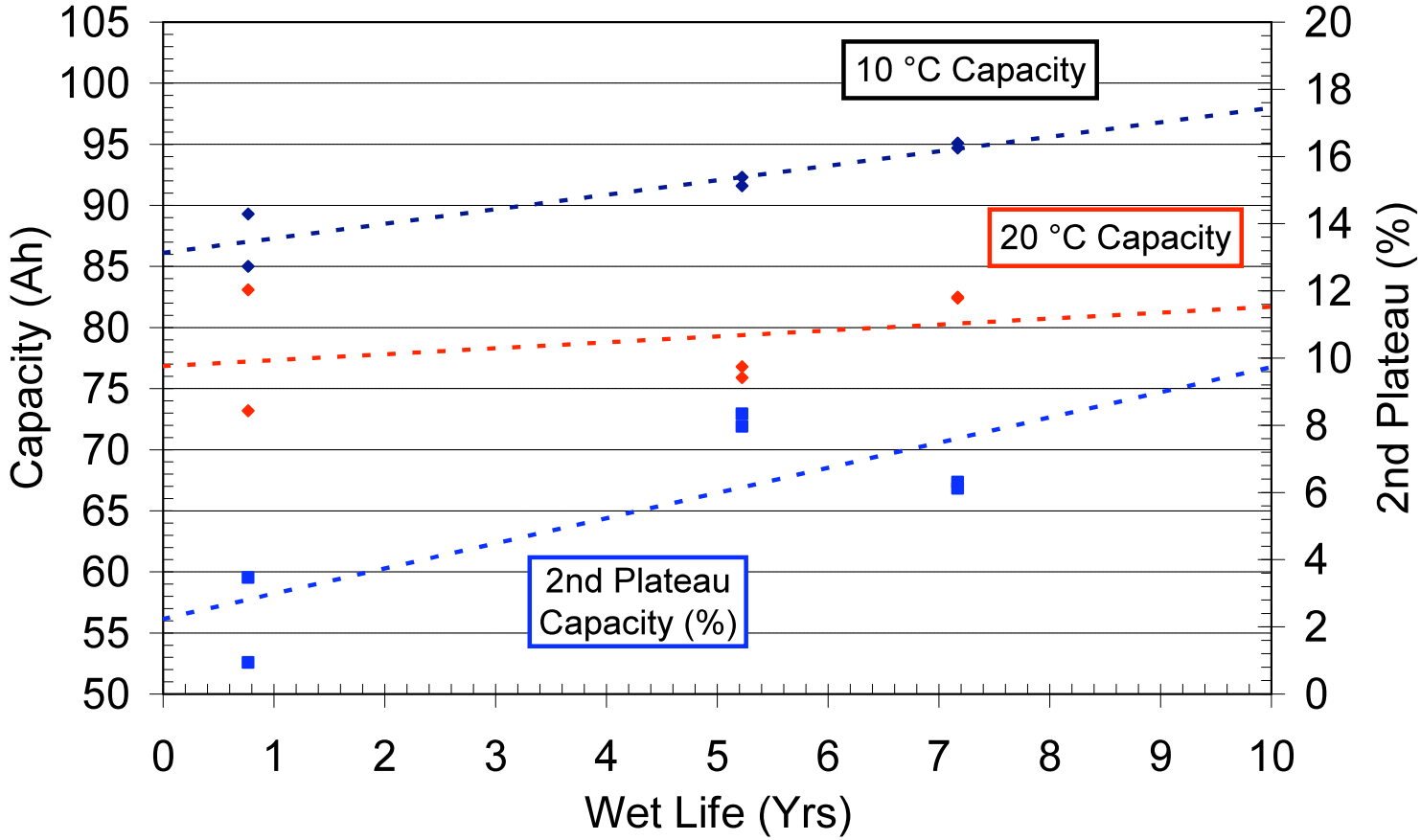
SM-4 Battery Shelf Life Study

Wet DPA Cell Analysis
Electrochemical Capacity Trending



10 °C Capacity increases with Wet Life
2nd Plateau Capacity Increases with Wet Life

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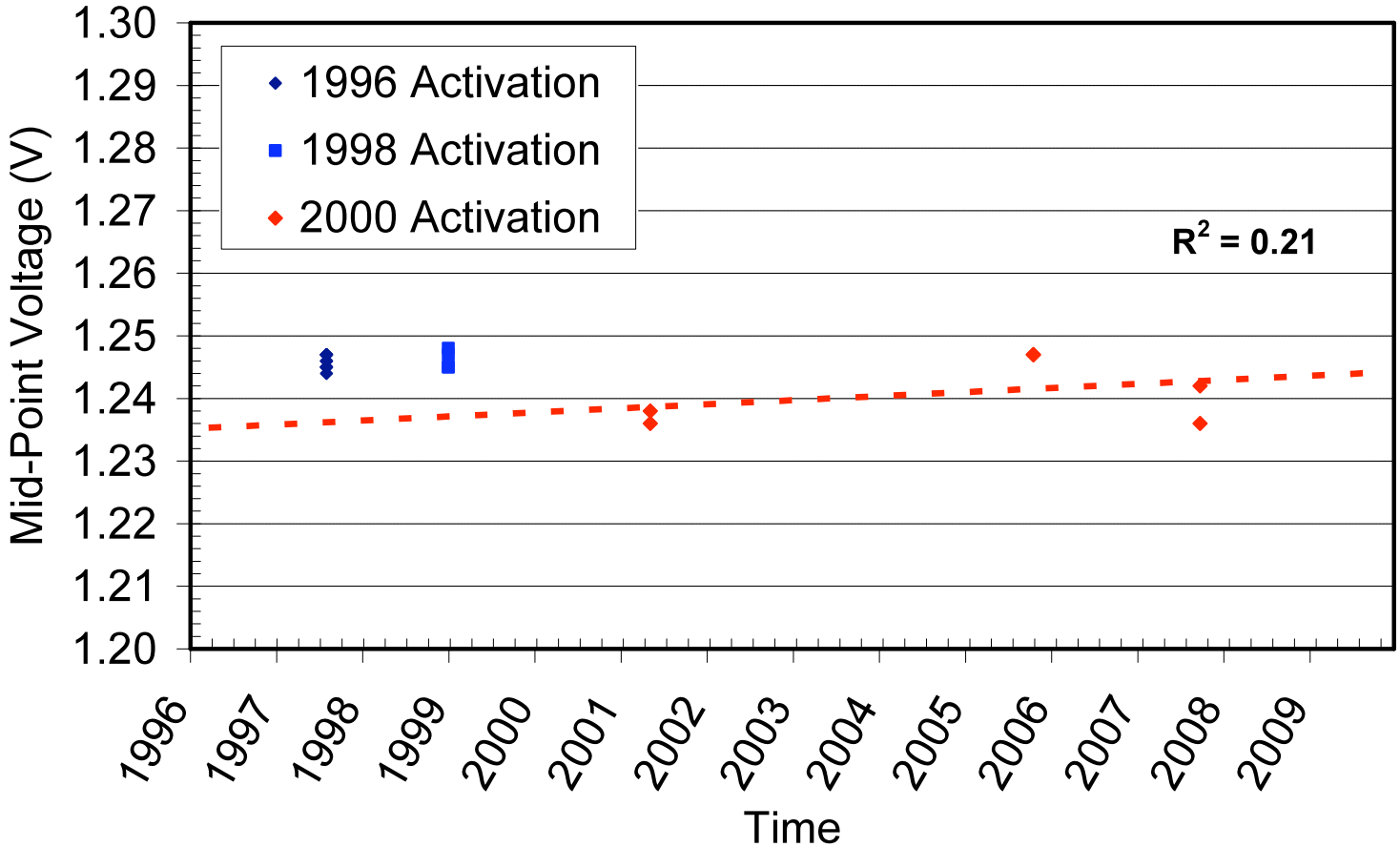
SM-4 Battery Shelf Life Study

Wet DPA Electrochemical Test
Mid-Point Discharge (Ni Plaque)



Mid-Point Discharge Voltage – Minor Wet Life Impact

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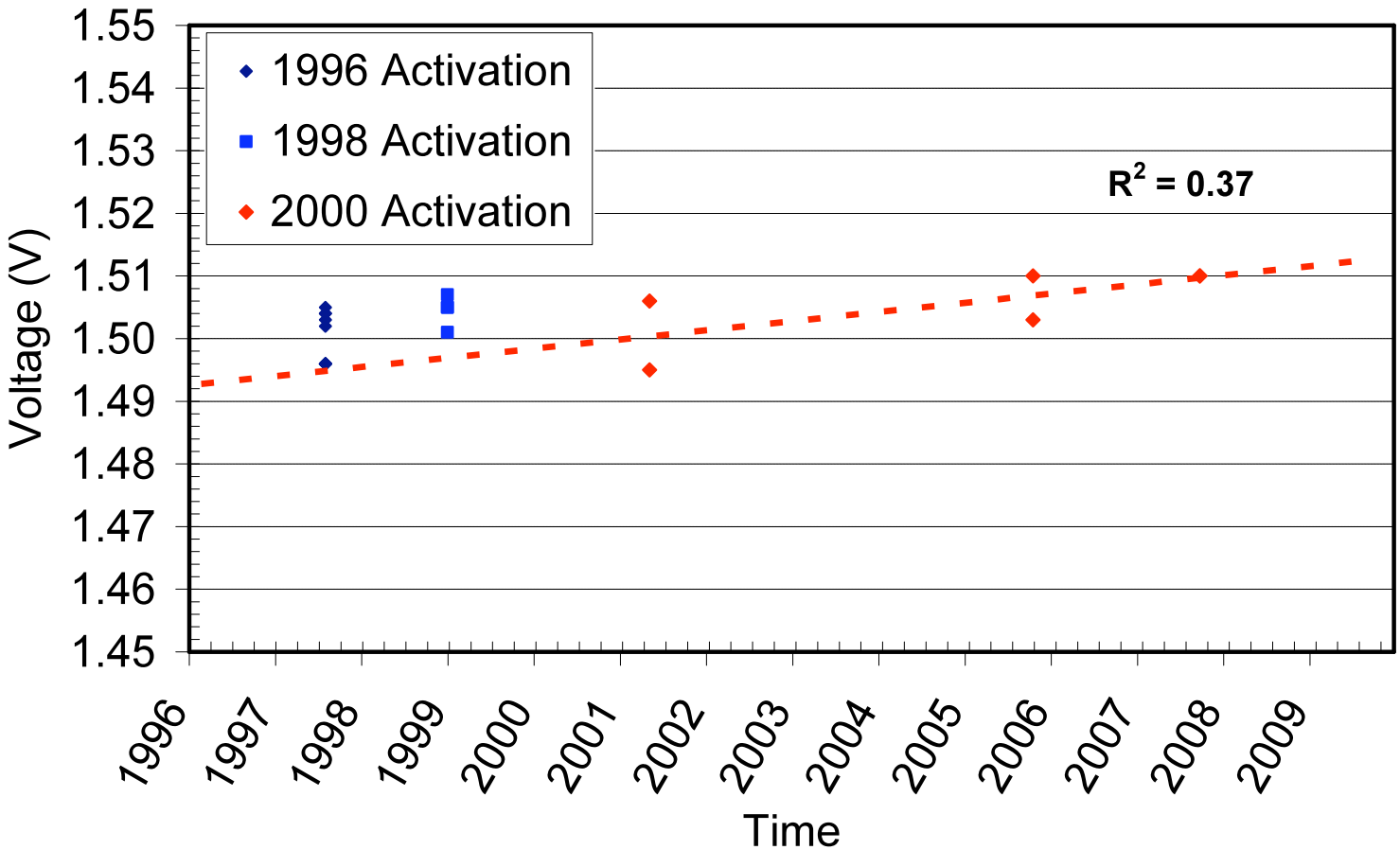
SM-4 Battery Shelf Life Study

Wet DPA Electrochemical Test
End-of-Charge Voltage



End of Charge Voltage Has Slight Impact With Wet life

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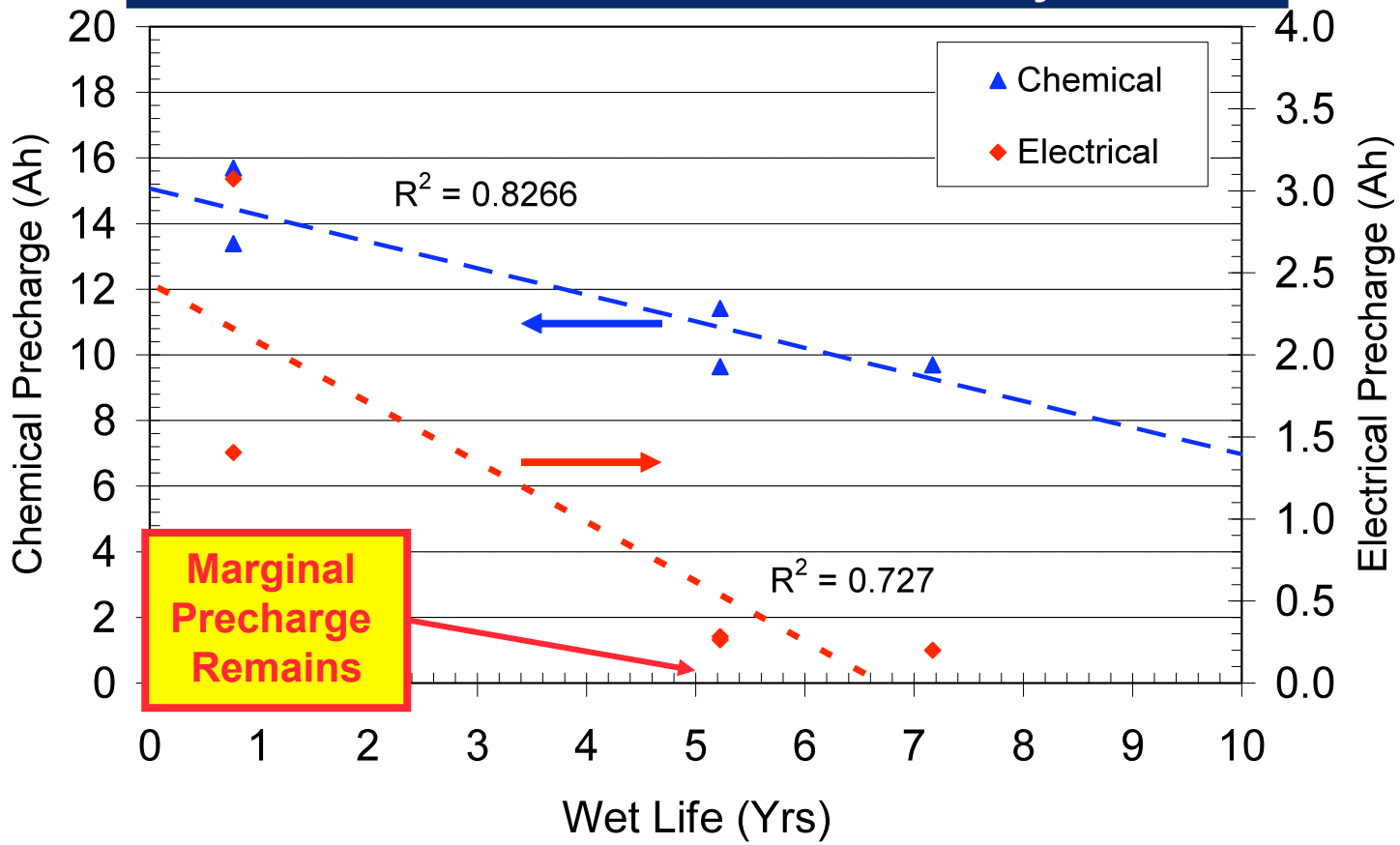
SM-4 Battery Shelf Life Study

Wet DPA Nickel precharge Analysis
Chemical vs. Electrical Plate Analysis



Precharge Capacity Loss with Wet Life
Electrical Precharge Loss Most Significant

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SM-4 Battery Shelf Life Study

DPA Observations of Cell Components

S/N	HISTORY	Activation Date	Test Date	POSITIVE Plates (Nickel Plaque)	NEGATIVE Plates (Hydrogen Electrode)	SEPARATORS	SCREENS
S/N 10-599	ATP	Jun-96	Aug-97	Some Blistering; One Burn Mark	One Burn Marks; Slight Pinholes; Fraying Of Platinum Common	Slightly Dirty; Two Burn Marks	Wet
S/N 10-515	ATP	May-98	Jan-99	Minimal Blisters (Several Large): Green Material On Tab	Wet; 2 Burn Marks; Slight Pinholes; Fraying Of Platinum Common	Slightly Dirty; One Burn Mark	Wet
S/N 10-511	ATP	May-98	Jun-00	Some Blistering; One Burn Mark	Minimal Pinholes; Fraying Of Platinum Common	Slightly Dirty; Minor Burn Marks	Wet: Slight Dirt
S/N 11-740	ATP	Aug-00	May-01	No Blistering; Green Material On Tabs	3 Burn Marks; Fraying Of Platinum Extensive	Minimally Dirty; Green Stain: Some Platinum	Slightly Wet
S/N 10-583	ATP	Aug-00	Oct-05	Minor Blistering; Platinum Particles On One; Green Material	3 Burn Marks; Minimal Pinholes; Fraying Of Platinum Extensive:	Compression Slightly Dirty; Green Staining	Wet
S/N 10-605	ATP	Aug-00	Jul-07	Some Blistering; Several Have Rough Surfaces; One Plate Coined Are Bent	No Burn Marks; Only One Plate With Pinholes; Fraying Of Platinum Extensive	Slightly Dirty; Green Staining; Some Platinum	Wet But Generally Few Drops; Two Dirty
RNH 90-9 Lockheed Cells							
S/N 3-142	ATP 6X mini ATP	Mar-97	Aug-06	Extensive Blistering	4 Burn Marks; Slight Pinholes	Slightly Dirty; One Has Platinum	Wet: Burn Mark At Core
S/N 3-172	ATP 6X mini ATP	Mar-97	Aug-06	Extensive Blistering	1 Burn Mark; Slight Pinholes	Slightly Dirty	Wet
S/N 3-102	ATP	Mar-97	Jul-07	Extensive Blistering	2 With Pinholes, 1 Burn Mark; One Shows Compression; One Has Loose Pt	Slightly Dirty; Several Surfaces Torn By Blister On Adj. Pos.	Wet, One Burn Mark

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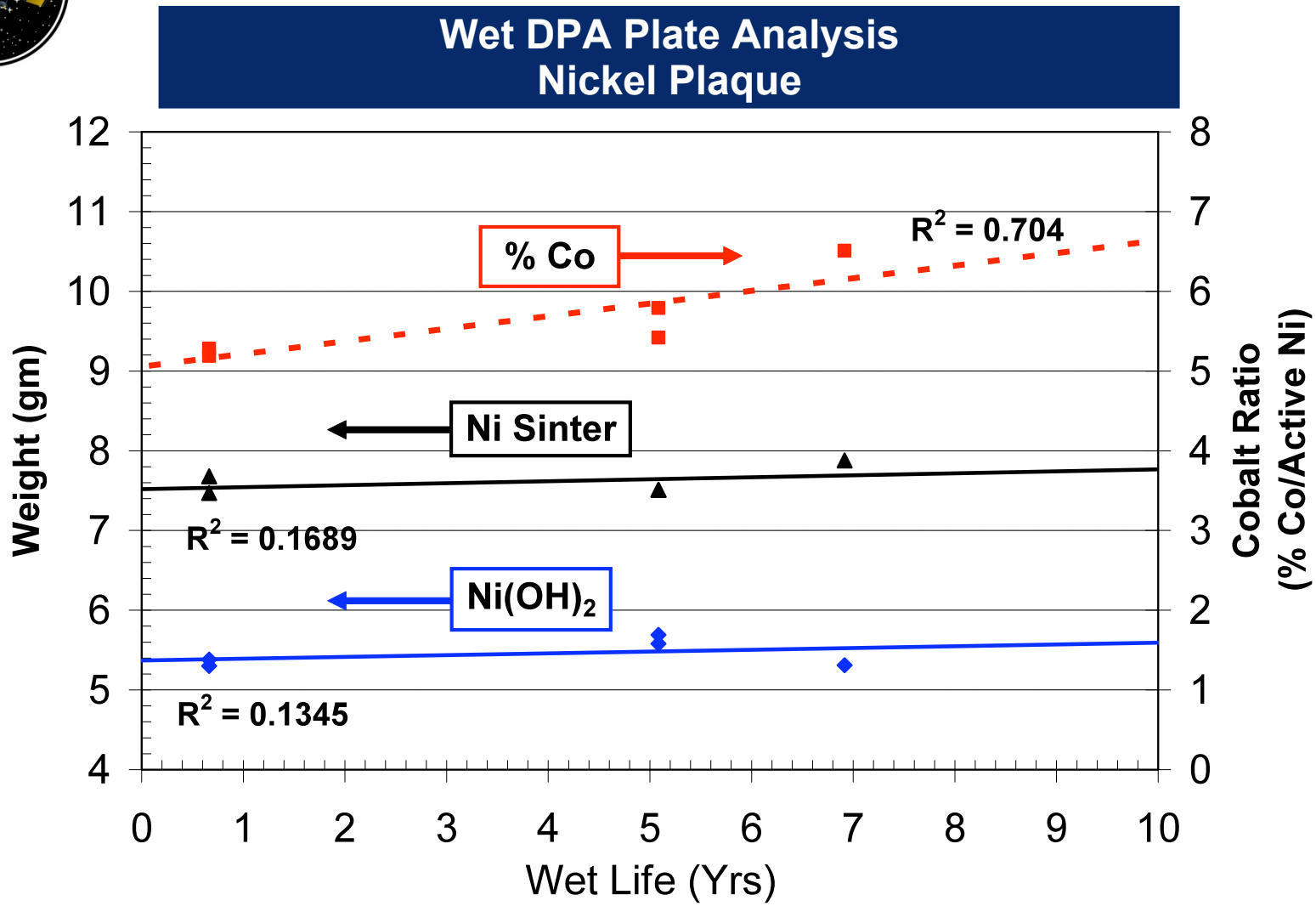
SM-4 Battery Shelf Life Study



Cobalt to Active Nickel Ratio Increases with Wet Life

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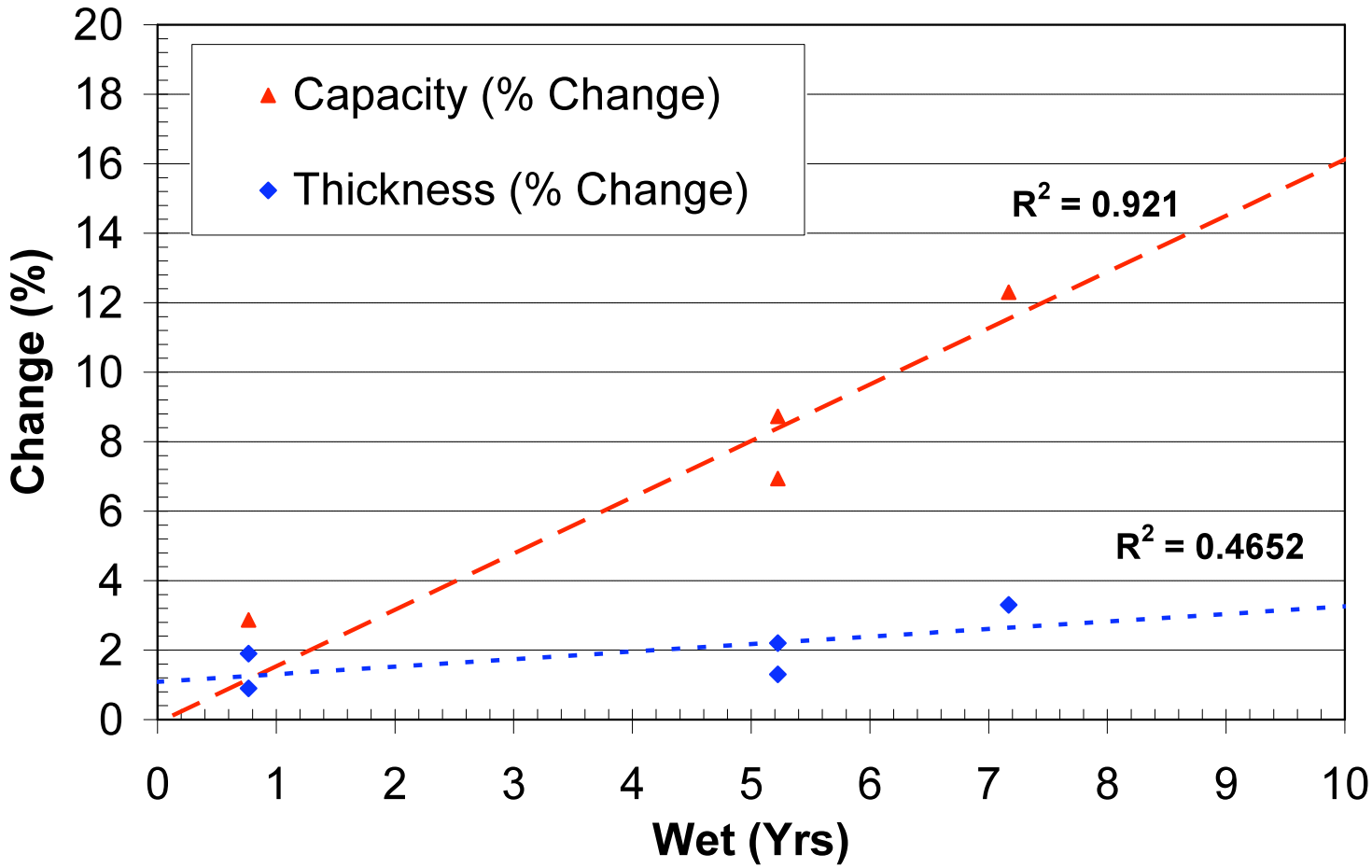
SM-4 Battery Shelf Life Study

Wet DPA Plate Stress Analysis
Plaque Physical Dimensions



Plaque Capacity & Thickness Increase with Wet Life

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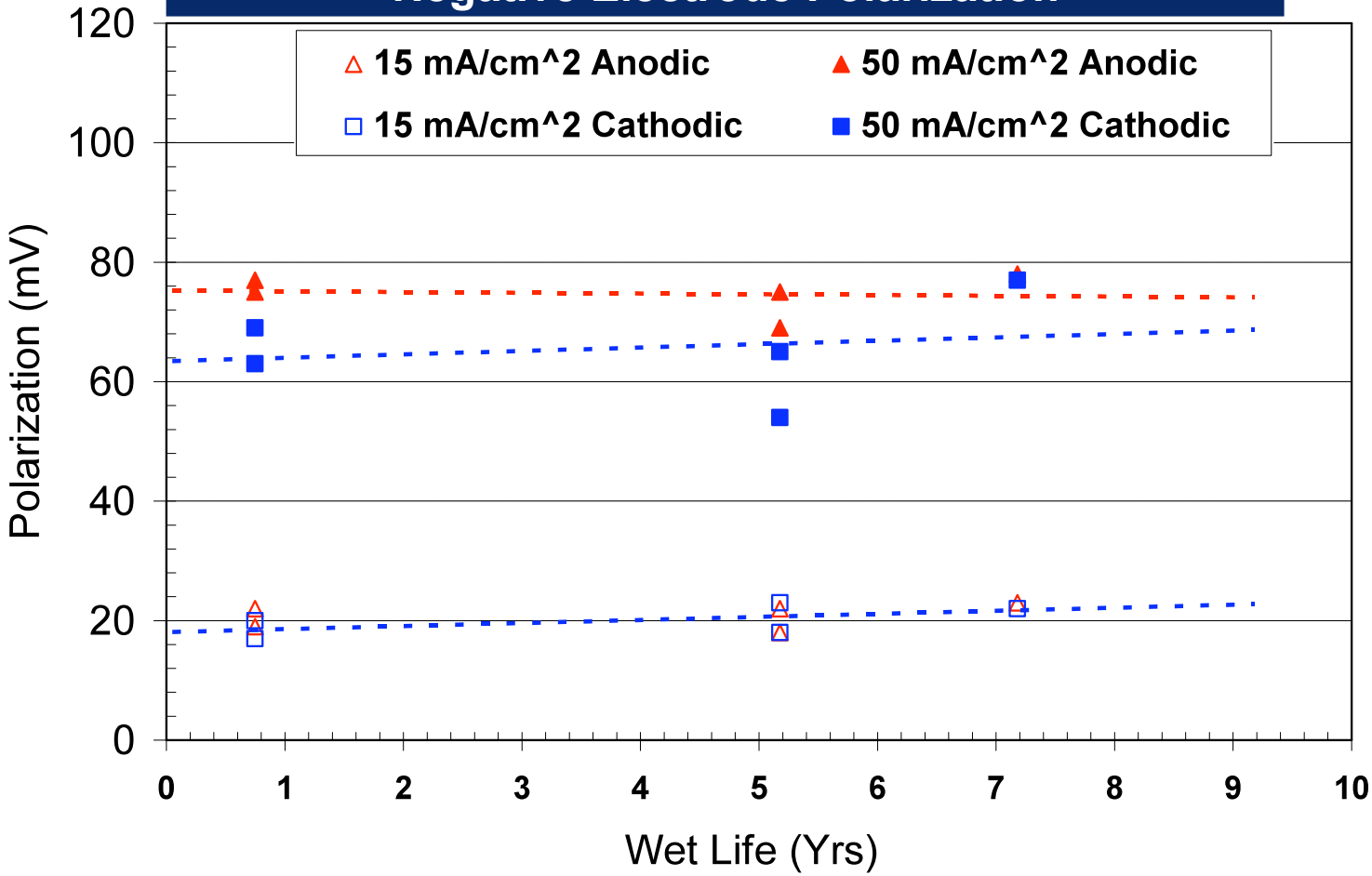
SM-4 Battery Shelf Life Study

Wet DPA Plate Stress Analysis
Negative Electrode Polarization



Hydrogen Electrode Not Impacted By Wet life

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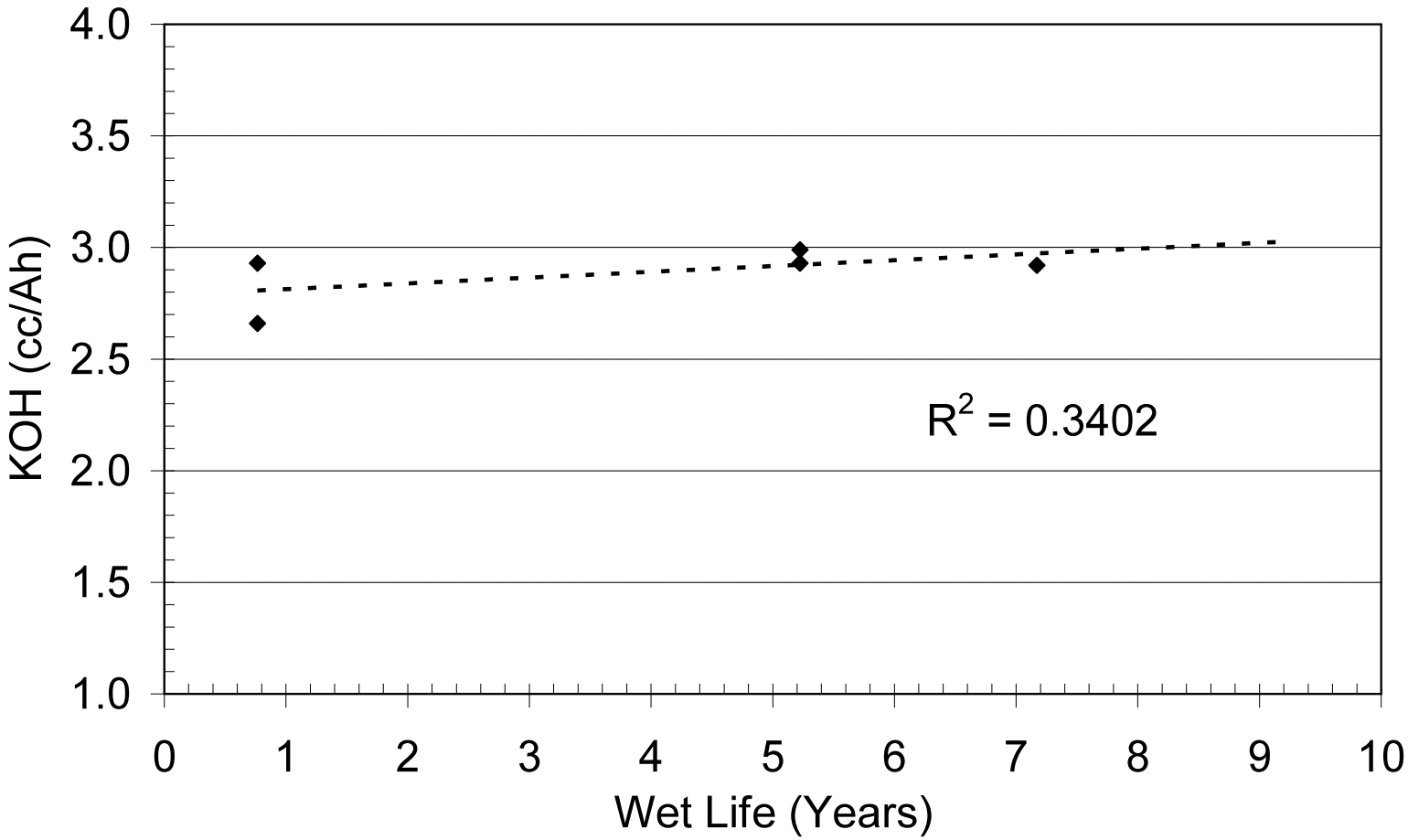
SM-4 Battery Shelf Life Study

Wet DPA Stack Analysis
Electrolyte Concentration



Electrolyte Concentration Within Stack Increases

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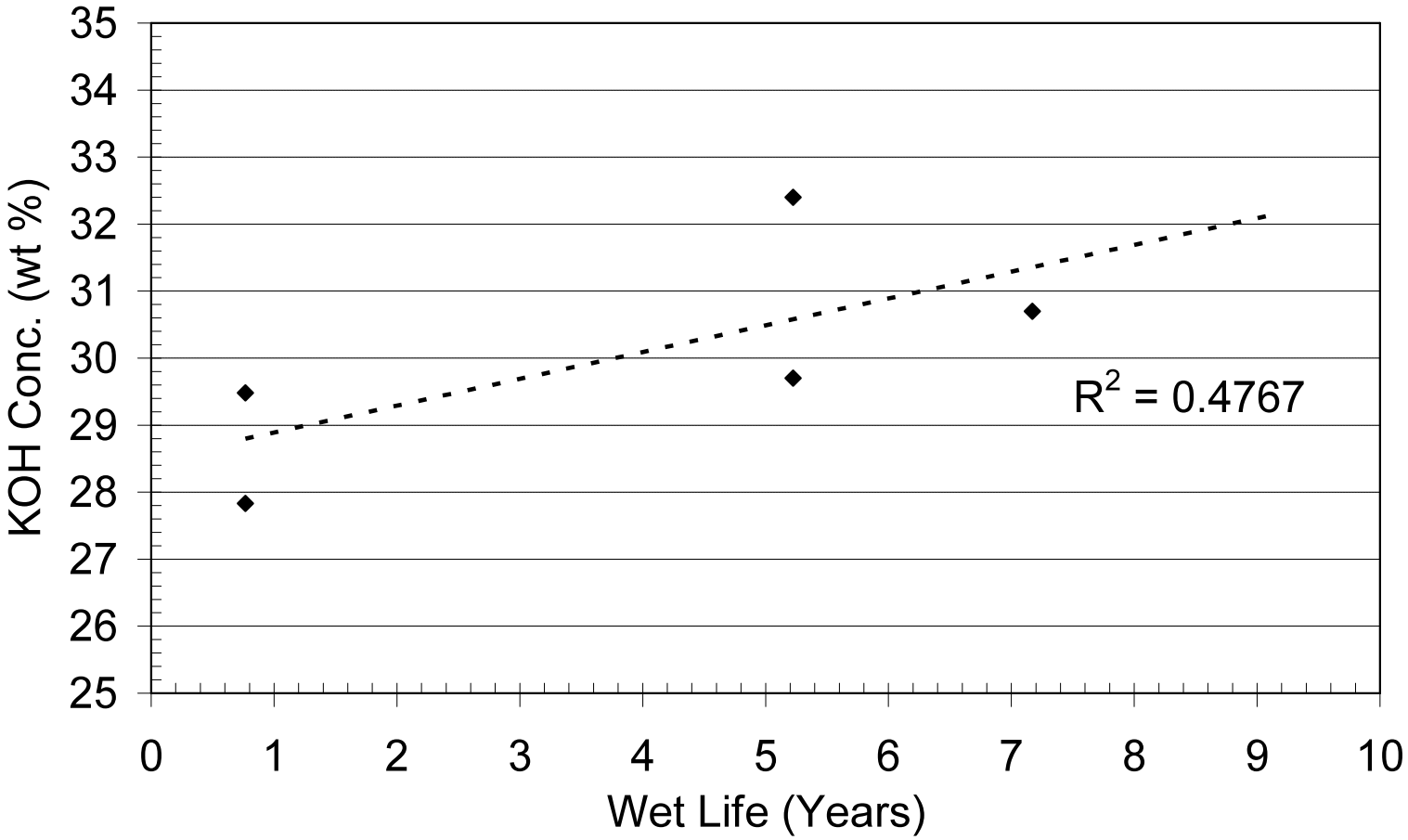
SM-4 Battery Shelf Life Study

Wet DPA Plate Analysis
Separator Electrolyte Absorption



Electrolyte Concentration in Separator Increases

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Nickel Precharge Reversal Test

"Reversal as a Tool For Assessing Precharge of Nickel Hydrogen Cells", J. Brill & R. Smith, NASA Aerospace Battery Workshop, 1998, p. 559

"Storage of Activated Nickel-Hydrogen Cells and Batteries", A. Zimmerman, Aerospace Report TR-2002(8555)-9, Oct 10, 2002

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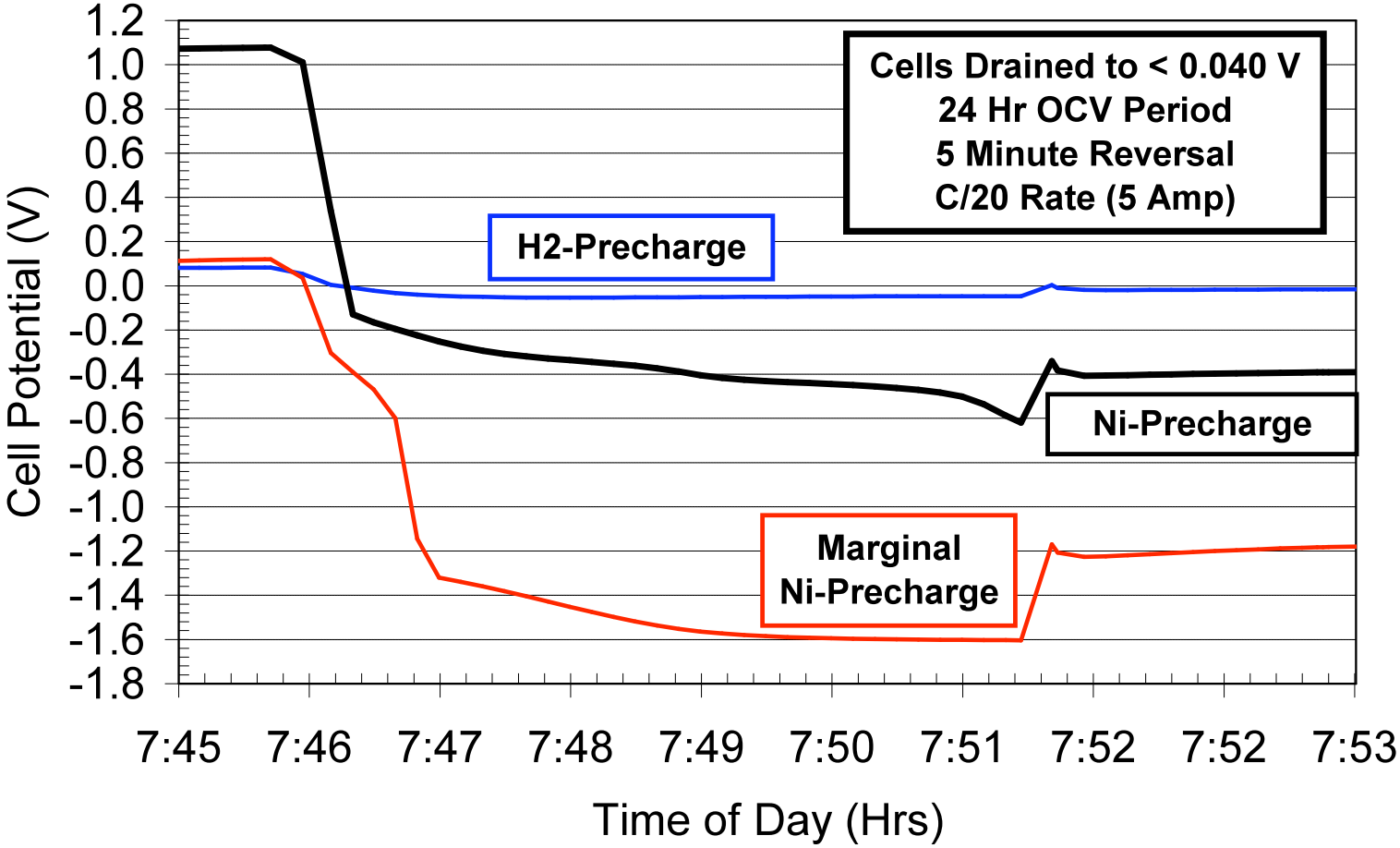
SM-4 Battery Shelf Life Study

Electrochemical Nickel Precharge Reversal Signatures



Typical Cell Reversal Voltage Signatures

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SM-4 Battery Shelf Life Study

Wet DPA Electrochemical Analysis
Nickel Precharge Reversal Test

	Act.	DPA	Wet	Reversal Voltage (V)			Precharge (Ah)	
	Date	Date	Yrs	0.5 min	2.5 min	5 min	Electric	Chemical
HST 10/11								
S/N 10-515	May-98	Jun-99	1.1				1.4	11.8
S/N 10-511	May-98	Jun-00	2.1				0	7.9
S/N 10-621	Aug-00	May-01	7.7	-0.185	-0.298	-0.332	3.1	13.4
S/N 11-740	Aug-00	May-01	7.7	-0.125	-0.268	-0.329	1.4	15.7
S/N 10-583	Aug-00	Oct-05	8.2	-0.10	-0.42	-0.56	0.3	8.6
S/N 11-643	Aug-00	Oct-05	8.2	-0.06	-0.43	-0.56	0.3	11.4
S/N 10-605	Aug-00	Jul-07	7.9	-0.20	**-1.42**	**-1.52**	0.2	9.7
S/N 11-718	Aug-00	Jul-07	7.9	-0.20	**-1.40**	**-1.51**		
LM 90-9								
S/N 3-142	Mar-97	Aug-06	11.4	-0.11	-0.26	-0.39	0.5	11.5
S/N 3-172	Mar-97	Aug-06	11.4	-0.08	-0.23	-0.35	1.7	15.7
S/N 3-102	Mar-97	Jul-07	11.4	-0.01	-0.30	-0.38	0.5	8.3
S/N 3-165	Mar-97	Jul-07	11.4	-0.01	-0.29	-0.36		

HST SM4 Flight Battery Cells Probably Have Marginal Nickel Precharge – Handle With Care !

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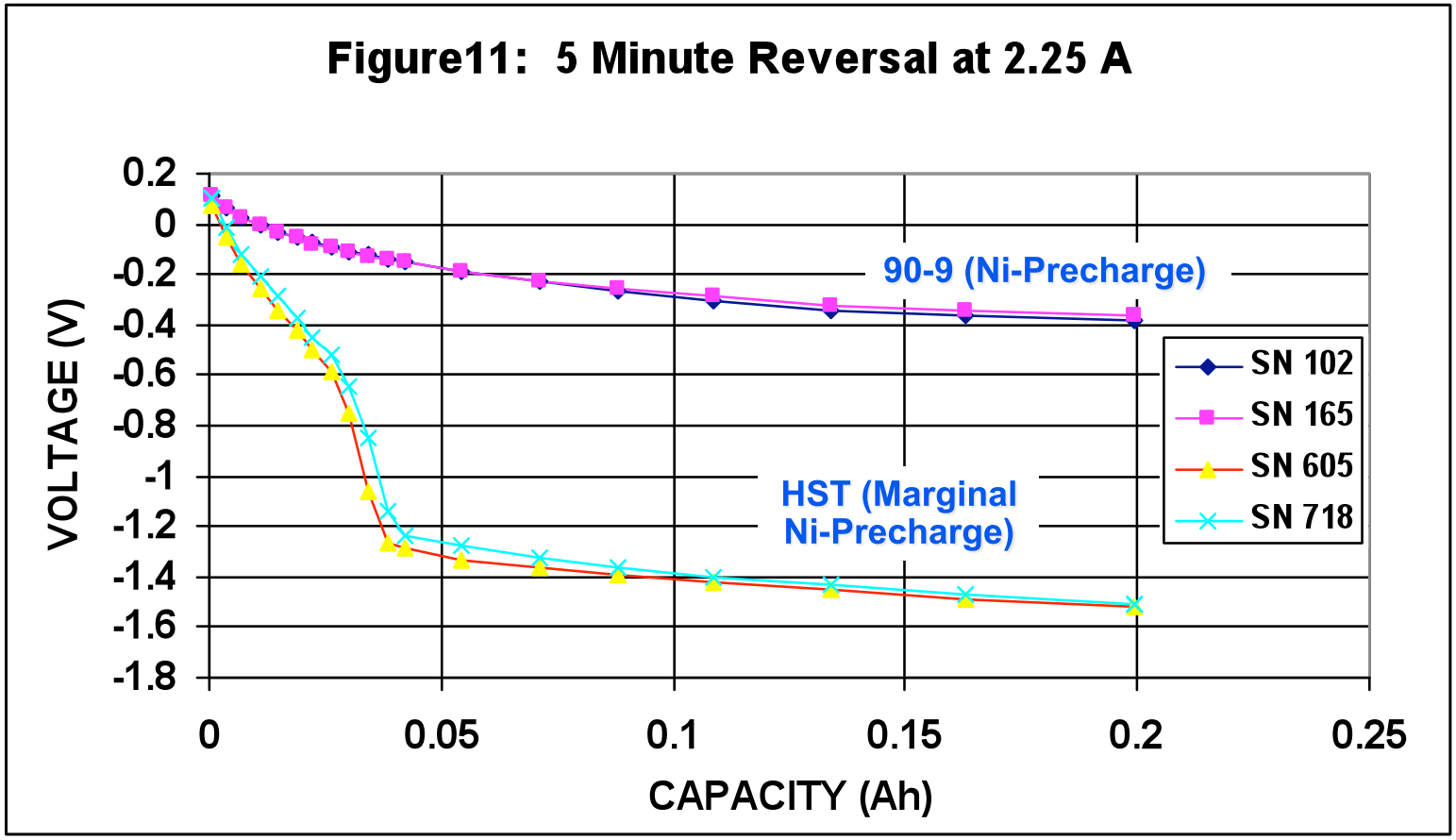
SM-4 Battery Shelf Life Study

Electrochemical Nickel Precharge
HST Cells vs. 90-9 Cells



HST Cells Exhibit Marginal Precharge Reversal Signature
90-9 Cells Have Normal Ni-Precharge Signature

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SM-4 Battery Shelf Life Study

Aerospace Corp. Gas Analysis (2007)

Gas Analysis	S/N 11-718	S/N 3-165
Chamber Volume (cc)	1422.84	1422.75
Cell Volume (cc)	708.71	643.46
Cell Pressure (psia)	**0.78**	**1.36**

	Pressure (%)	Pressure (%)
Hydrogen	**2.00**	**0.02**
Helium	0.04	0.01
Methane	0.40	0.04
Water	52.00	0.40
Nitrogen	41.00	73.00
Oxygen	**3.60**	**25.00**
Argon	8.97	1.10
Carbon Dioxide	0.21	0.03
Wet Life (Yrs)	**7.2**	**10.6**

11-718 (HST) O_2/H_2 Analysis ➔ Marginal Ni-Precharge (0.005%)
S/N 3-165 (LM) Cell O_2 Analysis ➔ Ni-Precharge

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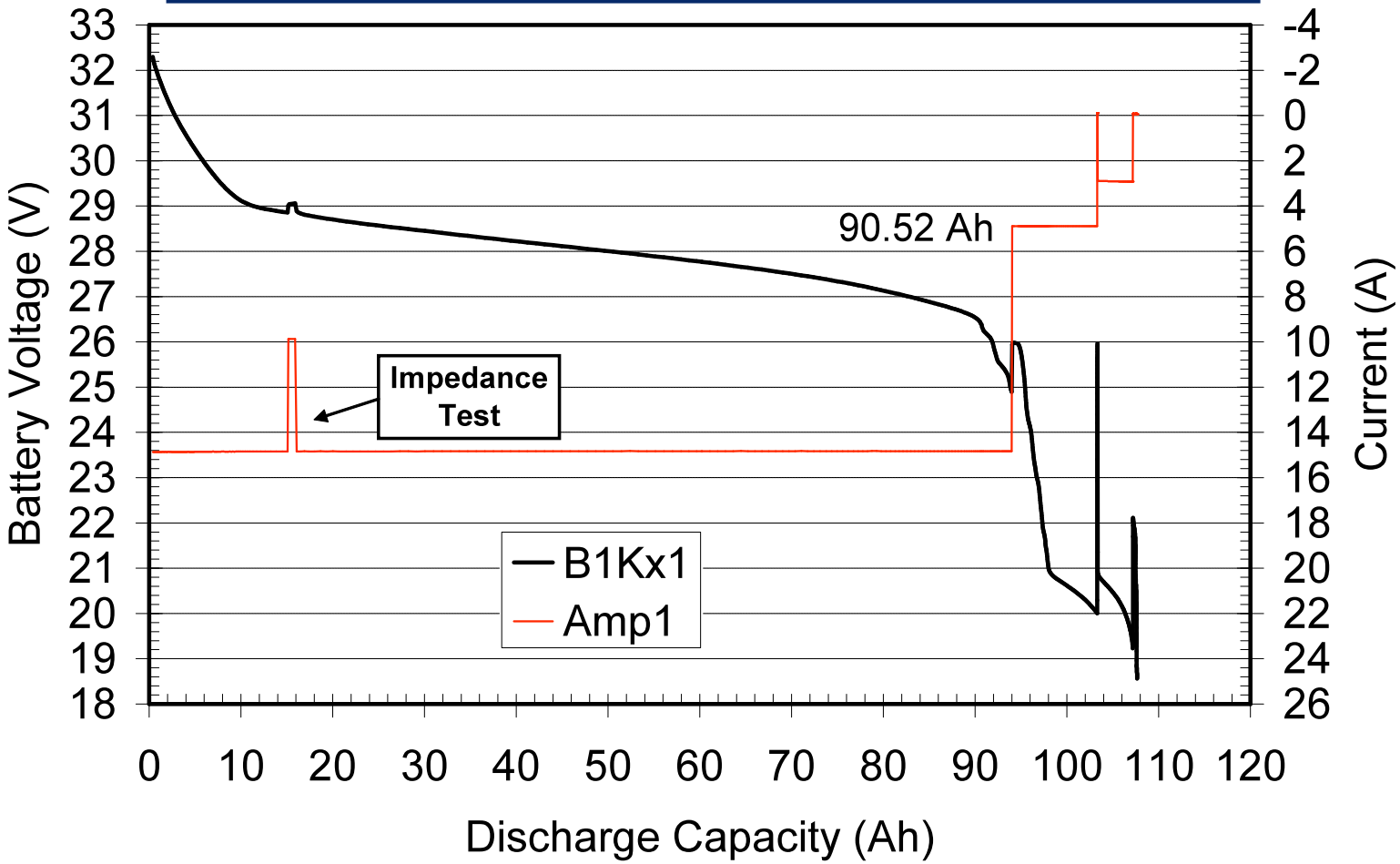
SM-4 Battery Shelf Life Study

March-2008 BMA 0 °C Capacity Test
Battery S/N 1161



Surge-Load Test @ 15 Ah DOD Gives Impedance Data

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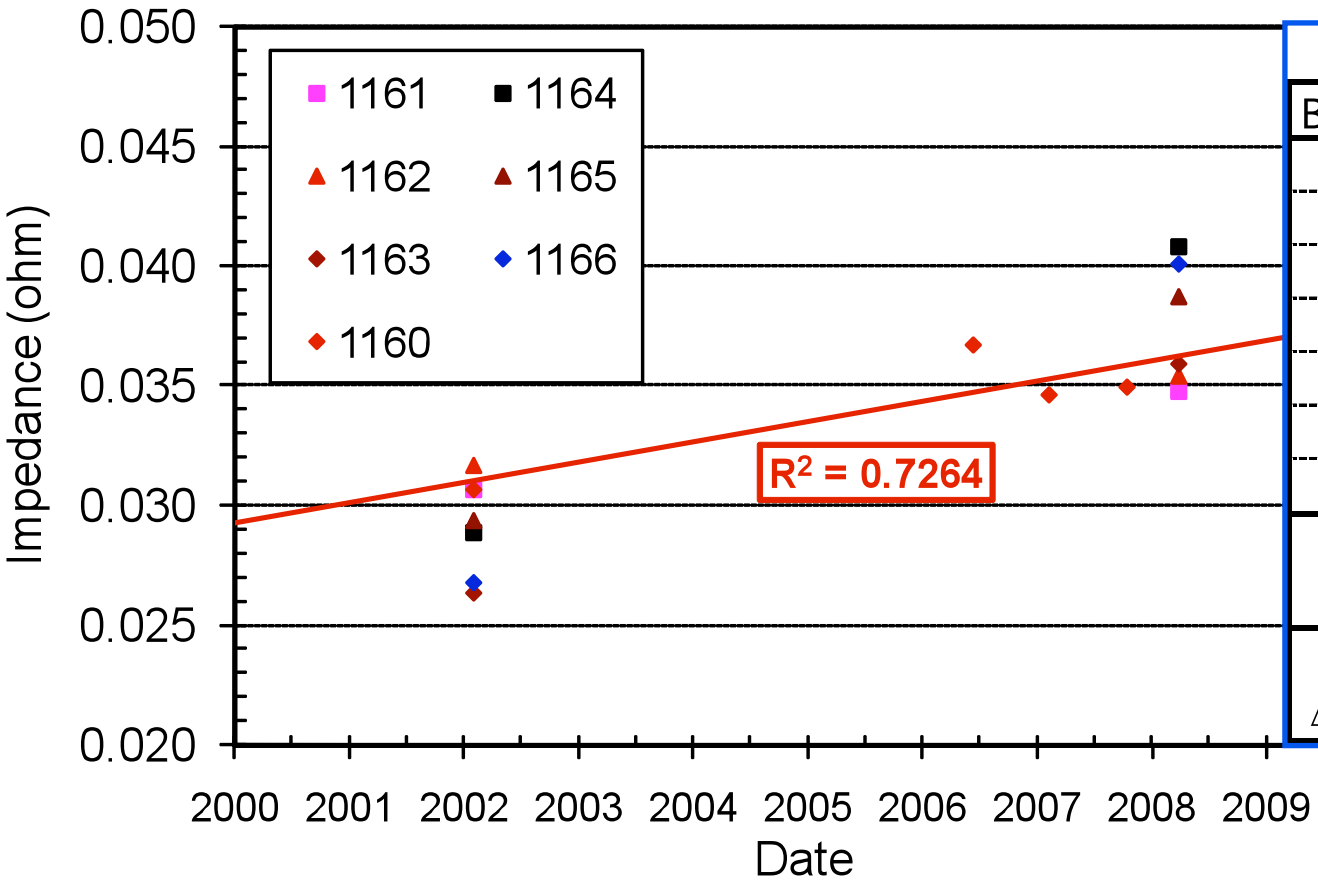
SM-4 Battery Shelf Life Study

Surge Load Impedance Trend



Trend (milliohm/Yr)	
Battery (S/N)	Impedance
1160	0.844
1161	0.658
1162	0.599
1163	1.549
1164	1.935
1165	1.511
1166	2.152
Ave =	1.321
95% Conf.	1.781

Impedance From Surge Load Test Increases With Age
Lot 11 Cells Increasing Faster Than Lot 10

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HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Summary of Wet Life Study Observations

- **Cell DPA Studies**
  - 10 °C Capacity Increases with Wet Life (Precharge Loss)
  - Second Plateau Capacity Increases with Wet Life
  - KOH Concentration in Stack Increases with Wet Life
  - KOH Concentration in Separator Increases with Wet Life
  - Chemical Nickel Precharge Capacity Remains
  - Electrical Nickel Precharge Lost In 5-7 Years
  - Marginal Nickel Precharge Observed in HST Flight Cells (2007)

- **Flight Battery Tests**
  - Impedance Increases With Wet Life (BMA Surge Load Tests)

Acknowledgement

- **This Work Was Supported by NASA Contract Mod 593 Dated 2 June 1987**
  - Directed LMSC to Design, Develop and Deliver Nickel-hydrogen Battery Modules
  - For the Hubble Space Telescope Low Earth Orbit Mission
    - Per NAS 8-32697 and NAS 5-5000

- **The Authors Wish to Acknowledge the Technical Support From**
  - **Aerospace Corporation** for Cell DPA Testing and Gas Analysis
    Albert Zimmermann and Mick Quinzio