NASA Technology Evaluation for Environmental Risk Mitigation
Kennedy Space Center, FL 32899

Validation of Environmentally-preferable Coatings for Launch Facilities

Final Stage 1 Test Report

July 31, 2014

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National Aeronautics and Space Administration (NASA)

Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM)

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PREFACE

This report was prepared by International Trade Bridge, Inc. (ITB) through the National Aeronautics and Space Administration (NASA) Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM). The structure, format, and depth of technical content of the report were determined by NASA TEERM, Government contractors, and other Government technical representatives in response to the specific needs of this project.

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- Ms. Joni Richards
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- Mr. Teddy Back
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- Mr. Rich Bliss
- Mr. Jim Trammel
- Ms. Diane Buhrmaster

This document has been prepared solely to report the results of the testing performed during this project and is not intended to and does not connote endorsement of any product by NASA.

EXECUTIVE SUMMARY

As people become more aware of the concerns associated with protective coatings, safety and environmental regulations increase. In response, manufacturers have developed coatings with lower volatile organic compound (VOC) content and that do not contain isocyanates and heavy metals. These coating systems must be evaluated, however, to determine whether they can meet the unique requirements of NASA launch facilities and ground support equipment.

The objective of this project is to determine the feasibility of environmentally friendly corrosion resistant coatings for carbon steel applications. The focus of the project is corrosion resistance and survivability of coatings for outdoor ambient (Zone 4) applications (as defined by NASA-STD-5008B, *Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment*, which can be found at http://corrosion.ksc.nasa.gov/pubs/NASA-STD-5008B.pdf) with the goal to reduce the amount of necessary maintenance and associated costs.

A group of project stakeholders from NASA Centers and the United States (U.S.) Air Force identified those key performance requirements that they felt were necessary to qualify alternative coating systems. The tests were divided into two phases. The screening tests deemed most important were identified at Phase 1 Tests and secondary tests were identified as Phase 2 tests in the Joint Test Plan (JTP) titled *Joint Test Protocol for Validation of Environmentally Preferable Coatings for Launch Facilities at Kennedy Space Center*, dated December 13, 2011, prepared by ITB.

A survey of commercially available coatings was conducted to identify potential alternatives for consideration. The group then reviewed each identified alternative and those showing the most promise were selected to undergo the validation process. This information was compiled into a Potential Alternatives Report (PAR) titled *Potential Alternatives Report for Validation of Environmentally-preferable Coatings for Launch Facilities*, dated April 20, 2012, prepared by ITB.

This Stage 1 Test Report covers the Phase 1 testing identified in the JTP of the potential alternatives identified in the PAR. Those coatings that show acceptable performance in Stage 1 Testing will then be subjected to the Phase 2 tests as identified in the JTP under the title of Stage 2 Testing.

TEERM worked with the NASA Corrosion Technology Laboratory (CTL) to conduct Stage 1 Testing which included the following performance requirements:

- Pot Life
- Ease of Application
- Surface Appearance
- Atmospheric Exposure Testing
- Heat Adhesion

Based on the results of the Stage 1 Testing, it is recommended that the following systems continue to Stage 2 Testing:

- System 2 (isocyanate-free)
    - Primer: Carboline Carbozinc 11 WB
    - Intermediate: Carboline Carbotherm 3300
    - Topcoat: Carboline Carbocyrlic 3359

- System 4 (isocyanate-free)
    - Primer: Polyset Ply-Zinc WB 18
    - Topcoat: Polyset Ply-Guard ME

- System 9 (isocyanate-free and zinc-free)
    - Primer/Topcoat: EonCoat Alloyed Coating for Steel

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LIST OF ACRONYMS/SYMBOLS

F	Degrees Fahrenheit
ΔE	Overall Color Change
AFSPC	Air Force Space Command
APL	Approved Products List
ASTM	American Society for Testing and Materials
CTL	Corrosion Technology Laboratory
DFT	Dry Film Thickness
GSDO	Ground Systems Development and Operations
in	inch
ITB	International Trade Bridge, Inc.
JTP	Joint Test Protocol
KSC	NASA John F. Kennedy Space Center
mil	0.001 inches
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
PAR	Potential Alternatives Report
psi	pounds per square inch
SMEs	Subject Matter Experts
SSPC	The Society for Protective Coatings
TEERM	Technology Evaluation for Environmental Risk Mitigation Principal Center
U.S.	United States
VOC	Volatile Organic Compound

1. INTRODUCTION

National Aeronautics and Space Administration (NASA) Headquarters chartered the Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) to coordinate agency activities affecting pollution prevention issues identified during system and component acquisition and sustainment processes. The primary objectives of NASA TEERM are to:

- Be an integration activity for the Agency to help improve NASA's ability to adopt new environmental or energy technologies to reduce unacceptable mission risks in a more proactive and cost effective manner, and to better position itself to respond to new global regulatory and business paradigms.
- Foster collaboration on projects to reduce duplication of effort and costs of technology validation.
- Ensure project results are applicable to current and future NASA programs.

The Ground Systems Development and Operations (GSDO) Program at NASA John F. Kennedy Space Center (KSC), Florida, has the primary objective of modernizing and transforming the launch and range complex at KSC to benefit current and future NASA programs along with other emerging users. Described as the "launch support and infrastructure modernization program" in the NASA Authorization Act of 2010, the GSDO Program will develop and implement shared infrastructure and process improvements to provide more flexible, affordable, and responsive capabilities to a multi-user community.

In support of NASA and the GSDO Program, the objective of this project is to determine the feasibility of environmentally friendly corrosion protecting coatings for launch facilities and ground support equipment. The focus of the project is corrosion resistance and survivability with the goal to reduce the amount of maintenance required to preserve the performance of launch facilities while reducing mission risk. The project compares coating performance of the selected alternatives to existing coating systems or standards.

In keeping with the NASA TEERM mission, Subject Matter Experts (SMEs) were identified from within and outside of NASA to ensure project results have applicability to multiple NASA Centers and/or Programs. Project stakeholders are included from the following entities:

- NASA GSDO Program
- KSC
- NASA John C. Stennis Space Center (SSC)
- NASA Wallops Flight Facility
- NASA White Sands Test Facility
- U.S. Air Force Space Command
- Cape Canaveral Air Force Station
- Air Force Space and Missile
- University of Dayton Research Institute

A joint group led by ITB and consisting of SMEs from NASA and other entities reached technical consensus on engineering, performance, and testing requirements for environmentally-preferable alternative coatings. The joint group defined critical tests with procedures, methodologies, and acceptance criteria to qualify alternatives against these technical requirements in a Joint Test Protocol (JTP) titled *Joint Test Protocol for Validation of Environmentally Preferable Coatings for Launch Facilities at Kennedy Space Center*, dated December 13, 2011, prepared by ITB.

A potential alternatives report (PAR) titled *Potential Alternatives Report for Validation of Environmentally-preferable Coatings for Launch Facilities*, dated April 20, 2012, prepared by ITB, provides technical analysis of identified alternatives to the current coatings, criteria used to select alternatives for further analysis, and a list of those alternatives recommended for Stage 1 Testing. An addendum to the PAR was prepared that identified additional alternatives for testing titled *Addendum to Potential Alternatives Report for Validation of Environmentally-preferable Coatings for Launch Facilities*, dated May 28, 2013, prepared by ITB.

Due to the amount of funding received, the project was divided into three (3) stages.

- Stage 1 Testing: Phase 1 testing as identified in the JTP on the original coating alternatives selected in the PAR.
- Stage 2 Testing: Phase 2 testing as identified in the JTP on the original coating alternatives selected in the PAR that showed acceptable performance during Stage 1 Testing.
- Stage 3 Testing: Phase 1 and Phase 2 Testing as identified in the JTP on the additional coating alternatives identified in the addendum to the PAR.

Stage 1 Testing only includes Phase 1 Testing (as described in the JTP) of the potential alternatives identified in the original PAR. This report documents the results of the laboratory testing as well as any test modifications made during the execution of the Stage 1 Testing only. The technical stakeholders agreed upon any test procedure modifications documented in this document. This report is made available as a reference for future pollution prevention endeavors by GSDO Program, other NASA Centers, the Department of Defense (DOD) and commercial users to minimize duplication of effort.

2. BACKGROUND

NASA is responsible for a number of facilities/structures with metallic structural and non-structural components in a highly corrosive environment. Metals require periodic maintenance activity to guard against the insidious effects of corrosion and thus ensure that structures meet or exceed design or performance life. The standard practice for protecting metallic substrates in atmospheric environments is the application of corrosion protective coating system. These coating systems work via a variety of methods (barrier, galvanic and/or inhibitor) and adhere to the substrate through a combination of chemical and physical bonds.

Maintenance at KSC is governed by NASA-STD-5008B (*Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment*, which can be found at http://corrosion.ksc.nasa.gov/pubs/NASA-STD-5008B.pdf), which establishes practices for the protective coating of launch facilities used by or for NASA programs and projects.

The Standard is also recommended guidance for all NASA Centers and is for the design of non-flight hardware used to support the operations of receiving, transportation, handling, assembly, inspection, test, checkout, service, and launch of space vehicles and payloads at NASA launch, landing, or retrieval sites. The criteria and practices contained within the Standard may be applied to items used at the manufacturing, development, and test sites upstream of the launch, landing, or retrieval sites.

NASA-STD-5008B includes an "Approved Products List" (APL) of coatings that have previously been tested and qualified. The APL, however, includes coatings that have very high volatile organic compound (VOC) levels which are no longer compliant with current environmental regulations. Some contain other hazardous constituents that are also subject to regulation. The limited number of approved coatings in NASA-STD-5008B presents a risk to NASA if the material should become unavailable.

The anticipated benefits to the Government from this project include:

- Project builds off of previously successful NASA and Air Force Space Command (AFSPC) testing.
- Reduced risk for materials obsolescence from environmental, safety, and health concerns for coatings with VOCs and heavy metals.
- Reduced environmental impacts from VOCs, hazardous air pollutants (HAPs), and other materials controlled under various Federal and State regulations.
- Improved worker safety.

If a qualified technology is implemented, it may:

- Help NASA meet environmental and safety regulatory requirements.
- Decrease risk of environmental, worker, and public exposure.
- Reduce maintenance costs and government liability.

This project considered the findings of coatings project work completed or in progress by NASA TEERM, industry, and other United States (U.S.) Federal Agencies and builds upon previous NASA TEERM work to qualify coatings for use on launch facilities and ground support equipment including:

- Eastern Range Coatings Support Project
- Coatings Demonstration/Validation at Vandenberg Air Force Base Project
- Launch Coatings Phase 3 Project
- Low VOC Coatings and Depainting Field Testing Phase 2 Project
- Isocyanate-free Coatings for Structural Steel Project

The primary objective of this effort is to demonstrate and validate environmentally-preferable alternatives in accordance with NASA-STD-5008B which can then be added to the APL used as a specification in contracts by NASA. Many other entities, such as AFSPC, also reference the Standard in their corrosion control plans, thus providing additional government benefits.

3. JOINT TEST PROTOCOL

A joint group consisting of SMEs from NASA and other entities reached technical consensus on engineering, performance, and testing requirements for environmentally-preferable alternative coatings. The joint group defined critical tests with procedures, methodologies, and acceptance criteria to qualify alternatives against these technical requirements in the JTP.

During the initial development of this project, there was uncertainty regarding the amount of funding that would be available to conduct testing. In order to provide the most valuable data regardless of the amount of funding received the testing requirements were divided into two (2) phases. Tests deemed those that would provide the most valuable data to project participants were identified as Phase 1 performance requirements and secondary tests were identified as Phase 2 in the JTP titled *Joint Test Protocol for Validation of Environmentally Preferable Coatings for Launch Facilities at Kennedy Space Center*, dated December 13, 2011, prepared by ITB.

Stage 1 Testing only included the Phase 1 test requirements. Table 1 summarizes the Phase 1 test requirements for validating alternative coating systems against existing approved coating systems. The table includes acceptance criteria and the reference specifications, if any, used to conduct the tests. The tests and evaluation are based on the aggregate knowledge and experience of the assigned technical project personnel and prior testing where "None" appears under *Test Methodology References*. The most recent revision was used unless otherwise noted.

Copies of the specifications cited may be found at the NASA Standards and Technical Assistance Resource Tool website (https://standards.nasa.gov/), The Society for Protective Coatings (SSPC) website (http://www.sspc.org/), The American Society for Testing and Materials (ASTM) website (http://www.astm.org/), and NACE International website (http://www.nace.org/standards/).

Table 1 Phase 1 Performance Requirements				
Test	***JTP Section***	***Test Specimen***	***Acceptance Criteria***	***Test Methodology References***
Pot Life	3.1.1.	Mixed Coating System	Equal to or better than control coating based upon Applicator Evaluation	None
Ease of Application	3.1.2.	Coupon	Based on Applicator Evaluation: Smooth coat, with acceptable appearance, no runs, bubbles or sags; Ability to cover the properly prepared/primed substrate with a single coat (one-coat hiding ability); Measure Dry Film Thickness	SSPC-PA-2
Surface Appearance	3.1.3.	Coupon	Based on Applicator Evaluation: No streaks, blistering, voids, air bubbles, cratering, lifting, blushing, or other surface defects/irregularities; No micro-cracks observable at 10X magnification	ASTM D 523; ASTM D 2244
Atmospheric Exposure	3.1.4.	Coupon	Gloss/color change and panel condition of candidate coating rated equal to or better than control coatings	ASTM D 2244; ASTM D 523; ASTM D 610; ASTM D 714; ASTM D 523; NASA-STD-5008B
Heat Adhesion	3.1.5.	Coupon	No loss of adhesion after heating at 750 degrees Fahrenheit (F) for 24 hours	ASTM D 4541; NASA-STD-5008B

4. POTENTIAL ALTERNATIVES ANALYSIS

The primary objective of this effort is to demonstrate and validate environmentally-preferable alternatives to currently used coating systems for Zone 4a applications as defined by NASA-STD-5008B:

> <u>*Zone 4a.*</u> *Surfaces not located in the launch environment but located in a neutral pH corrosive marine industrial environment or other chloride-containing environments.*

Identifying and selecting alternative materials and technologies that have the potential to reduce the identified hazardous materials, while incorporating sound corrosion prevention and control technologies, is a complicated task due to the fast pace at which new technologies emerge and rules change. Alternatives were identified through literature searches, electronic database and Internet searches, surveys, and/or personal and professional contacts.

4.1 Alternative Coating System Identification

A survey of commercially available technologies was performed to identify potential alternative coating systems. In addition to research using the World Wide Web, existing Potential Alternative Reports and Test Reports were reviewed along with other surveys to leverage available test and performance data for this project. Manufacturers and distributors of identified alternatives were contacted, and technical, environmental, safety, and occupational health information about the alternatives was gathered and compared with the baseline process.

Information about potential alternatives for Stage 1 Testing is documented in the *Potential Alternatives Report for Validation of Environmentally-preferable Coatings for Launch Facilities*, dated April 20, 2012, prepared by ITB. The following sections summarize the data gathered.

4.1.1 Commercial Availability

The first requirement for all alternatives is that they are commercially available in the U.S.; if not, they were not included as a potential alternative. Information about international products was documented, however, in order to continue to monitor their availability for future efforts.

4.1.2 Environmental, Safety, and Occupational Health Review

Each alternative was evaluated to determine the extent of its regulation under the major federal environmental laws. There may be additional state, local, or site specific regulations that were not considered in this project.

Based on the product Material Safely Data Sheet (MSDS), each alternative was evaluated for the following:

- Air Emissions per the Clean Air Act (CAA) and National Emissions Standards for Hazardous Air Pollutants (NESHAPs)
- Solid/Hazardous Waste Generation per the Resource Conservation and Recovery Act (RCRA)
- Reporting requirements per Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA)
- Hazardous Substances per Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

4.1.2.1. Volatile Organic Compounds (VOCs)

The general definition of VOCs is any organic chemical compound whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects; and can be an indoor or outdoor hazard.

The main concern indoors is the potential for VOCs to adversely impact the health of people that are exposed. While VOCs can also be a health concern outdoors, the U.S. Environmental Protection Agency (USEPA) regulates VOCs outdoors mainly because of their ability to create photochemical smog under certain conditions. VOCs are regulated by the USEPA under the Clean Air Act (CAA) [42 U.S.C. §7401 et seq. (1970)].

4.1.2.2. Hazardous Air Pollutants (HAPs)

HAPs, also known as toxic air pollutants or air toxics, are those pollutants that cause or may cause cancer or other serious health effects, such as reproduction effects or birth defects, or adverse environmental and ecologic effects.

National Ambient Air Quality Standards (NAAQS) were established by the USEPA under authority of the CAA that apply for outdoor air throughout the country. Primary standards are designed to protect human health, with an adequate margin of safety, including sensitive populations such as children, the elderly, and individuals suffering from respiratory diseases. Secondary standards are designed to protect public welfare from any known or anticipated effects of a pollutant.

The National Emissions Standards for Hazardous Air Pollutants (NESHAPs) are emission standards set by the USEPA for an air pollutant not covered by NAAQS. The USEPA is required to control 187 HAPs currently listed under the NESHAPs [Section 112 of the CAA published in 40 Code of Federal Regulations (CFR) Parts 61 and 63].

4.1.2.3. Isocyanates

Isocyanates are compounds containing the isocyanate group (-NCO). They react with compounds containing alcohol (hydroxyl) groups to produce polyurethane polymers, which are components of polyurethane foams, thermoplastic elastomers, spandex fibers, and polyurethane paints.

The Occupational Health & Safety Administration (OSHA) states that the effects of isocyanate exposure include irritation of skin and mucous membranes, chest tightness, and difficult breathing. Isocyanates are classified as potential human carcinogens and are known to cause cancer in animals. The main effects of overexposure are occupational asthma and other lung problems, as well as irritation of the eyes, nose, throat, and skin.

OSHA requires employers to provide a work environment that minimizes or eliminates exposure to isocyanate-containing products. A major concern is that despite working safely around the same materials for years, exposure to isocyanates have been known to suddenly produce sensitivities that can be deadly.

Although an isocyanate-free system is desired, there are not many isocyanate-free systems available that are applicable to the stated applications. The use of isocyanate-containing materials is banned at SSC, but not other NASA Centers; therefore some alternative systems selected for testing include isocyanates.

4.1.2.4. Heavy Metals

Heavy metals are chemical elements that have a specific gravity at least five (5) times that of water. The heavy metals most often associated with coating applications are lead, chromium, cadmium, and zinc.

Lead

Lead is a naturally-occurring element that can be harmful to humans when ingested or inhaled. Lead poisoning can cause a number of adverse human health effects and is particularly dangerous because there may be no unique signs or symptoms. Failure to treat lead poisoning in the early stages can cause long-term or permanent health damage.

Lead particles in the environment can attach to dust and be carried long distances in the air. Such lead-containing dust can be removed from the air by rain and deposited on surface soil, where it may remain for many years. In addition, heavy rains may cause lead in surface soil to migrate into ground water and eventually into water systems.

Lead was commonly used in paints until 1977 when the U.S. government's Consumer Product Safety Commission (CPSC) banned lead paint under 16 CFR 1303. For manufacturers, the CPSC instituted the Consumer Product Safety Improvement Act of 2008 which changed the regulations on lead content of paint from 0.06% to 0.009%.

The USEPA has established standards designed to limit the amount of lead in air. The National Institute for Occupational Safety and Health (NIOSH) also recommends that workers not be exposed to lead and limits the amount of exposure to less than 100 micrograms per cubic meter (µg/m^3) in a ten hour period.

Chromium

Chromium is a metallic element in the periodic table that is odorless and tasteless. Chromium is found naturally in rocks, plants, soil and volcanic dust, humans and animals. Chromium occurs in the environment primarily in two valence states, trivalent chromium (Cr III) and hexavalent chromium (Cr VI). Hexavalent chromium (Cr VI) is commonly used in industrial applications such as chromate pigments in dyes, paints, inks, and plastics; chromates added as anticorrosive agents to paints, primers, and other surface coatings; and chromic acid electroplated onto metal parts to provide a decorative or protective coating.

All forms of hexavalent chromium are regarded as carcinogenic to workers according to numerous regulatory and advisory bodies, including the USEPA, the National Toxicology Program (NTP), the International Agency for Research on Cancer (IARC), and the American Conference of Governmental Industrial Hygienists (ACGIH). The risk of developing lung cancer increases with the amount of hexavalent chromium inhaled and the length of time that the worker is exposed.

Hexavalent chromium can also irritate the nose, throat, and lungs. Direct eye contact with chromic acid or chromate dusts can cause permanent eye damage. Prolonged skin contact can result in dermatitis and skin ulcers. Some workers develop an allergic sensitization to chromium such that even small amounts can cause a serious skin rash.

Cr VI is listed as a HAP under Title III of the CAA and emissions are regulated under the NESHAPs. Other regulations include the Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA), and Emergency Planning and Community Right-To-Know Act (EPCRA). The Department of Transportation also enforces special requirements for marking, labeling, and transporting Cr VI.

In February 2006, OSHA lowered the Cr VI time weighted average permissible exposure limit for general industry from 100 µg/m^3 (micrograms per cubic meter) to 5 µg/m^3 under 29 CFR 1910.1026. OSHA included a special section of regulations for the aerospace industry and set a higher exposure limit of 25 µg/m^3 for large scale hangar-type operations. The regulation specifically refers to painting of aircraft or large aircraft parts in the aerospace industry. An Action Level was set at 2.5 µg/m^3, and at this threshold, the use of personal protective equipment and/or the implementation of engineering controls is required.

Another requirement that affects Cr VI usage is Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*. Federal organizations are encouraged to reduce the quantities of toxic and hazardous materials, such as Cr VI, that are acquired, used, or handled. Some Department of Defense (DoD) contracts already prohibit the use of Cr VI in finished products.

Cadmium

Cadmium is a metallic element in the periodic table that is an extremely toxic metal commonly found in industrial workplaces. Cadmium is used extensively in electroplating and is also found in some industrial paints.

Acute exposure to cadmium fumes may cause flu-like symptoms including chills, fever, and muscle aches. Symptoms may resolve after a week if there is no respiratory damage. More severe exposures can cause permanent respiratory tract damage. Inhaling cadmium-laden dust leads to respiratory tract and kidney problems which can be fatal. Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and kidneys. Cadmium poisoning can also cause bones to become soft, lose bone mineral density, and become weaker. Compounds containing cadmium are considered carcinogenic.

Cadmium is classified as a toxin and as a known or probable carcinogen by numerous regulatory and advisory bodies, including the USEPA, NTP, IARC, ACGIH, and NIOSH. Cadmium is also listed as a HAP under Title III of the CAA and emissions are regulated under the NESHAPs.

OSHA has published a new standard for occupational exposure to cadmium, applicable to general industry and agriculture and maritime (29 CFR 1926.63). A separate standard regulating exposure to cadmium in the construction industry was also developed, because the differences in job duration, exposure and worksite conditions warrant unique treatment.

The new standard establishes a single eight (8)-hour time weighted average permissible exposure limit of 5 $\mu g/m^3$ of air for all cadmium compounds, including dust and fumes. Employers are required to comply with this limit primarily by means of engineering and work practice controls. For a small number of industries, OSHA has also established separate engineering control air limits of either 15 $\mu g/m^3$ or 50 $\mu g/m^3$ as the lowest feasible levels above the PEL that can be achieved by engineering and work practice controls.

Another requirement that affects cadmium usage is Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*. Federal organizations are encouraged to reduce the quantities of toxic and hazardous materials, such as cadmium, that are acquired, used, or handled.

Zinc

Zinc is one of the most common elements in the earth's crust. It is found in air, soil, and water, and is present in all foods. It has a number of characteristics that make it well-suited for use as a coating for protecting iron and steel products from corrosion. The excellent field performance of zinc coatings results from the dense adherent corrosion product film that they form and the fact that its rate of corrosion is considerably lower than that of ferrous materials. The zinc acts as a sacrificial barrier between the substrate and environment.

Although zinc is an essential element for humans, it can also be toxic at high exposure levels. It can cause stomach cramps, anemia, and changes in cholesterol levels. The primary effects of zinc are the development of metal fume fever and effects of zinc on copper status.

Zinc is listed by the USEPA as one of Priority Pollutants under the CWA (Appendix A to 40 CFR Part 423). Zinc is also included in the Priority List of Hazardous Substances under the CERCLA as amended by SARA [42 U.S.C. §9601 et seq. (1980)]. To protect workers, OSHA and NIOSH have set standards for worker exposure to zinc chloride fumes and zinc oxide dusts and fumes in the workplace.

Zinc can have a significant local environmental impact. In parts of the world where there are large deposits, zinc can get into the water supply at levels which are toxic to fish and potentially to humans. Zinc can accumulate in aquatic organisms but not in plants, and be toxic to such species and those that feed off them.

At KSC, soil and sediment samples from the launch pads during a RCRA Facility Investigation (RFI) in 1998 showed increased levels of zinc. The Addendums for the investigation determined that there were potential impacts to the ditch and lagoonal system surrounding the pads. The Hazard Quotients for ecological receptors is very high for zinc and the USEPA and Florida Department of Environmental Protection agreed that no further assessment would be conducted during the Space Shuttle Program (SSP). Since the completion of the SSP, additional assessments will be conducted to determine the actual risk and a decision made regarding potential clean-up.

Although a zinc-free system is desired, there are not many zinc-free systems available that are applicable to the stated applications. Most zinc-free systems are powder coatings that require oven curing which is not feasible on large structures. Zinc use is not banned at this time, so some alternative systems selected for testing include zinc.

4.1.3 Technical Feasibility

Potential alternatives were also evaluated for their technical feasibility. It was decided by project participants that a "drop-in replacement" was preferred. A "drop-in replacement" means that the alternative should use similar equipment and have similar requirements as the baseline material.

The baseline process information was gathered by method of interview of participants. The descriptions are based on "typical" and generalized coating application processes, and are not the exact processes used by any of the participants of this project. Although the typical system is three coats, there are applications where only a one coat system (primer) is used. There are also two coat systems approved (primer and topcoat) in which an intermediate coat is not required. Therefore, one-, two-, and three-coat systems were considered for this project.

Finally, the anticipated performance of the coating system was considered based on a comparison of advantages and disadvantages and available test data.

4.2 Selected Coating Alternatives for Stage 1 Testing

Sixteen (16) coating alternative manufacturers were identified as making potential replacements for a total of 21 potential alternatives for consideration. A total of 11 alternative coatings were selected for testing through a series of discussions and decision making that occurred over several months, as outlined below.

By February 2012, the technical team had selected nine (9) alternatives deemed most promising for testing, as documented in the PAR dated April 20, 2012. The number of coatings selected was based on project budget and technical potential while also being environmentally friendly. The PAR evaluated each potential alternative based on various aspects of environmental, health and occupational safety concerns; required process equipment; and anticipated performance. Group members reviewed and discussed this information during team meetings.

In May 2012, after the PAR was published, a tenth alternative—EonCoat™ —was added to the list of alternatives to be tested at the suggestion of the NASA CTL. This decision resulted from new information learned about the alternative. EonCoat™ had originally been evaluated during the PAR process, but was rejected for technical reasons—it requires the use of dual component spray equipment which is not typically used by NASA. Aside from that limitation, EonCoat™ appeared promising, having performed well in corrosion tests conducted by the NASA CTL earlier. Based on those results, the fact that the required equipment is not cost prohibitive, and that there was funding available to include it in the project budget; project participants decided that they would like additional test data on EonCoat™.

NASA CTL has also been working with the GSDO Program on further development of a “smart” coating. The basis of the “smart” coating is microcapsules that contain both a corrosion indicator (pH indicator) and corrosion inhibitor. The coatings are called “smart” because they change material properties in response to an environmental stimulus. Their advantage is that they can effectively send a signal to maintenance crews when the underlying metal is corroding, thus optimizing maintenance resources.

The NASA CTL has been working with coating manufacturers to incorporate the microcapsules into commercially available products. During the initial alternative identification, a product was not yet available. However, in July 2012, a coating system by Carboline incorporating the NASA CTL developed microcapsules became available for testing. Project participants decided to include this “smart” coating in this study because it further supports the GSDO Program and did not add any significant costs to the project.

Table 2 identifies those alternatives selected for Stage 1 Testing along with the baseline control coating system.

Table 2 Coating Alternatives Selected for Stage 1 Testing			
Manufacturer	***Primer***	***Intermediate***	***Topcoat***
A&E Group	N/A	N/A	Alocit 28.15 Standard Grade Epoxy Coating Primer/Finish
A&E Group	Alocit 28.14 Epoxy Coating-Zinc Primer	N/A	Alocit 28.15 Standard Grade Epoxy Coating Primer/Finish
Carboline	Carbozinc 11 WB	Carbotherm 3300	Carbocyrlic 3359
Carboline	Carbomastic 615	Carboguard 893	Carbothane 134 MC
Polyset	Ply-Zinc WB 18	N/A	Ply-Guard ME
Polyset	N/A	N/A	Ply-Guard ME
Pratt & Lambert	Universal HP Acrylic Primer Z6631	N/A	Acrylic Waterborne DTM Z6841
Shield Products	SKU40003	N/A	SKU20059VC
Tesla	TESLAN ZN Primer (Low VOC)	N/A	TESLAN Low VOC Urethane Topcoat (XUR-12041)
EonCoat	N/A	N/A	EonCoat
Carboline	Carbomastic 615 with uCapsules	Carboguard 893	Carbothane 134MC
Ameron **(Baseline System)**	Dimetcote 9H	Amerlock 400	Amercoat 450H

N/A = Not Applicable

5. TESTING ACTIVITIES

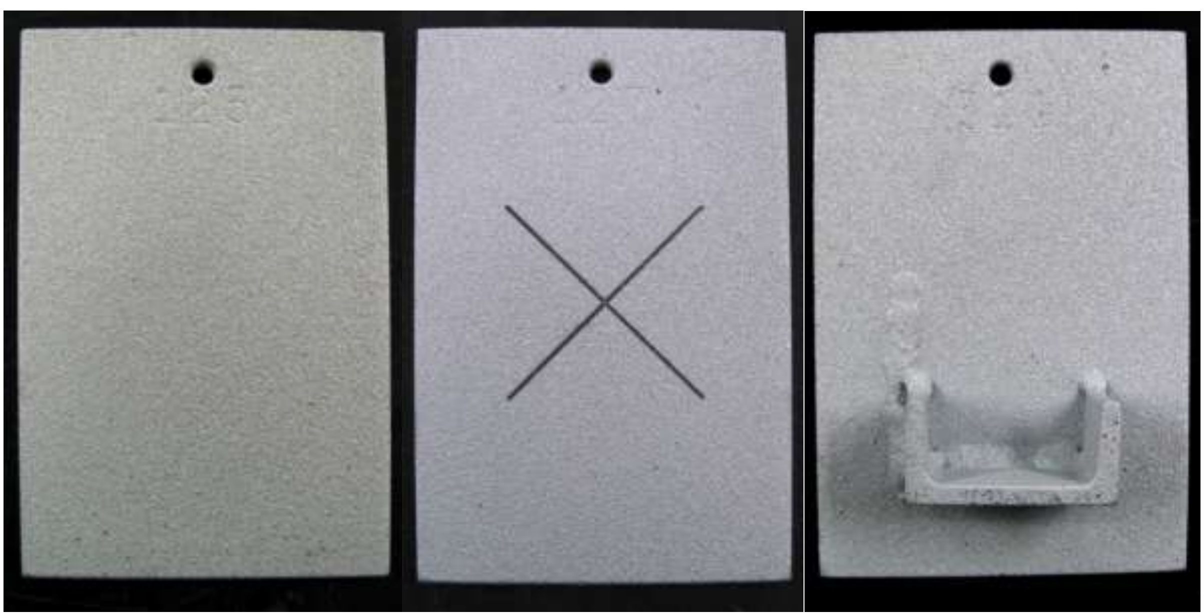
The testing activities for this project were performed by the NASA CTL located at KSC. The NASA CTL has the facilities and expertise necessary to provide reliable data that allows project participants to feel confident in project results.

The following sections present the results of Stage 1 Testing.

5.1 Testing Preparation

The NASA CTL support contract was recently awarded to a new contractor and as a result, there were some issues encountered due to changes in procedures. For example, the NASA CTL was responsible for purchasing testing materials. The new contractor's purchasing process is different and takes longer than the old process which resulted in a delay in the start of actual testing of approximately two (2) months. This did not affect the overall project schedule however.

The NASA CTL procured the required test coupons and alternative coating systems. The test panels were KTA-Tator 4 inches x 6 inches x 3/16 inches flat and composite panels, fabricated from ASTM A 36 (*Standard Specification for Carbon Structural Steel*) hot rolled carbon steel. The composite panels have a 1" channel welded on the front face. The composite test panels incorporate common surface irregularities such as welds, crevices, and sharp edges. Figure 1 shows the type of panels prepared for this project.



Flat ***Flat Scribed*** ***Composite***

Figure 1 Typical Test Panels Used for this Project

All panels were abrasive blasted to a white metal per SSPC-SP-5 (*White Blast Cleaning*) to remove any mill scale and weld slag. The anchor profile created by the abrasive blasting was measured ranging from 2.5 to 3.0 mils (1 mil = 0.001 inches) as measured by the Test-X replica tape method prior to coating. All surfaces of the test panels were coated with the prescribed coating system.

The coating of test coupons was documented using the Application Record Sheet in NASA-STD-5008B, or an equivalent form. For each test requiring coupons, a minimum of five (5) coupons were prepared; those with the best coating as determined by the technician were used in accordance with the number of coupons required as specified in the *Test Methodology*. Unless otherwise noted, test coupons are 4 inches wide by 6 inches long.

Test coupons were allowed a minimum of 24 hours of unaided drying time prior to dry film thickness measurements. Test coupons were also allowed to cure for an additional 14 days before undergoing any destructive testing to ensure full polymerization of the coating.

Each coating system was prepared and applied according to instructions provided by the manufacturer. Coating systems were applied by spraying to the dry film thickness recommended by the coating manufacturer. If a topcoat was applied over the primer, the topcoat was applied within 24 hours of primer application.

Figures 2 and 3 show test panels being prepared by NASA CTL engineers.

Figure 2 Application of Alternative Coating to Test Panel

Figure 3 Quality Control Check during Application of Alternative Coating to Test Panel

5.2 Pot Life Testing

Test Description

This test is based on the Applicator Evaluation who makes note of any issues experienced by the applicator in regards to pot life during the application process. This evaluation was conducted while preparing test coupons.

Rationale

This test provides data to characterize the pot life envelope. Pot life is a concern for project participants because it can affect the time available to maintenance personnel to apply the coating and if too short, can cause an unacceptable coating resulting in poor performance.

Data Analysis and Reporting

- This test was conducted while the test panels required for this project were prepared and is based on Applicator Evaluation.
- Coatings were mixed according to the manufactures' recommendations.
- Results Summary
    1. A&E Group had two (2) coating systems selected (One Coat System: Alocit 28.15 Epoxy Topcoat as a stand-alone and Two Coat System: Alocit 28.14 Zinc Epoxy Primer and 28.15 Epoxy Topcoat) for testing.
        - The coatings heated up very quickly; however, and catalyzation began before application could commence.
        - Due to these difficulties, test panels for only one A&E Group coating system were prepared for testing (Two Coat System: Alocit 28.14 Zinc Epoxy Primer and 28.15 Epoxy Topcoat).
        - The One Coat System (Alocit 28.15 Epoxy Topcoat as a stand-alone) was removed from the test matrix.
    2. The "Smart" Carboline system (Carbomastic 615 with uCapsules Primer, Carboguard 893 Intermediate and Carbothane 134MC Topcoat) was also very fast reacting and required a static mixing tip that mixed the coating constituents while being sprayed in order to avoid Pot Life issues. The coating was applied successfully using a Plas-Pak, Ratio-Pak® Industrial Spray Dispenser plural component system.
    3. The other alternative coating systems had no issues with Pot Life.
- Table 3 shows the coating systems that had test panels prepared for this project and the system designations that will be referred to throughout the remainder of this report.

Table 3 Coating Systems Tested under Stage 1				
System	***Manufacturer***	***Primer***	***Intermediate***	***Topcoat***
Baseline System	Ameron	Dimetcote 9H	Amerlock 400	Amercoat 450H
1	A&E Group	Alocit 28.14 Epoxy Coating-Zinc Primer	N/A	Alocit 28.15 Standard Grade Epoxy Coating Primer/Finish
2	Carboline	Carbozinc 11 WB	Carbotherm 3300	Carbocyrlic 3359
3	Carboline	Carbomastic 615	Carboguard 893	Carbothane 134 MC
4	Polyset	Ply-Zinc WB 18	N/A	Ply-Guard ME
5	Polyset	N/A	N/A	Ply-Guard ME
6	Pratt & Lambert	Universal HP Acrylic Primer Z6631	N/A	Acrylic Waterborne DTM Z6841
7	Shield Products	SKU40003	N/A	SKU20059VC
8	Tesla	TESLAN ZN Primer (Low VOC)	N/A	TESLAN Low VOC Urethane Topcoat (XUR-12041)
9	EonCoat	N/A	N/A	EonCoat
10	Carboline	Carbomastic 615 with uCapsules	Carboguard 893	Carbothane 134MC

5.3 Ease of Application

Test Description

As test coupons were prepared, the applicator noted appropriate coating application processes and equipment. This evaluation was conducted while preparing test coupons and made note of any issues experienced by the applicator. Dry Film Thickness (DFT) measurements in accordance with SSPC-PA-2 (*Measurement of Dry Coating Thickness with Magnetic Gages*) were also recorded.

Rationale

This procedure is used to determine how easily a coating system may be applied. It is conducted to identify and eliminate those candidate coating systems that are difficult to properly apply under normal maintenance operation conditions. Difficult to apply coatings can cause an unacceptable coating resulting in poor performance.

Data Analysis and Reporting

- This test was conducted while the test panels required for this project were prepared and is based on Applicator Evaluation.
- DFT measurements were collected for each coating layer (primer, intermediate, topcoat) in accordance with SSPC-PA-2. Measurements were made during the application process using a Delfesko Positector 6000, type II coating thickness gauge (accuracy of +/-0.05 mils +1%).
- Results Summary:
    1. The zinc primers were applied using a pressurized agitated pot with a conventional spray gun.
    2. Other non-zinc primers, intermediates, and topcoats were applied using standard application techniques and a high velocity, low pressure spray gun except for Systems 1 and 10.
        - System 1 test panels were prepared by mixing small amounts of coating and using a brush for application due to the Pot Life issues. This is a slow and tedious process if used for large areas.
        - System 10 required a specialized static mixing tip attached to a spray gun due to Pot Life issues, but was easily applied utilizing the recommended equipment.
- Table 4 shows the applied and recommended DFT for each coating system.

Table 4 Applied and Recommended DFT's per System

System	***Primer***		***Intermediate***		***Topcoat***	
	Applied *	***Range***	***Applied ****	***Range***	***Applied ****	***Range***
Baseline	3	2-4	5	4-8	3	2-3
1	9	4-8	n/a	n/a	8	8-16
2	3	3-4	30	15-25**	3	2-3
3	9	5-10	7	4-10	4	2-3
4	3	2-4	n/a	n/a	7	4-6
5	6	4-6	n/a	n/a	n/a	n/a
6	2	2-4	n/a	n/a	3	2.5-4
7	n/a	n/a	n/a	n/a	3	1-2**
8	5	2-6	n/a	n/a	4	2-4
9	56	Up to 60	n/a	n/a	n/a	n/a
10	9	5-10	6	4-10	3	2-3

* Total DFT average of 12 panels in set
** per coat/multiple coats allowed

5.4 Surface Appearance

Test Description

The surface of each coated test coupon was examined for coating defects with the unaided eye and with 10X magnification. Defects include micro-cracks extending no more than ¼-inch from the panel edge or an orange peel appearance. The surface appearance of the topcoat is evaluated only after the entire coating system was applied. This evaluation was conducted while preparing test coupons and makes note of any issues experienced by the applicator.

Rationale

This test is conducted to provide critical detailed evaluation of coating appearance and integrity. Surface appearance can equate to an unacceptable coating resulting in poor performance.

Data Analysis and Reporting

- A minimum of 19 panels per alternative system were prepared.
  1. Atmospheric Exposure Testing:
     - Four (4) Primer-only composite panels
     - Four (4) Full System composite panels
     - Four (4) Full System flat panels with 0.32 centimeter (1/8 inch) scribe
     - Four (4) Full System extra panels
  2. Heat Adhesion Testing: Three (3) Primer-only flat panels
- Results Summary: No micro-cracks or defects were noted on any of the coatings.
- Figure 4 shows the coupon matrix prepared for each alternative coating system.

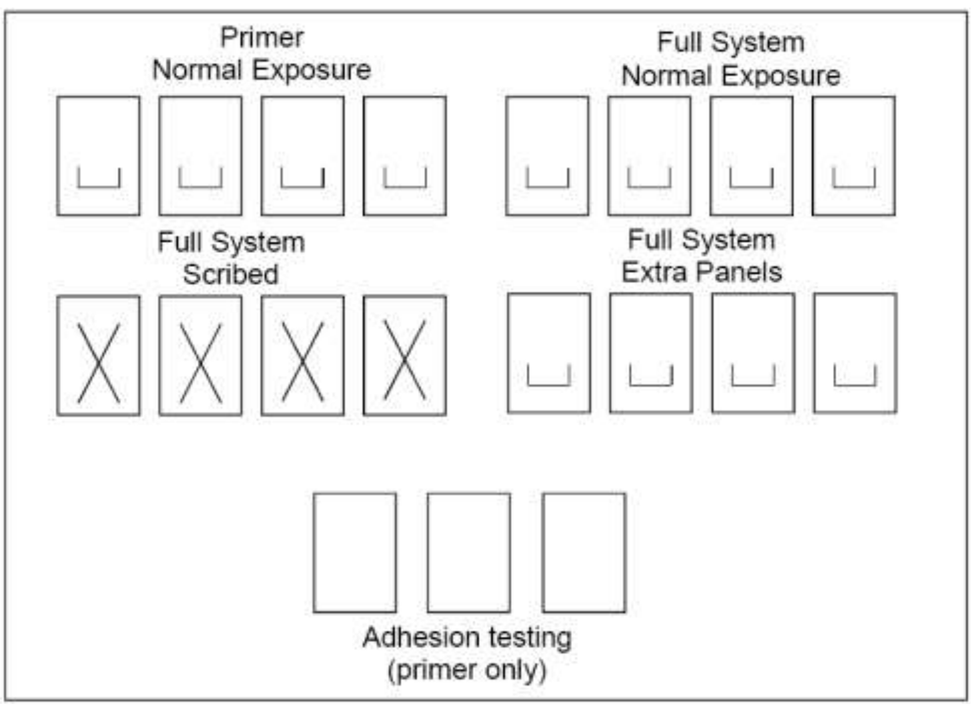


Figure 4 Coating System Coupon Matrix

5.5 Atmospheric Exposure Test

Test Description

After all coating systems were applied and allowed to cure; the panels were mounted on the test racks and transported to the KSC Beachside Corrosion Laboratory. The distance of the test stands from the mean high tide line is approximately 150 feet from the Atlantic Ocean. The site is located approximately 1.5 miles south of Launch Complex 39A (Figure 5).

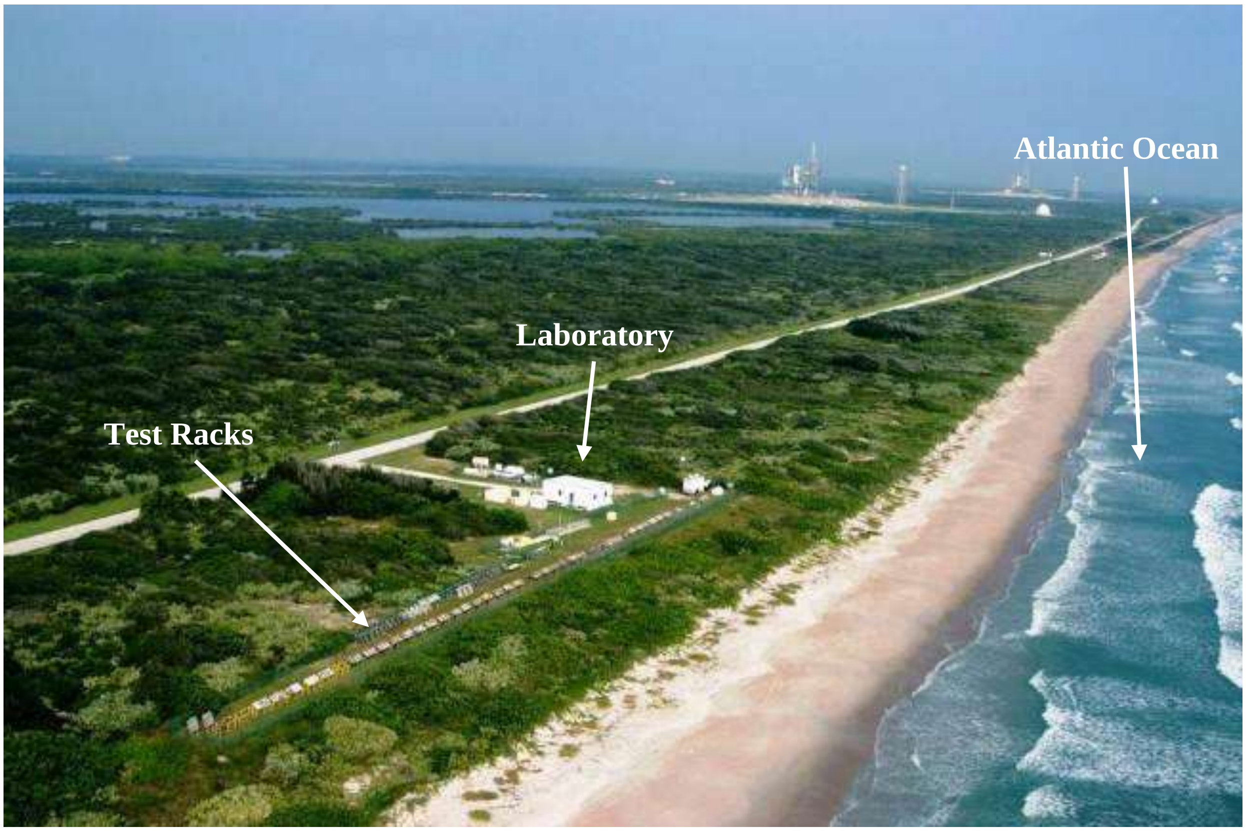


Figure 5 NASA CTL Beachside Corrosion Laboratory Location

All KSC procedures for fasteners, exposure angle, and inspection interval were followed. The coated test panels were installed on stainless steel racks that use porcelain insulators as standoffs. The racks were installed on galvanized pipe test stands which oriented the samples at a 30° angle facing the ocean (Figure 6).

Figure 6 KSC Beachside Atmospheric Test Facility Test Racks

Rationale

This test evaluates the alternative coating systems over 18 months of outdoor exposure. Exposure of the coatings includes ultraviolet radiation, as well as different cycles of natural salt spray exposure. This test is meant to evaluate coatings' long term performance.

The test panels are examined for color retention, gloss retention, degree of rusting, scribe creepage, and degree of blistering. NASA requires this test for validation of alternative coating systems under NASA-STD-5008B.

Data Analysis and Reporting

- Stage 1 test panels were placed at the KSC Beachside Atmospheric Test Facility in mid-August 2012. Table 5 shows the evaluation schedule.

Table 5 Test Panel Evaluation Schedule			
Inspection	***Date***	***Frequency***	***Inspection Type***
1	08/13/2012	0 months	Initial Gloss, Initial Color, and Corrosion
2	02/13/2013	6 months	Gloss and Color
3	08/16/2013	12 months	Gloss and Color
4	02/16/2014	18 months	Gloss, Color, and Corrosion
5	08/16/2017	60 months	Corrosion

- Results Summary
  1. Color Retention
     - Color retention was measured on the full system panels every six (6) months per ASTM D 2244 (*Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates*).
     - A Dr. Lange SpectroColor handheld portable color meter using the CIE L*a*b* format, D-65 illuminant, and a 10° observer was used.
     - A color's "lightness" (L*) runs from light (white=100) to dark (black=0). A more reddish color will give a positive a* value, and conversely, a more greenish color will give a negative a* value. A more bluish color will give a positive b* value, and conversely, a more yellowish color will give a negative b* value.
     - A single number indicator of overall color change (ΔE) was produced by calculating the square root of the sum of the squares of the lightness (L*) and color differences (a* and b*) according to the following equation (Eq. 1).

$$\Delta E = \sqrt{(L_i - L_f)^2 + (a_i - a_f)^2 + (b_i - b_f)^2} \qquad \textbf{Eq. 1}$$

Where:

L_i = Initial Lightness Value
L_f = Final Lightness Value
a_i = Initial Red/Green Value
a_f = Final Red/Green Value
b_i = Initial Blue/Yellow Value
b_f = Final Blue/Yellow Value

- The color change (ΔE) was calculated at six (6) month intervals for a total of 18 months and is reported in Table 6.

Table 6 Color Differences of Full Coating Systems per ASTM D 2244

System	***6 Month ΔE***	***12 Month ΔE***	***18 Month ΔE***
Control	0.7	0.1	1.1
1	10.1	12.6	9.4
2	1.0	0.7	1.6
3	2.2	1.4	4.8
4	2.0	2.1	1.4
5	3.4	2.6	17.3
6	2.9	0.3	0.8
7	2.9	0.8	4.7
8	3.1	1.4	6.9
9	13.7	13.2	16.7
10	1.8	1.2	6.2

- As a general rule, a ΔE value of one (1) would be discernable by the human eye in a side by side comparison. However, in less than ideal lighting, a ΔE of two (2) or three (3) can still be considered the same color. The color change (ΔE) was calculated at six (6) month intervals for a total of 18 months and is reported in Figure 7.

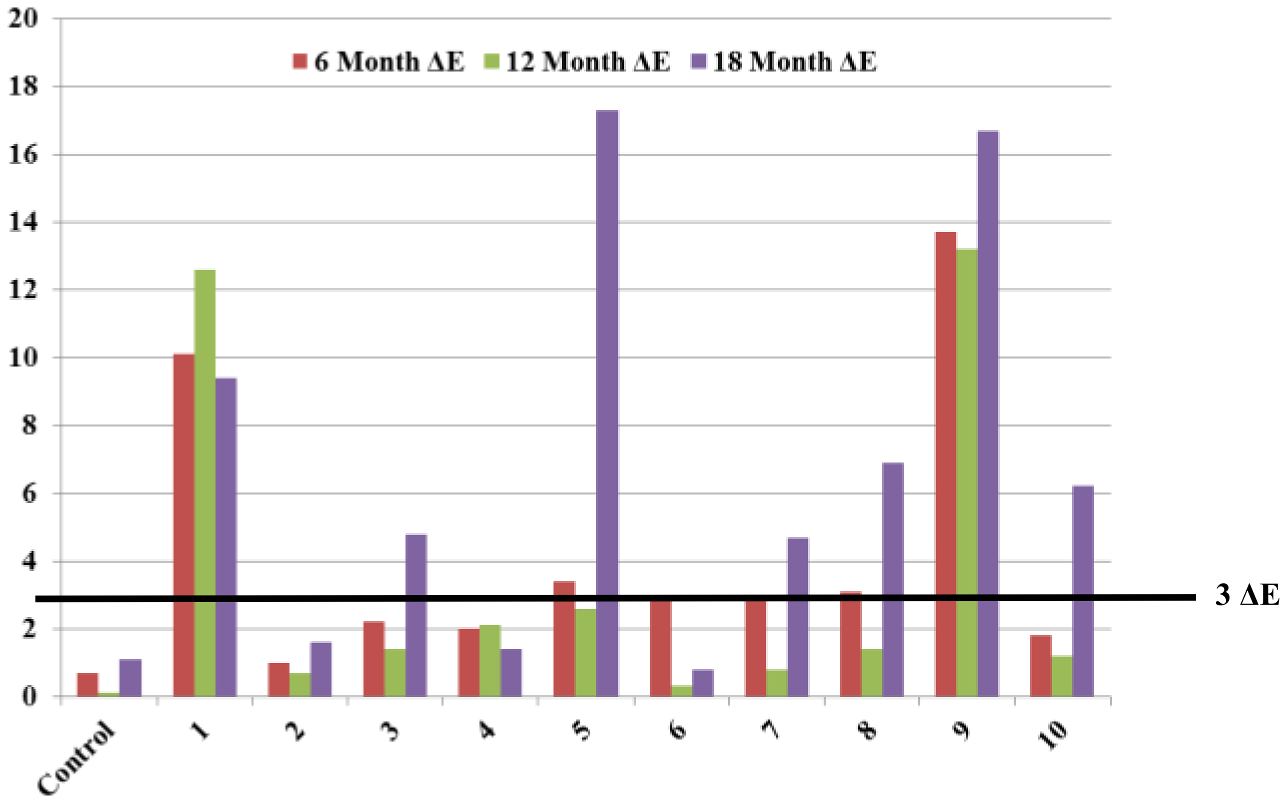


Figure 7 Color Differences of Full Coating Systems

- Only Systems 2, 4, and 6 showed acceptable color retention. Color retention, however, does not necessarily indicate that the coating will not provide the necessary protection and will not prohibit a system from being approved and added to the APL.

2. Gloss Retention
    - Full system test panels were evaluated for gloss retention every six (6) months per ASTM D 523 (*Standard Test Method for Specular Gloss*) using a BYK Gardner Tri-Gloss portable gloss meter at a 60° angle.
    - Gloss meters record the amount of reflective illuminated light at specified angles of 20°, 60°, or 85°, and give a value in gloss units (GUs). The 60° geometry is used for most specimens, and is the initial angle used to determine whether the 20° or 85° angles may be more applicable. The 20° angle is used when the 60° angle gloss values are higher than 70 GUs, while the 85° angle is used when the 60° angle gloss values are less than 10 Gus. The 60° angle was used for the systems in this report since most of the values were between 10-70 GUs.
    - Gloss measurements were performed on the unexposed surfaces. Measurements were taken in three (3) spots on the panel face and averaged.
    - The initial and interval GU data are presented in Table 7.

Table 7 Gloss Data for Full Coating Systems per ASTM D 523

System	*Initial Gloss*	*6 Month Gloss*	*12 Month Gloss*	*18 Month Gloss*	*Percentage Retention*
Control	69.2	60.7	69.7	68.6	99%
1	14.1	0.6	0.2	0.8	6%
2	21.4	32.3	35.7	38.5	180%
3	37.6	68.1	71.1	65.5	174%
4	20.6	2.3	2.3	1.5	%
5	21.5	2.1	2.0	5.5	26%
6	34.5	35.9	34.5	34.3	99%
7	26.1	32	29.9	35.2	135%
8	48.7	33.6	32.4	35.6	73%
9	5.3	2.2	1.7	2.1	40%
10	63.0	51.9	36.2	37.6	60%

- It is important to note that the initial value is not of importance except to act as a comparison to the final reading in order to determine the coating's gloss retention.
- The final gloss retention percentages are shown in Figure 8.

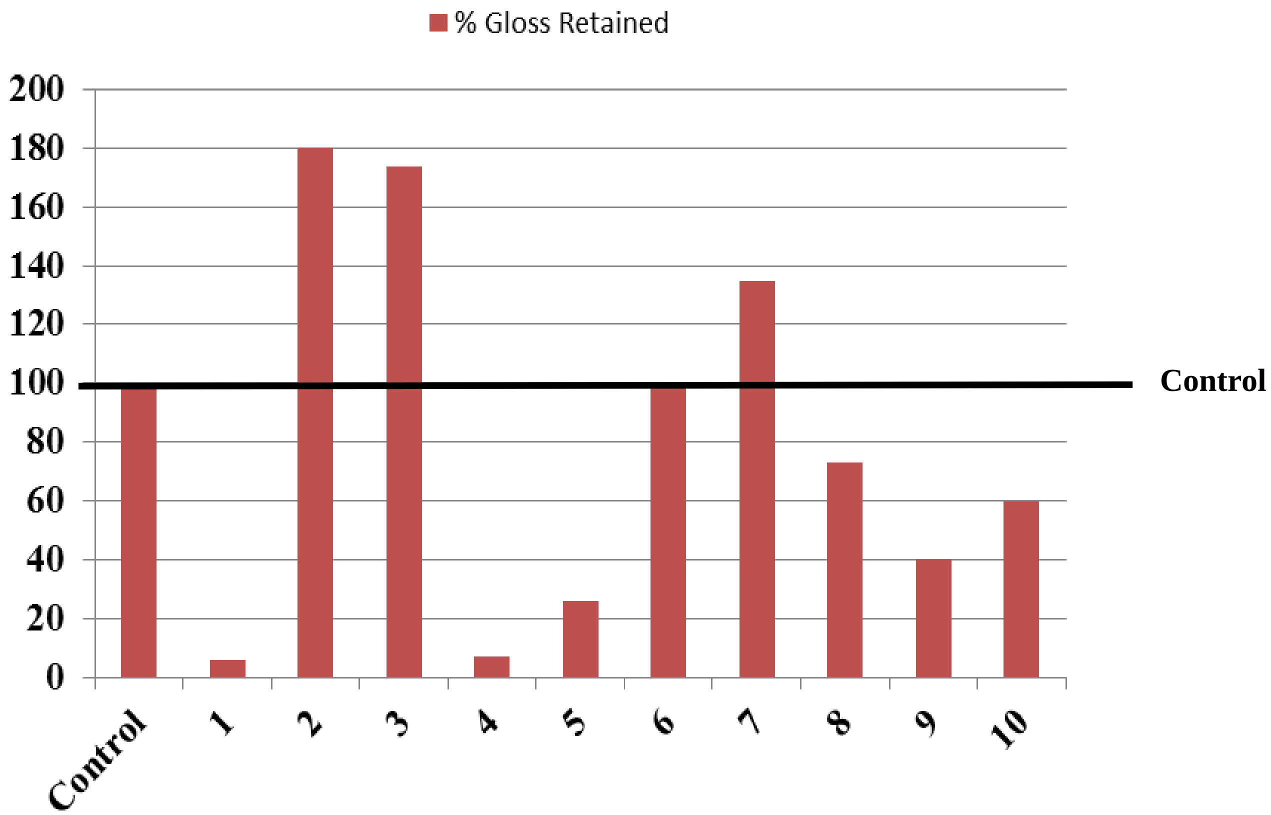


Figure 8 Gloss Retention of Full Coating Systems per ASTM D 523

- It is surmised that a coating system's gloss value may seem to increase over time due to the cleaning performed prior to the readings being taken. The cleaning may remove the duller portions on the top of the coating resulting in an increase in gloss retention.
- Only Systems 2, 3, 6, and 7 showed performance equal to or better than the control coating system. Gloss retention, however, does not necessarily indicate that the coating will not provide the necessary protection and will not prohibit a system from being approved and added to the APL

3. Degree of Rusting
   - After 18 months of exposure, the condition of the primer-only and full system composite panels were rated per ASTM D 610 (*Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*); using the numerical grade scale in ASTM D 610, Table 1, *Scale and Description of Rust Grades*, where 0 indicates 100% surface rusting and 10 indicating less than 0.01% surface rusting.
   - The composite panels used for this testing has approximately 32 square inches of exposed area. This calculates to 0.0096 square inches for a rating of "9", 0.032 square inches for a rating of "8", 0.096 square inches for a rating of "7", and so on.
   - Table 8 shows the Rust Grade Ratings Scale per Table 1 of ASTM D 610.

Table 8 ASTM D 610 Rust Grade Ratings Scale

Rating	***Description***
10	No rusting or less than 0.01% of surface rusted
9	Minute rusting, less than 0.03% of surface rusted
8	Few isolated rust spots, less than 0.1% of surface rusted
7	Less than 0.3% of surface rusted
6	Extensive rust spots, but less than 1% of surface rusted
5	Rusting to the extent of 3% of surface rusted
4	Rusting to the extent of 10% of surface rusted
3	Approximately 1/6 of the surface rusted
2	Approximately 1/3 of the surface rusted
1	Approximately 1/2 of surface rusted
0	Approximately 100% of surface rusted

   - Typically, all rating values were determined from an average of four (4) ratings. Where the panel ratings differed from panel to panel, a simple arithmetic mean is reported. In cases where the panel rating for a single panel showed extraneous degradation in comparison to the other three (3), the rating was not included in the average due to the possibility of application or preparation defects.
   - The primer-only composite panels must achieve an ASTM D 610 rating of nine (9) or better, and the full system panels must achieve an ASTM D 610 rating of eight (8) or better, after 18 months of exposure to be considered for addition to the NASA-STD-5008B APL. These systems

must then continue to provide acceptable protection and performance for a period of five (5) years in order to remain on the APL.

- Table 9 shows the Rust Grade Ratings for the Primer-only and Full Coating Systems.

Table 9 Degree of Rusting per ASTM D 610

System	***SSPC-VIS 2 "G" Ratings***				
	Panel 1	***Panel 2***	***Panel 3***	***Panel 4***	***Average***
Control - Primer	9	9	10	9	9.3
Control - Full	8	9	8	9	8.5
1 - Primer	2	2	2	2	2.0
1 - Full	2	2	2	2	2.0
2 - Primer	**9**	**9**	**10**	**9**	**9.3**
2 - Full	**8**	**8**	**8**	**9**	**8.3**
3 - Primer	3	3	3	3	3.0
3 - Full	7	7	7	7	7.0
4 - Primer	**10**	**10**	**10**	**9**	**9.8**
4 - Full	**10**	**8**	**9**	**8**	**8.8**
5 - Primer	3	3	3	3	3.0
5 - Full	3	3	3	3	3.0
6 - Primer	4	4	4	4	4.0
6 - Full	4	4	4	4	4.0
7 - Primer	2	2	2	2	2.0
7 - Full	2	2	2	2	2.0
8 - Primer	2	2	2	2	2.0
8 - Full	3	4	3	3	3.3
9 - Primer	**10**	**9**	**9**	**10**	**9.5**
9 - Full	**10**	**10**	**10**	**10**	**10.0**
10 - Primer	4	4	4	4	4.0
10 - Full	5	5	5	5	5.0

- Only Systems 2, 4, and 9 (Bold Text in Table above) showed acceptable performance.

4. Scribe Creepage
   - The full system flat scribed panels were rated at the end of the 18-month exposure using ASTM D 1654 (*Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments)*.
   - This test shows how well a coating system protects against corrosion when damaged.
   - Table 10 shows the rating scale per ASTM D 1654.

Table 10 ASTM D 1654 Rating Scale Representative Mean Creepage from Scribe

Millimeters	***Approximate Inches***	***Rating Number***
0	0	10
Over 0.0 - 0.5	0 - 1/64	9
Over 0.5 - 1.0	1/64 - 1/32	8
Over 1.0 - 2.0	1/32 - 1/16	7
Over 2.0 - 3.0	1/16 - 1/8	6
Over 3.0 - 5.0	1/8 - 3/16	5
Over 5.0 - 7.0	3/16 - 1/4	4
Over 7.0 - 10.0	1/4 - 3/8	3
Over 10.0 - 13.0	3/8 - 1/2	2
Over 13.0 - 16.0	1/2 - 5/8	1
Over 16.0	5/8 - more	0

- Table 11 shows the results of the coating systems per ASTM D 1654.

Table 11 Scribe Failure Ratings per ASTM D 1654				
System	***Panel 1***	***Panel 2***	***Panel 3***	***Average***
Control	10	10	10	10.0
1	0	0	0	0.0
2	**8**	**10**	**10**	**9.3**
3	0	0	0	0.0
4	**10**	**10**	**10**	**10.0**
5	0	0	0	0.0
6	0	0	0	0.0
7	0	0	0	0.0
8	0	0	0	0.0
9	**10**	**10**	**10**	**10.0**
10	0	0	0	0.0

- Only Systems 2, 4, and 9 (Bold Text in Table above) showed acceptable performance.

5. Degree of Blistering
    - A phenomenon peculiar to painted surfaces is the formation of blisters relative to some system weakness. This test provides a standard procedure of describing the size and density of the blisters so that comparisons of severity can be made.
    - After 18 months, the condition of the full system test panels was also evaluated for blistering per ASTM D 714 (*Standard Test Method for Evaluating Degree of Blistering of Paints*).
    - Figure 9 shows the reference standards in ASTM D 714, section 3.

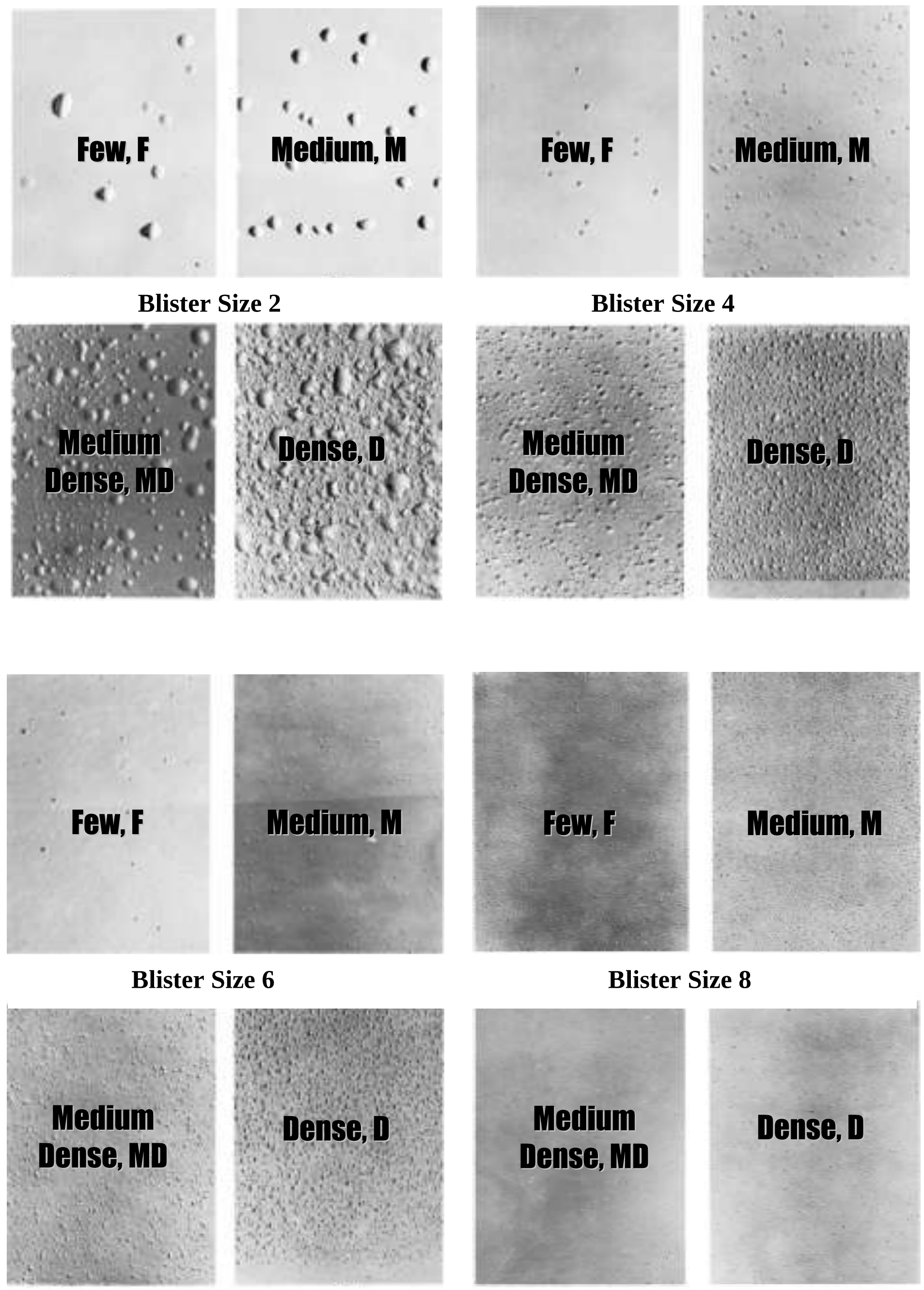


Figure 9 Condition Ratings per ASTM D 714

- Table 12 shows the results of the full coating systems per ASTM D 714.

Table 12 Degree of Blistering per ASTM D 714

System	***Panel 1***	***Panel 2***	***Panel 3***	***Panel 4***	***Average***
Control - Primer	10	10	10	10	10.0
Control - Full	10	10	10	10	10.0
1 - Primer	2F	2F	2F	2F	2.0
1 - Full	2F	2F	2F	2F	2.0
2 - Primer	**10**	**10**	**10**	**10**	**10.0**
2 - Full	**10**	**8F**	**8F**	**8F**	**9.5**
3 - Primer	2F	2F	2F	2F	2.0
3 - Full	8F	8F	8F	8F	8.0
4 - Primer	**10**	**10**	**10**	**10**	**10.0**
4 - Full	**10**	**10**	**10**	**10**	**10.0**
5 - Primer	2M	2M	2M	2M	2.0
5 - Full	2M	2M	2M	2M	2.0
6 - Primer	4M	4M	4M	4M	4.0
6 - Full	4M	4M	4M	4M	4.0
7 - Primer	2M	2M	2M	2M	2.0
7 - Full	2M	2M	2M	2M	2.0
8 - Primer	6D	6D	6D	6D	6.0
8 - Full	4F	6F	6M	6M	5.5
9 - Primer	**10**	**10**	**10**	**10**	**10.0**
9 - Full	**10**	**10**	**10**	**10**	**10.0**
10 - Primer	4F	4F	4F	4F	4.0
10 - Full	6F	6F	4F	6F	5.5

- Only Systems 2, 4, and 9 (Bold Text in Table above) showed acceptable performance.

Atmospheric Exposure Testing Documentation

The panels were installed at the KSC Beachside Atmospheric Test Site on 08/13/2012. The test racks are designed according to ASTM G 50 (*Standard Practice for Conducting Atmospheric Corrosion Tests on Metals*). They form a matrix of five (5) rows, numbered 1-5 and five (5) columns lettered A-E. The following figures show the arrangement of the panels as they were installed on the racks and identify the coating system for each unique number as shown in Figure 10 below.

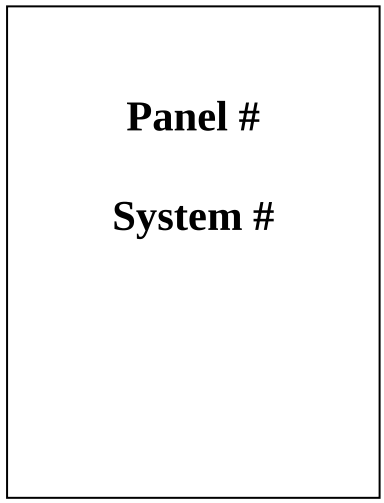


Figure 10 Key for Test Panels for Atmospheric Exposure Testing

The figures showing performance over the 18 month exposure period at the KSC Beachside Atmospheric Testbed are:

- Systems 1-5 Primer-only: Figures 11-15
- Systems 6-10 Primer-only: Figures 16-20
- Full Systems 1-5: Figures 21-25
- Full Systems 6-10: Figures 26-30
- Full Systems 1-10 Scribed: Figures 31-35

For the Primer-only panels, System 2 was used as the control coating since it is already approved and included in the NASA-STD-5008B APL.

	A	B	C	D	E
5	#201 System 1	#097 System 1	#060 System 1	#183 System 1	Empty
4	#149 System 2	#012 System 2	#062 System 2	#098 System 2	Empty
3	#137 System 3	#022 System 3	#088 System 3	#171 System 3	Empty
2	#140 System 4	#188 System 4	#176 System 4	#139 System 4	Empty
1	#041 System 5	#080 System 5	#184 System 5	#025 System 5	Empty

Figure 11 Key for Systems 1-5 Primer-only Test Panels

Figure 12 Systems 1-5 Primer-only Test Panels – Initial (08/13/2012)

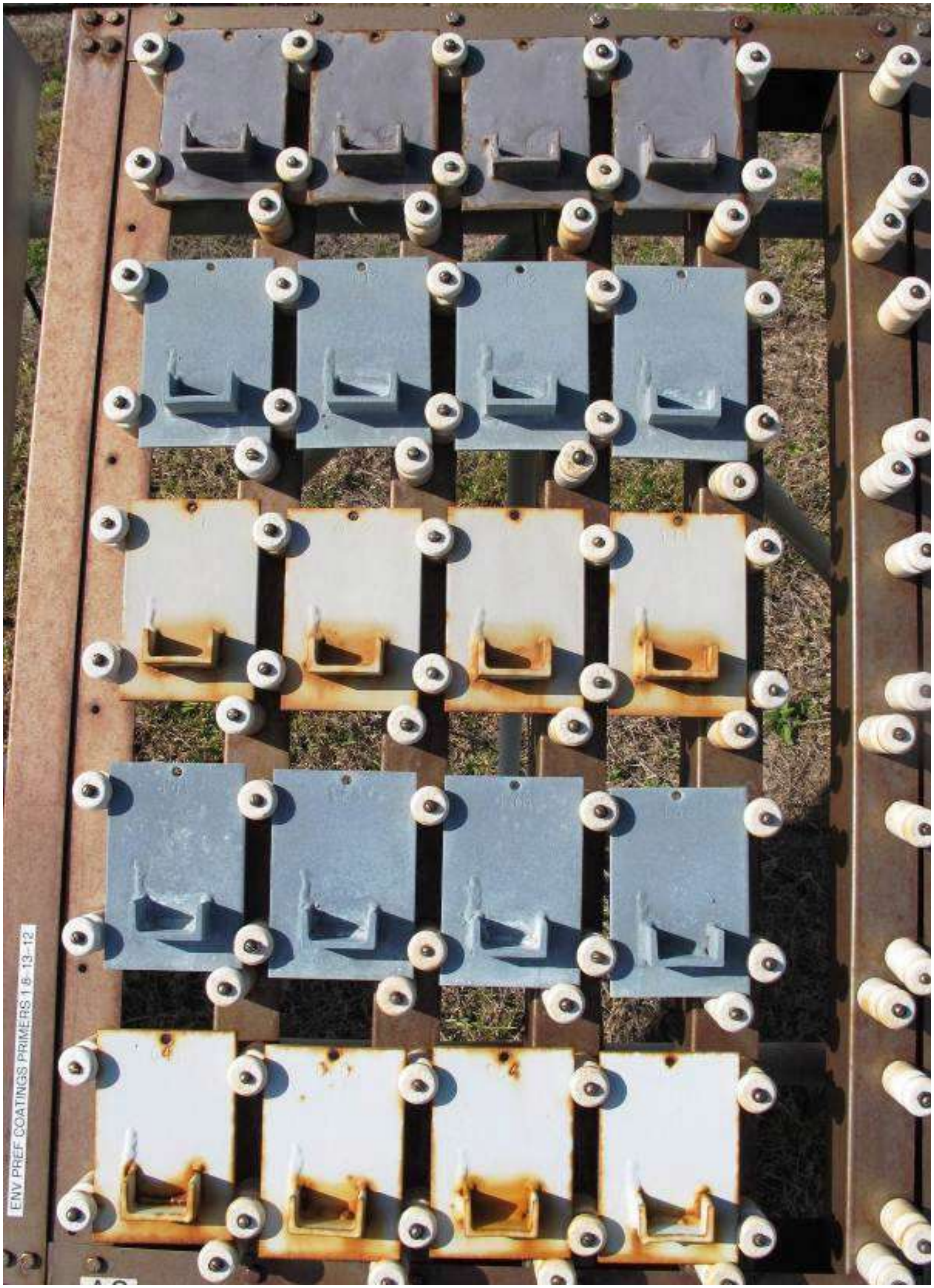


Figure 13 Systems 1-5 Primer-only Test Panels – 6 Months (02/13/2013)

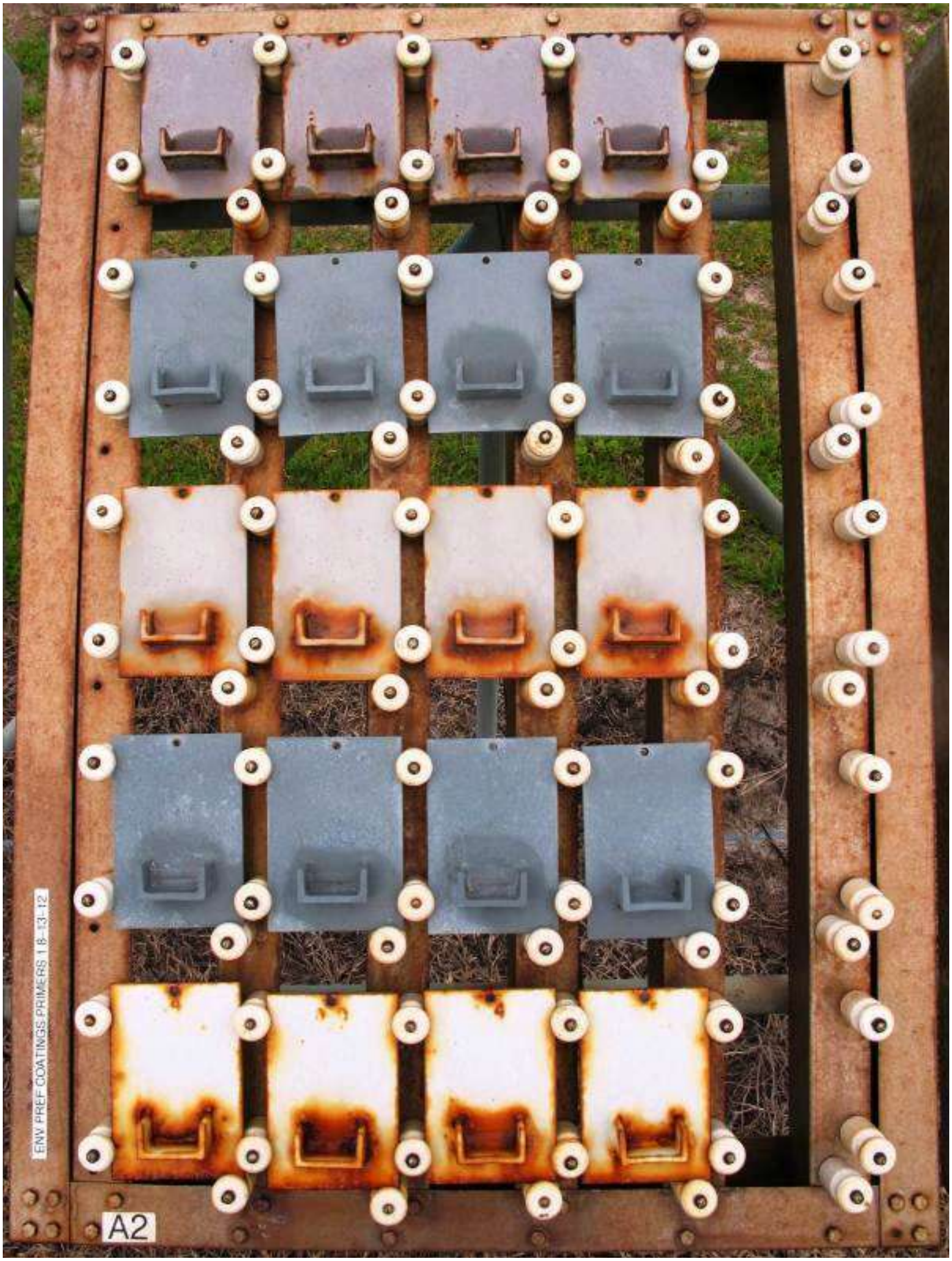


Figure 14 Systems 1-5 Primer-only Test Panels – 12 Months (08/16/2013)

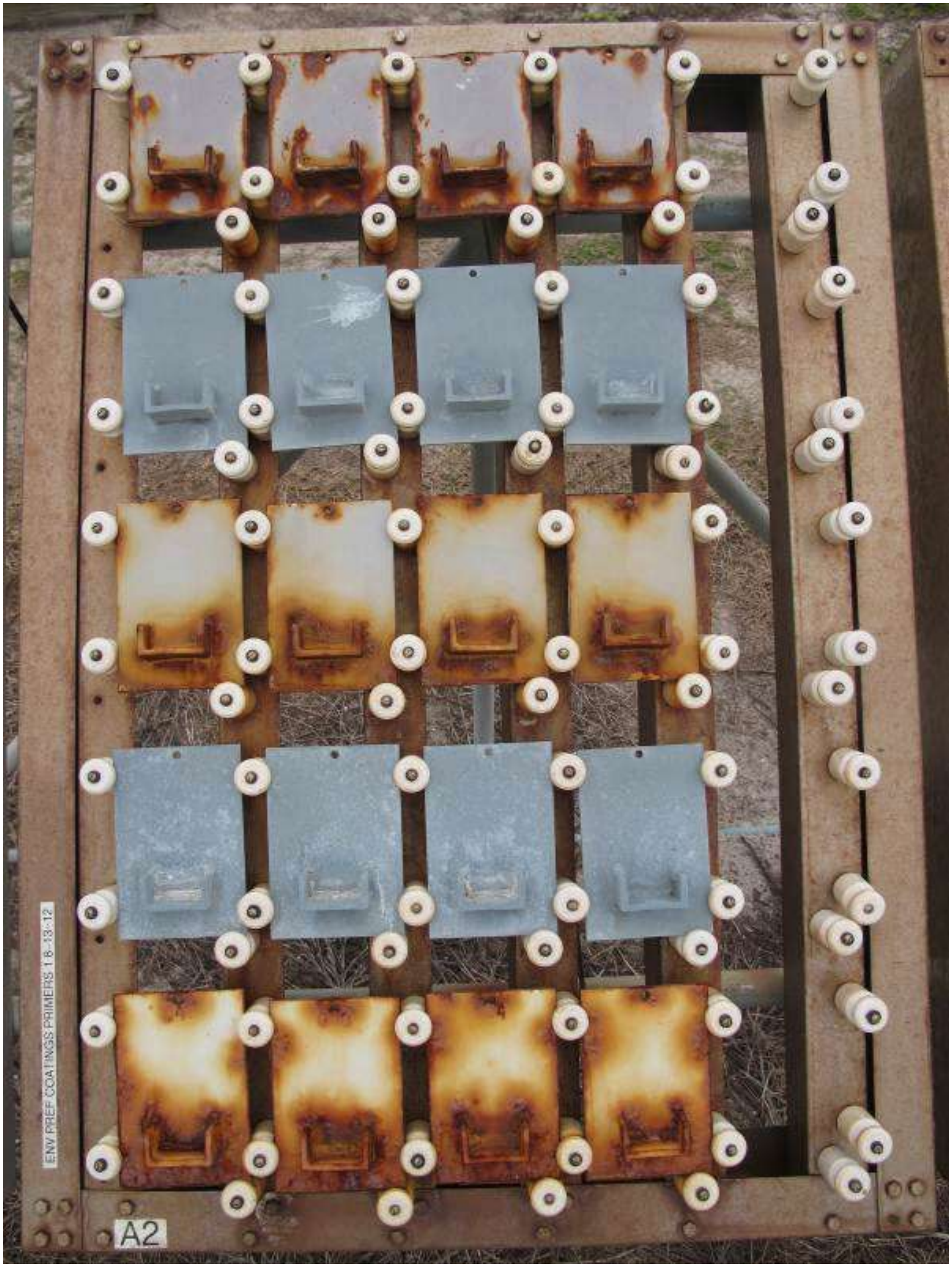


Figure 15 Systems 1-5 Primer-only Test Panels – 18 Months (02/16/2014)

	A	B	C	D	E
5	#078 System 6	#068 System 6	#198 System 6	#167 System 6	Empty
4	#150 System 7	#735 System 7	#746 System 7	#039 System 7	Empty
3	#161 System 8	#160 System 8	#093 System 8	#077 System 8	Empty
2	#715 System 9	#703 System 9	#742 System 9	#721 System 9	Empty
1	#811 System 10	#815 System 10	#781 System 10	#725 System 10	Empty

Figure 16 Key for Systems 6-10 Primer-only Test Panels

Figure 17 Systems 6-10 Primer-only Test Panels – Initial (08/13/2012)

Figure 18 Systems 6-10 Primer-only Test Panels – 6 Months (02/13/2013)

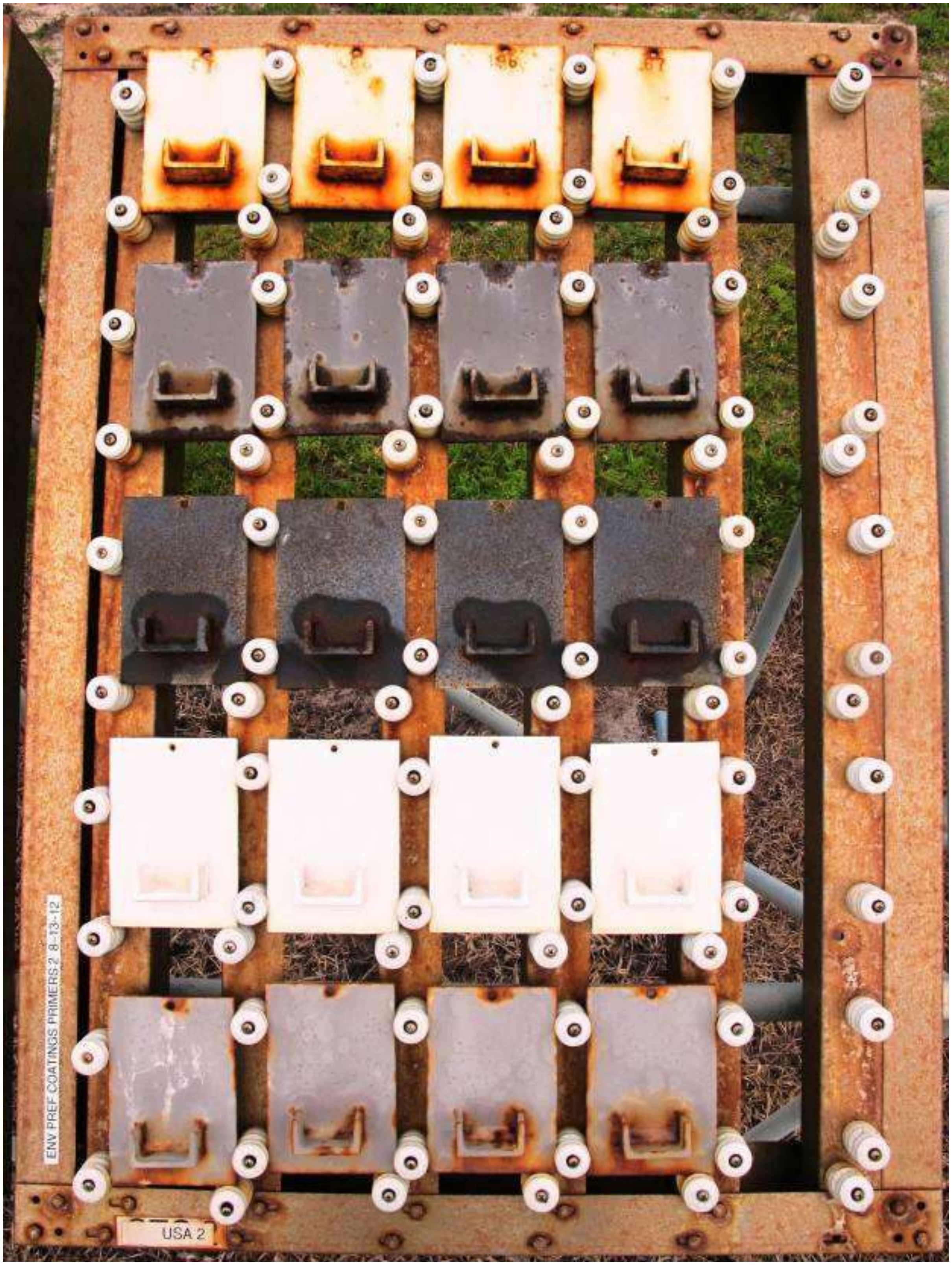


Figure 19 Systems 6-10 Primer-only Test Panels – 12 Months (08/16/2013)

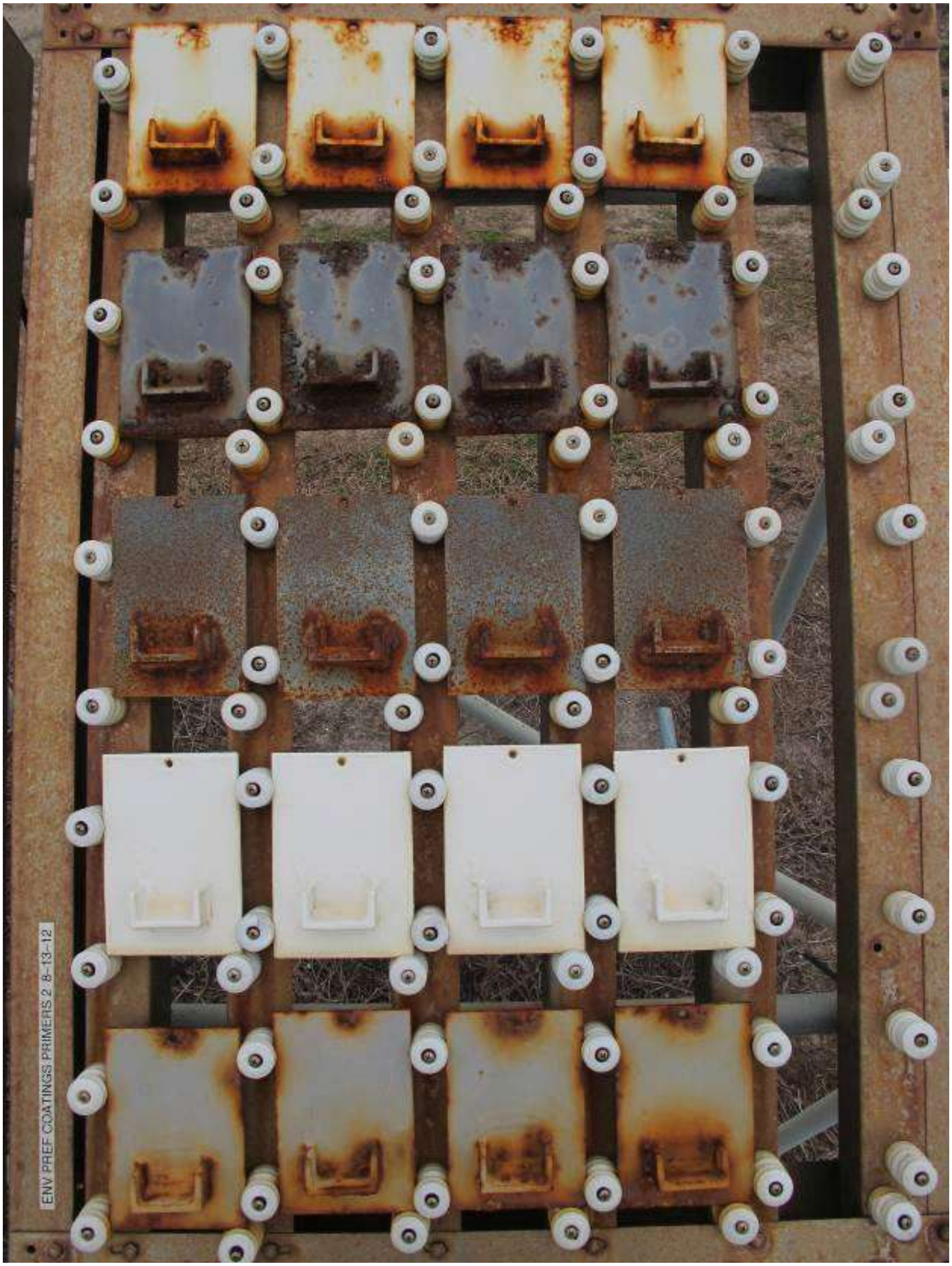


Figure 20 Systems 6-10 Primer-only Test Panels – 18 Months (02/16/2013)

	A	B	C	D	E
5	#066 System 1	#243 System 1	#162 System 1	#1154 System 1	#610 Control
4	#210 System 2	#203 System 2	#123 System 2	#190 System 2	#550 Control
3	#158 System 3	#092 System 3	#131 System 3	#099 System 3	#600 Control
2	#165 System 4	#145 System 4	#144 System 4	#207 System 4	#714 Control
1	#004 System 5	#029 System 5	#175 System 5	#073 System 5	Empty

Figure 21 Key for Systems 1-5 Full System Test Panels

Figure 22 Systems 1-5 Full System Test Panels – Initial (08/13/2012)

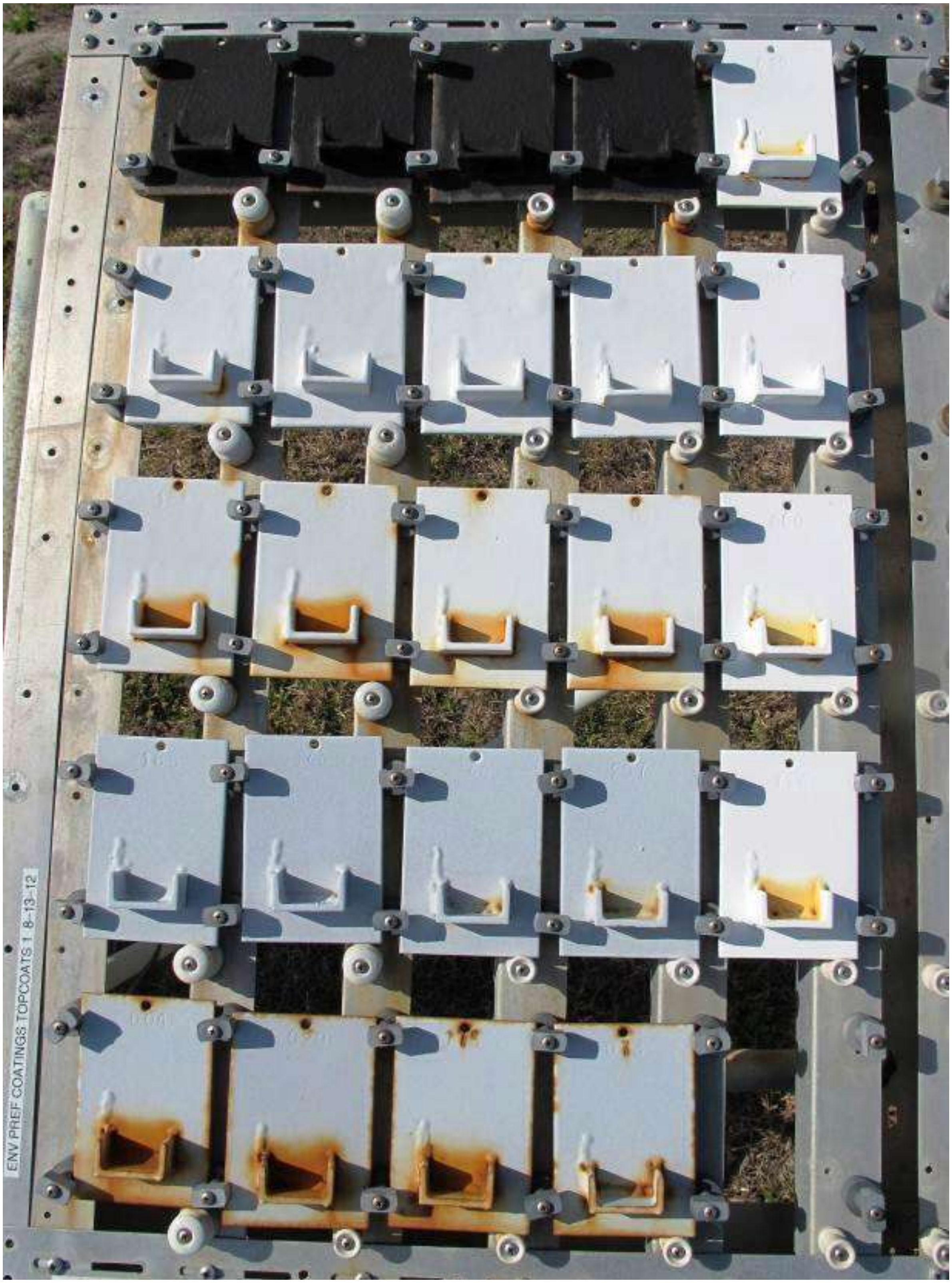


Figure 23 Systems 1-5 Full System Test Panels – 6 Month (02/13/2013)

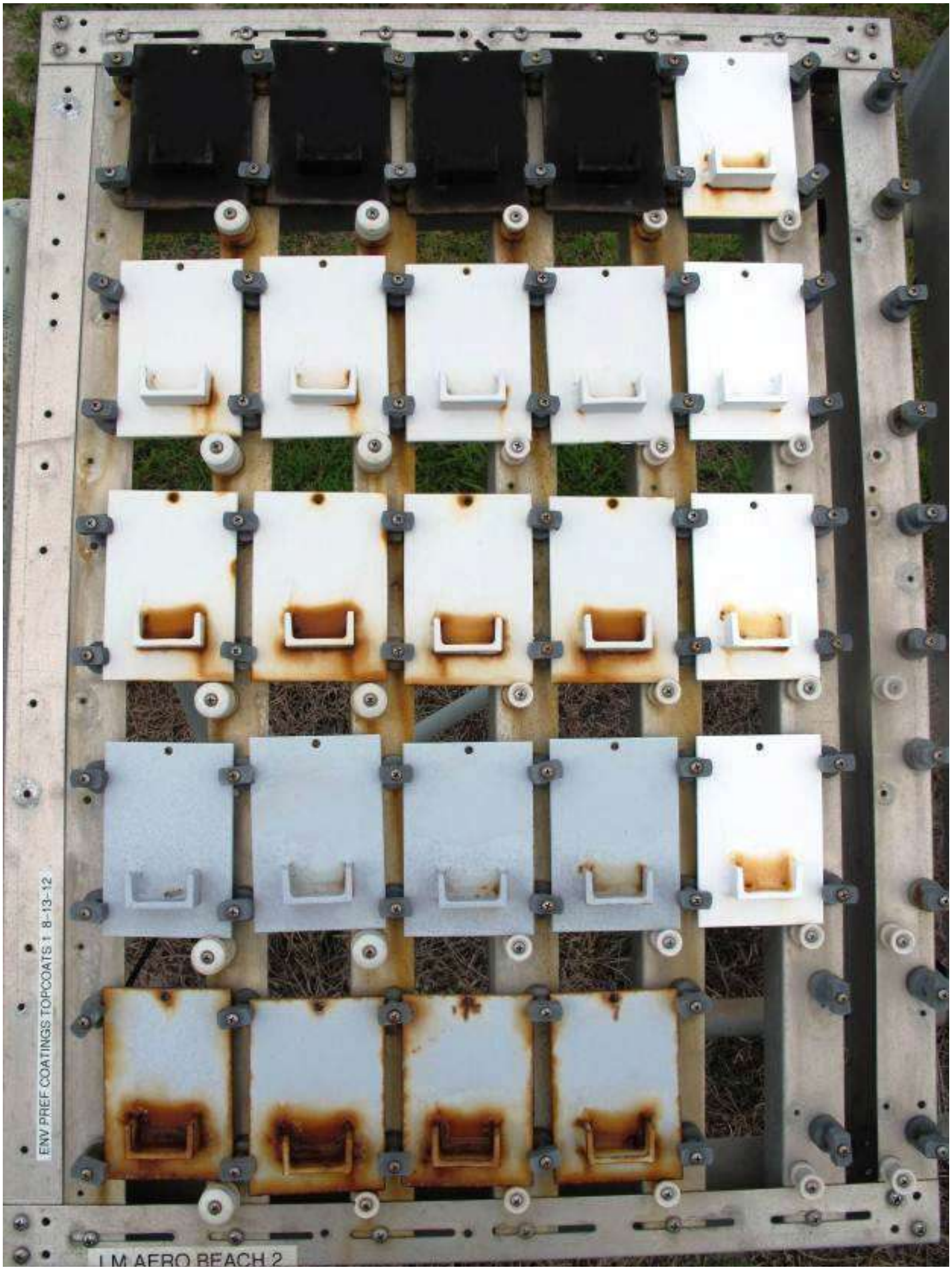


Figure 24 Systems 1-5 Full System Test Panels – 12 Month (08/16/2013)

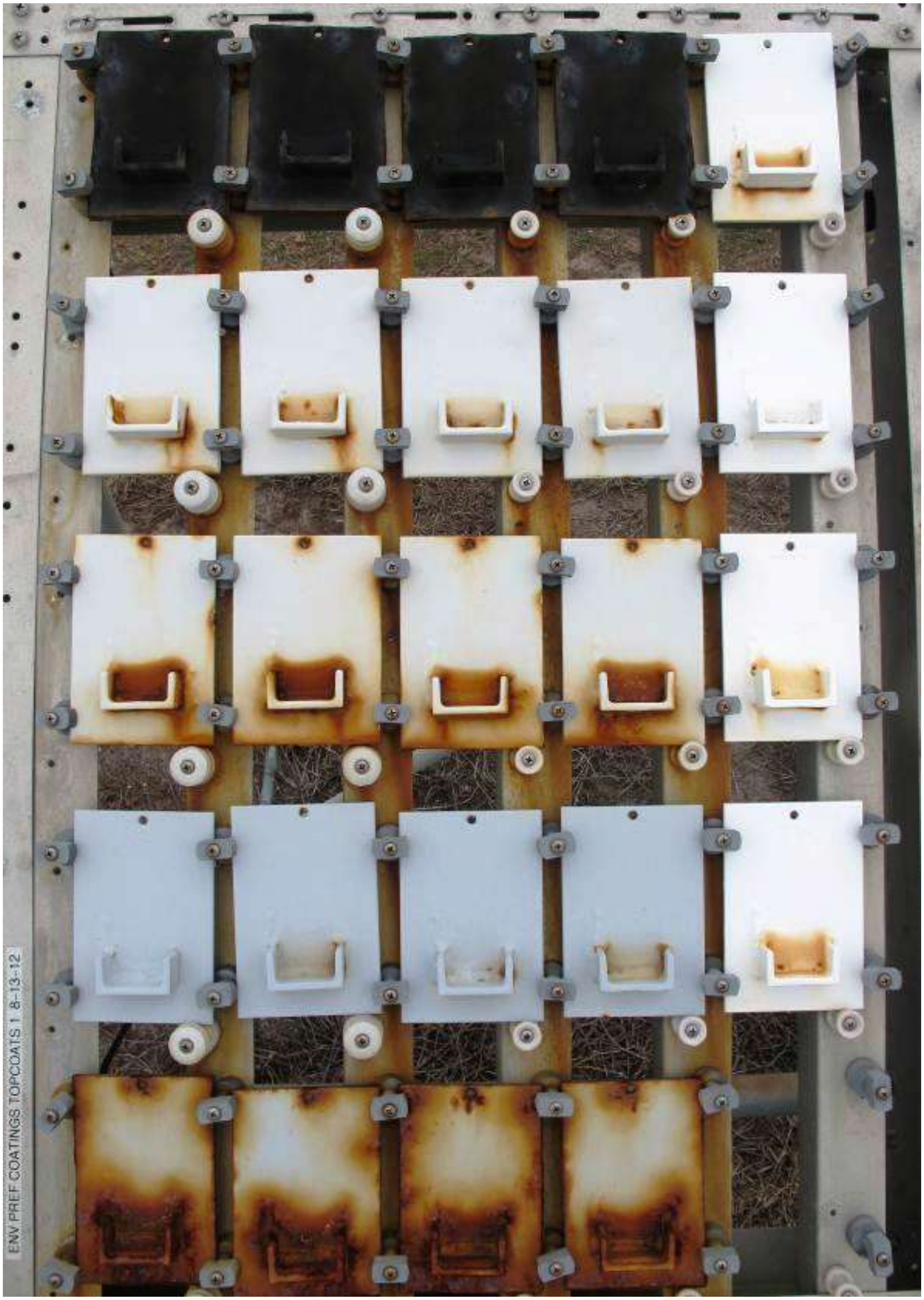


Figure 25 Systems 1-5 Full System Test Panels – 18 Month (02/16/2013)

	A	B	C	D	E
5	#152 System 6	#170 System 6	#181 System 6	#052 System 6	Empty
4	#111 System 7	#002 System 7	#750 System 7	#780 System 7	Empty
3	#185 System 8	#199 System 8	#061 System 8	#130 System 8	Empty
2	#818 System 9	#801 System 9	#744 System 9	#732 System 9	Empty
1	#716 System 10	#776 System 10	#705 System 10	#777 System 10	Empty

Figure 26 Key for Systems 6-10 Full System Test Panels

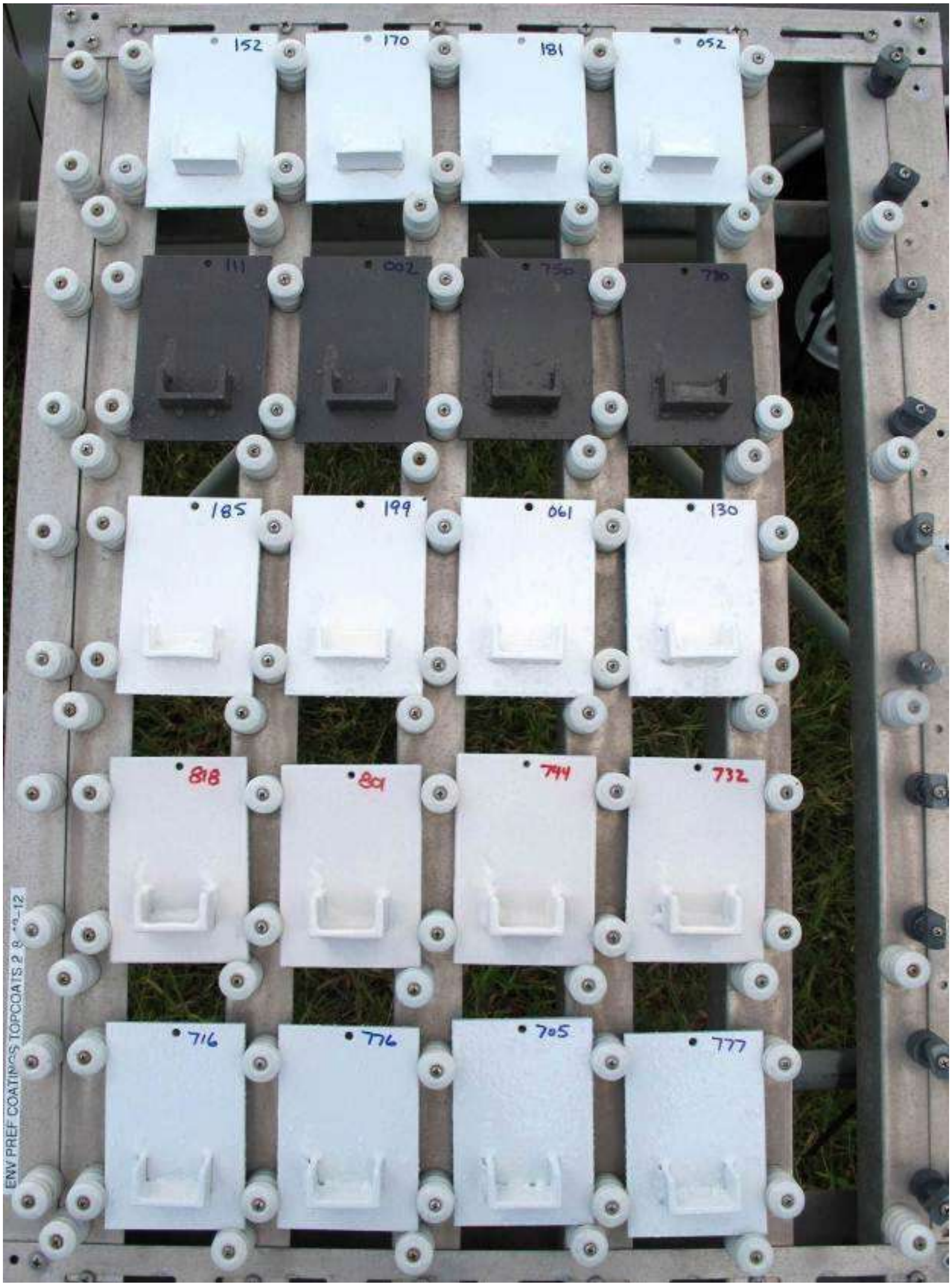


Figure 27 Systems 6-10 Full System Test Panels – Initial (08/13/2012)

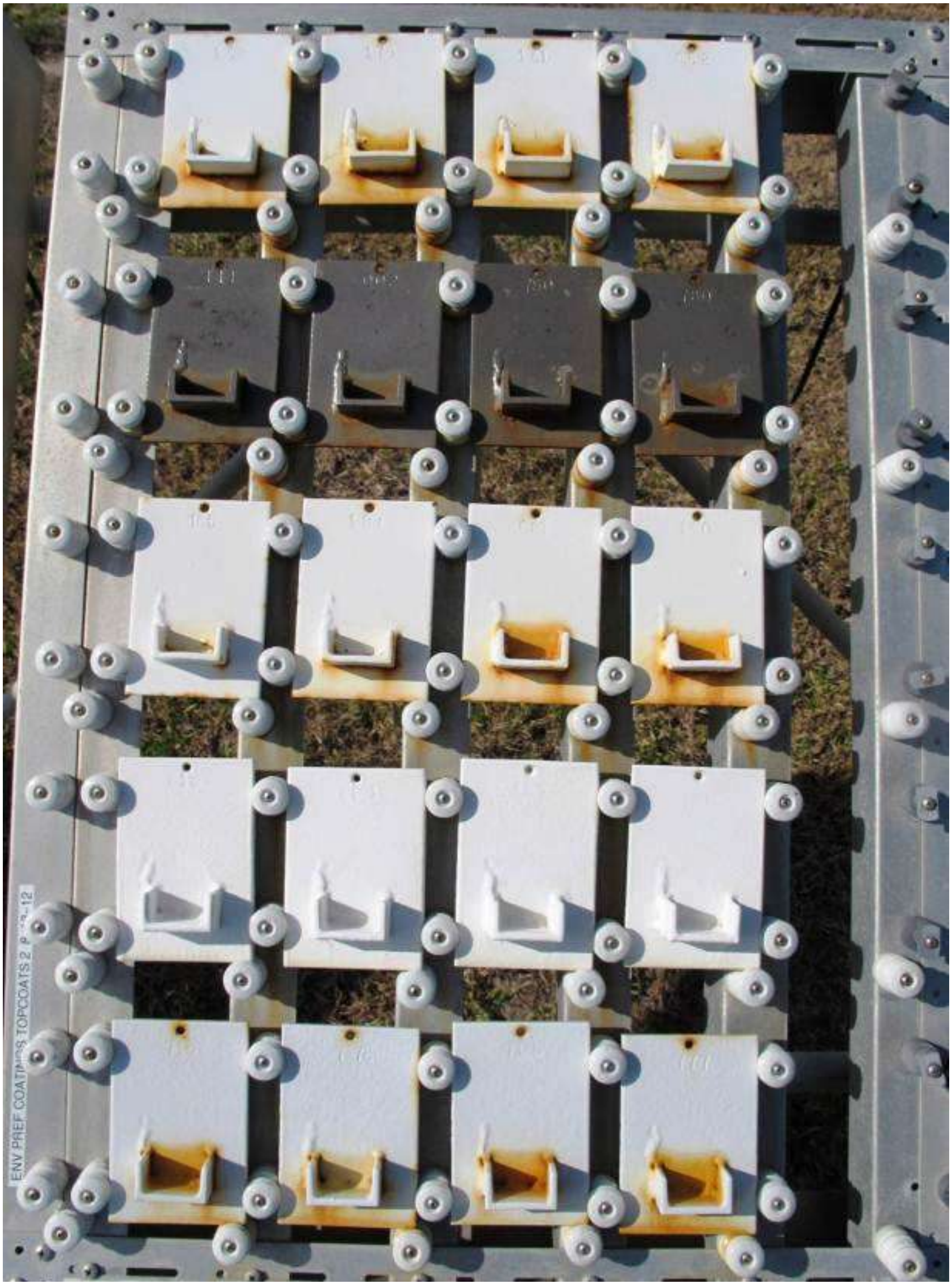


Figure 28 Systems 6-10 Full System Test Panels – 6 Months (02/13/2013)

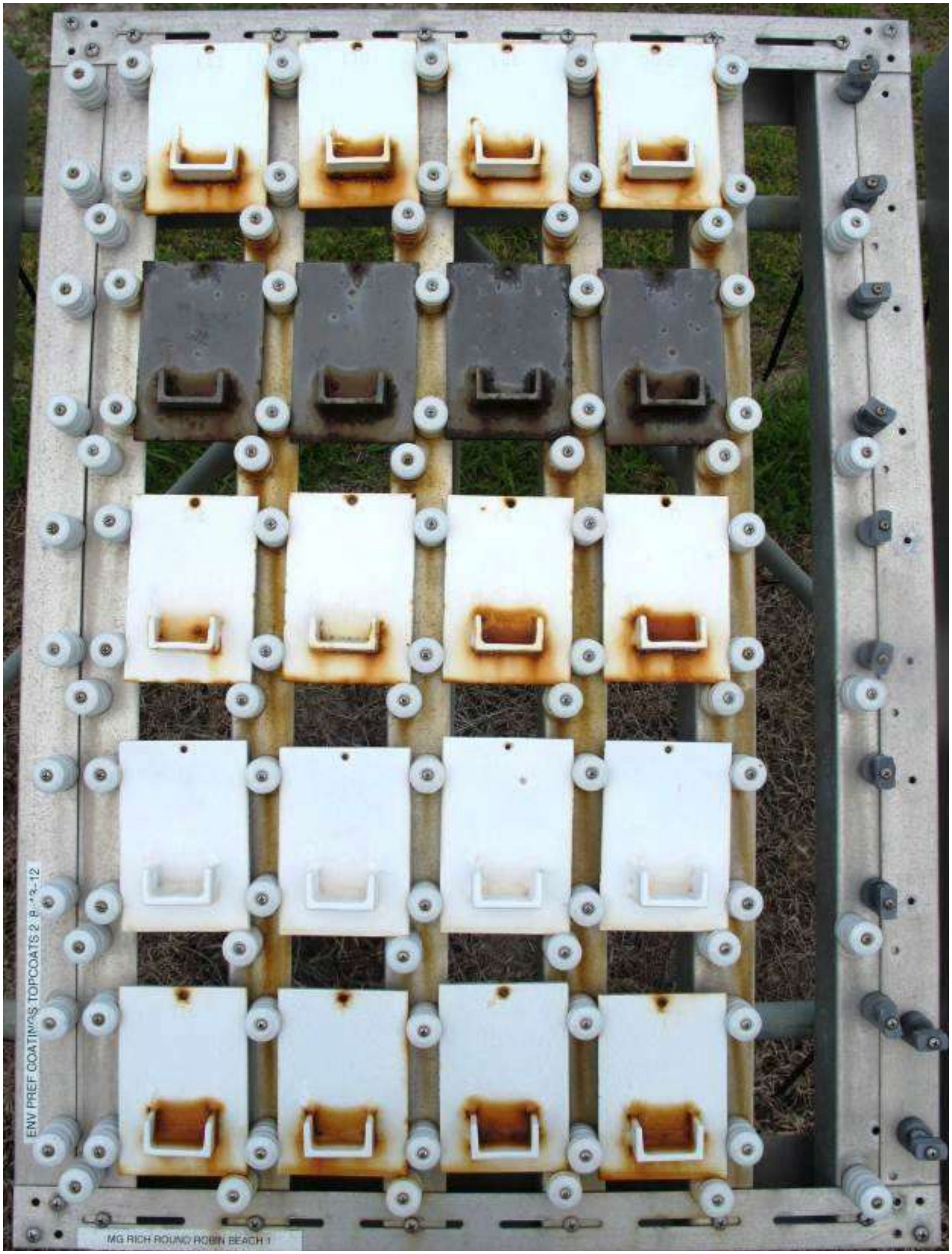


Figure 29 Systems 6-10 Full System Test Panels – 12 Months (08/16/2013)

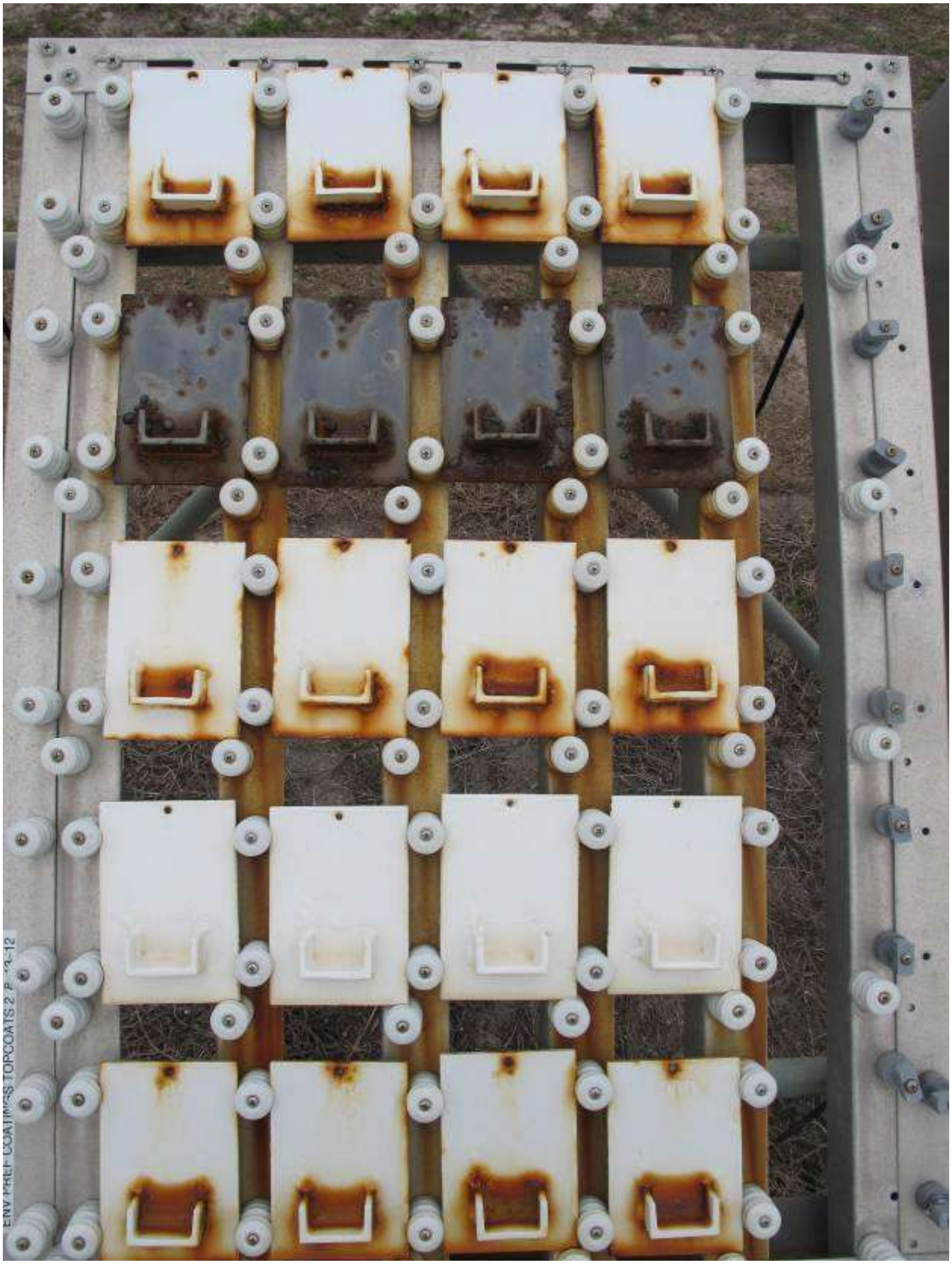


Figure 30 Systems 6-10 Full System Test Panels – 18 Months (02/16/2013)

	A	B	C	D	E	F
5	#148 System 1	#147 System 1	#078 System 1	#040 System 2	#162 System 2	#018 System 2
4	#220 System 3	#222 System 3	#227 System 3	#231 System 4	#240 System 4	#247 System 4
3	#100 System 5	#099 System 5	#060 System 5	#191 System 6	#036 System 6	#193 System 6
2	#209 System 7	#212 System 7	#142 System 7	#808 System 8	#75 System 8	#785 System 8
1	#790 System 9	#793 System 9	#700 System 9	#133 System 10	#023 System 10	#129 System 10

Figure 31 Key for Full System Scribed Test Panels

Figure 32 Full System Scribed Test Panels – Initial (08/13/2012)

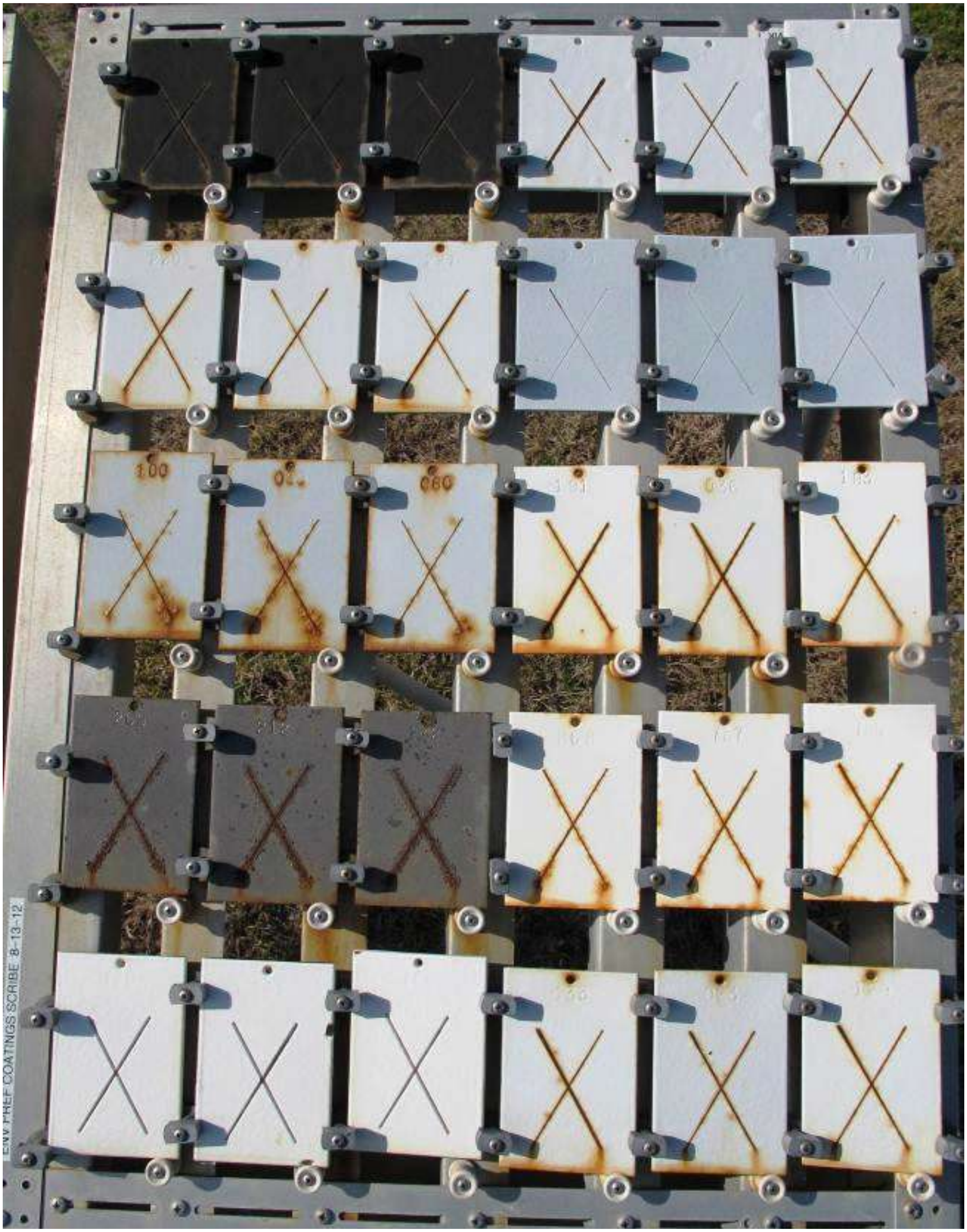


Figure 33 Full System Scribed Test Panels – 6 Months (02/13/2013)

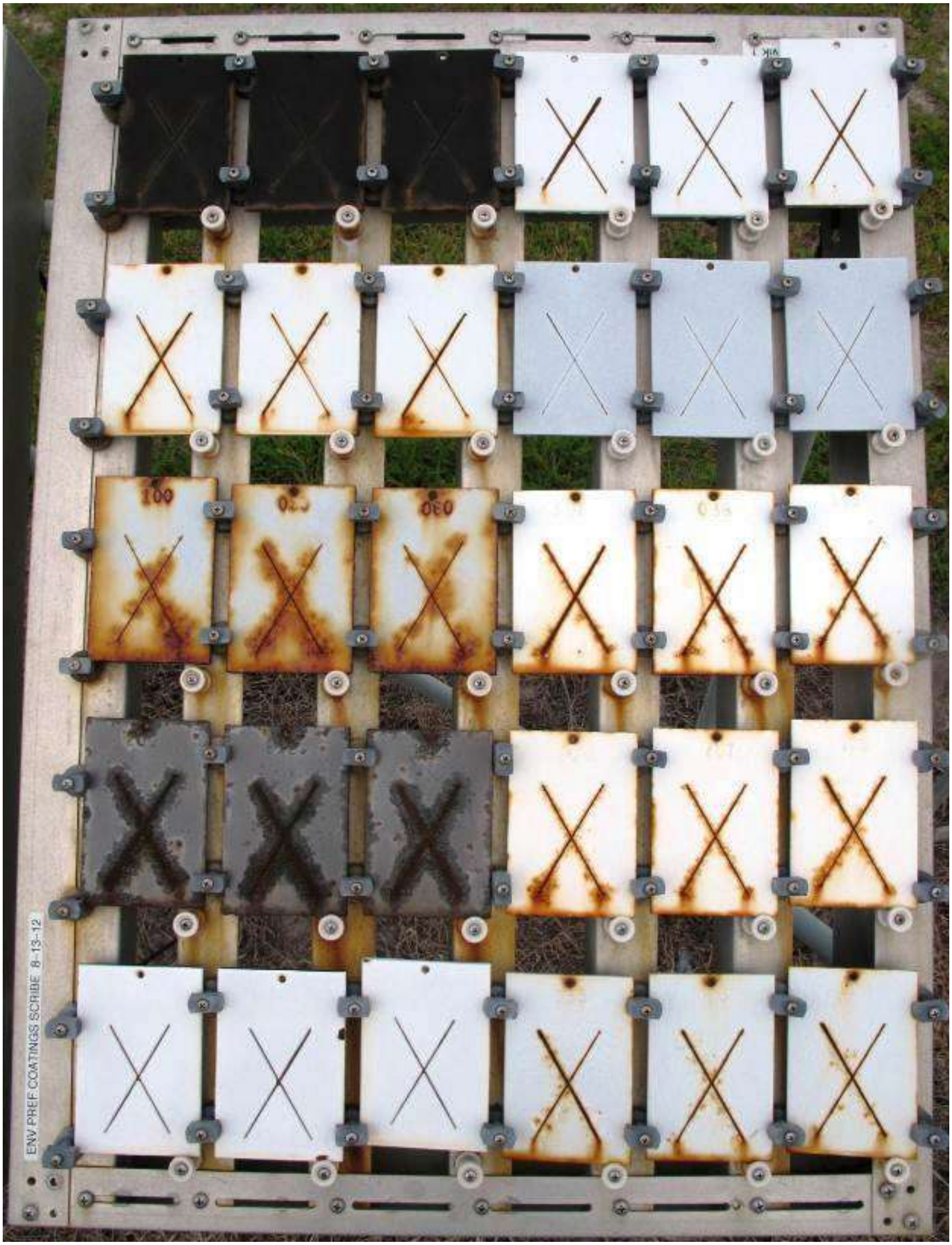


Figure 34 Full System Scribed Test Panels – 12 Months (08/16/2013)

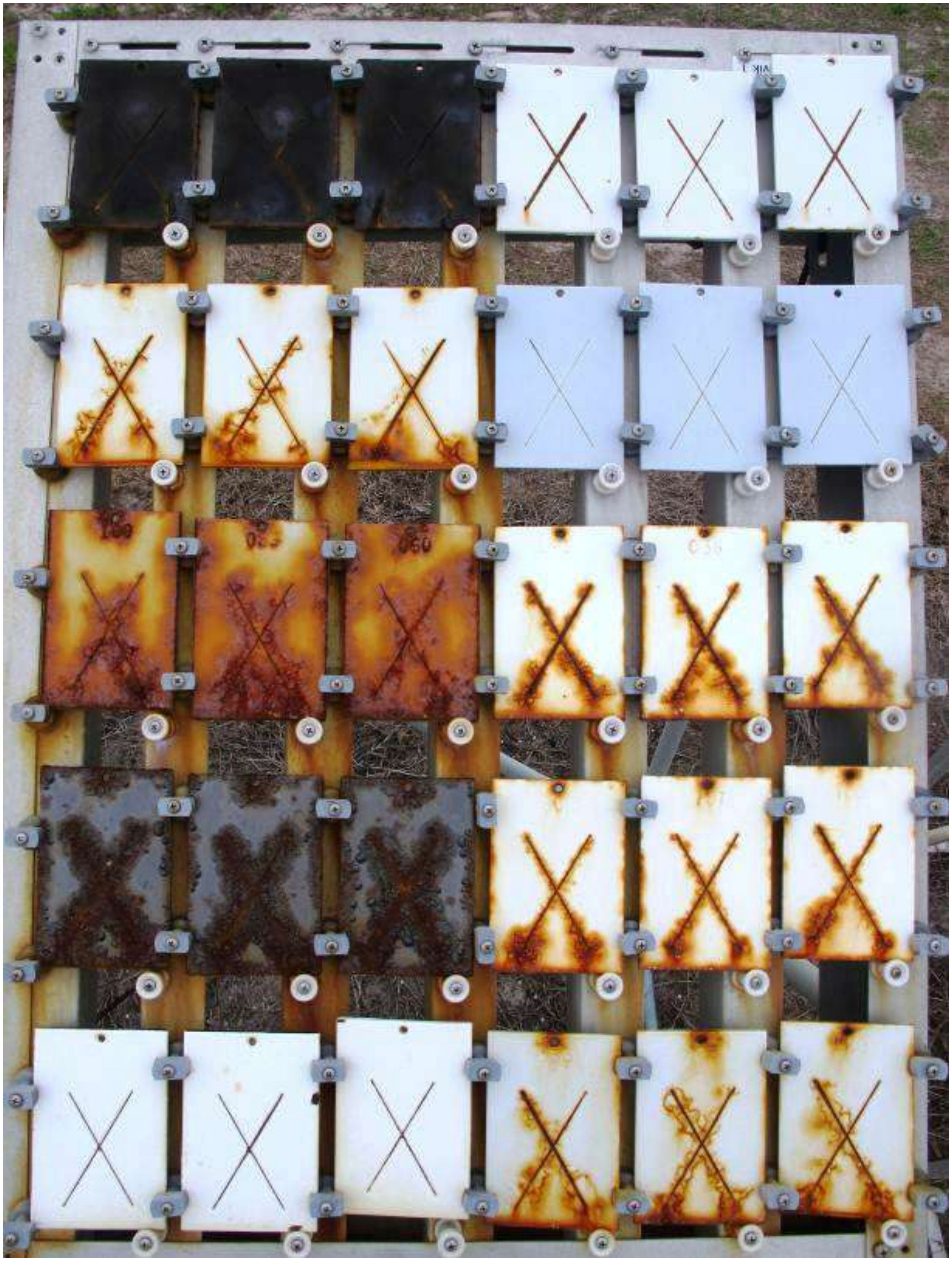


Figure 35 Full System Scribed Test Panels – 18 Months (02/16/2014)

5.6 Heat Adhesion

Test Description

Flat primer-only coated panels were tested for tensile adhesion using ASTM D 4541 (*Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers*). The same primer-only coated panels were then exposed in a high temperature oven to a temperature of 750° F for 24 hours. The panels were allowed to cool at room temperature. The coating was then re-tested for tensile adhesion to check for adhesion loss or film deterioration caused by the heating.

Rationale

This test evaluates the performance of primers after exposure to prolonged heat as required by NASA-STD-5008B for Zones 1 and 2. This test documents the exposure of the primers to heat followed by adhesion testing. Its purpose is to identify a coating's resilience after exposure to high temperatures.

Although this test is not required for Zone 4 applications, stakeholders agreed that the data would be valuable to know to determine if the alternative primers could be used in Zones 1 and 2.

Data Analysis and Reporting

- The pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system.
- The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. Four (4) possible failure modes (and percent failure) are reported. The failure modes are discussed as follows.

    1. Substrate failure – The adhesive value of coatings typically exceeds the tensile strength of substrate thereby causing a substrate failure prior to a coating adhesion failure. This failure mode is common on concrete.
    2. Adhesive failure – A failure at the substrate/coating interface or between two layers of coatings.
    3. Cohesive failure – A failure within a single coating layer.
    4. Glue failure – Occurs when the adhesive used fails.

- Frequently, there is not one failure mode, but rather a combination of modes. Figure 35 is an example of an adhesion test which resulted in an 80% adhesive coating failure (between coating and substrate) and 20% cohesive coating failure (within coating layer).

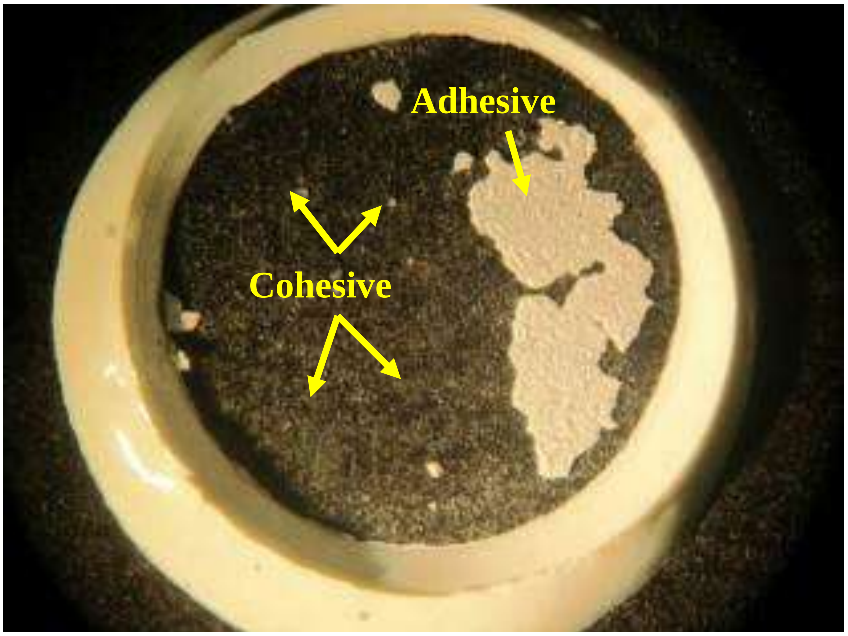


Figure 36 Example of Adhesive and Cohesive Failure

- The pull-off strength is computed based on the maximum indicated load, the instrument calibration data and the original surface area stressed. An Elcometer 110 PATTI pneumatic adhesion tester was used to determine the burst pressure in psi. A picture of the apparatus is shown in Figure 36.

Figure 37 Elcometer 110 PATTI Adhesion Tester

- Once the burst pressure is determined, the pull-off tensile adhesion (POTS) is calculated as follows (Eq. 2).

$$POTS = [(BP \times Ag) - C]/Aps \qquad \textbf{Eq. 2}$$

Where:

POTS = Pull-off Tensile Strength (pounds per square inch or psi)
BP = Burst Pressure (psi)
Ag = Contact Area Between Gasket (in^2)
C = Piston Constant (lbs)
Aps = Area of Pull-stub (in^2)

- Results Summary
    1. Three (3) panels per system were evaluated by performing one pull per panel. The resulting burst pressure was recorded and the pull-off adhesion was calculated (in psi).
    2. An analysis of the data was performed according to ASTM D 4541 specifications to determine if the replicate measurements were acceptable at a 95% confidence level. According to the standard, a Type IV intra-laboratory instrument requires results obtained by the same operator to be considered suspect if they differ by more than 29%. The difference in percent relative for the three (3) results is the absolute value of:

    $$[(\text{Max Value} - \text{Min Value})/(\text{Max Value} + \text{Min Value})/2] \times 100\%$$

    3. The results are shown in Table 13 (Pre-heat) and Table 14 (Post-heat) and summarized in Table 15.

Table 13 Pre-heat Primer Adhesion Results					
System	***Panel ID***	***PSI***	***Average PSI***	***Failure Mode***	***Relative Percentage Difference****
1	79	2607	2382	100% glue	21
	50	2640		100% glue	
	196	1898		100% glue	
2*	19	2339	2236	50% cohesive, 50% glue	6
	9	2146		50% cohesive, 50% glue	
	163	2224		50% cohesive, 50% glue	
3	238	2459	2610	100% glue	22
	221	2207		100% glue	
	224	3164		100% glue	
4	30	1061	1287	100% glue adhesion to coating	25
	108	1581		100% glue adhesion to coating	
	171	1218		100% glue adhesion to coating	
5	120	2946	2349	100% glue adhesion to coating	29
	160	1820		100% glue adhesion to coating	
	98	2282		100% glue adhesion to coating	
6	37	3205	2933	100% glue	10
	34	2735		70% cohesion, 30% glue	
	93	2859		80% cohesion, 20% glue	
7	244	1354	1340	100% glue adhesion to coating	16
	234	1164		100% glue adhesion to coating	
	143	1502		100% glue adhesion to coating	
8	720	3154	2929	80% cohesion, 20% glue	26
	775	3403		75% cohesion, 25% glue	
	759	2204		5% cohesion, 95% glue	
9	792	0	386	Test re-run with smaller piston	8
	728	362		100% coating adhesion	
	729	410		100% coating adhesion	
10	130	3424	3181	10% cohesion, 90% glue	9
	134	3156		15% cohesion, 85% glue	
	29	2962		100% glue	

***** System 2 Primer is already on APL so used as the Control

****** Relative Percentage Difference is the difference between values for each panel and is used for quality control purposes

Table 14 Pre-heat Primer Adhesion Results					
System	***Panel ID***	***PSI***	***Average PSI***	***Failure Mode***	***Relative Percentage Difference*****
1	79	0	0	Coating failed due to heat	0
	50	0		Coating failed due to heat	
	196	0		Coating failed due to heat	
2*	19	1742	1731	100% coating cohesion	1
	9	1732		100% coating cohesion	
	163	1719		100% coating cohesion	
3	238	0	0	Coating failed due to heat	0
	221	0		Coating failed due to heat	
	224	0		Coating failed due to heat	
4	30	1701	1779	100% coating cohesion	6
	108	1849		100% coating cohesion	
	171	1787		100% coating cohesion	
5	120	0	0	Coating failed due to heat	0
	160	0		Coating failed due to heat	
	98	0		Coating failed due to heat	
6	37	0	0	Coating failed due to heat	0
	34	0		Coating failed due to heat	
	93	0		Coating failed due to heat	
7	244	0	0	Coating failed due to heat	0
	234	0		Coating failed due to heat	
	143	0		Coating failed due to heat	
8	720	0	0	Coating failed due to heat	0
	775	0		Coating failed due to heat	
	759	0		Coating failed due to heat	
9	792	0	0	Coating failed due to heat	0
	728	0		Coating failed due to heat	
	729	0		Coating failed due to heat	
10	130	0	0	Coating failed due to heat	0
	134	0		Coating failed due to heat	
	29	0		Coating failed due to heat	

***** System 2 Primer is already on APL so used as the Control

****** Relative Percentage Difference is the difference between values for each panel and is used for quality control purposes

Table 15 Primer Heat Adhesion Summary			
System	***Adhesion Gain/(Loss) %***	***Coating Condition***	***Pass/Fail***
1	(100)	100% coating failed due to heat	**Fail**
2*	(23)	23% loss, but still > 1000 psi	**Pass**
3	(100)	100% coating failed due to heat	**Fail**
4	38	38% increase in adhesion	**Pass**
5	(100)	100% coating failed due to heat	**Fail**
6	(100)	100% coating failed due to heat	**Fail**
7	(100)	100% coating failed due to heat	**Fail**
8	(100)	100% coating failed due to heat	**Fail**
9	(100)	100% coating failed due to heat	**Fail**
10	(100)	100% coating failed due to heat	**Fail**

***** System 2 Primer is already on APL so used as the Control

4. An analysis of the adhesion data set indicate that none of the data collected deviated by more than 29.0% as required in ASTM D 4541.
5. Only System 4 performed better than the Control (System 2) as required in NASA-STD-5008B.
6. System 2 and System 4 were the only inorganic zinc primers in the test matrix. All of the other systems have an organic resin base which could not withstand the heat test. While not a disqualifier from being approved; they should not be used in Zones of Exposure (1 and 2) with elevated temperatures.

6. RECOMMENDATIONS

This Stage 1 Test Report covers the Phase 1 testing of the potential alternatives identified in the PAR. The performance of the potential alternatives was compared to those of a Control System selected from the APL of NASA-STD-5008B. Those coatings that show acceptable performance in Stage 1 Testing will then be subjected to the Phase 2 tests as identified in the JTP under the title of Stage 2 Testing.

Under NASA TEERM project management, the NASA CTL performed the Stage 1 Testing which included the following performance requirements:

- Pot Life
- Ease of Application
- Surface Appearance
- Atmospheric Exposure Testing (Color Retention, Gloss Retention, Degree of Rusting, Scribe Creepage, and Degree of Blistering)
- Heat Adhesion

Pot Life, Ease of Application, and Surface Appearance were evaluated during the preparation of the test panels and are based on the applicator's evaluation. As test coupons were prepared, the applicator noted any issues with pot life, application processes and equipment, and the coating appearance.

There were no issues with the mixing process and pot life except for two (2) systems. System 1 (the coating heated up quickly and kicked off before application could commence). The group had originally selected two (2) coating systems from the manufacturer A&E Group: a two-coat system including a primer and a topcoat and a single coat system comprised only of the topcoat. Due to the issues experienced during application only the two-coat system was included in testing.

System 10 is a Carboline system that incorporated the NASA CTL uCapsules into the primer coat. The primer was fast reacting and required a static mixing tip that mixed the coating while being sprayed, but was applied successfully with no further issues.

Of the 10 alternative coating systems subjected to the 18-month Atmospheric Exposure Testing, only three (3) systems showed acceptable performance. The majority of the alternative systems showed poor corrosion resistance, color retention, and gloss retention.

Only two (2) of the alternative primers passed the post-heat adhesion testing, and one of those was a primer that had already been approved and included in the NASA-STD-5008B APL.

A summary of the results are shown in Table 16.

Table 16 Stage 1 Testing Results as Compared to the Baseline System									
System	*Pot Life*	*Ease of Application*	*Surface Appearance*	*Primer Heat Adhesion*	*Atmospheric Exposure Testing (after 18 months)*				
					Corrosion	*Blistering*	*Scribe*	*Color*	*Gloss*
1 (Iso-free)	✗	✗	✓	✗	✗	✗	✗	✗	✗
2 (Iso-free)	✓	✓	✓	=	=	=	=	=	✓
3 (Zinc-free)	✓	✓	✓	✗	✗	✗	✗	✗	✓
4 (Iso-free)	✓	✓	✓	=	✓	=	=	=	✗
5 (Iso- + Zinc-free)	✓	✓	✓	✗	✗	✗	✗	✗	✗
6 (Iso- + Zinc-free)	✓	✓	✓	✗	✗	✗	✗	✓	=
7 (Iso- + Zinc-free)	✓	✓	✓	✗	✗	✗	✗	✗	✓
8 (Iso-free + Reduced Zinc)	✓	✓	✓	✗	✗	✗	✗	✗	✗
9 (Iso- + Zinc-free)	✓	✓	✓	✗	✓	=	=	✗	✗
10 (Zinc-free)	✗	✗	✓	✗	✗	✗	✗	✗	✗

Based on the results, it is recommended that the following systems continue to Stage 2 Testing:

- System 2 (isocyanate-free)
    - Primer: Carboline Carbozinc 11 WB
    - Intermediate: Carboline Carbotherm 3300
    - Topcoat: Carboline Carbocyrlic 3359

- System 4 (isocyanate-free)
    - Primer: Polyset Ply-Zinc WB 18
    - Topcoat: Polyset Ply-Guard ME

- System 9 (isocyanate-free and zinc-free)
    - Primer/Topcoat: EonCoat Alloyed Coating for Steel

7. REFERENCE DOCUMENTS

Table 17 documents the standards and test methods referenced in the JTP.

Table 17 Summarized Test and Evaluation Reference Listing			
Reference Document	***Title***	***Test***	***JTP Section***
ASTM A 36	*Standard Specification for Carbon Structural Steel*	Test Descriptions	3.
ASTM D 522	*Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*	Mandrel Bend Flexibility	3.2.7.
ASTM D 523	*Standard Test Method for Specular Gloss*	Surface Appearance, Atmospheric Exposure Test, Reparability	3.1.3., 3.1.4., 3.2.6.
ASTM D 610	*Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*	Atmospheric Exposure Test	3.1.4.
ASTM D 714	*Standard Test Method for Evaluating Degree of Blistering of Paints*	Atmospheric Exposure Test	3.1.4.
ASTM D 2244	*Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates*	Surface Appearance, Reparability	3.1.3., 3.2.6.
ASTM D 2512	*Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold* and *Pass-Fail Techniques*)	LOX Compatibility	3.2.2.
ASTM D 3359	*Standard Test Methods for Measuring Adhesion by Tape Test*	Reparability	3.2.6.
ASTM D 4541	*Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers*	Heat Adhesion, Tensile (Pull-off) Adhesion	3.1.5., 3.2.4.

Reference Document	Title	Test	JTP Section
ASTM D 4752	*Standard Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub*	Cure Time (MEK Solvent Rub)	3.2.3.
ASTM G 155	*Standard Practice for Operating Light Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials*	Removability	3.2.5.
ASTM G 50	*Standard Practice for Conducting Atmospheric Corrosion Tests on Metals*	Atmospheric Exposure Test	N/A
FED-STD-141	*Paint, Varnish, Lacquer and Related Materials*	X-Cut Adhesion	3.2.4.
KSC Report MTB-175-88	*Procedure For Casual Exposure Of Materials To Hypergolic Fluids*	Hypergol Compatibility	3.2.1.
NACE-STD-RP0281	*Method for Conducting Coating (Paint) Panel Evaluation Testing In Atmospheric Exposures*	Test Descriptions	3.
NACE-STD-RP0287	*Field Measurements of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*	Test Descriptions	3.
NASA-STD-5008B	*Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment*	Introduction, Atmospheric Exposure Test, Heat Adhesion	1., 3.1.4., 3.1.5.

Table 17 Summarized Test and Evaluation Reference Listing

Table 17 Summarized Test and Evaluation Reference Listing			
Reference Document	***Title***	***Test***	***JTP Section***
NASA-STD-6001	*Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion*	Hypergol Compatibility, LOX Compatibility	3.2.1., 3.2.2.
SSPC-PA-2	*Measurement of Dry Coating Thickness with Magnetic Gages*	Test Descriptions, Ease of Application, Removability	3., 3.1.2., 3.2.5.
SSPC-SP-1	*Solvent Cleaning*	Test Descriptions	3.
SSPC-SP-5	*White Blast Cleaning*	Test Descriptions	3.