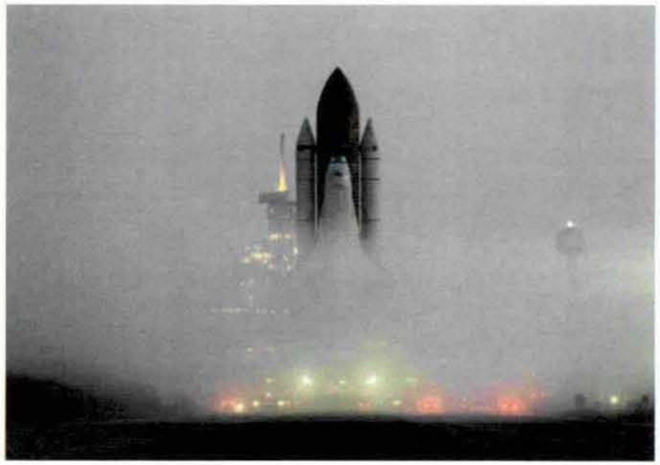
NASA TEERM Hexavalent Chrome Alternatives Projects

Business Operations Branch, Management Integration Services Office
Engineering Directorate
Kennedy Space Center, FL



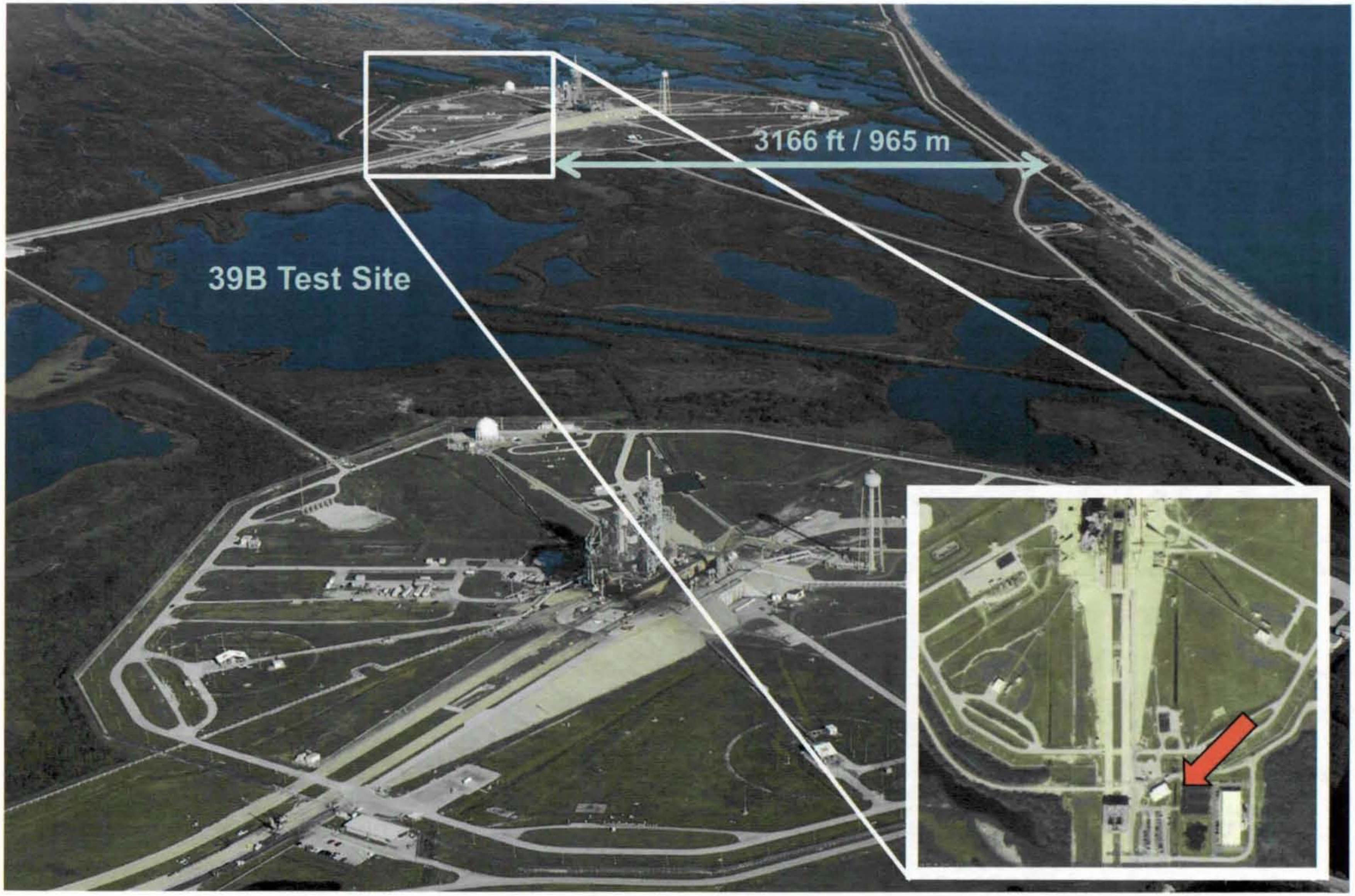
SERDP/ESTCP

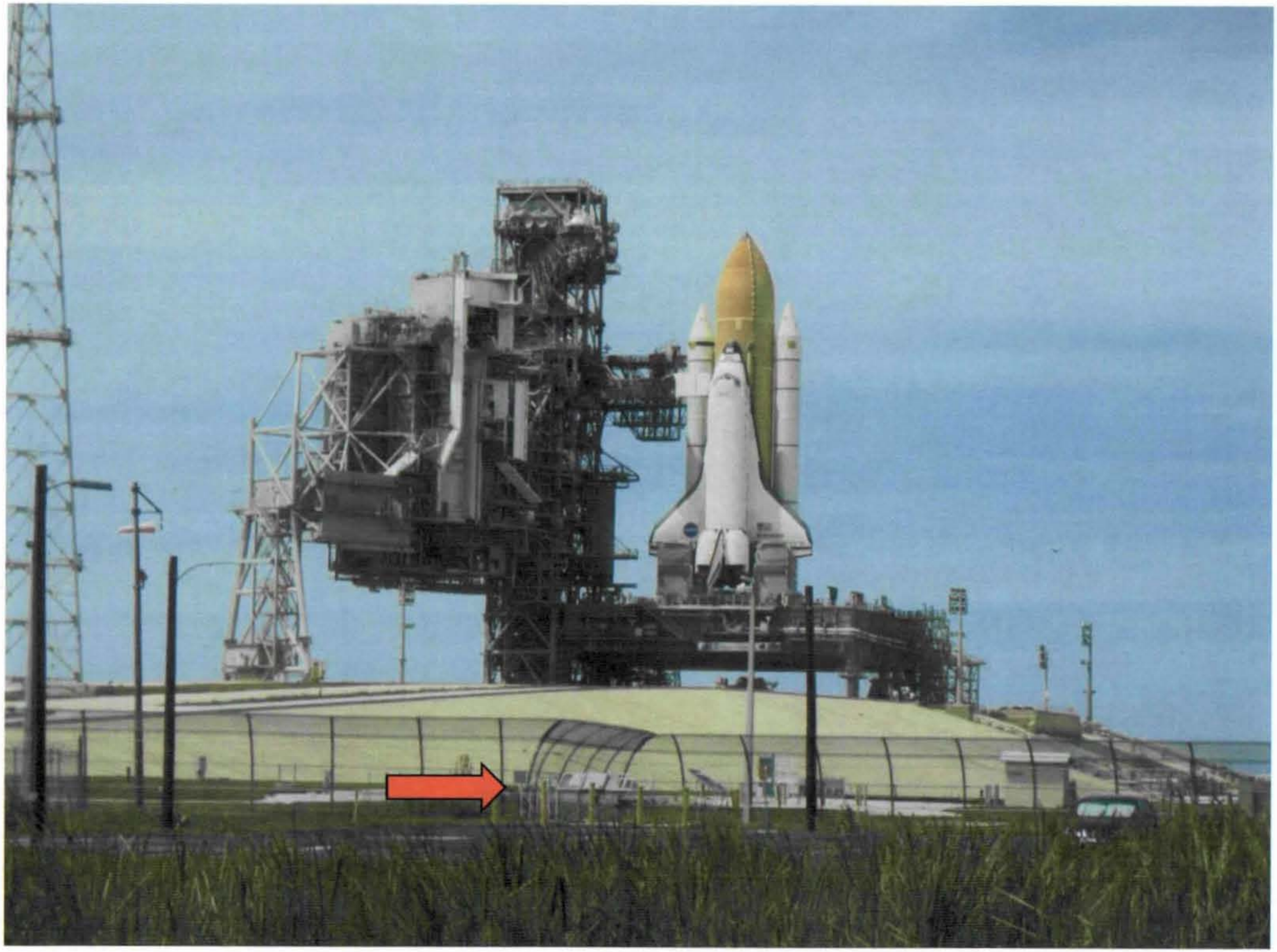
Partners in Environmental Technology Technical Symposium & Workshop

Presenter(s): Rusty McLaughlin, ITB Inc.


LC-39A
LC-39B
3166 ft / 965 m
3.1 mi / 5 km
Beach Test Site
100 ft / 30 m

National Aeronautics and Space Administration (NASA)





HISTORIC TESTING AND RESEARCH WITHIN THE AGENCY

National Aeronautics and Space Administration (NASA)

External Tank Research

Testing between 1992-2007:

Looking For:

- Replacements for Iridite 14-2 (pretreat)
- Replacements for DeSoto K719 (primer)

Tested:

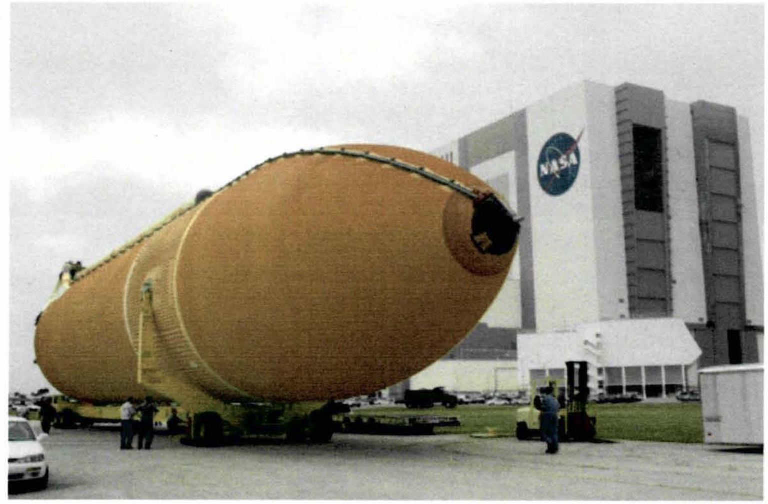
- Tested primers (≈30) → None passed
- Tested pretreatments (≈ 6) → None passed

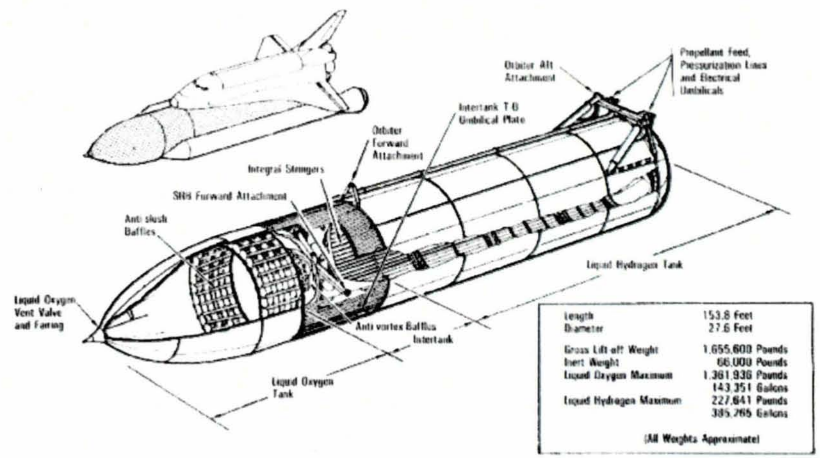
Positive results, (but not fully successful):

- TCP (Metalast, Alodine)
- Hentzen Primers (good corrosion protection)

Issues (Very difficult tests to pass):

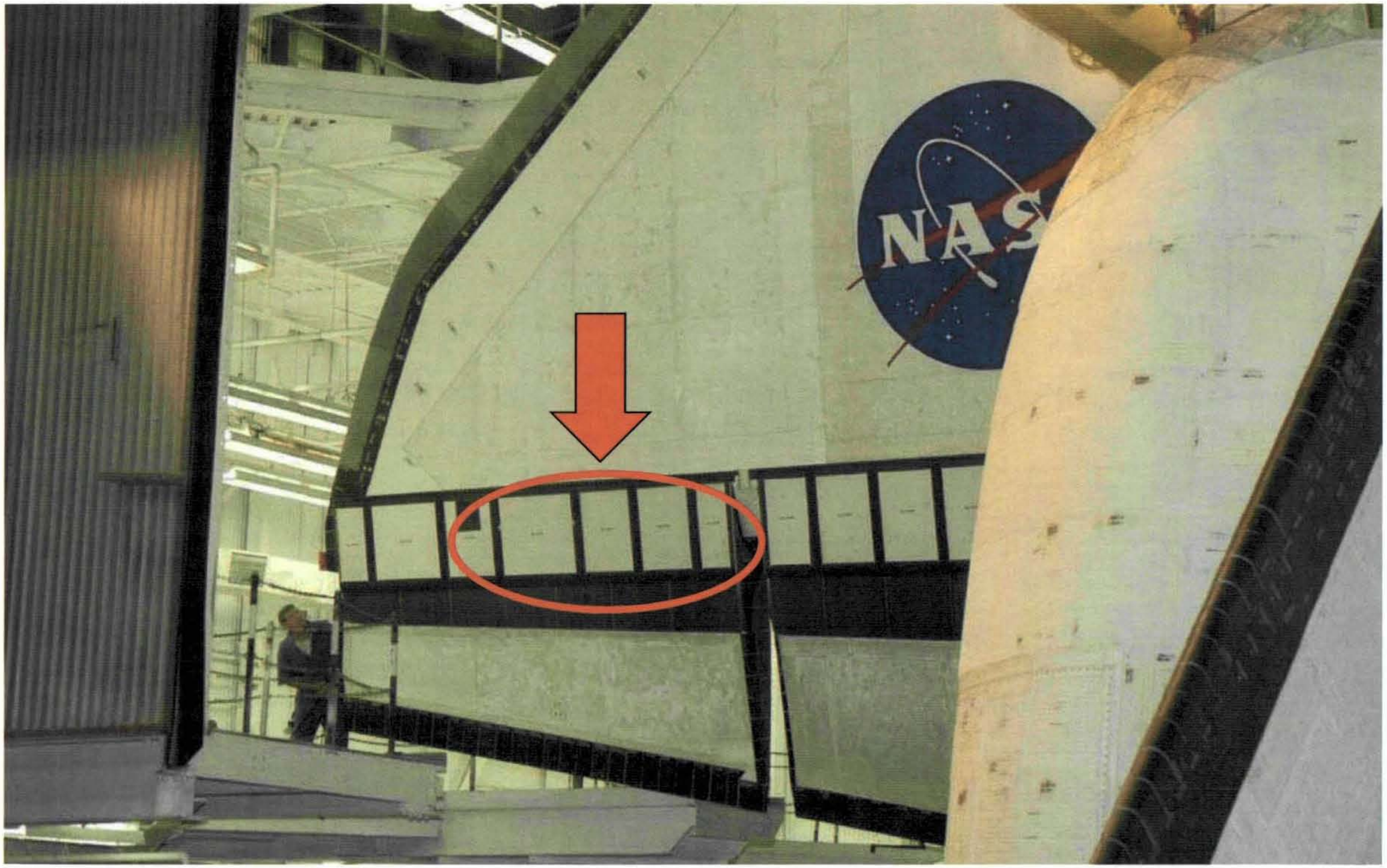
- Cryoflex Adhesion
- SLA Cryogenic Flexibility
- Corrosion (2000+ Hrs)
- LOX Compatibility





Lightweight External Tank

Orbiter Dem-Val



Orbiter Dem-Val

Columbia (OV-102)
Field Demonstration (1998-2003):

Looking For:

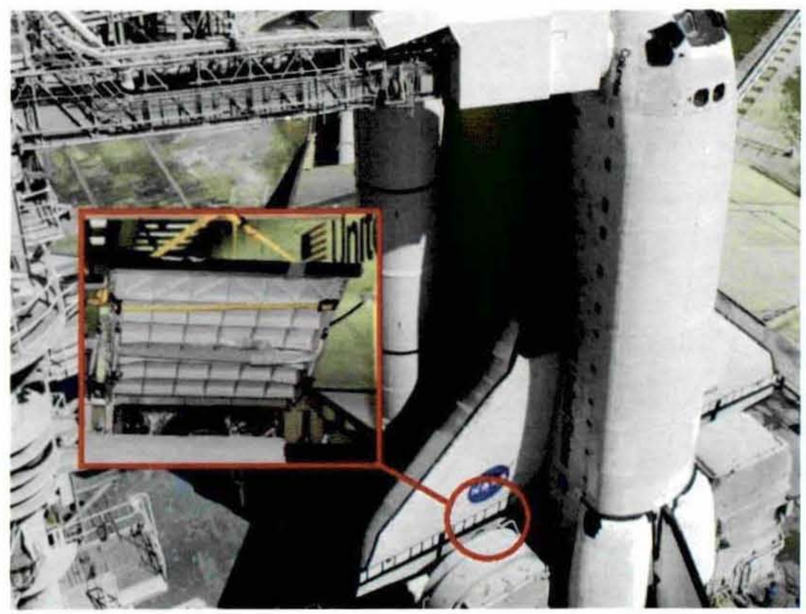
- Replacements for Alodine 1200 (pretreat)
- Replacements for Koropon (primer)

Tested:

- Elevon Cove Seal Doors
- Identified as "drip points" and areas subject to more than average corrosion
- Every-other door coated with Control
- Every-other door coated with Alternative

Coating Tested:

- Dexter Aerospace Materials / Crown Metro Aerospace: 10PW22-2/ECW-119
- Coating performed well in this test for 2+ years at KSC, and performed well in other tests performed by JGPP.



SRB Implementation

Testing and Qualification of Coating Systems:

Two-Phase Project Resulting in:

- Replacements for Alodine 1200 (pretreat)
- Replacements for Deft 44-GN-7 (primer)
- Replacements for Deft 03-W-127A (topcoat)

Initial Testing:

- 6 Pretreatments, 6 Primers

Secondary Testing:

- 3 Pretreatments, 3 Primers → 3 Passed

Approved Coating Systems for SRB Aluminum

Pretreatment	Primer	Topcoat
Alodine 1201	Deft 44GN7	Deft 03W127
Alodine 1201	Hentzen 05510WEP-X/05511CEH-X	Hentzen 4636WUX-3/4600CHA-SG
Alodine 1201	Lord 9929 A/B	Lord A276
Alodine 5700	Deft 44GN7	Deft 03W127
Alodine 5700	Hentzen 05510WEP-X/05511CEH-X	Hentzen 4636WUX-3/4600CHA-SG
Alodine 5700	Lord 9929 A/B	Lord A276
Chemidize 727	Deft 44GN7	Deft 03W127
Chemidize 727	Lord 9929 A/B	Lord A276

SSME Implementation

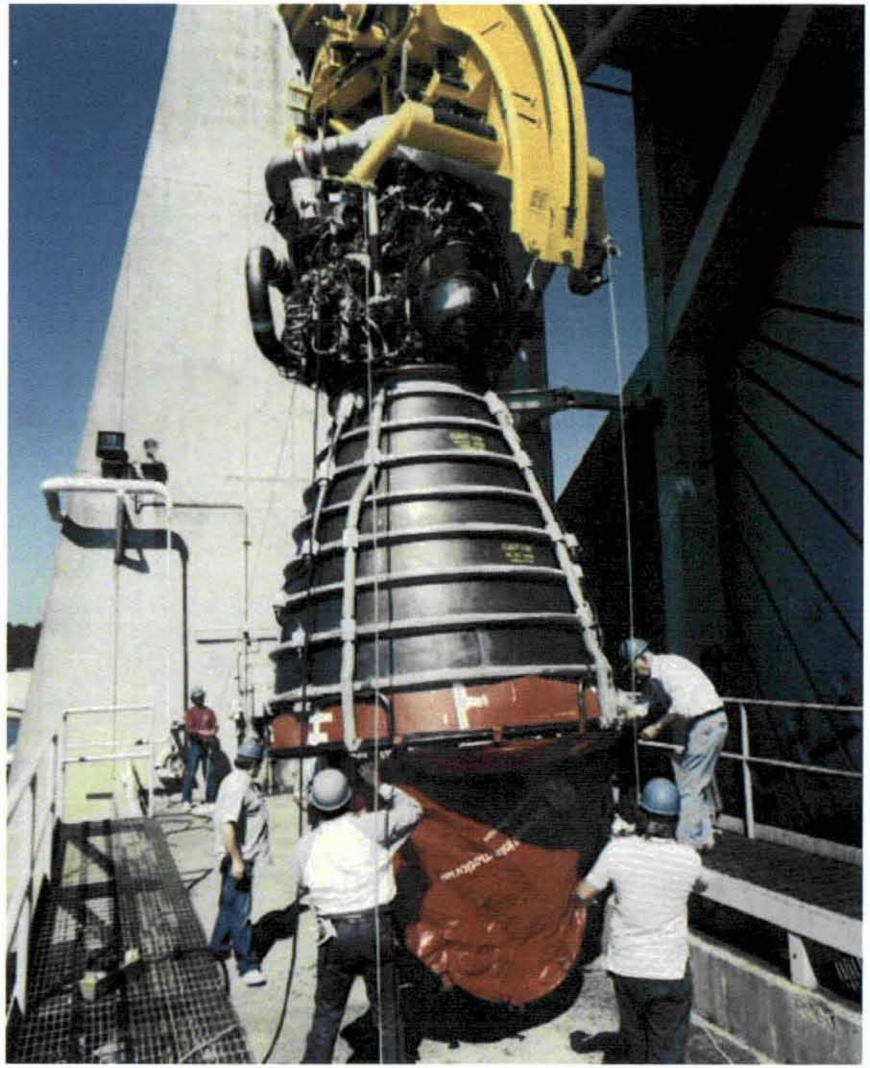
Testing and Qualification of Coating Systems:

Looking For:

- Replacements for TT-P-1757, MIL-P-23377, and Desoto 515X346 (primers)
- Replacements for zinc chromate (primer)

Coating Tested/Implemented:

- TT-P-2756 (self-priming topcoat)
- Zinc chromate was replaced with thermal spray coating.



TEERM INITIATED RESEARCH AND TESTING (PAST, PRESENT, FUTURE)

TEERM Projects

Demonstration / Validation Testing of Coating Systems

Past:

- •Phase I – Completed 2007
- •Intl. Collaboration NASA/C3P/TAP – Completed 2007

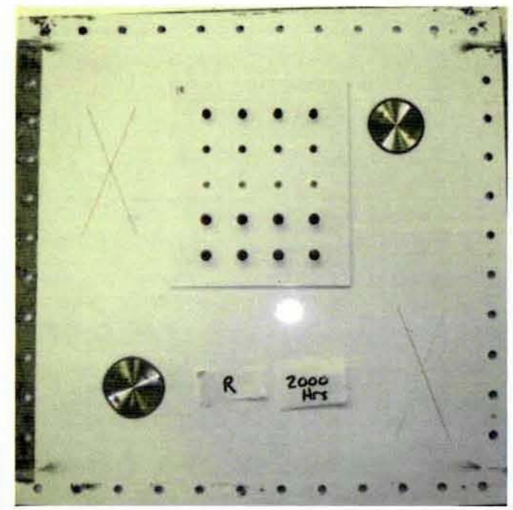
Present:

- •Phase II - Oct 2010 (Testing Complete)
- •Lifecycle Corrosion Project - Feb 2011
  - •Corrosion Rate Study – Oct 2010
  - •Combined Environment Testing – Nov 2010
  - •Mini-CBA of moving beyond hex-chrome – Feb 2011
  - ~~•Repair/Rework Study (First Stage CxP)~~
- •Electronics / Avionics – March 2010 (Development)

Future:

- Continued International Collaboration (ESA/NASA)
- ESTCP Full Matrix Testing
- Cadmium / Chromium for Electronic Connectors
- Identification of coating alternatives for heavy-lift and commercial sector (space)

TEERM Phase I



Testing between 2005-2007:

Looking For Systems Alternatives:

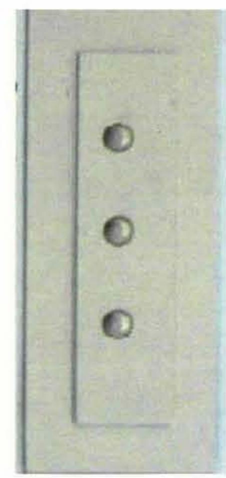
- Sys C: Alodine 1200 + Deft 02-Y-40 + Deft 03-GY-321

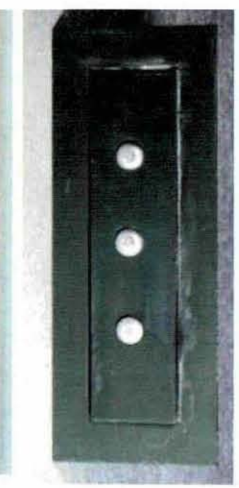
Substrates:

- 2219, 2195, 6061, 2024 Bare, 2024 Clad, and 7075

Systems Tested:

- Sys T: Alodine 5700 / Sicopoxy 577-630 / Deft 03-GY-321
- Sys N: PreKote / Mg-Rich / Deft 03-GY-321
- Sys H: Alodine 5700 / Hentzen 05510WEP-X / Deft 03-GY-321
- Sys D: Boegel AC-131CB / Dupont Corlar 13570S / Deft 03-GY-321
- Sys S: PreKote / AquaSurTec Crosslinker / AquaSurTec D45





Positive results, (but not fully successful):

- System T, System N, System H

Tests Performed:

- 3000 Hr. Salt-Spray, 2,000 Hr. Cyclic Corrosion, Filiform Corrosion, Dissimilar Metals Corrosion, SAS, Hydrogen Embrittlement & Adhesion

Hex-Chrome Free Systems Phase I
3000 Hour Salt Fog Results

	Primer and Topcoat	Primer Only	Primer and Topcoat	Primer Only	Primer and Topcoat	Primer Only	Primer and Topcoat	Primer Only	Primer and Topcoat	Primer Only	Primer and Topcoat	Primer Only
Coating System	2219-T81	2219-T81	2024-T3	2024-T3	2024-T3 Clad	2024-T3 Clad	7075-T6	7075-T6	6061-T6	6061-T6	2195-T8M4	2195-T8M4
C	C2-1 C2-2	C3-1 C3-2	C4-1 C4-2	C5-1 C5-2	C6-1 C6-2	C7-1 C7-2	C8-1 C8-2	C9-1 C9-2	C10-1 C10-2	C11-1 C11-2	C12-1 C12-2	C13-1 C13-2
T	T2-1 T2-2	T3-1 T3-2	T4-1 T4-2	T5-1 T5-2	T6-1 T6-2	T7-1 T7-2	T8-1 T8-2	T9-1 T9-2	T10-1 T10-2	T11-1 T11-2	T12-1 T12-2	T13-1 T13-2
N	N2-1 N2-2	N3-1 N3-2	N4-1 N4-2	N5-1 N5-2	N6-1 N6-2	N7-1 N7-2	N8-1 N8-2	N9-1 N9-2	N10-1 N10-2	N11-1 N11-2	N12-1 N12-2	N13-1 N13-2
H	H2-1 H2-2	H3-1 H3-2	H4-1 H4-2	H5-1 H5-2	H6-1 H6-2	H7-1 H7-2	H8-1 H8-2	H9-1 H9-2	H10-1 H10-2	H11-1 H11-2	H12-1 H12-2	H13-1 H13-2
D	D2-1 D2-2	D3-1 D3-2	D4-1 D4-2	D5-1 D5-2	D6-1 D6-2	D7-1 D7-2	D8-1 D8-2	D9-1 D9-2	D10-1 D10-2	D11-1 D11-2	D12-1 D12-2	D13-1 D13-2
S	S2-1 S2-2	S3-1 S3-2	S4-1 S4-2	S5-1 S5-2	S6-1 S6-2	S7-1 S7-2	S8-1 S8-2	S9-1 S9-2	S10-1 S10-2	S11-1 S11-2	S12-1 S12-2	S13-1 S13-2

3000 Hrs

< 2500 Hrs

< 2000 Hrs

< 1500 Hrs

< 500 Hrs

TEERM International Collaboration

Dem / Val & Field-testing of Coating Systems

Looking For:

- Replacements for hex-chrome pretreatments
- Replacements for hex-chrome primers

Coatings Tested:

- Sys M: M790E + Aviox CF + Aviox Finish 77702
- Sys P: PreKote SP + Aviox CF + Aviox Finish 77702

Laboratory Testing:

- Gloss, Color, Adhesion, Impact, Flexibility, Fluid Resistance, Filiform Corrosion, Salt-Spray Corrosion, Artificial Weathering, Stripability, Restoration & Heat Stability

Field Testing:

- Painted exterior service door of a TAP Airbus A319 (2004)
- Visual inspections (2+ Yrs) appeared favorable with no visual signs of corrosion, deterioration in thickness or in color. (2007)

TEERM Phase II (Non-Chrome Systems Testing)

Laboratory & Atmospheric Testing of Coating Systems

Coatings Tested:

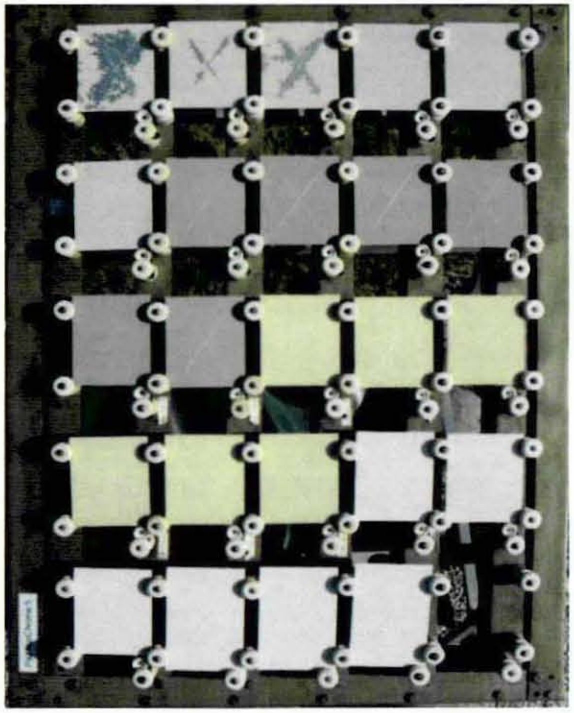
- Systems H, N, T, P + Others
- CxP contributed other coatings to be tested

Pretreatments:

- Alodine 1200, Iridite 14-2, Alodine 5200, Surtec 650, Prekote, Metalast TCP-HF, Metalast TCP-HF/EPA, Alodine 5900T, VpCl-440

Primers:

- Koropon (515X346 / 910x520) (Control), STMK719 Superkoropon (Control), ANAC / Mg Rich XP417-183, Hentzen 05510WEP-X / 05511CEH-X, Hentzen 16708TEP / 16709CEH (Type I), Hentzen 7176KEP / 16709CEH (Type II), Sicopoxy 577-630, Aviox CF Primer (TC) 330312, Deft 44GN098 (Waterborne), Deft 02GN084 (High Solid), VpCl-373 (Vapor Phase Cl), Lockheed Martin (CF Epoxy Primer), Ecoprime CF, Hentzen Epoxzen



Testing:

- Atmospheric Exposure (Beach & Pad), Adhesion, Bare Corrosion Resistance (limited), Corrosion Rate → (Field Testing Complete in November 2010)

6 Months Exposure

System	Pretreatment	Primer	Topcoat	Avg Pad	Avg Beach
C1	Alodine 1200s	Koropon (515X346 / 910x520)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	10
C2	None	Koropon (515X346 / 910x520)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	10
S1	PreKote	ANAC / Mg Rich	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	10
S2	Alodine 5200	Sicopoxy 577-630	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	9.6	4.5
S3	METALAST TCP-HF/EPA	Deft 084 (High Solid)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	10
S4	METALAST TCP-HF/EPA	Deft 098 (Waterborne)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	9.2
S5	METALAST TCP-HF/EPA	Hentzen (Type I - 16708TEP / 16709 CEH)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	9.1
S6	METALAST TCP-HF/EPA	Hentzen (Type II - 7176KEP / 16709 CEH)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	9.2
S7	Alodine 5200	Hentzen Primer (05510WEP-X / 05511CEH-X)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	9.4	4.3
S8	VpCI-440	VpCI-373	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	9.6
S9	PreKote	Aviox CF Primer (TC)	MIL-PRF-85285B Type 1, Class H PRC-Desoto CA8211/F27925	10	8.2

6 Months Exposure

System	Pretreatment	Primer	Topcoat	Avg Pad	Avg Beach
W-20129/1	None	Ecoprime	None	0	0
W-19235	None	SuperKoropon 515-346	None	10	10
W-19236	None	SuperKoropon 513-003	None	10	10
W-19656/1	None	Hentzen Epoxen	None	6.5	5.4

6 & 12 Months Exposure

Coating System	Substrate	6-Months Pad B	6-Months Beach	12-Months Pad B	12-Months Beach
C1	2024-T3	10	10	10	10
C2	2024-T3	10	10	10	10
S1	2024-T3	10	10	10	10
S2	2024-T3	10	4	7	2.66
S3	2024-T3	10	10	10	8.66
S4	2024-T3	10	10	10	10
S5	2024-T3	10	10	10	9.33
S6	2024-T3	10	10	10	10
S7	2024-T3	10	2.7	6.33	0
S8	2024-T3	10	10	10	9
S9	2024-T3	10	8.3	10	8.33

Coating System	Substrate	6-Months Pad B	6-Months Beach	12-Months Pad B	12-Months Beach
C1	7075-T6	10	10	9	10
C2	7075-T6	10	10	10	8.66
S1	7075-T6	10	10	10	10
S2	7075-T6	10	2	10	0.33
S3	7075-T6	10	10	10	10
S4	7075-T6	10	10	10	10
S5	7075-T6	10	10	10	10
S6	7075-T6	10	10	10	9.66
S7	7075-T6	10	3.3	10	1.33
S8	7075-T6	10	9.3	10	8
S9	7075-T6	10	7.3	10	6.33

Coating System	Substrate	6-Months Pad B	6-Months Beach	12-Months Pad B	12-Months Beach
C1	2195-T8	10	10	10	10
C2	2195-T8	10	10	10	10
S1	2195-T8	10	10	10	10
S2	2195-T8	8.3	7	7	6.66
S3	2195-T8	10	10	10	10
S4	2195-T8	10	10	10	10
S5	2195-T8	10	10	10	10
S6	2195-T8	10	10	10	10
S7	2195-T8	10	6	7.33	6
S8	2195-T8	10	10	10	10
S9	2195-T8	10	9.3	10	7.33

Coating System	Substrate	6-Months Pad B	6-Months Beach	12-Months Pad B	12-Months Beach
C1	2219-T87	10	10	10	10
C2	2219-T87	10	10	10	10
S1	2219-T87	10	10	10	10
S2	2219-T87	10	5	7	4.66
S3	2219-T87	10	10	10	5.66
S4	2219-T87	10	6.7	9	5.66
S5	2219-T87	10	6.3	9	5.66
S6	2219-T87	10	6.7	10	6
S7	2219-T87	7.7	5	7	4.66
S8	2219-T87	10	9	10	6.33
S9	2219-T87	10	8	10	7

Concurrent Corrosion Study

KSC Pad Atmospheric Corrosion Testing Schedule

- Aluminum Substrates
  - 2195
  - 2024
  - 2219
  - 2014
  - 6061
  - 7075
  - 7050
- Steel Substrates:
  - 4340 or D6ac
  - A286
  - 304SS
  - 1080
  - PH17-4
- Couples
  - A286 with 7075/2219/6061/2195
  - 4340 (or D6ac) with 6061/7075/2195/7050
  - 304 SS with 6061/7075/2219/2195/2024

Life Cycle Corrosion of Space Vehicles

Understanding the KSC Performance Environment:

Details:

- Characterize KSC Environment (XPS) (Salt Solution)
- Determine ideal testing conditions and equipment
- Design 2k-Factorial Experiment
- Compare results to
  - Phase II Testing
  - Corrosion Rate Testing at KSC (Pad and Beach)
  - Historical Corrosion Rates at KSC (Beach)
- Utilize Silver as Indicator Substrate for Testing / Analysis

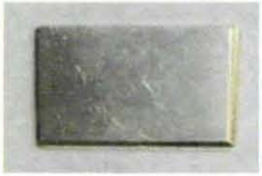
Factors of consideration:

- Temperature, Humidity, Salt Type, Salt Concentration, Light (UV / Xeon-Arc), Ozone (KSC < 50ppb on Avg.)

Equipment of consideration:

- Combination of B117 Salt-Fog Cabinet, UV / Xeon-Arc Chamber, Thermotron
- Modified Corrosion Cabinet w/ UV Lights & Ozone

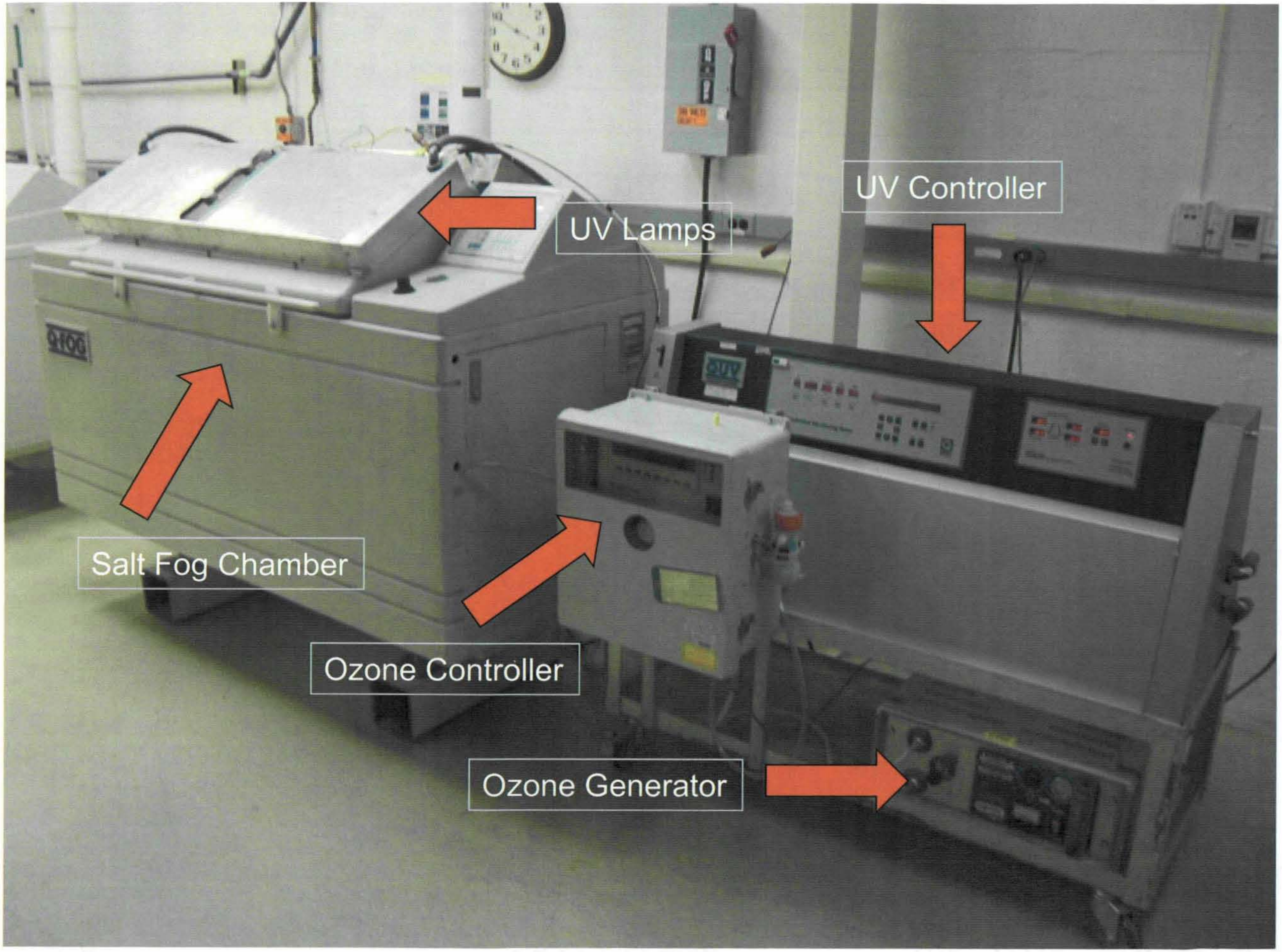
Fresh sample



1 week – B117

1 month – B117

22 hours - B117
O3 +UV


UV Lamps
UV Controller
Salt Fog Chamber
Ozone Controller
Ozone Generator

Combined Environment Testing

Final Settings

Ozone:

- Ozone High = 800ppb
- Ozone Low = 100ppb

Light:

- UV High = 86% of UV Bulb Intensity
- UV Low = 10% of UV Bulb Intensity

Salt:

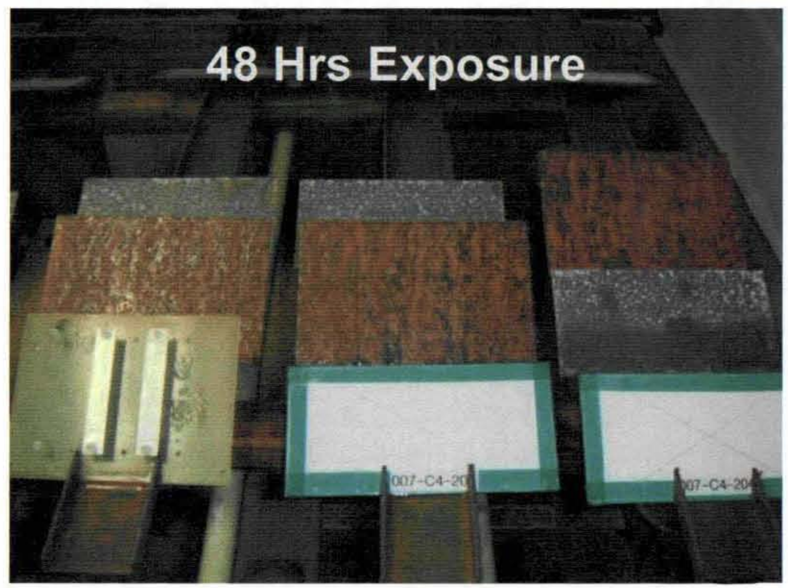
- Salt Mixture 1 - 5% NaCl
- Salt Mixture 2 – XPS Determined
  - Simulated KSC Salt Solution
    - (H_2SO_4, NaCl, CuCl, $Mg(OH)_2$, $CaCl_2$, Cu_2O, MgF_2, $Cu(OH)_2$, Ammonia)
    - pH ≈ 5.4

Temperature:

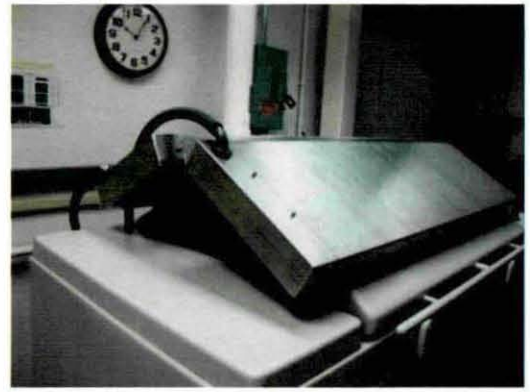
- Constant - 46° C

Humidity:

- ≈ 90 - 100%

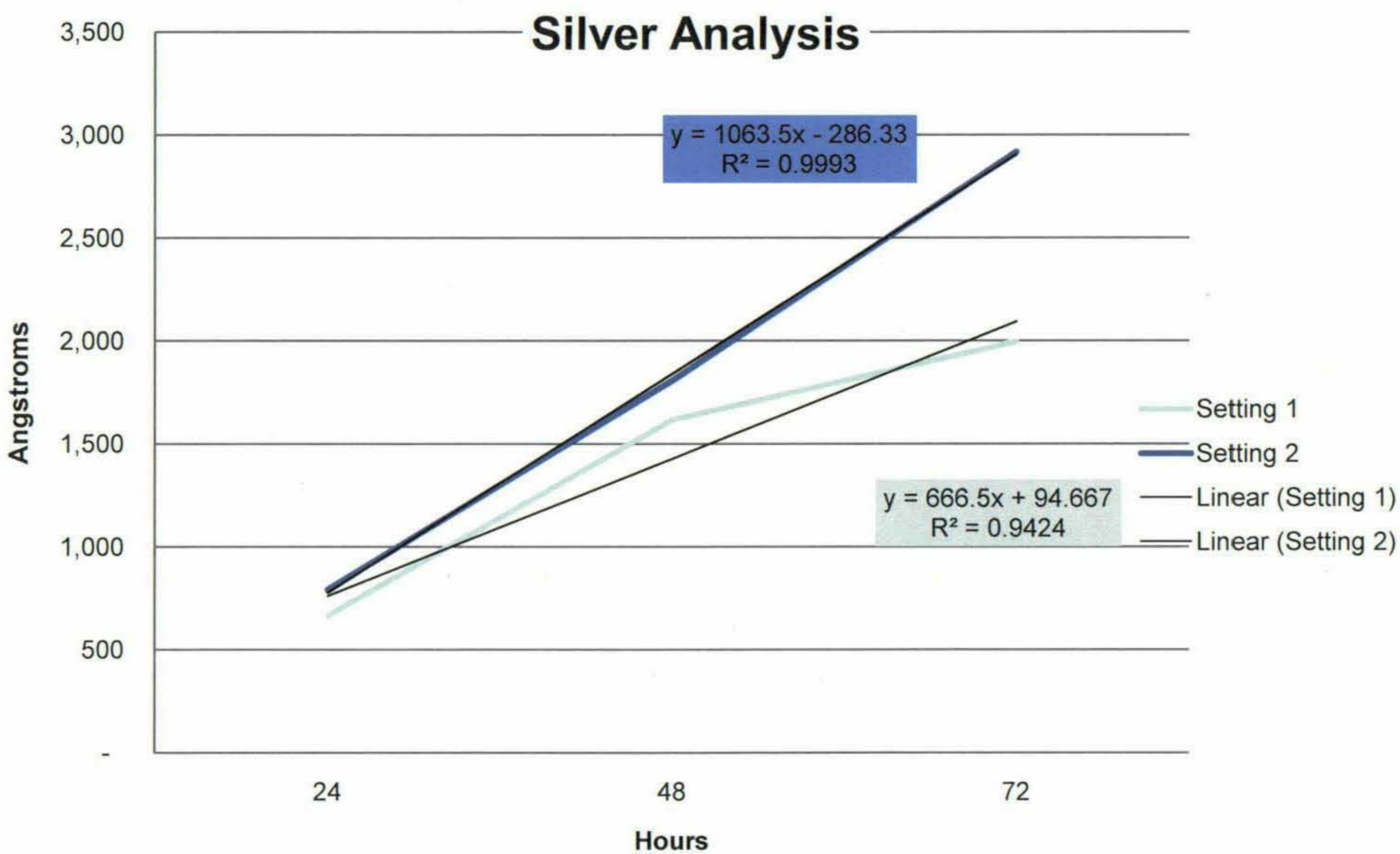


Combined Environment Test chamber and Experimental Design



Setting	UV	Ozone	Salt Mix	Bare			Coated - System 2			Coated - System 7			Bare			Bare			Coated - Control			DATA POINTS
				Hours Exposure			Hours Exposure			Hours Exposure			Hours Exposure			Hours Exposure			Hours Exposure			
				24h	48h	72h	24h	48h	72h	24h	48h	72h	24h	48h	72h	24h	48h	72h	24h	48h	72h	
				Substrate AL-2024			Substrate AL-2024			Substrate AL-2024			Substrate ST-1010			Substrate Ag			Substrate AL-2024			
Setting 1	Low	Low	B117 - 5%	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 2	High	Low	B117 - 5%	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 3	Low	High	B117 - 5%	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 4	High	High	B117 - 5%	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 5	Low	Low	KSC (XPS)	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 6	High	Low	KSC (XPS)	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 7	Low	High	KSC (XPS)	4	4	4		4			4		4	4	4	1	1	1		1		36
Setting 8	High	High	KSC (XPS)	4	4	4		4			4		4	4	4	1	1	1		1		36
			Data Points:	32	32	32		32			32		32	32	32	8	8	8		8		288
				Total: 96			Total: 32			Total: 32			Total: 96			Total: 24			Total: 8			

Initial Results – (NO DOE Analysis yet)



New Project – March 2010
Hexavalent Chrome Free Coatings for Electronics / Avionics

Hex Chrome Free Coatings for Electronics (NASA-DoD)

Description:

Looking For:

- Replacements for Iridite 14-2 (pretreat)
- Replacements for Alodine 1200 (pretreat)

Drivers:

- Hex-Chrome PEL
- RoHS
- DFAR

Testing:

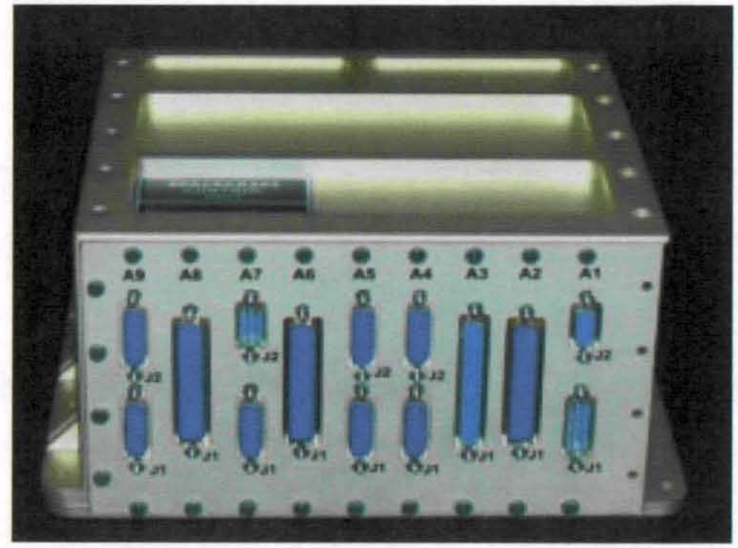
- Bare Corrosion Resistance, Resistivity
- Little historic knowledge for (EIS, EMI, RF)

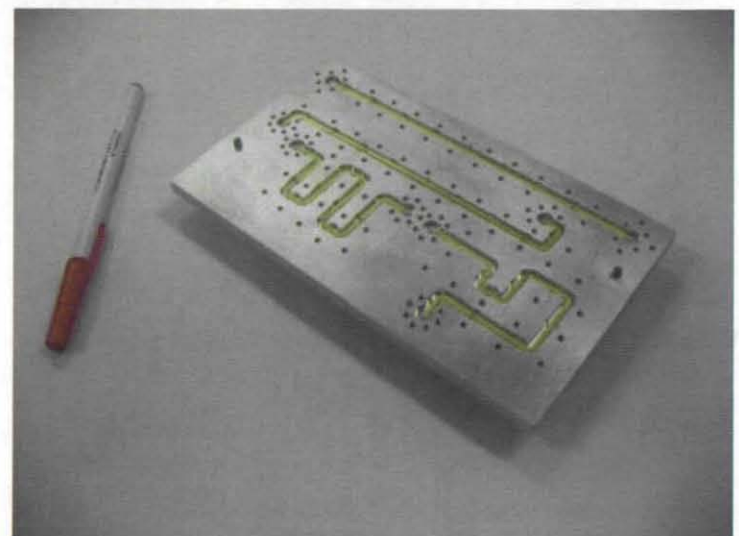
Substrates:

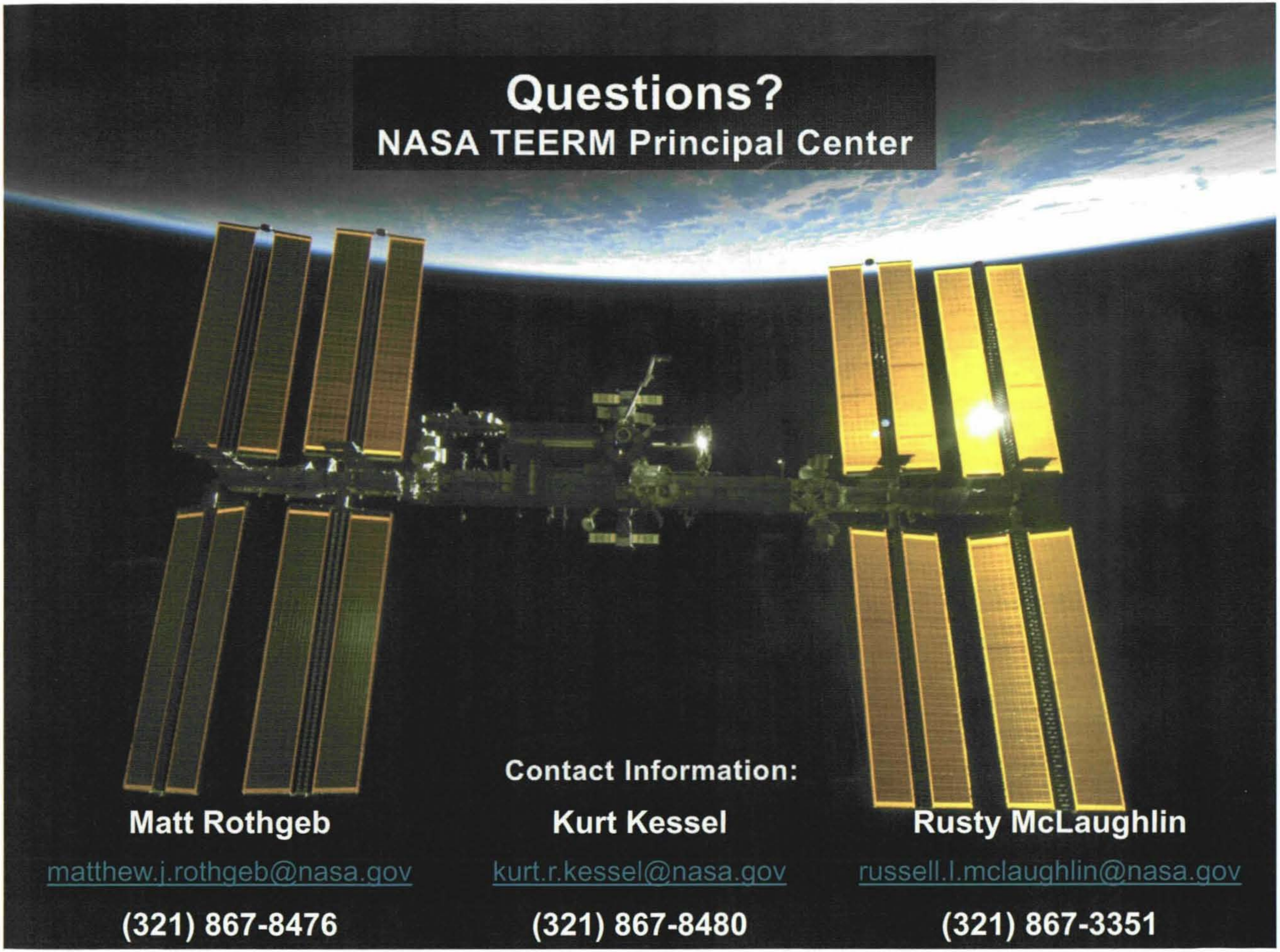
- 6061-T6, 7075-T73, 2024-T3, 5052-H32

Stakeholders:

- 60+ Active Participants from NASA, DoD and Private Sector






Questions?
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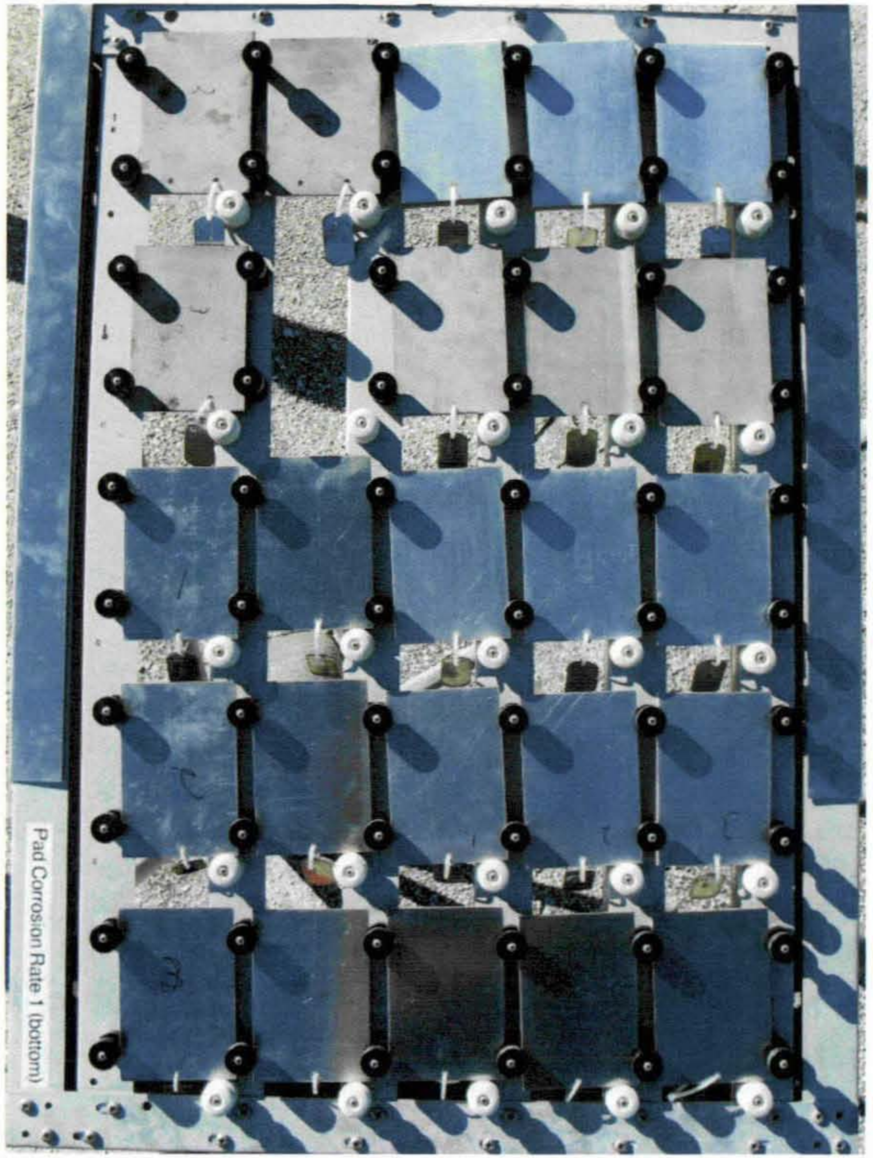
Backup / Extra Slides

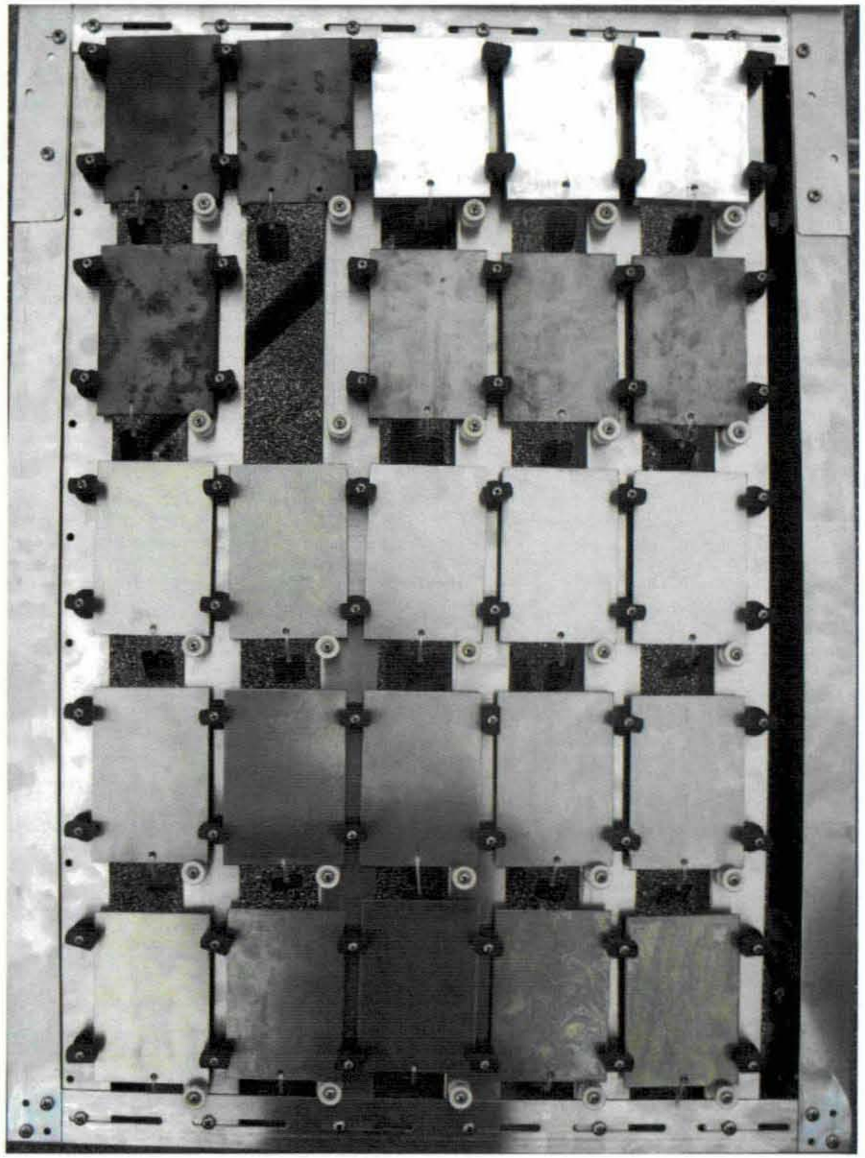
Hex-Chrome Free Systems Phase I & II
Project POCs & Participants

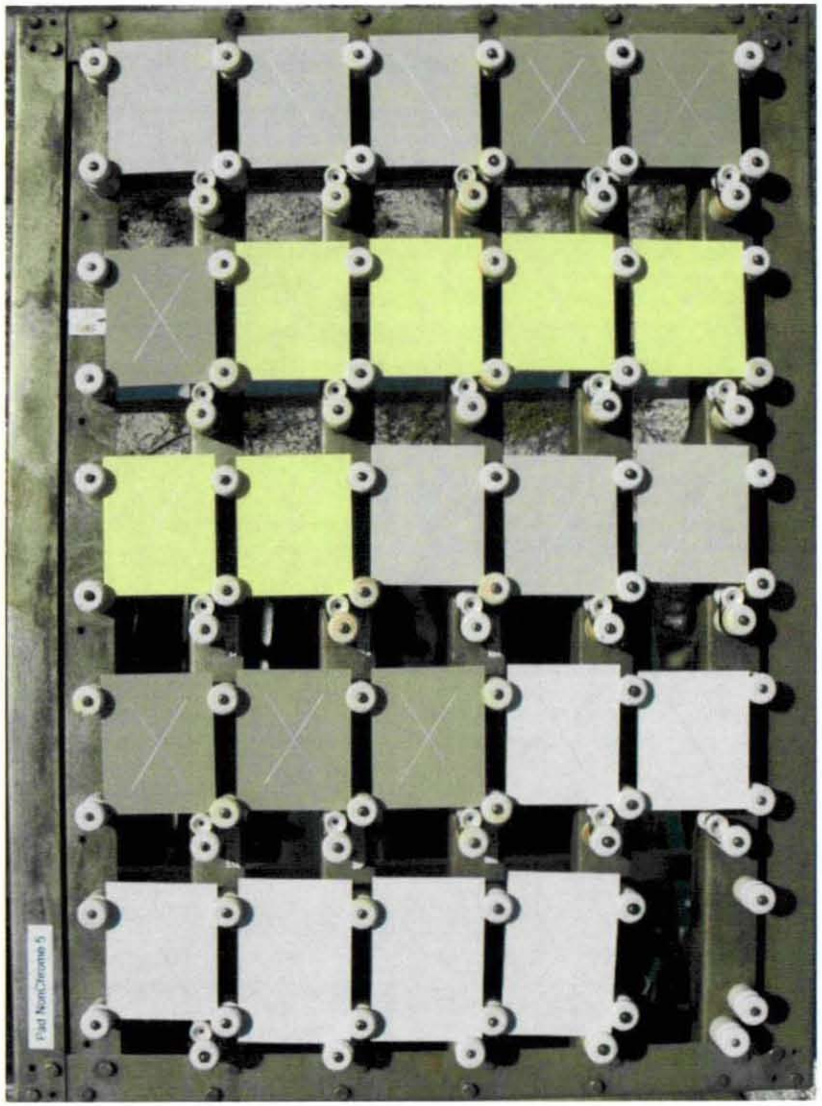
- **NASA**
  - Orion – Mike Pedley (NASA), David Shindo (NASA)
  - Ares I Upper – Rhonda Libb (NASA)
  - Ares I Lower – John Bailey (USA) / A. Priskos (NASA)
  - Other – Steve Hudson (NASA), Andrew Hodges (Vista)

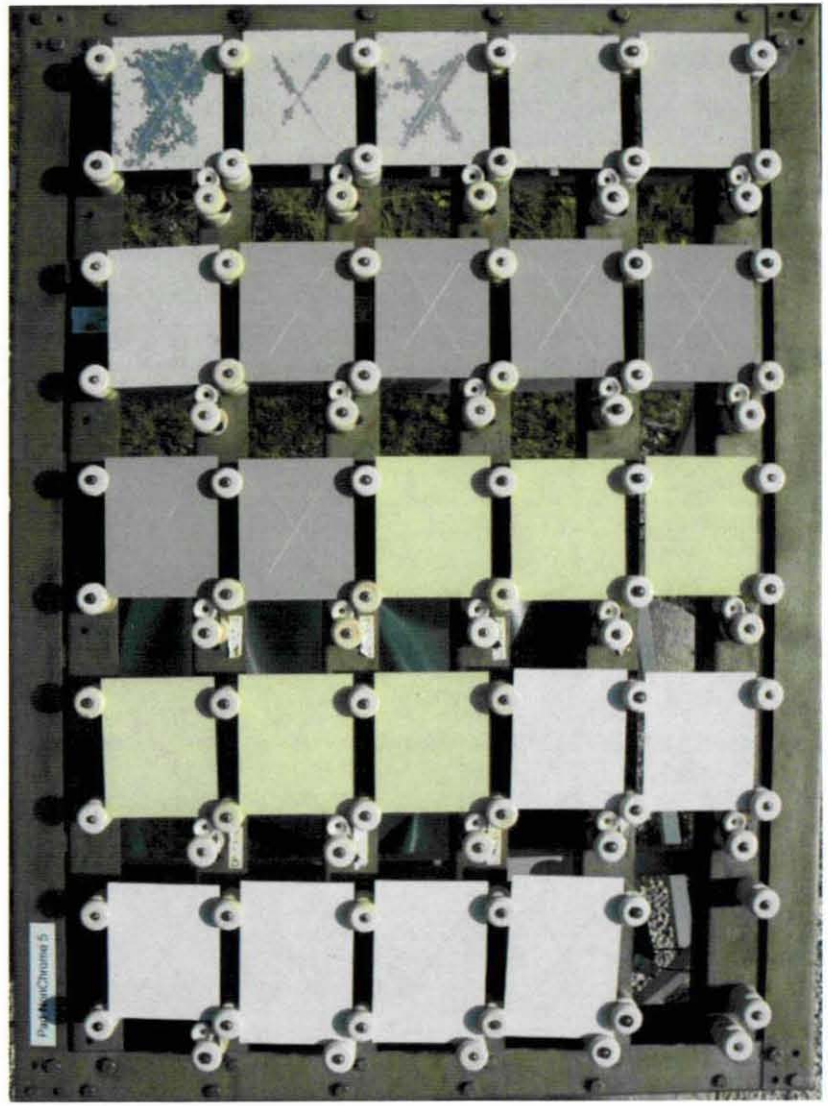
- **DOD**
  - Air Force
    - AFRL / RXSSO (Chris Joseph)
    - AFRL / CTIO (Bill Culhane)
    - Hill AFB (Wayne Patterson)
  - Navy
    - Craig Matzdorf, Steve Brown (NAVAIR)
  - Army
    - Steven Carr (ARMY)

- **Private Sector / OEMs**
  - Raytheon – Rich Spitzer
  - Lockheed Martin – Steve Deblasio
  - Spirit Aerosystems – Gary Taylor
  - ATK – Robert McBride


Pad Corrosion Rate 1 (bottom)




Pad NonChrome 5



JG-PP Research

Past Projects:

Chrome-Free Conversion Coating
Project Number: J-95-OC-001

Chromium-Free Primer for Inserts and Fasteners
Project Number: J-95-MF-003

Nonchromate Primers for Aircraft Exteriors
Project Number: J-95-OC-002

Low/No-VOC and Nonchromate Coating System for Support Equipment
Project Number: J-99-OC-014

Nonchromate Aluminum Pretreatments
Project Number: S-00-OC-016

Non-Chromate Primers for Military Applications
Project Number: 06-OC-030

Validation of Novel Electroactive Polymers (EAP) as Environmentally Compliant Coatings for Replacement of Hexavalent Chrome Pretreatments
ESTCP Project Number - WP-0527

Hexavalent Chrome Coating Alternatives for DoD/NASA Applications
Project Number: 08-OC-036 (Completed 2009)