Final Report

ASSESSMENT OF THERMAL CONTROL AND PROTECTIVE COATINGS

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ABSTRACT

A contract was awarded to AZ Technology by NASA, George C. Marshall Space Flight Center, for the "Assessment of Thermal Control and Protective Coatings". AZ Technology, under this contract, developed new and/or modified thermal control and protective coatings that have helped to resolve many difficult issues for the International Space Station and other spacecraft.

The program initially identified significant ISS coating issues, determined those that had the potential to be resolved and then defined tasks to resolve those coating issues. Initially two major coating issues were identified as being very important. Those were related to the development and production of the white (low solar absorptance/high thermal emittance) thermal control radiator coatings and space stable color marker coatings.

The first significant issue was to optimize the processing of the production, deposition and curing parameters of the white thermal control coating Z93P and AZ93P. This material is widely used on ISS and the goal of this task was to significantly reduce the difficulty and uncertainty in manufacturing and deposition of this material.

The second issue was development of space-stable, colored inorganic coatings for possible use on ISS. The colors to be investigated were yellow, red, blue, and green; with primary focus on yellow which could be used on ISS handholds. Current anodized coatings have poor brightness and color matching to Federal Standard 595 number 33538 yellow. A need was identified for space-stable inorganic coatings that could be deposited as arrows, lettering and symbols on the various ISS components. These markings are required to have good visual detection and long-term stability in the Low Earth Orbit (LEO) environment.

Five marker coatings, a bright yellow handrail coating, protective overcoat for ceramic coatings, and specialized primers for composites (or polymer) surfaces were developed and commercialized by AZ Technology during this program. Most of the coatings have passed space environmental stability requirements via ground tests and/or flight verification. Marker coatings and protective overcoats were successfully flown on the Passive Optical Sample Assembly (POSA) and the Optical Properties Monitor (OPM) experiments flown on the Russian space station MIR. To date, most of the coatings developed and/or modified during this program have been utilized on the International Space Station and other spacecraft. For ISS, AZ Technology manufactured the "UNITY" emblem now being flown on the NASA UNITY node (Node 1) that is docked to the Russian Zarya (FGB) utilizing the colored marker coatings (white, blue, red) developed by AZ Technology. The UNITY emblem included the USA American flag, the Unity logo, and NASA logo on a white background, applied to a Beta cloth substrate.

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ACRONYMS AND ABBREVIATIONS

α	absorptance
α_s	solar absorptance
$\Delta\alpha_s$	delta change of solar absorptance
ε	emittance
ε_T	thermal emittance (at ambient temperatures, ~25C)
$\Delta\varepsilon_T$	delta change of thermal emittance
μ	microns (used in this report as to a wavelength of electromagnetic radiation)
AF	amorphous fluorocarbon
AO	Atomic Oxygen
AOBF	Atomic oxygen bean facility (at NASA/ MSFC)
AZ-93	AZ Technoloy's version of Z-93 white ceramic thermal control coating
AZT	AZ Technology, Incorporated
CRTD	Combined Radiation Testing Data
EH12	Physical Science & Environmental Effects Branch at MSFC
EVA	Extravehicular Activity
MAPTIS	Materials and Processes Technical Information System
MEEP	Mir Environmental Effects Payload
MIR	Russian space station
mils	0.001 inches
MPEEN	Materials, Processes, and Environmental Engineering Network
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
nm	nanometers
OOM	order of magnitude
OPM	Optical Properties Monitor
PBR	Pigment to binder ratio
POSA	Passive Optical Sample Assembly (flown on Mir)
SF	(crystalline) fluorocarbon
TC	Thermal control
TMC	
UV	Ultraviolet
UV/AO	Ultraviolet and Atomic Oxygen
VCMO	Vacuum Condensable Material Optical
VUV	Vacuum Ultraviolet
Z-93P	IITRI designation for the ZnO pigment/Potassium Silicate binder coating

1.0 INTRODUCTION

The typical means of spacecraft thermal control (including the International Space Station (ISS) are classified as active and passive. Both methods are dependent upon tailoring the thermal-optical properties of the external surfaces of the spacecraft or radiators. Space Station thermal control is achieved by balancing the heat emitted to space against the heat generated internally and absorbed from the sun and other close planetary bodies reflecting sunlight. This process is controlled by the optical properties of the spacecraft external surfaces covering the wavelength range from near ultraviolet (UV) to the infrared (IR) portion of the spectrum. External surfaces of the spacecraft are covered with special films or materials that are known as thermal control coatings. The optical and thermal properties of these unique materials are designed to provide the required heat balance of the spacecraft.

The natural and induced space environment can cause significant damage to the external surfaces of a spacecraft. Understanding the damaging effects of the space environment and how it relates to the thermal control materials is critically important for ISS. The increased size and complexity of ISS, compared to earlier spacecraft, and its longer-duration mission have increased the difficulty of maintaining ISS's thermal control materials and systems. Even with the availability of highly complex thermal control (TC) systems utilizing fluid loops and heat pipes, the ultimate regulation of absorbed solar energy and generated thermal energy from internal systems still remains dependent on the thermal-optical properties of the Space Stations thermal control surfaces.

Many, if not all, spacecraft thermal control materials to be used on ISS have one or more significant problems. Some of these problems are long term contamination potential, radiation or atomic oxygen (AO) instability, electrical charging, application difficulties and poor mechanical properties. Some of the primary issues facing ISS designers are the following: 1) efficient rejection of solar energy, 2) functional life-time of the thermal control surface, 3) effective emittance of absorbed or generated energy, and 4) long-term maintenance of the temperature environment for human inhabitants. In order to resolve these problems, ISS designers have had to consider many tradeoffs between optimum material properties, stability, functionality and human compatibility.

While a variety of surface materials, finishes, and coatings are available, those that can be used on spacecraft are limited by various constraints. Instability of most nonmetallic materials in the space environment is the primary reason which severely limits the number of useful coatings. Other coating restrictions are material and labor costs, elevated temperature curing, handling, cleanability of the surface, reparability, stability, and substrate compatibility.

There are four classes of thermal control materials: solar absorbers, solar reflectors, flat absorbers, and flat reflectors. For spacecraft applications, far more consideration is given to the solar reflector (radiator) coatings than to the other thermal control surfaces. This is because of its critical function of maintaining the spacecraft's desired temperature, the difficulty in maintaining its long-term stability and in obtaining the desired electrical properties. Coating selections are

usually made on the basis of both the initial solar absorptance-to-emittance ratio (α_S/ε_T) and the long term stability in the space environment.

On May 3, 1995, a contract was awarded to AZ Technology by NASA, monitored through the Marshall Space Flight Center, for the "Assessment of Thermal Control and Protective Coatings". AZ Technology, under this contract, developed new and/or modified thermal control and protective coatings that have helped to resolve many difficult issues.

2.0 PROGRAM OBJECTIVES

In general, the program objectives were to identify significant ISS coating issues, identify those that had the potential to be resolved, and then to identify tasks to resolve those coating issues. Initially two major coating issues were identified as being very important. Those were related to the development and production of the white (low absorptance/high thermal emittance) thermal control radiator coatings and space stable color marker coatings.

The first task was to initiate a study to optimize the processing of the production, deposition and curing parameters of the white thermal control coating Z93P and AZ93P. This material is widely used on ISS and the goal of this task was to significantly reduce the difficulty and uncertainty in manufacturing and deposition of this material.

The second task was to initiate the development of space-stable, colored inorganic and organic coatings for possible use on ISS. The colors to be investigated were yellow, red, blue, black, and green with primary focus on yellow which could be used ISS handholds. Current anodized coatings have poor brightness and color matching of Federal Standard 595 number 33538 yellow. A need was identified for space-stable inorganic coatings that could be deposited as arrows, lettering and symbols on the various ISS components. These markings are required to have good visual detection and long-term stability in the Low Earth Orbit (LEO) environment.

3.0 OVERVIEW OF COATINGS DEVELOPMENT

Five Marker coatings, handrail coating, protective overcoat for ceramic coatings, and specialized primers for composites and polymer surface coating were developed and commercialized by AZ Technology during this program. To date, several of the coatings developed and/or modified during this program have been utilized on the International Space Station and other spacecraft.

*Marker coatings were successfully developed for the following colors: Black, Yellow, Red, Blue, White, and Green.

*Identification, synthesis or processing to produce colored pigments that are resistant to energetic oxygen and radiation.

*Development of production process to demonstrate the feasibility of producing semi-conductive variants of some of the colored pigments.

*Coatings were developed and formulated into two forms, (1) Inorganic water glass type and (2) Silicone polymer organic solvent based. The development of these two basic types of coatings was undertaken to solve a variety of use application problems.

*Accomplishments of the inorganic glass based coatings
1. Typically very high degree of space environment stability
2. Water based, environmentally friendly coating systems
3. Developed coatings have excellent opacity and surface coverage.
4. Non flammable
5. Excellent NASA toxicity ratings
6. Excellent volatile condensable materials (VCM) ratings
7. Excellent physical properties (Many of the developed coatings can be bent around small radii without failure.)
8. Coatings were successfully designed to be used in conjunction with many different types of substrate materials
9. Coatings were successfully engineered to be deposited using standard painting spraying equipment.
10. Coatings were successfully engineered to be capable of being deposited into small intricate patterns or on to large and complex surfaces.
11. Marker coatings successfully flown on POSA and OPM on the Russian space station MIR.
12. Prepared UNITY emblem utilizing the colored marker coatings (white, blue, red) now being flown on the NASA UNITY node (Node 1) that is docked to the Russian FGB (Zarya). This emblem included the USA American flag, the Unity logo, and NASA logo on a white background, applied to a Beta cloth substrate.

*Accomplishments of the Silicone polymer based coatings
1. Good to high level of space environment AO, VUV, NUV stability
2. Current developed coatings are designed to be one part and self-priming
3. Marker coatings successfully flown on OPM on the Russian space station MIR.

*Fabrication of pin hole cameras and radiometers flown on the Mir Environmental Effects Payload (MEEP) exposing the marker coatings to the Mir space station external environment. This activity provided the first on orbit exposure of these marker coatings and the protective overcoat, which provided vital data for future customer acceptance.

*Fabrication of sample trays and fixtures for ground based space environmental effects simulation testing.

*Demonstrated the feasibility of using a specialized solution based Fluorocarbon polymer as a protective overcoat for thermal control (TC) coatings. Application and curing can be achieved in ambient conditions.

*Overcoat protected thermal control surfaces from ground handling contamination.

*Overcoat was also designed to be eroded in space leaving a pristine TC surface.

*Demonstrated feasibility decreasing cure time for water glass based (ceramic type) TC coatings by a elevated temperature cure.

*AZ Technology has commercialized many of these coating developments.

*The marker coatings are being used for external signs, labels, and emblems on ISS and other space vehicles.

*Because of this program, AZ Technology was able to work with Boeing MSFC and JSC to produce the Unity emblem currently in orbit.

*This emblem was made from inorganic marker (white, blue & red) coatings applied to a beta cloth substrate all of which was bendable.

*Fluorocarbon polymer protective overcoat was also used on Unity emblem and other ISS hardware and has/is providing ground handling protection from contamination. Coatings can be cleaned with ordinary solvents.

4.0 COATING DEVELOPMENT

4.1 White Pigments & Coatings

4.1.1 Optimization of Process Conditions for the Adhesion and Curing of Z-93

AZ Technology evaluated various methods and conditions to improve the processing of AZ-93 (Z-93P). The purpose of this effort was to reduce the processing time required to cure the coating without degrading the coating's adhesion properties on aluminum substrates. Reduction of processing time will reduce costs and time associated with the application of this widely used thermal control coating. Results indicate that the cure time may be reduced from 4 days to less than 1 day without negative impact to adhesion or optical properties. These results were based on evaluation and testing of the coating deposited onto 1.5" x 6.0" and 3.0" x 6.0" aluminum panels.

Evaluation of accelerated cure and adhesion was performed by space environmental effects testing at MSFC. A series of samples were prepared for space environmental effects testing at MSFC. Twenty AZ93 white ceramic coating test samples were prepared utilizing ML-P300AZ as a primer to enhance bonding. Table 1 is a matrix giving the thermal optical properties versus cure times, temperatures, and coating thickness. Results of the space environmental effects analysis of the AZ93 samples both with and without MLP-300 primer, yielded virtually no difference in thermal optical properties between the two types of samples.

Table 1 AZ93 over MLP-300 Primer

SAMPLE#	MLP-300 AMBIENT CURE	MLP-300 24HR @ 100°C CURE	AZ93 AMBIENT CURE	AZ93 24HR @ 100°C CURE	SOLAR ALPHA α_s	MEAN THICKNESS mils (0.001")
Z1-1-1	X		X		0.158	4.57
Z1-1-2	X		X		0.158	4.83
Z1-1-3	X		X		0.160	4.57
Z1-1-4	X		X		0.157	4.63
Z1-1-5	X		X		0.161	4.58
Z1-2-1	X			X	0.154	5.55
Z1-2-2	X			X	0.154	5.40
Z1-2-3	X			X	0.154	5.22
Z1-2-4	X			X	0.155	4.94
Z1-2-5	X			X	0.156	4.56
Z2-1-1		X	X		0.160	4.75
Z2-1-2		X	X		0.156	4.90
Z2-1-3		X	X		0.156	5.04
Z2-1-4		X	X		0.151	5.55
Z2-1-5		X	X		0.152	5.39
Z2-2-1		X		X	0.157	5.18
Z2-2-2		X		X	0.156	4.94
Z2-2-3		X		X	0.157	5.20
Z2-2-4		X		X	0.157	4.75
Z2-2-5		X		X	0.157	4.85

4.1.3 Protective Overcoat Development for AZ-93

The goal of this study effort was to provide a thin protective coating on the thermal control (TC) surface through the use of a fluorocarbon polymer film. This protective coating is primarily being designed for protection against contamination from the manufacturing and integration environment, not the orbital environment. Use of this coating will reduce particulate and molecular contamination on or from the TC coating. This coating will intrinsically have very low surface energy which will not tend to attract or hold contamination and will be easy to clean when necessary. It will also seal the surface from the absorption of water in vapor or solid phase during assembly, storage and launch environments. Overcoating will also seal the coating to minimize spalling of coating particles, a known problem with spray deposited coatings. Ceramic coatings are more susceptible to this phenomenon because of their high surface morphology and the brittle, high modulus nature of this class of material. The effective use of this overcoating material could therefore help to eliminate concerns of operational problems when utilizing ceramic coatings for spacecraft applications.

Initially it was planned to overcoat our test samples with the amorphous form of this fluorocarbon polymer (AF). However, after obtaining additional specific information concerning the new semi-crystalline form of the fluorocarbon polymer (SF) a decision was made to evaluate both forms as protective overcoating for ceramic type thermal control coatings. This

new material very similar optical properties as the amorphous fluorocarbon polymer, but is substantially lower cost to produce with better physical and mechanical properties.

Experiments with this coating system deposited on to a polymer film have demonstrated much increased flexibility and excellent cleaning characteristics. Overcoated AZ-93 has demonstrated the materials capability to seal the surface from the absorption of water. This was demonstrated by weighing a sample, then 18 Megohm water was placed on the protective coating and remained for a period of one hour. At the end of the period the protective coating was wiped dry, weighed, and visually observed. No mass or visual changes occurred to the coating system when a thickness of 0.20 mils or greater of the protective coating was used. Samples with a protective coating thickness of less than 0.20 mils tended to absorb the water droplet, increasing in mass with a visual darkening of the coating around the droplet occurring.

Forty aluminum coupons (0.995 inch diameter) were coated with AZ-93 white thermal control coating. Twenty of these samples were primed with MLP-300AZ for space environmental testing at MSFC. These samples were cured in the normal manner and overcoated with the fluorocarbon polymer. The purpose of this comparison test at MSFC was to determine: 1) if there is any differences in how the two polymers are affected by the UV/AO vacuum environment. 2) does the way in which the materials are affected by the test environment result in increased solar absorptance of the underlying AZ-93 coating. These samples have been divided into two basic groups; one group coated with the amorphous fluorocarbon polymer (AF) and the other with the semi-crystalline fluorocarbon polymer (SF) with the protective coating thickness of ~ 0.25 and ~ 0.50 mils. Table B-1 in Appendix B, provides sample composition and properties information. Finished samples were submitted to MSFC for evaluation and testing.

The UV/AO test was conducted by Ms. Rachel Kamenetzky of EH12 at NASA, George C. Marshall Space Flight Center. The MSFC test data is shown in Table B-2 & -3 in Appendix B. Initial findings indicate that the protective coating does not adversely affect the thermal optical properties of the underlying ceramic coating. No discoloration of the samples (turning brown or gray) was observed during or after the testing, nor was there any significant change in solar absorptance detected after exposure. However, one sample (ZP.50.A-15) did exhibit an appreciable thermal emittance change of 0.014, almost twice as great as the change for any other test sample.

UV/AO test number one, conducted by EH12, had an AO fluence of approximately 10^{20} atoms/cm^2 and resulted in a high percentage (~95-99%) of removal of the protective overcoating. This test, which accumulated 6202 VUV Equivalent Sun Hours (ESH), had a mean and standard deviation for solar absorptance of -0.002 and +0.003 respectively, which was determined from data in Table B-3 in Appendix B. This slight decrease in solar absorption is likely due to water loss during vacuum exposure, resulting in lower near-infrared absorption. The second and longer test of 12,303 VUV (ESH) resulted in a mean and standard deviation of +0.002 and +0.002, respectively, for solar absorptance. This slight increase in solar absorptance is thought to be the onset of degradation to the ceramic coating indicated by an increasing mean solar absorptance. This test demonstrated that overall use of room temperature deposited and cured fluorocarbon

polymer as a sacrificial protective coating for space station hardware is a viable, effective process based on currently available data.

Thermal cycle testing was initiated through MSFC and was performed by McDonnell Douglas (now Boeing - Huntington Beach) at their request. Samples (6"x6" aluminum plates) of fluorocarbon polymer-coated AZ-93 were submitted to MSFC for characterization and delivery to McDonnell Douglas for testing. Two panels were coated on both sides with AZ-93 at approximately 5 mils thickness. Once cured, both of these panels were over-coated with fluorocarbon polymer, one side to a thickness of 0.5 mils and the other side to 0.25 mils. In addition, flight hardware samples of this same coating system were sent to SPAR Aerospace in Quebec, Canada and have been thermal cycled at least twenty times to date with no visible failures. Thermal cycling temperatures were -48 to +78°C during SPAR testing. Also, AZ Technology successfully performed thermal shock testing on coated panels, with test conditions of +100°C to equilibrium liquid nitrogen temperatures (approximately -142°C).

4.2 Development and Optical evaluation of Yellow Pigments & Coatings

4.2.1 Yellow Pigment

A pigment and binder compatibility study between inorganic yellow pigments was initiated. Potassium silicate inorganic binder and pigments were blended together and allowed to sit for several days in both polymer and glass test tubes to determine their intrinsic reactivity. No vigorous reaction was observed to have taken place. There was no agglomerating or precipitation visible within the test tubes indicating that the materials are compatible and will not uncontrollably gel or solidify. Of the yellow pigments evaluated, the Ferro material is a better match to the federal standard colors required by ISS. Coatings were formulated to evaluate their optical properties, deposition characteristics, opacity, adhesion, and cohesive properties.

For the yellow ceramic pigment, a decrease in NIR absorptance of ten percent or greater has been achieved by heat treating the neat pigment in air. Thermal processing of these pigment material candidates can successfully reduce solar absorptance in the NIR which makes it easier to engineer a coating system that will have an acceptable operating temperature to both manage possible rates of degradation and touch temperature. It is hypothesized that the decrease in absorptance attained by heat treating small batch quantities of pigment is achieved by more complete conversion of the starting material to the product. The manufactures may not have complete conversion because of large quantities that they process as a single batch. This may result from ineffective control of reactants such as oxygen from batch to batch. In addition, contaminates from packaging, handling, or atmospheric reaction may be converted or removed during this process.

4.2.2 Yellow Coating

Two batches of an inorganic yellow coatings were prepared for evaluation. Formulation of the coating used only inorganic materials and was deposited onto twenty, 1 inch diameter coupons and one, 3 x 6 inch aluminum panel. The yellow pigment is a zirconium oxide

compound and was formulated into an inorganic coating using potassium silicate $K_2O:SiO_2$. A ratio of 3:1 to 5:1 pigment to binder (PBR) yielded tough coatings with good color at a thickness of 2.5-3.0 mils. A sample was irradiated with ultraviolet (UV) radiation in AZ Technology facilities. Also, several samples were submitted to the NASA COTR for space environmental exposure and evaluation.

Optical data obtained from the in-house UV exposure test is given in Figures A-1 through A-3. Figure A-1 is the reflectance spectra for the exposed test sample and was measured over a wavelength range of 0.25 to 2.5 microns, using an the AZ Technology's LPSR-200 spectroreflectometer. In general, this coating has good reflectance characteristics for a yellow coating, with a thickness of only 2.7 mils. Much of the solar absorptance value can be attributed to the materials good Near Infrared (NIR) characteristics. The solar absorptance continued to decrease as a function of exposure duration. This is evident in all of the Figures. Most of the reflectance increase occurred in the NIR, from what we believe is due to the loss of water from the coating. Figure A-3 illustrates the coating's fundamental absorption edge with a small but consistent trend of this band to shift towards the shorter wavelengths. This change in the material is the result of water desorption or a slight bleaching from an interaction with the UV radiation and possibly some form of oxygen.

Samples of the yellow marker coating were exposed to a low pressure UV source in air for our initial testing, no precautions or measures were taken to control the sample temperature. As a result, the back side temperature of the sample tends to remain between 85-91°C (185-195.8°F), far above the normal exposure temperature of 20-25°C (68-77°F). The relative humidity within the exposure area was measured to be at 17%. In addition, the possibility exists for oxygen reactions with the sample since the UV source may have generated ozone (O_3) - the odor of which can be detected when working around the exposure area. Even with the coating maintaining a back surface temperature of 85-91°C, it still required at least 3 days for most of the water (both chemically and physically bound) to be desorbed. The loss of water from the coating may have continued onto the eleventh or fourteenth days of measurement by the increase in reflectance in the IR portion of the spectrum, as shown in Figure A-1. Figure A-2 provides an expanded representation of a portion of the NIR spectrum for the irradiated coating. The primary feature illustrated is the extinction of the water absorptance band centered at about 1950nm. Also, a general broad band increase in sample reflectance is shown. This general increase in reflectance is likely the result of the formation of scattering centers caused from the desorption of water from the coating. Also of interest is the re-absorption of water into the sample, as is indicated by the dashed line spectra in Figure A-2. There was some increase in optical absorptance, but recovery to the original value did not occur for the three days of exposure to ambient humidity of 50 to 60 percent. The elevated temperature condition is allowed to continue since our sample exposure is an easy screening test and may be considered one of the worst case scenarios. The exposure is used to find any gross stability problems before time and material is used in conducting a vacuum UV or combined radiation environment test.

4.2.3. Space Simulation Testing And Evaluation of TMS-800-IY

Space Simulation testing was performed on samples of TMS-800-IY yellow inorganic coating at NASA/MSFC. These tests consisted of UV/AO and a combined radiation test. The types of radiation used for this test are NUV, VUV, and electrons. Electron energy used was typically 50 Kev produced by an electron flood gun. The samples of the coating were deposited onto aluminum coupons, typically 0.995 inches in diameter with a coating average thickness of 3 to 4 mils.

Exposure to the UV/AO test environment had little effect on the coatings. A review of the spectra showed a slight increase in the reflectance in the NIR portion of the spectrum. This increase, as noted previously is the result of water loss from the coating causing void formations and increasing the scattering efficiency of the system. Bi-directional reflectance of the coating sample also increased as a result of exposure to the UV/AO environment.

Analysis of the Combined Radiation Testing Data (CRTD) indicated that there is little change in the solar absorptance value as a function of radiation dose. The results of this test demonstrate that this coating has good stability to all environmental constituents to which it has been tested.

4.2.3 Yellow Inorganic Handrail Coating

The ceramic powder used in the TMS800-IY yellow coating for the handrails was processed by heat treated at 900°C for four hours. This results in a ceramic powder with a deep yellow color with high NIR hemispherical reflectance. The ceramic powder is ball milled for a period of four hours with a jar loading of 60 to 80 percent and yields a fine powder and a non-abrasive coating.

Two sample ISS handrails were received for coating with TMS 800IY marker coatings. Several handrail mockups were prepared and coated before the ISS supplied handrails were coated. The results of the TMS 800IY application test were positive since no unusual difficulties were experienced with respect to coating the complex shape of the handrails. In addition, TMS 800IY was applied over the primer MLP-300, as well as unprimed aluminum substrates to observe the deposition properties of the yellow coating. No unusual effects were noted in any of the configurations.

A second handrail was coated with TMS-800IY and returned to NASA MSFC EH 12 for evaluation. The fluorocarbon polymer film was applied to half of the coated handrail, to evaluate the performance of the two systems.

4.2.4. Protective Overcoat for Yellow Coating

Figures A-4 through A-8 provide the solar absorptance spectra for four test coupons and one witness coupon coated concurrently with the handrail. Table 2 provides a comparison of the film thickness affect on solar absorptance values for both TMS800-IY (yellow) and AZ-93 (white) coatings, overcoated with the fluorocarbon polymer. The spectra and table indicate only slight change in absorptance characteristics, which occurs broadband and along the absorption

edge. The broadband absorptance is demonstrated in the spectra shown in Figures A-4, A-5, and A-8. This absorptance occurs when the overcoat is below 1.16 mils thickness. Test samples having a greater film thickness showed a spectral absorptance of fluorocarbon polymer matching that of the base TMS800-IY coating (Figures A-6 and A-7).

The change in absorptance edge for all samples including one of AZ93 white Thermal Control (TC) coating (Figure A-9) shifted towards the UV portion of the spectrum. Currently, we do not have a good understanding of this phenomenon. Two hypotheses being considered for this phenomenon are that this spectral shift is (a) the result of a change in scattering characteristics of the surface, or (b) the result of the far different electronic structure of the Fluorocarbon polymer at the surface from that of the ceramic coating.

Both hypotheses for this phenomenon are a function of film thickness for the overcoat. The fluoropolymer has a high dielectric characteristic, while the metal oxide - potassium silicate systems demonstrate semiconductor characteristic under ambient conditions. This semiconductor characteristic can result from intrinsic material properties or chemically absorbed water.

The implementation of a fluorocarbon polymer, or some similar type material as a protective overcoat for alkali silicate spacecraft coatings can solve many problems associated with this class of materials. These problems include protecting the TC coating from damage and contamination during ground handling, storage, and component assembly. Other problems that the overcoat may aid in solving are the alkali silicates potential for reacting with atmospheric constituents including CO_2 and water vapor. Such a reaction results in formation of long, very thin crystals, and tends to be initiated at the surface of the substrate growing through the coating. The formation and growth of such crystals reduces coating strength and may generate particulate contamination. Absorption of water will also add mass to the coating and degrade both optical and mechanical properties. When implemented, the protective overcoat will protect the TC coating from such reactions and seal the surface from water absorption.

Table 2. Fluorocarbon polymer Overcoat and Its Effect on Inorganic Spacecraft Coatings

Sample Designation	TC Coating Thickness	TC Coating Solar Absorptance	Thickness with Fluorocarbon polymer	Mean Fluorocarbon polymer Thickness	TC & Fluorocarbon polymer Coating Solar Absorptance
TMS800IY Sample #1	5.61 mils	0.469	6.41 mils	0.80 mils	0.467
TMS800IY Sample #2	6.20 mils	0.467	7.14 mils	0.94 mils	0.463
TMS800-IY Sample #3	6.64 mils	0.478	7.86 mils	1.22 mils	0.470
TMS800-IY Sample #4	4.71 mils	0.456	5.87 mils	1.16 mils	0.459
TMS800-IY Witness Panel (Handrail)	3.42 mils	0.356	3.96 mils	0.54 mils	0.361
AZ93 Coating Sample	5.31 mils	0.154	6.36 mils	1.05 mils	0.157

4.2.5. Electrically Conductive Yellow Coating Development

The standard TMS-800IY yellow coating was modified to be electrically conductive and to enhance the coating's abrasion and impact resistance. Several different formulations utilizing a modified TMS-800IY pigment were developed and evaluated. For purposes of electrical evaluation and a possible alternative coating development, a polymethylsiloxane (organic) binder was used in the preliminary formulations. Several of these formulations suffered mechanical failure due to shrinkage and thermal shock when removed from the oven (set at 100°C) used to accelerate drying. Later formulations using a 3:1 pigment-to-binder ratio (PBR) did not have the susceptibility to cracking that the 2:1 PBR coatings demonstrated. Some cracking did occur, but only on the glass slide used for electrical conductivity measurements.

Figure A-10 shows the spectral reflectance and solar absorptance for the two samples of batch D-130. This coating is diffuse in appearance and has significantly lower solar absorptance than the inorganic TMS-800IY. Inorganic TMS-800IY typically has a solar absorptance of 0.46 - 0.47 compared to 0.33 for the organic (silicone) based coating. Not only does this coating achieve a lower solar absorptance, but also has an 80-86 percent reflectance range over much of the NIR portion of the spectrum (700-2100 nm).

Table 3 provides electrical resistivity data for the organic (silicone) based coating. This electrical data is graphically presented in Figure A-11. This coating demonstrated good surface resistivity values with all data falling within the range of 6.0×10^7 to 3.7×10^8 ohms/sq. Maximum surface charge voltage maintainable for this coating is 100 VDC. These resistance values are effective in minimizing or eliminating electrostatic charge build up on coated substrates. Volume or bulk resistivity measurements of this same coating demonstrated good results, with an average resistivity of 3.2×10^6 ohms-cm. Both of these measurement methods exhibit a trend of slightly decreasing resistance as charging voltage increases, as shown in Figures A-11. Maximum charge voltage achievable during volume resistivity testing was only 0.7 volts at the maximum current of 100 μa. This maximum charging potential is the lowest measured to date by these researchers for any spacecraft sprayable coating.

Figure A-12 is the reflectance spectra for the inorganic (silicate) analogue of the yellow organic (silicone) coating. A comparison of Figures A-10 and A-12 demonstrate a significant difference in spectral reflectance characteristics between the two coatings. Both coatings have the same relative masses of pigment and binder materials. The broad NIR absorptance band is characteristic of the Kasil 1 potassium silicate binder used in this developmental coating. Both silicone and silicate binders yield a coating with good color. However, Kasil 1 was used for this coating over P.Q. 2130 or 2135 because it tends to have better impact, crack, and abrasion resistance, while sacrificing some NIR transmittance or reflectance efficiency. Solar absorptance for this coating is ($\alpha_S = 0.41$ to 0.49), which is higher than the silicone version by 8 to 16 percent. The silicate coatings were exposed to low vacuum using a glass desecrator and a mechanical roughing pump. Samples were exposed to the vacuum for a period of 2 days and then re-measured for solar absorptance. The solar absorptance for these samples exhibited a decrease of approximately 2%.

Table 3. Electrical Resistivity of Yellow Polymethyl Siloxane

(organic silicone) Handrail Coating.

Charging Voltage V DC	Surface Resistivity (Ohms/sq.)	3:1 PBR Volume Resistivity (Ohms-cm)
0.1		3.48E+06
0.2		3.42E+06
0.5		3.03E+06
0.7		2.88E+06
1.0	3.66E+08	
10.0	2.22E+08	
25.0	1.47E+08	
50.0	9.92E+07	
100.0	6.00E+07	

Readings made at 76 degrees F, 30% RH
Mean thickness for volume measurements = 5.6 mils

Table 4. Volume Resistivity of Yellow Inorganic Silicate Handrail Coating.

Charging Voltage V DC	2.5:1 PBR Volume Resistivity	3:1 PBR Volume Resistivity
0.1	3.71E+08	2.06E+09
1.0	5.34E+08	1.77E+09
2.0	4.18E+08	1.53E+09
5.0	5.64E+08	1.48E+09
7.5	5.62E+08	1.31E+09
10.0	2.87E+08	1.25E+09
15.0	2.31E+08	1.18E+09
20.0	2.25E+08	9.84E+08
25.0	2.44E+08	9.97E+08
30.0	2.04E+08	
50.0		4.70E+08

Readings made at 76 degrees F, 47% RH
Mean thickness for volume measurements = 4.8 mils for 2.5:1
Mean thickness for volume measurements = 3.9 mils for 3:1

Electrical resistivity of the inorganic coatings was greater than that of the silicone coatings by approximately an order of magnitude (OOM) for volume resistivity and two OOM's for surface resistivity (compare Tables 4 and 5). Figures A-13 and A-14 are plots of the surface and volume resistivity data versus the charging voltage for the inorganic (silicate) coatings at two different PBR's. Since electrical measurements of these inorganic coatings were performed in

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air, atmospheric moisture absorbed on the surface and in the bulk may affect the accuracy of these measured values. In an effort to minimize effects caused by adsorbed water, samples were baked at 100°C for approximately 24 hours and then stored in an evacuated glass desecrator when not being tested.

Surface resistivity of the two inorganic coatings is essentially the same, as shown in Figure A-13. Resistivity of 3:1 PBR coating is slightly less than that of 2.5:1 PBR as one would predict. The higher concentration of conductive material in 3:1 PBR coating should yield the results measured for surface resistivity, however the measured values for volume (bulk) resistivity do not follow the expected trend. Volume resistivity is less for 2.5:1 PBR than 3:1 PBR coating. As the charging voltage was increased, resistivity of 3:1 PBR coating begins to approach that of 2.5:1 PBR coating. The two coatings approach similar resistivities before maximum instrument current (100 μa) is reached. Differences in the surface and volume resistivity of the inorganic coatings may result from viscosity and solvent differences which effect spraying and drying characteristics. The 3:1 PBR coating required a small increase in water content to yield a coating which had good deposition quality. As a result, the deposited coating remained fluid for a longer period potentially making it susceptible to component segregation.

Table 5. Electrical Surface Resistivity of Yellow Inorganic Silicate Handrail Coating.

Charging Voltage VDC	D140A, 2.5:1 PBR	D140B, 3:1 PBR
1.0	2.22E+10	1.25E+10
10.0	5.45E+09	4.51E+09
25.0	5.02E+09	5.14E+09
50.0	5.53E+09	5.97E+09
100.0	5.94E+09	6.25E+09
250.0	5.67E+09	4.92E+09
500.0	4.62E+09	2.87E+09
750.0	4.24E+09	2.05E+09
1000.0	4.09E+09	2.05E+09

Readings made at 76 degrees F, 38% RH

The electrical resistivity properties of the produced coatings are acceptable for the intended purpose of electrical charge dissipation. Coatings produced from a organic (silicone) base have better optical and electrical properties than those produced using inorganic base (potassium silicate, Kasil 1). The lower solar absorptance of the inorganic coatings may improve when exposed to a high vacuum environment. High vacuum and 25°C exposure may liberate physically and chemically absorbed water which results in the NIR absorptance in these coatings. The somewhat higher electrical resistivity of the inorganic coatings is likely the result of voids or cracks in the coating. These flaws impede the flow of electrons both across the surface and to a lesser degree through the volume or bulk of the coating to the substrate.

4.2.6. Marker and Warning Labels

AZ Technology pursued utilizing the yellow pigment with silicate and silicone binders to develop applications other than for handrails. Formulations were produced having promising properties utilizing both silicone and silicate binders with the yellow, white, and black space stable pigments. Good adhesion results have been achieved for silicone based coatings on various substrates including ceramic coatings, Beta cloth, electro-less nickel, and aluminum. As a result, coatings have evolved that can provide symbology for EVA and general integration activities. A number of these coatings have been tested through MAPTIS (MPEEN) and have readily passed all test requirements.

A potential application for International Space Station (ISS) is the utilization of the yellow marker coatings to provide ESD sensitive symbology for various electronic housings and enclosures. This development was pursued due to multiple inquiries from various organizations developing ISS hardware. A number of organizations indicate that no long-term, stable, labeling materials are currently known. In most cases, only hydrocarbon-based polymer decals are available for this function. These decals are not likely to have good LEO stability.

A ESD label developed and evaluated to determine potential applicability of spray deposited maker coatings. The currently configured label is composed of a diffuse yellow background with black symbols and characters. This provides high contrast and easy detection on most backgrounds, including white thermal control coatings. This label development effort demonstrated the ability to produce a variety of labels that can be made available to the space station which are robust and easy to apply. Potential label production could be performed using thick aluminum foil (2-3 mils thick) backed with Y-966 type acrylic adhesive and die cut to the correct label dimensions. The correct symbology could then be sprayed onto many labels in a short period of time.

4.3 Development and Optical evaluation of Red Pigments & Coatings

The need for another additional space stable colors (red and blue) for use on space station was established. Their development provided further options for marking various items which need to be readily identified on orbit. Use of these coatings will provide needed visual identification through their color and or symbology. Figures 15 and 16 provide the spectral reflectance curves for the two materials. The red ceramic pressed powder sample shown in figure 15 demonstrates a similar trend of high near infrared reflectance, to that of the ceramic yellow coating developed earlier in this program. This characteristic will be useful for controlling touch temperatures and general solar absorptance of coated surfaces.

4.3.1 Red commercial pigments

AZ Technology made an extensive survey of known commercial sources for red ceramic powders that have the potentially to be used as pigments. One of our primary criteria in performing this task was to search for materials that can be exposed to high temperatures (800 to

900°C) in air without alteration of their visual color or UV-NIR spectrum. This criteria was used because the low earth orbit AO exposure of materials will have a similar effect of readily changing the oxidation state of a compound. Changing of oxidation state can cause such materials to become dark brown, black, or even white through reaction with or loss of oxygen on orbit.

A number of "red" ceramic pigment color charts have been received from various manufactures, however none of them are what would be considered a true red color. They fall into to basic classes, (1) materials that are a brownish red and (2) others that are a purplish red in color. Figures A-17 through A-19 provide reflectance spectrum for three examples of these materials. These materials tend to have iron or chrome respectively in their chemistry. We evaluated commercial color chips against ISS specification requirements and federal standard 595B in order to obtain the best visual color match prior to requesting samples for actual spectral evaluation. All of the candidates that closely match Federal Standard 595B color chip samples contain cadmium compounds. True red, inorganic, non cadmium materials are not available. Most of the red pigments currently available are pink and do not even remotely resemble the colors in Federal Standard 595B. Samples of several of these pigments were obtained from the following companies for evaluation. Companies are Ferro Corporation, Degussa Corporation, American Chemet Corporation, Shepherd, Cerac, and Fusion, all of which produce ceramic powders for pigments generally capable of withstanding exposure to an oxidative elevated temperature environment.

Only one inorganic red pigment was been found that is a potential match to Federal Standard 595B color chip. That red pigment material remains stable only at lower temperatures (300-400 °C), above which it under goes a change in oxidation state and loss of desired color. The best red ceramic pigment identified is a cadmium compound. Because of detrimental health and possible environmental contamination issues with the cadmium pigment a search for other candidate inorganic red pigments was continued.

Other red material types were obtained, but upon examination of their color chips or sample powders they also were found to be an orange, purple or maroon, not a true red. Samples of red pigments have been received from Fusion which are red only when they are fired in a frit. The dry K-4237 pigment is pink rather than red. The primary reason for this lack of products is that cadmium is the primary component used to produce the color red in most pigments and it has been banned by OSHA and EPA because of its heavy metal, toxic classification. Other red materials are available, however they are organic based dyes with a significantly high concentration of double bonds in there structure. These double bonds tend to be very effective at absorbing highly energetic UV photons, which in turn readily cause bond opening reactions to occur, degradation of the materials molecular and electronic state and loss of the desired color. These compounds also tend to be susceptible to AO interaction.

In summary, the initial testing and evaluation of red pigments did not yield any promising potentially stable materials. Using our quick look technique of exposing candidate materials to elevated temperature for several hours did not produce any satisfactory results. All tested

materials have generated dark gray, black or white residues, with no red material remaining after test exposure.

4.3.2.1 Encapsulation Techniques

Since none of the candidate pigment materials or any alternative red pigments which do not have cadmium in their composition were capable of passing our evaluated temperature acceptance tests, protection techniques were identified that have the potential to eliminate or minimize potential reactivity of the cadmium based pigment with the LEO environment. Encapsulation of pigments is a method often used to enhance their stability. In addition, the encapsulation approach ties up the cadmium making it much less of a health threat.

Several techniques for pigment encapsulation or alloying schemes are available to protect this pigment from oxidation and color change during AO exposure. One is to incorporate the pigment into a frit. Another is to encapsulate the pigment in potassium silicate. A third technique is utilization of a sol-gel process.

Firing in a Frit
Samples of cadmium stabilized frits were obtained for evaluation. Frits are mixed metal oxide combinations that form a glass when fired.

Encapsulation in Kasil 2130
An initial attempt to encapsulate the pigment material in Kasil 2130 seemed marginally successful. The pigment was placed in a 300ml beaker with Kasil 2130 and water then heat treated. This mixture was allowed to cool slightly and then was filtered. It was then allowed to dry overnight at room temperature. The next morning, it was placed into an oven at 100°C to complete the drying process. A characteristic sulfur smell was evident during the encapsulation process. In addition, a sulfur odor was present in this dry pigment.

Encapsulation of in TEOS
Initial attempts to encapsulate red pigment material in a tetraethylorthosilicate (TEOS) polymer appeared somewhat more successful than the Kasil 2130.

The pigment was placed in a 1 liter beaker with TEOS, water and ethanol. After mixing thoroughly, 1 ml of concentrated HCL was added to catalyze the TEOS. Then the mixture was heat treated to help accelerate the reaction. This mixture was then filtered and placed on a piece of Tedlar in a Fluorocarbon polymer pan and heated in an oven to drive the reaction to completion. After drying overnight, the pigment was then ground in a mortar and pestle and milled in a jar mill. Due to over-milling the pigment turned a re-brown color instead of the desired bright red.

Another attempt was made using a base catalyzed process with 5 molar potassium hydroxide (KOH). The pigment was added to a 1 liter beaker along with ethanol and water thoroughly mixed. Sixteen milliliters of KOH solution was added with vigorous stirring until the

pigment dropped out of solution into a different phase. This precipitate was then filtered, washed with ethanol, and dried overnight to drive the reaction to completion. The pigment was ground in a mortar and pestle then formulated into a coating that was sprayed onto an aluminum panel. This coating did not have a sulfur smell as did the others during milling. After the coating cured, water began condensing on the coating's surface. Attempts to wash the liquid off with xylene and isopropyl alcohol were unsuccessful so the liquid was removed with a KayDry towel. After further curing, a white powder was present on the panel. A few drops of water were applied to the coating surface to check the pH of the powder. The pH of the water that was applied was approximately 10. The white powder is presumably excess KOH that was not washed out with the ethanol. Washing the pigment with water before it is dried should remove any excess KOH.

Optical analyses were performed on the three encapsulated pigments in their pressed powder forms. As seen in Figure 20, there is little difference in the solar alpha for each of the encapsulated pigments compared to the original pigment material. The difference in color can be seen visibly with the naked eye. The Kasil 2130 encapsulated pigment had dark areas in the pressed powder. The TEOS encapsulated pigment was visibly the same color as the original pigment. The original pigment had a slightly higher reflectance than the other two in the infra-red region of the spectrum.

4.3.2 Red Coatings

Coatings were prepared with the red pigment in Kasil 2130. While milling the coating, a pungent sulfur odor was detected. The presence of this odor indicates some form of reaction between the pigment and binder has occurred. When formulated into an inorganic coatings there seems to be a reaction between the red pigment and the potassium silicate producing a sulfur odor and bubble formation. Sample coatings were sprayed onto aluminum Q-panels for evaluation. After one day curing there seemed to be no adverse effects from the reaction between the Kasil 2130 and the pigment material. However, after several days the coating began to develop color centers. The appearance of color centers and presence of the odor led us to believe that the pigment material must be protected prior to incorporation into a coating. Refer back to the previous section on encapsulation of pigments. Coatings prepared with the Kasil 2130 encapsulated pigments have proven to be very successful.

4.4 Blue Pigments and Coatings

4.4.1 Blue Commercial Pigments

An extensive survey was made of known commercial sources for blue ceramic powders to potentially be used as pigments. One of our primary criteria in performing this task was to search for materials that can be exposed to high temperatures (800 to 900°C) in air without alteration of their visual color or UV-NIR spectrum. This criteria is the same used for the other colors. Results of this survey identified a fairly wide variety of blue ceramic powders.

Figure A-16 is the spectral reflectance curve for one of the first blue ceramic powders investigated. Evident from the spectra is that this material does not have the high NIR

reflectance of the red and yellow ceramic pigments. An evaluation of the material based on its UV through NIR optical properties indicates that this material if used, could result in a coating that will operate very warm in a space environment because of its intrinsic high solar absorptance. The materials potential for high operating temperature can result in increased reaction rate kinetics (degradation rates) and combined with its intrinsic UV absorptance will tend to result in a coating with poor color stability. Therefore this material was used for initial development only, other materials with better initial optical properties and stability potential were obtained.

Eleven blue ceramic pigments from the following companies were evaluated: Cerdec, Ferro, Harshaw, and Mason. Of these materials we have selected those which provide a good visual color match for blue colors called out in SSP 50006A (ISS Internal & External Decals & Placards Specification) and in Federal standard 595B. Figures 21 and 22 provide the spectrum for two of the better pressed powders of blue pigments compared to the visible spectrum for the blue color standards called out in SSP 50006A. Evaluation of the visible portion of this spectrum demonstrates good signature matching between blue figure A-22 and provided reference coupon spectra with a slight broadening of the peak centered about 450 nanometers (nm). A second band it present in this material with a small portion of it present in the visible portion of the spectrum. This band covers a wavelength range of about 650-1300 nm and is not present in the measured color chips. Blue pigment shown in figure A-21 is a poorer signature match to the reference chips This candidate has one significant reflectance band starting from a wavelength less than 250nm to about 550nm. It also has a second reflectance band but starting slightly deeper into the visible spectrum at about 625nm and continues to 1225nm in contrast to the reference color plates. Even though these candidates pigments do not perfectly match the spectrum generated from the federal standard 595B they still appear to be a good match when visually observed.

Two of the blue pigments evaluated have good visual contrast to white and metallic type backgrounds and therefore should provide good color contrast coatings to the white and anodized thermal control surfaces of space station. Although these pigments are the closest match to federal standard colors, of those evaluated by AZ Technology, it would have been better to have a blue coating with better IR reflectance. Such a coating will allow the developer greater flexibility in trying to control surface and touch temperatures if required for the application. This is important not only for human contact (such as during astronaut EVA's) with the surface but, even more importantly for reducing general surface temperature to control reaction kinetics. Absorptance of solar energy by these blue pigments is exacerbated by the NIR absorptance bands which are indicative of the cobalt used in both of these pigments. Through identification or modification of materials to have lower NIR absorptance, better control of solar absorptance can be achieved. Hence surface temperature and thermal kinetic parameters which affect rates of change or degradation would be reduced. If further research could be done, the addition of a ceramic oxide which exhibits low NIR absorptance, may be useful. All of which is important for long term mission performance required by ISS and many future missions to the planets or habitats on the Moon or Mars.

AZ Technology has also investigated the effects of heat treating several of these blue pigment materials. They were heat treated in air to observe their thermal stability. Each processed pigment powder was pressed into a pellet for solar absorptance and thermal emittance evaluation.

Optical and thermal analyses were performed on the three best blue pigments. Figure A-23 shows the spectral reflectance data for the neat pigments listed in Table 6. Figures A-24 and A-25 contains spectral data for the heat treated pigments in comparison to the non-heat treated material. Data analysis indicates a slight increase in reflectance once the pigment is heat treated. Resulting spectrum show a small decrease in solar absorptance throughout the measured solar spectrum (250-2800 nm). Based on our work with colored ceramic powders, it has been demonstrated that the NIR absorptance can be reduced to a greater extent than was obtained for the blue pigments.

Table 6 also contains the results of the thermal evaluation for a calculated touch temperature. Thermal analysis was performed to determine the equilibrium temperature of these materials when exposed to a worst-case scenario (full sun exposure) on ISS.

Table 6. Blue pigment data

Manufacturer	Processing Conditions	Solar Absorptance α_S	Thermal Emittance ε_T	Touch Temp Degrees F	Touch Temp Degrees C
Blue Batch #E053a	Fired 900°C	0.548	0.877	217.6	103.12
Blue Batch #E053a	Unfired	0.559	0.877	218.8	103.75
Blue Batch #E053b	Fired 900°C	0.628	0.829	244.0	117.80
Blue Batch #E053b	Unfired	0.629	0.826	244.8	118.21
Blue Batch #E245b	Unfired	0.549	0.896	215.1	101.69

In every case, a broad absorption band is evident from approximately 900 nm to 1750 nm. Solar absorption through these wavelengths is of concern because of the amount of energy radiated by the sun in this region of the spectrum. A reduction in this absorption would be beneficial from a touch temperature and damage kinetics standpoint. If a silicone binder is used in the coating rather than a silicate, lower temperature will translate into a lower probability of polymer degradation due to absorption of radiant solar energy. Currently the two candidate pigments contain cobalt, which is thought to be the cause of the strong IR absorption. Through the course of our vendor search, a number blue pigments were found that do not contain cobalt but do not have the intensity or hue required to closely match the color chips in the federal standard. Figure A-25 pigment was discarded as a candidate due to poor optical properties and incorrect color matching compared to the standard.

4.4.2 Blue Coatings

Blue pigment batch #282 was formulated into an inorganic coating for optical analysis. Figure A-26 contains the optical data for this 3:1 PBR inorganic coating for comparison of optical properties with the neat pigment. This spectra show an increase in IR reflectance and a decrease in UV/VIS reflectance in the coating compared to the neat pigment. However there is little change in over all solar absorptance between the two forms. Changes in wavelength reflectance are likely from changes in scattering and index of refraction which occur when potassium silicate wets the surface of another material and then dries. Coatings formulated using Kasil 2130 had a tendency to fade when cured (compared to the pigments' original color). A new candidate pigment was evaluated after being incorporated into a coating and retained its color after curing. The optical properties of the batch # 634 pigment were comparable to the other pigments as can be seen in Figure A-27. This pigment coloring also more accurately matches Feral Standard #35095.

Blue marker coatings have been of a concern because of their overall higher solar absorptance and hence potential to run warm which could result in a higher rate of optical degradation. However, exposure of this pigment to 1100 °C in a air convection furnace had no negative optical effects and therefore it should be highly resistant to AO.

4.5 Red and Blue Coating Evaluation

Development of red and blue marker coatings presented some of the most challenging tasks of this program.

Three one inch (1") diameters samples each of the most promising blue and red marker coatings were tested by NASA EH12 for UV/AO space environmental resistance using the AOBF system at MSFC. Test results, provided in Table 7 showed a decrease in solar absorptance for both the red and blue silicate coatings. In the visible portion of the spectrum both colors have a decrease in absorptance of 7 to 10 percent between the wavelengths of ≈530 to 650 and 350 to 600 nanometers (nm) for the blue and red coatings respectively). This loss of absorptance results in a slightly lighter shade of these color coating .

The red coatings that were tested included two different pigment to binder ratios (PBR's). Batch E710 was produced using a 2:1 PBR and Batch E589 was produced using a PBR of 4.5:1. However there is no apparent stabilizing effect on the red coating with increasing binder concentration as one would expect from the potassium silicate glass. Even though E710 has a far higher binder concentration and is glass encapsulated (which acts as a protective layer for some oxides) than E589, the difference is small, with a $\Delta\alpha$ of 0.005 between E710-1 and E589-2. E589-2 also demonstrated poorer stability than it's E589–4 batch partner.

This red coating demonstrated reduced solar absorptance in two regions of the spectrum after exposure, the first in the 350 to 600 nm range and the second is from about 1500 to 2500 nm. The change in solar absorptance in the first region is likely the result of several effects.

First is a interaction of the sample with the UV/AO environment, which caused the coating to become bleached to a limited extent. Second, loss of water from vacuum exposure will cause void (scattering center) formation that will effect the visible region to a small amount and is the cause of near infrared (NIR) (1500-2500 nm) solar absorptance decrease. Three, the pigment used in the red coating seems to fluoresce in the 350 to 400 nm wavelength region after the UV/AO exposure.

Table 7. Results of UV/AO Testing at MSFC

RED				BLUE			
Batch No.	Pre-test α_s	Post-test α_s	$\Delta\alpha_s$	Batch No.	Pre-test α_s	Post-test α_s	$\Delta\alpha_s$
E710-1	0.512	0.485	-0.027	E486-2	0.658	0.610	-0.048
E589-2	0.466	0.433	-0.033	E486-3	0.657	0.607	-0.050
E589-4	0.431	0.421	-0.010	E486-4	0.659	0.608	-0.051

The blue developmental inorganic coating, batch E486, was produced and tested at a single PBR, since previous work had demonstrated good batch to batch beginning of life reproducibility and which produces a good robust coating. This coating demonstrated reduced solar absorptance in three regions of the spectrum after exposure, the first in the 530 to 650 nm range, the second 1200 to 1500 nm range and the third is from 1900 to 2500 nm. The change in solar absorptance of the first two regions is a reaction with the UV/AO environment that caused the coating to become bleached or lighter in color. The third region is from loss of water cause by vacuum exposure (discussed previously), which is normal for this type of inorganic coating. The inorganic blue coating demonstrated very consistent results from exposure to the simulated UV/AO testing, the standard deviation associated with these $\Delta\alpha$ results are 0.001, this demonstrates good consistency for this coating.

The change in solar absorptance for both the red and blue are quit good for marker coatings. It is likely that the amount of change indicated by the post test spectra can be attributed to a slight change in oxidation state of the pigments. In addition, the absorptance change is also attributed to removal of water from the matrix causing a broad band change in absorptance. The red coating did show some effects of classical degradation effects. In all the red marker coating samples tested there is a small increase in absorption close to the plasma edge characteristic of cadmium red.

4.6 Development and Optical evaluation of Green Pigments & Coatings

4.6.1 Green Commercial Pigments

AZ Technology surveyed green pigments available from commercial companies within the USA. As in past research for this program, several manufactures were identified as

producing candidate pigments and contacted. For the purposes of this program only those powders that are typically classified as high temperature materials were selected for review. This strategy effectively eliminates most pigments that will likely be affected by exposure to the space environment including atomic oxygen (AO) and substantially reduces the number of candidates to be evaluated. Six green pigment materials are were evaluated.

The candidate pigments were first tested for high temperature oxygen and thermal stability per our previous procedure. These pigments were then heat treated, as before, to remove any organic residue and is another good indicator of there resistance to atom oxygen. This procedure can also provide indirect insight about a material's optical stability when exposed to the combined space environment. Many pigment materials when exposed to such temperatures demonstrate degradation character similar to what one would find if the material were exposed to the space environment. Such degradation is identified by changes in the materials color (graying or tanning change in color) and optical spectrum changes after exposure.

AZ Technology conducted preliminary evaluation on two of the better green pigments that visually are bright. These pigments were heat treated to provide basic information on what effect temperature and flowing air would have on the materials optical properties covering the bandwidth of 250 to 2800 nanometers. The pre and post solar absorptance spectrum for these materials are provided in Figures A-28 and A-29.

Candidate A pressed powder sample experienced a slight decrease in solar absorptance after a heat treatment. Candidate B pressed powder sample experienced a very slight increase in solar absorptance. A bright green coating has been produced using Kasil 2130 silicate binder. This coating has been submitted to NASA MSFC for evaluation.

4.7   Low emittance coating

Another coating development task that was identified for the International space station (ISS) was for the modification and or development of a sprayable low emittance coating which will minimize heat loss to certain exposed regions of the vestibules and universal interface modules of space station. Thermal energy loss may occur when these components are exposed to space during various build up and docking operations of space station. The ISS region to be coated with a low emittance coating is the central dark gray area of the module around the hatch. There are currently sixteen of these regions throughout the space station which will need such a thermal control coating to minimize thermal losses. To meet this need AZ Technology initiated the modification of an existing low emittance coating (designated as AZ-1125LIA) for ISS. AZ Technology previously carried out research and development concerning low emittance coatings and had been able to achieve a thermal emittance of 0.25 to 0.28 and a solar absorptance of 0.24 to 0.30. The primary challenge of this undertaking was to find a way to effectively bond this ceramic based coating to the epoxy zinc chromate primer and maintain the stability of the thermal optical properties. Use of this primer was necessary in order to effectively protect the aluminum substrate material used on ISS, which is susceptible to corrosion because of the relatively high copper content.

Two alternative types of binder systems were considered for backup options to the inorganic silicate coating. These are the use of 1) a silicone or 2) a polyurethane binder. The silicone offers good environmental, physical, mechanical, and optical properties, the other, polyurethane, provided good primer compatibility, ease of deposition, low cost, good physical and mechanical properties. Sample quantities of the primer (BMS10-79) designated for use on ISS were obtained from Boeing Aircraft Company (Huntsville) through Mr. Dewey Erwin.

4.7.1 Primer evaluation

Experiments performed to determine bonding capability between AZ-1125LIA and the primer were successful. This result was unexpected because of the typical incompatibility between inorganic with organic coatings. Upon further research it was found that this primer has a considerable amount of silica and silicone based agents in it's formulation. Use of these substances tends to provide good chemical surface compatibility for bonding of silicate based coatings on to such primers. The only problem identified during this short test program using BMS10-79 was its poor flexure character. When in tension it performs well, however when flexed into compression it readily cracks and delaminates from the substrate unlike the MLP-300AZ which readily under goes this test without failure. However MLP-300AZ was not developed to provide corrosion resistance but to provide excellent compatibility to chemically dissimilar materials. Since the BMS10-79 primer's intended use was to be on rigid thick aluminum, it was determined that the compression failure mode of this material would not be an issue. As a result of this first success, our efforts were turned to improving optical and mechanical properties of the low emittance coating system.

Beyond the concern of adhesion with the BMS10-79 primer, our other objective was to achieve a minimum thermal emittance (ε_T) of 0.28 and a solar absorptance (α_s) of 0.30 or less. In order to determine the affect, if any, that the primer will have on these requirements, a number of test coupons were produced at different thickness of primer ranging from about 0.4 to 2.0 mils. Analysis of these coupons found that the primer under some conditions dominates the emittance properties of the coating system. This tends to occur when the primer has a thickness greater than 0.5 mils and the top coating opacity is insufficient because of low PBR or poor space filling by the aluminum metal flakes. Void or space formation in this coating tends to occur because of alignment and packing problems of the large diameter aluminum conglomerates initially used in this coating. Using a mixture of aluminum flakes composed of two or three different average sizes an improvement of the thermal optical properties was achieved. This resulted in the production of a coating with a thermal emittance of 0.28 to 0.29. A solar absorptance value of as low as 0.22 was obtained for this test series, however this was only achieved by building up a thickness of 3.5 mils or greater with the maximum thickness tested being 5.6 mils. The sample that was 5.6 mils thick did not demonstrate any better solar absorptance than the sample which was 3.5 mil thick, indicating that optimum thickness for this property had been reached.

4.7.2 Pigment protection

One phenomenon that was identified during this development was the tendency of the coating to undergo significant changes in emittance over a period of a few days or week. This change in emittance started from an initial value of 0.30 to a last measured value of 0.60 or 0.70 over a period of a few days to one week. Visible inspection of the sample revealed a white crystalline substance on the surface of the coating which when viewed at high angles appears to be composed of white or transparent crystals and some relatively long dendrite structures. When rubbed with a clean room wiper most of the hazy whitish material was removed. The cleaning process did reduce the thermal emittance value, but did not result in complete recovery to it's original value.

This phenomenon is likely caused by at least two mechanisms occurring concurrently: 1) unprotected aluminum pigment is reacting with the coating, atmospheric moisture and dissolved gasses to produce aluminum oxide and hydroxide, 2) Silicate binder material is reacting (possibly with the aluminum pigment as a catalyst) with atmospheric gases and moisture to produce dendrites of carbonates on the surface. Both of these reactions will have a deleterious effect on the low emittance requirement of the coating, resulting in a significant increase to coating emittance. As a result of observing this reaction or corrosion process we were interested in trying to identify a means of passivating the aluminum pigment or coating to potentially eliminate both emittance and physical changes in the coating.

Three approaches were evaluated, they were based on use of alodine to passivate the aluminum based coating. Alodine was selected because it is widely used and effective for protection of aluminum against corrosion, also based on optical measurements the clear version of this family of materials has little effect on the thermal optical properties of the base aluminum. Approach (1) was to react the aluminum pigment with alodine first prior to coating production. By so doing it was postulated that the aluminum reaction with silicate binder would be minimized or eliminated and the coatings reactivity with the ambient environment would stop. Approach (2) was to deposit the coating and once effectively cured then treat the surface with Alodine to passivate any reactive sites on the surface. Approach (3) was to passivate the aluminum pigment prior to coating production and then to provide further protection for the coating, treat the surface with Alodine again after curing has occurred. Through the use of this combined approach, maximum protection of the pigment and coating in general should be achievable if approaches one and two are inadequate.

Experimental analysis of approaches one and two found that the aluminum pigment was protected to some degree by pretreatment with alodine. Without treating the pigment with alodine a reaction begins to occur shortly after coating components are combined. This reaction generates and forms gas bubbles within the fluid coating and causes an increase in viscosity during the mixing operation. In most occurrences the viscosity increased to the point that more water had to be added in order to achieve spraying consistency. The cured coating, (when it could be deposited) resulted in poor mechanical and thermal optical properties. With this surface treatment the pigment still generated small amount of a gas, but the coating could be deposited

and produces good thermal emittance (0.28 - 0.33) and solar absorptance (0.24 to 0.30) values. However there is insufficient data at this time to demonstrate even short term ambient environmental stability of this coating. Some samples were measured 15 to 30 days after they were coated, they had an increase in emittance, from an initial value of 0.39 to a final value of 0.47. It has not been determined at this time if this apparent instability is from insufficient protection of the pigment, a corrosive interaction with the binder, and/or a reaction of the binder with one or more atmospheric components.

4.7.3 Coating Development and Testing

In addition to normal solar absorptance and thermal emittance tests, this coating underwent the following further tests: thermal shock, adhesion, thermal vacuum exposure, toxic offgassing, thermal vacuum stability, flammability and volatile condensable materials for optics (VCMO). The low emittance coating currently designated AZ 1125LIA passed all of the tests.

AZ Technology has made significant advancements in development and production of low emittance sprayable coatings. Because of our success, this type of thermal control coating should continue to be developed for space station and other programs which may have a need for a low emittance coating in the future.

5.0 UTILIZATION OF THE COATINGS DEVELOPED UNDER THIS CONTRACT

POSA Coating Samples flown on the Mir Space Station

AZ Technology has completed the preparation and deposition of the coatings as listed in Table 8. These coating coupons were submitted to NASA MSFC EH-12 for characterization and integration into the POSA hardware. Subsequently these coatings were exposed for 18 months to the MIR space station external environment, returned and evaluated. Some results have been discussed in this report.

Table 8. Samples Prepared for Flight on POSA

SAMPLE DESIGNATION	MATERIAL DESIGNATION
AZ93-300-1 THRU – 13	AZ93 OVER MLP-300
RMS800-IY THRU – 13	INORGANIC YELLOW
AZWEC-1 THRU – 13	ELECTRICALLY CONDUCTIVE WHITE
AZBEC-1 THRU –13	ELECTRICALLY CONDUCTIVE BLACK
2-6"x6" GOLD ANODIZED HALF COATED WITH TMS800-IY	
2 – 6" X 6" ½ AZ93 OVER MLP-300, ½ CONDUCTIVE WHITE	

Fluorocarbon Polymer Protective Overcoat

A number of organizations are greatly interested and have used the fluorocarbon polymer protective over-coat of the ceramic AZ93 (Z93) type thermal control surfaces for hardware used on space station. These organizations include NASA Johnson Space Flight Center, Lockheed Martin (2 divisions), Boeing (3+ divisions), and SPAR Aerospace, Canada.

The broad based need and acceptance of this coating for application on critical flight hardware provides the user with contamination protection for the underlying, ceramic thermal control coating during ground build up and integration operations. This coating is easily cleaned and has minimal affect on the performance of the thermal control surface once in orbit. Most of the components needing such a protective coating are highly complex shaped components many of which are housings for electronic systems, which will require extensive handling and testing before being integrated on to the space station. This protective overcoat has been utilized on many of the ISS hardware systems coated with the AZ-93 white ceramic coating. In use, this protective coating has permitted greatly improved cleaning of AZ-93 after contamination during ground assembly and testing. Components that utilized this coating but without protective over-coating have required extensive repairs and touchups. Another utilization of this coating was on the OPM experiment flown on the MIR space station, which again demonstrated its ease of cleaning after extensive ground handling prior to flight.

Space Stable Spacecraft Marker Coatings

The availability of colored space stable coatings for application on spacecraft in Low Earth Orbit (LEO) is becoming of ever more interest to the International Space Station (ISS) and the aerospace community. AZ Technology has fabricated a quantity of emblems, markers, and targets for the various ISS assemblies in addition to the emblem fabricated for the Unity module. Specific application besides the large emblem on Unity Module includes docking targets, connector identification, tank, and tubing marking.

The coating materials developed under this program have been used to produce approximately 130 visual astronaut aids for positioning and alignment of the replacement MLI on the Hubble Space Telescope HST surface during one of the repair missions.

The Japanese space agency (NASDA) is now evaluating samples of the marker coatings for use on their ISS module JEM. NASDA is planning to use these coatings both on beta cloth and various aluminum alloys.

We have also received inquires with various organizations involved with ISS hardware integration or fabrication, concerning possible uses of a green color for marking applications.

APPENDIX A.   SPECTRAL DATA
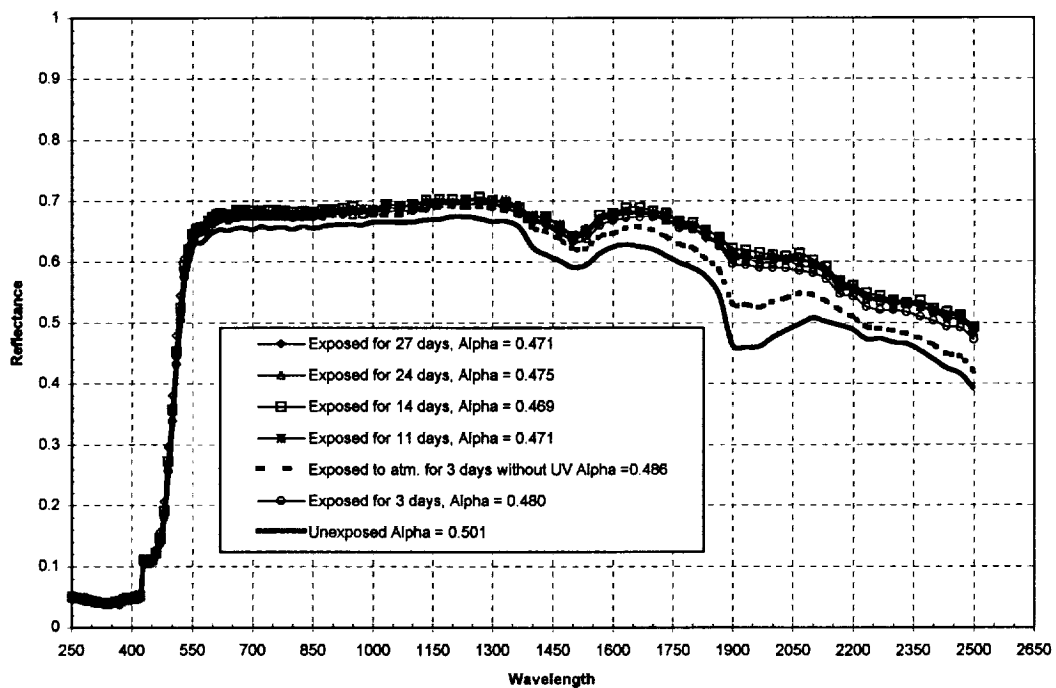
Figure A-1.   UV-NIR Spectral Reflectance of UV Exposed Yellow Inorganic Coatings
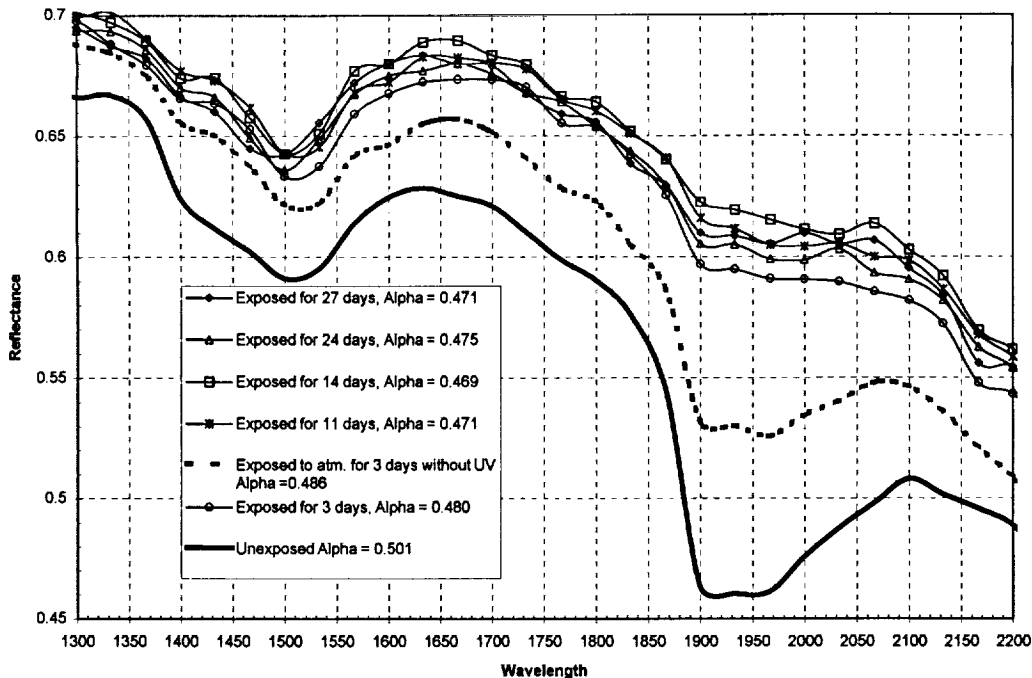
Figure A-2. IR Spectral Reflectance of UV Exposed Yellow Inorganic Coatings
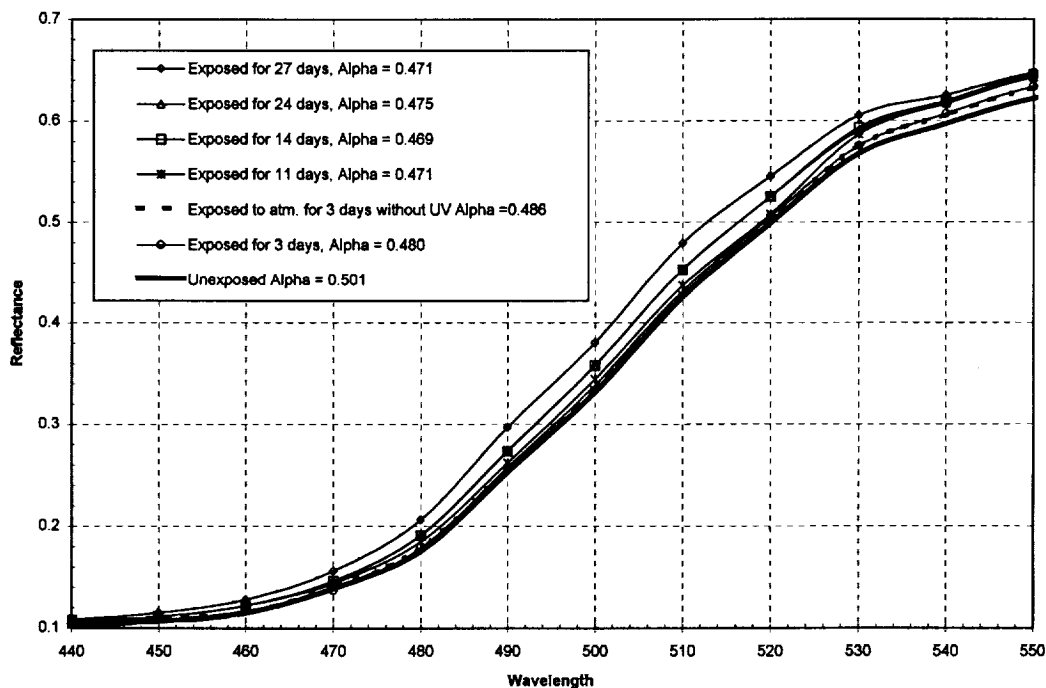

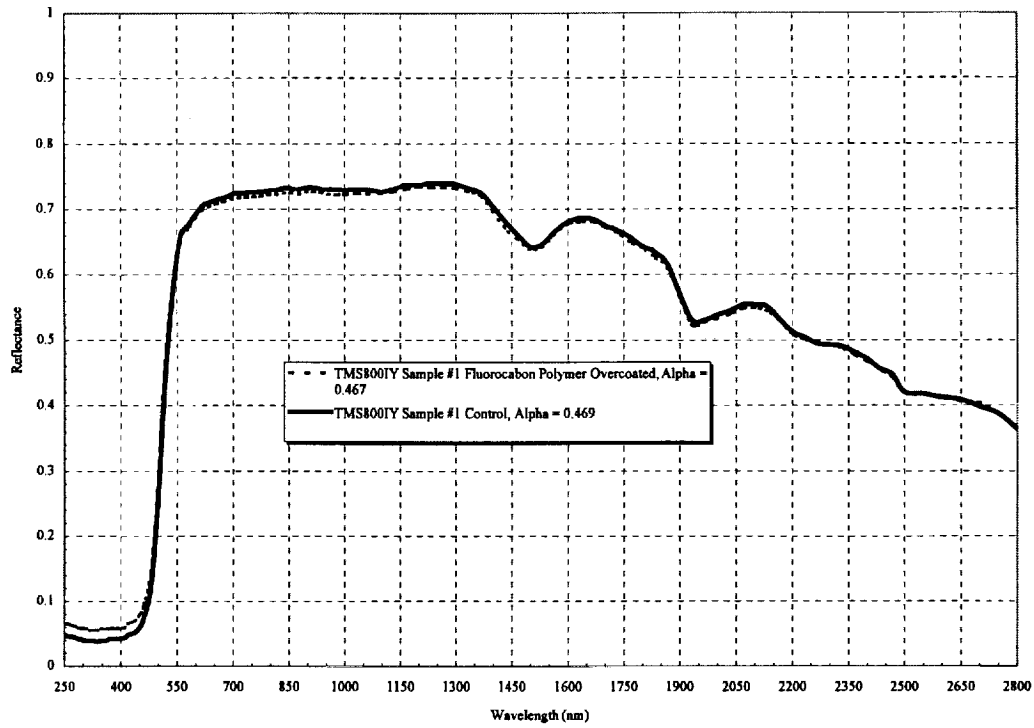Figure A-3. UV-VIS Spectral Reflectance of UV Exposed Yellow Inorganic Coatings

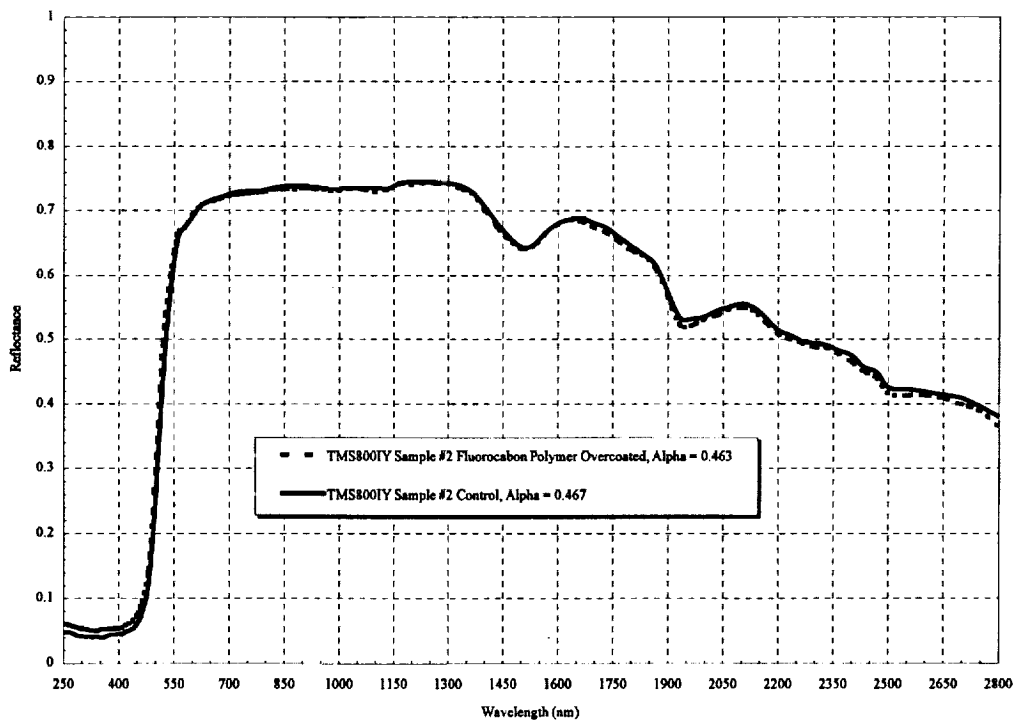Figure A-4. TMS800-IY Sample #1 Fluorocarbon Polymer Overcoat

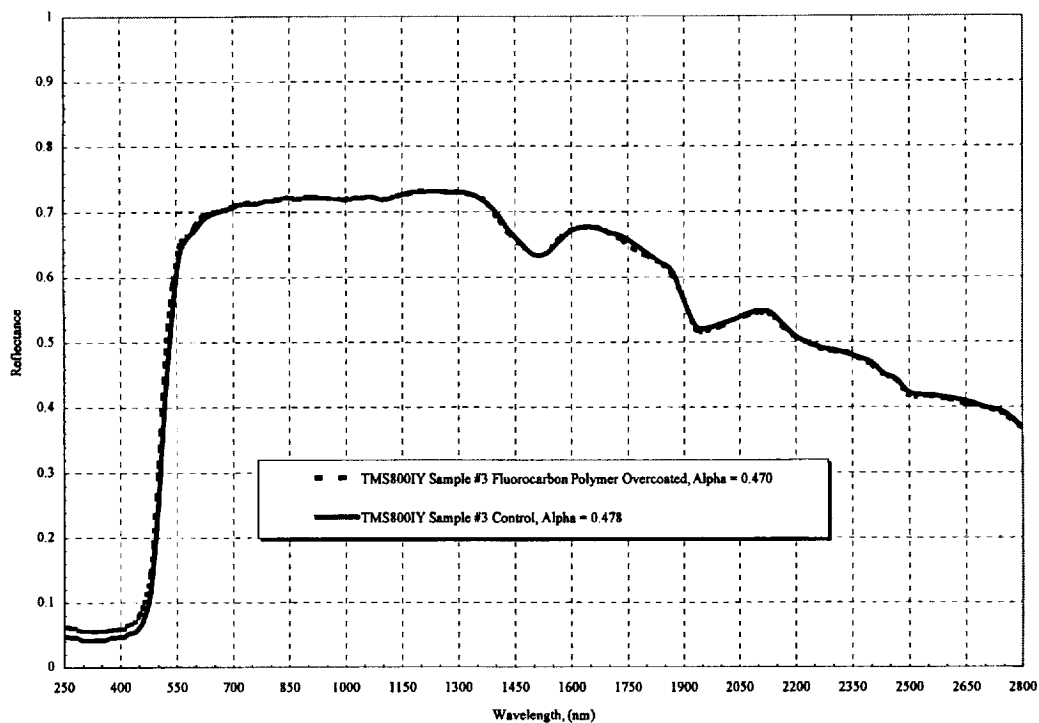Figure A-5. TMS800-IY Sample #2 Fluorocarbon Polymer Overcoat

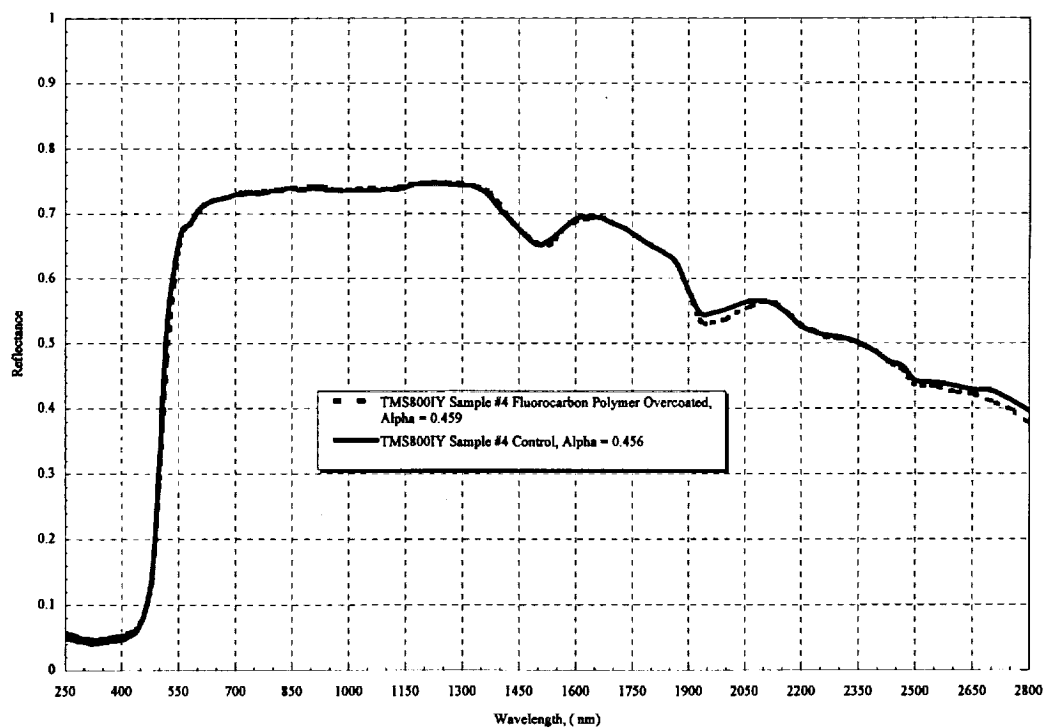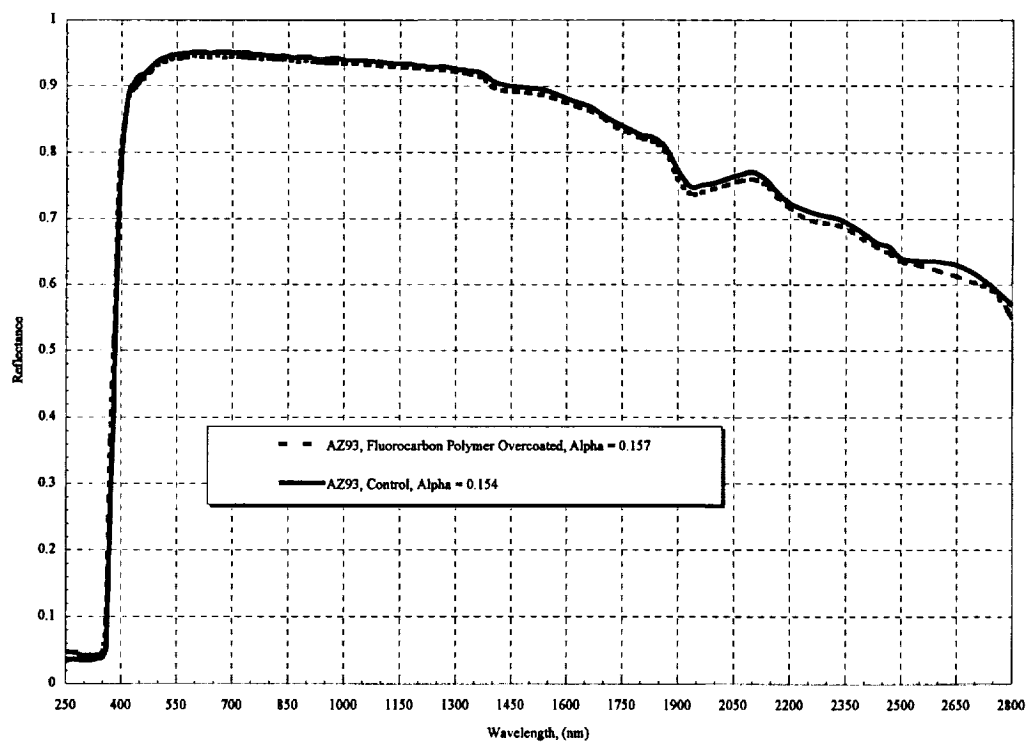Figure A-6. TMS800-IY Sample #3 Fluorocarbon Polymer Overcoat

Figure A-7. TMS800-IY Sample #4 Fluorocarbon Polymer Overcoat

Figure A-8. TMS800-IY Handrail Witness Panel with Fluorocarbon Polymer Overcoat

Figure A-9. Fluorocarbon Polymer Overcoat on AZ-93
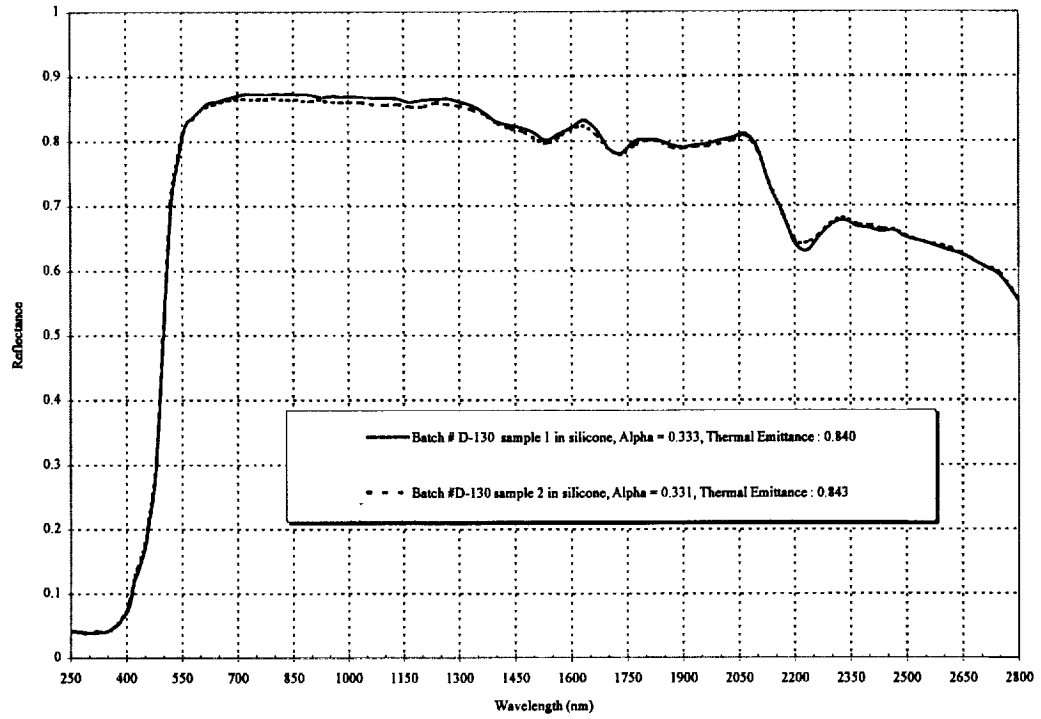
Figure A-10. Spectral Reflectance of Conductive Yellow Organic Silicone Based Coatings
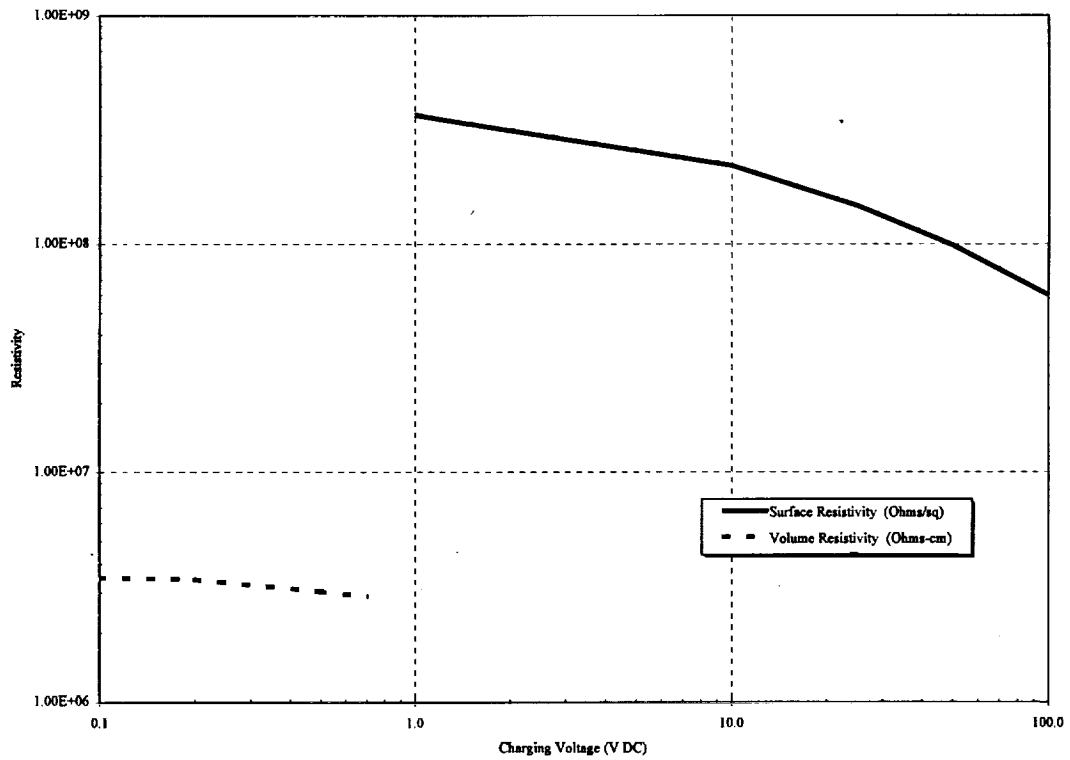
Figure A-11. Organic Silicone Yellow Coating Resistivity Measurements [surface & volume]

A- 6
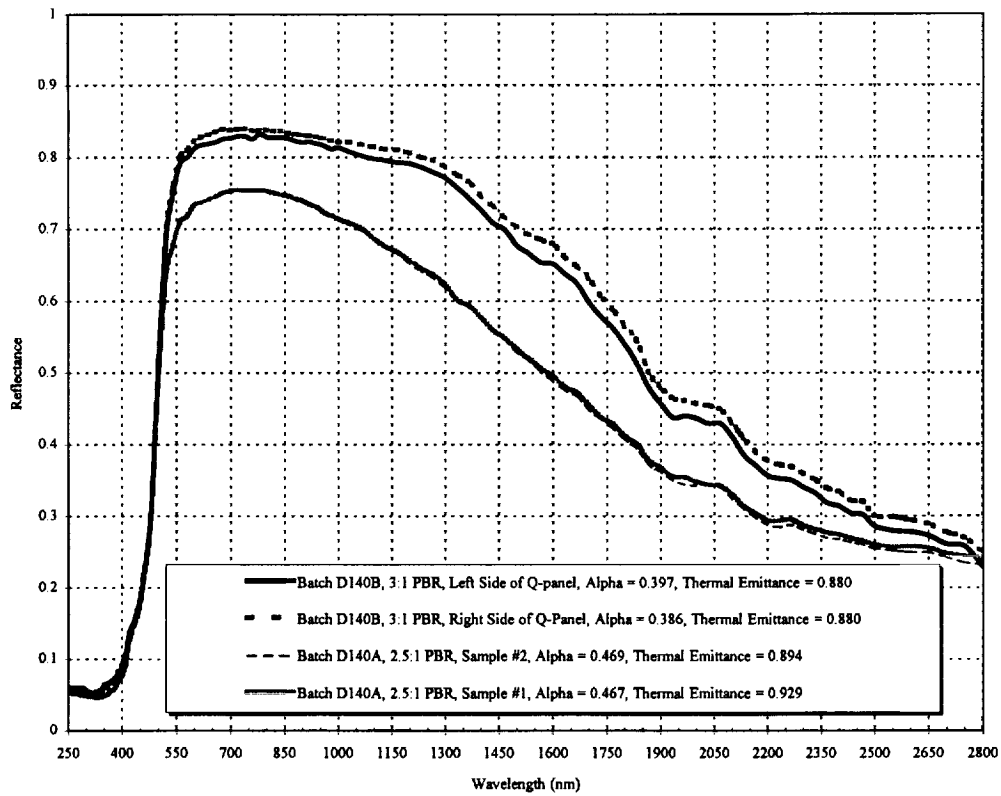
Figure A-12. Spectral Reflectance of Conductive Yellow Inorganic Silicate Based Coating
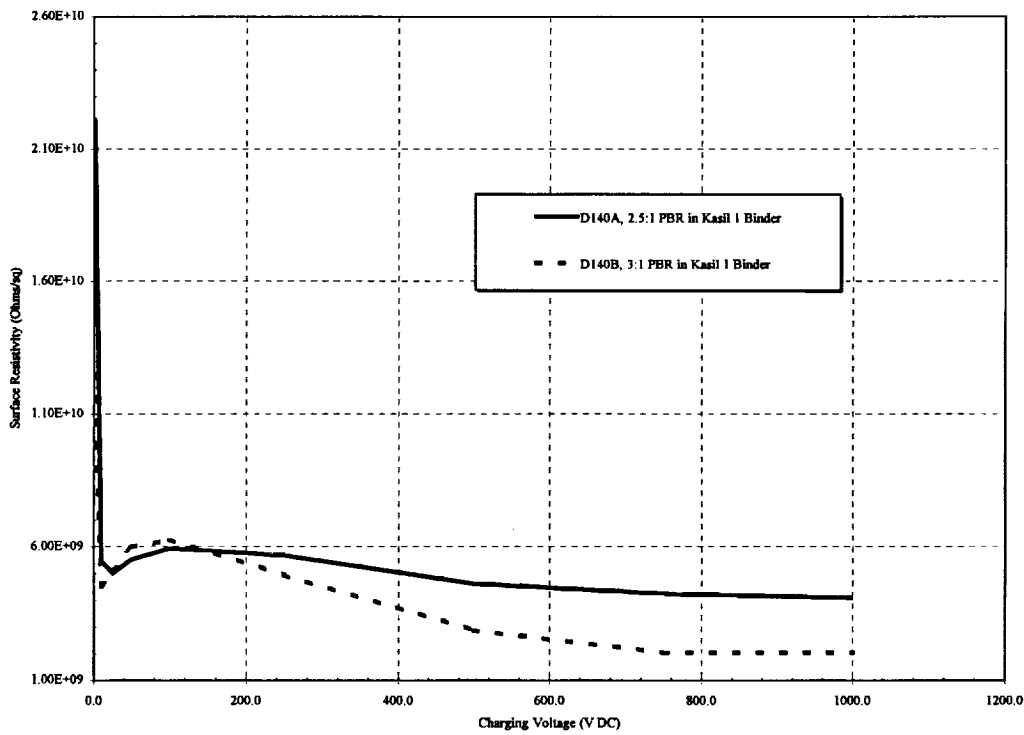
Figure A-13. Surface Resistivity of Yellow Inorganic Silicate Coatings
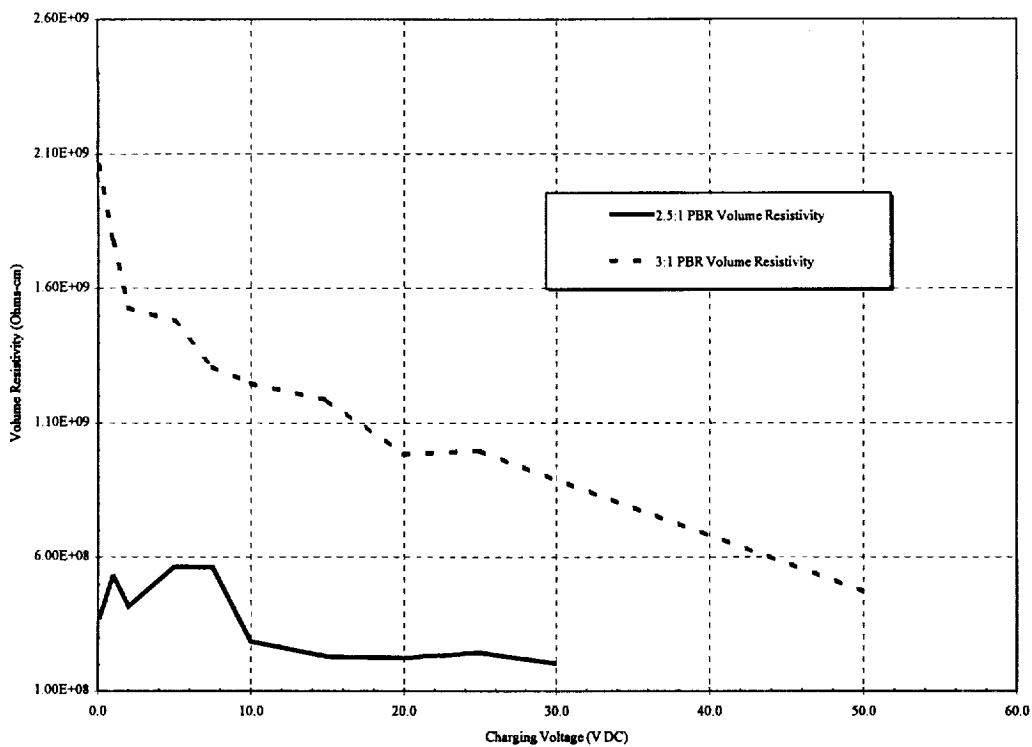
Figure A-14.   Volume Resistivity of Yellow Inorganic Silicate Coating
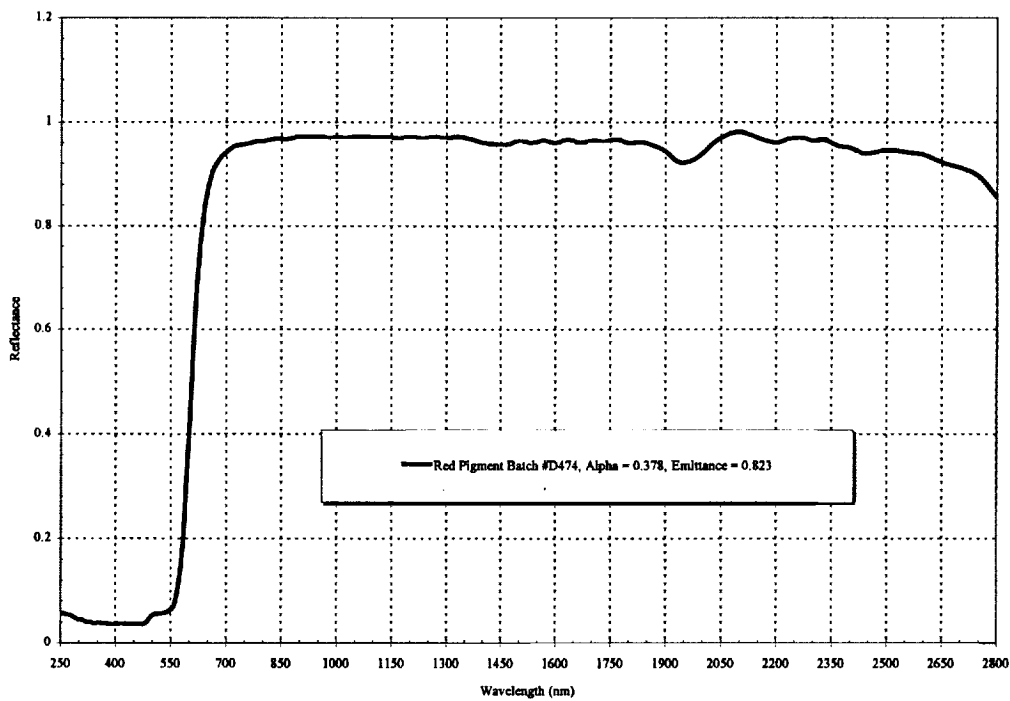
Figure A-15.   Red Pigment Batch #D474, Pressed Powder
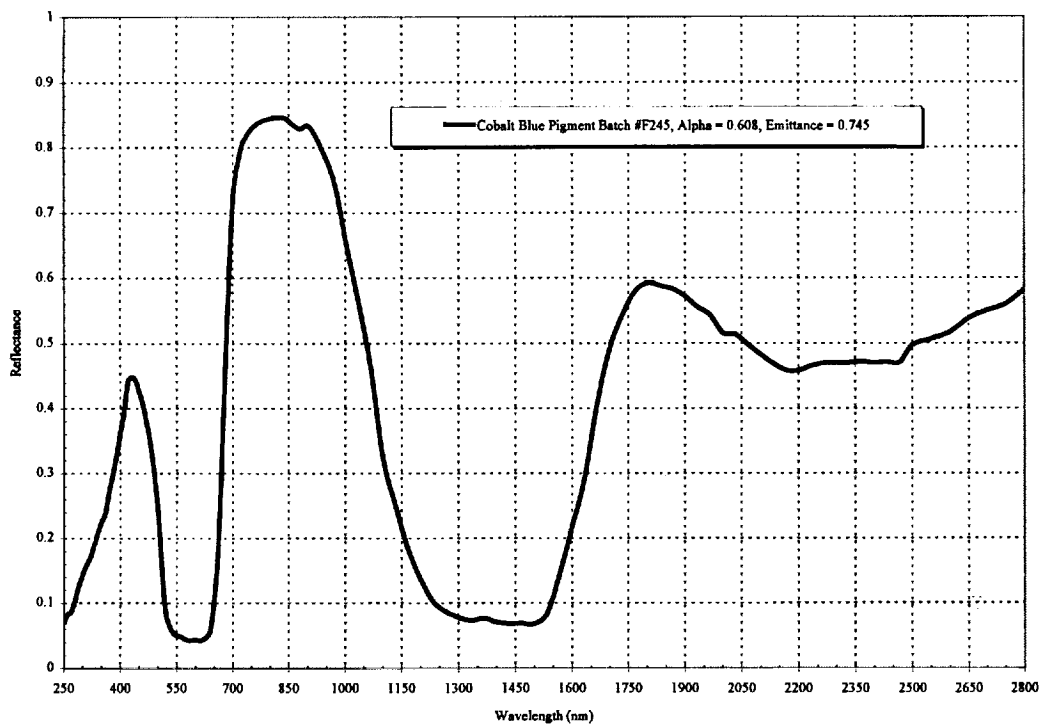
Figure A-16.   Cobalt Blue Pigment Batch #F245, Pressed Powder
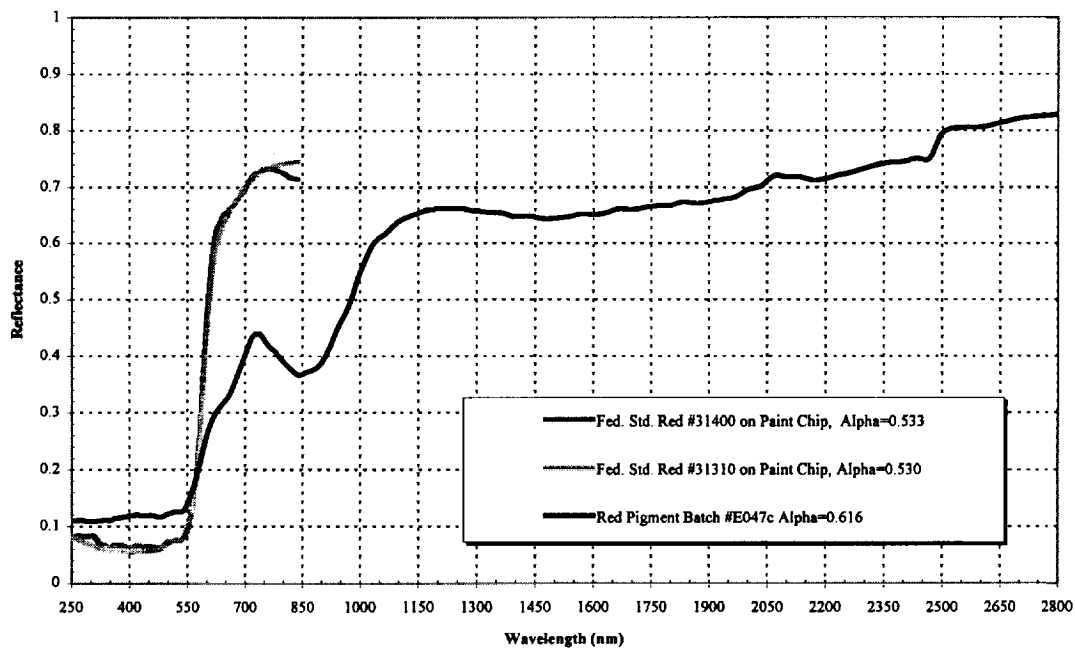
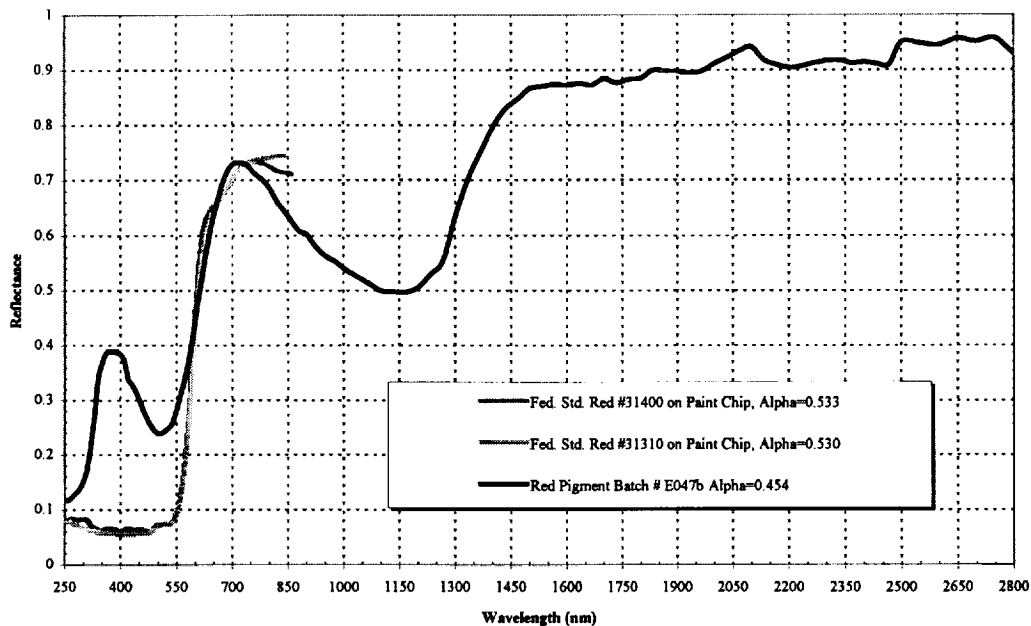Figure A-17.   Comparison of Red Color Chips and Batch #E047c Pigments

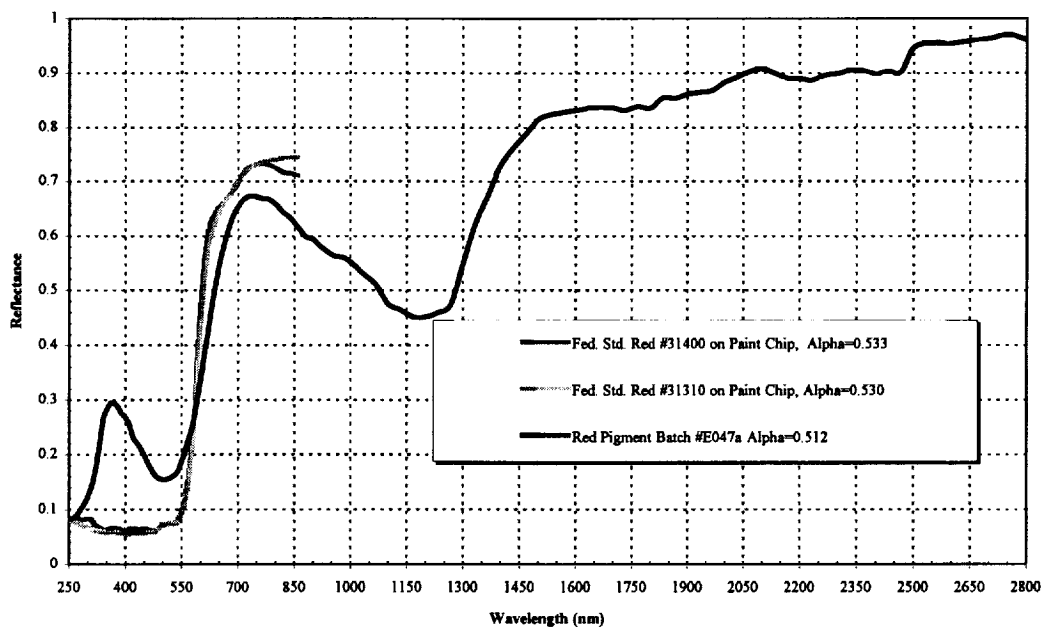Figure A-18. Comparison of Red Color Chips and Batch #E047b Pigments

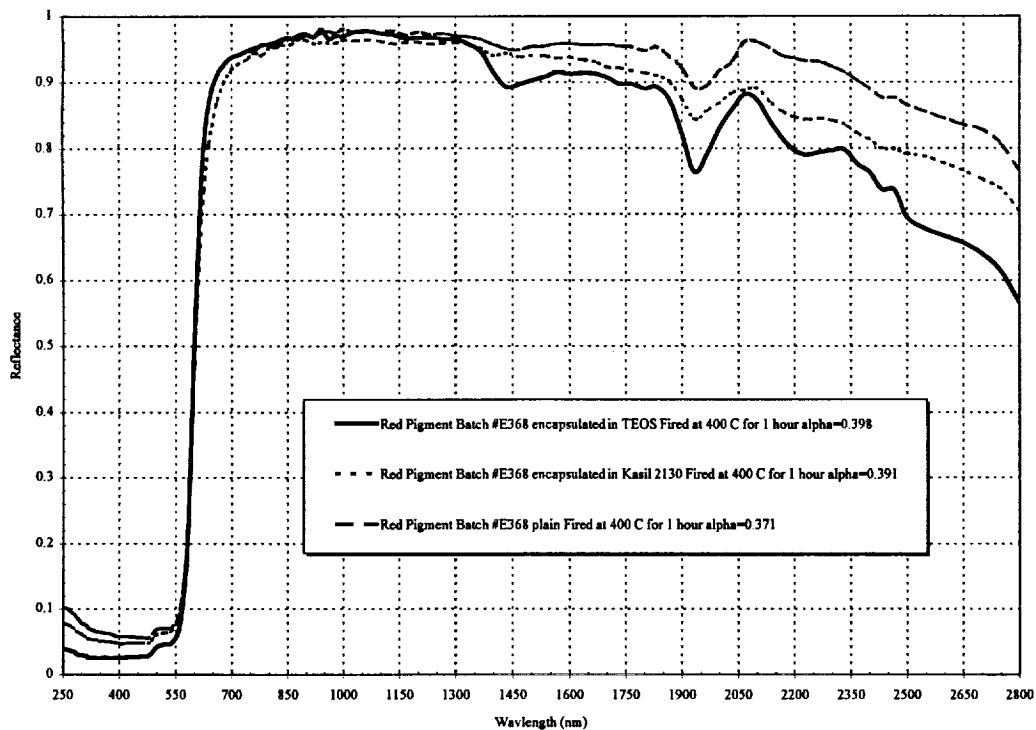Figure A-19. Comparison of Red Color Chips and Batch #E047a Pigments

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Figure A-20. Batch #E368 Red Pigment Fired at 400 degrees for 1 hour; Encapsulated Pigment-
Alpha Comparison

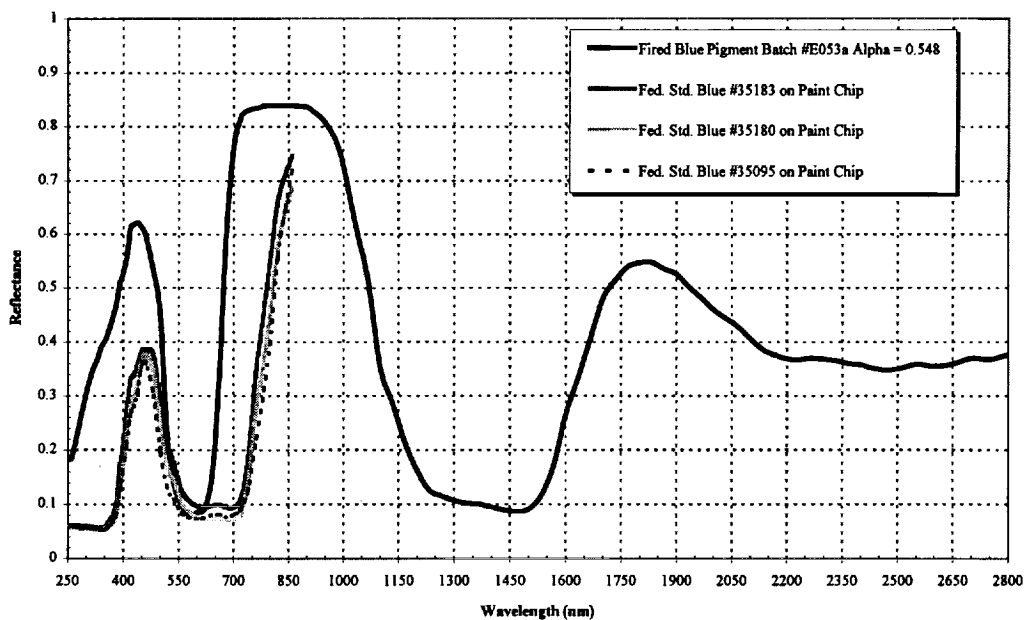
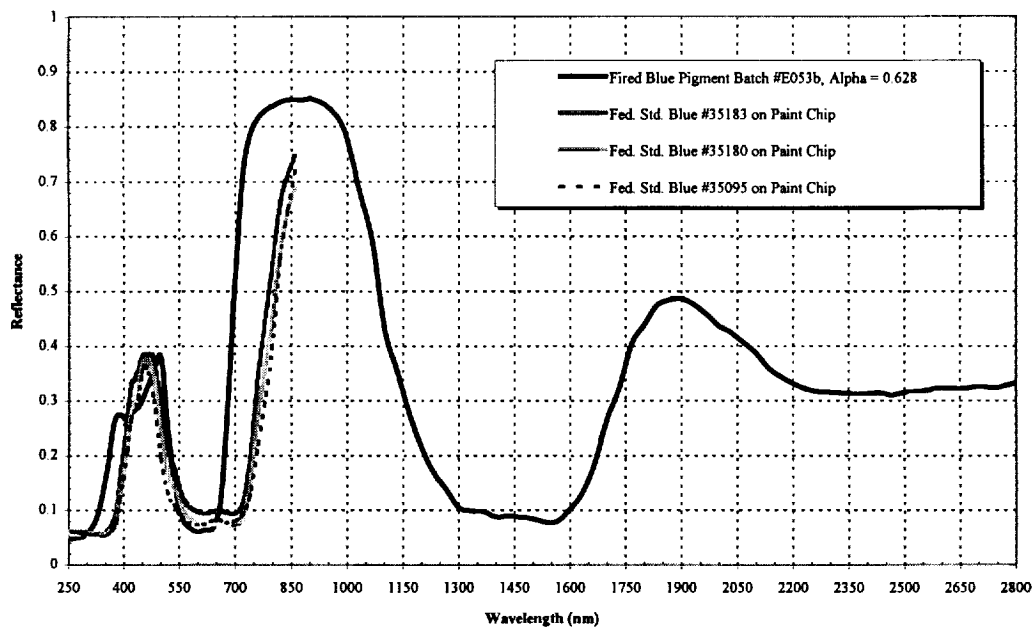Figure A-21. Comparison of Blue Color Chips and Pigment Batch #E053a

Figure A-22. Comparison of Blue Color Chips and Pigment Batch #E053b
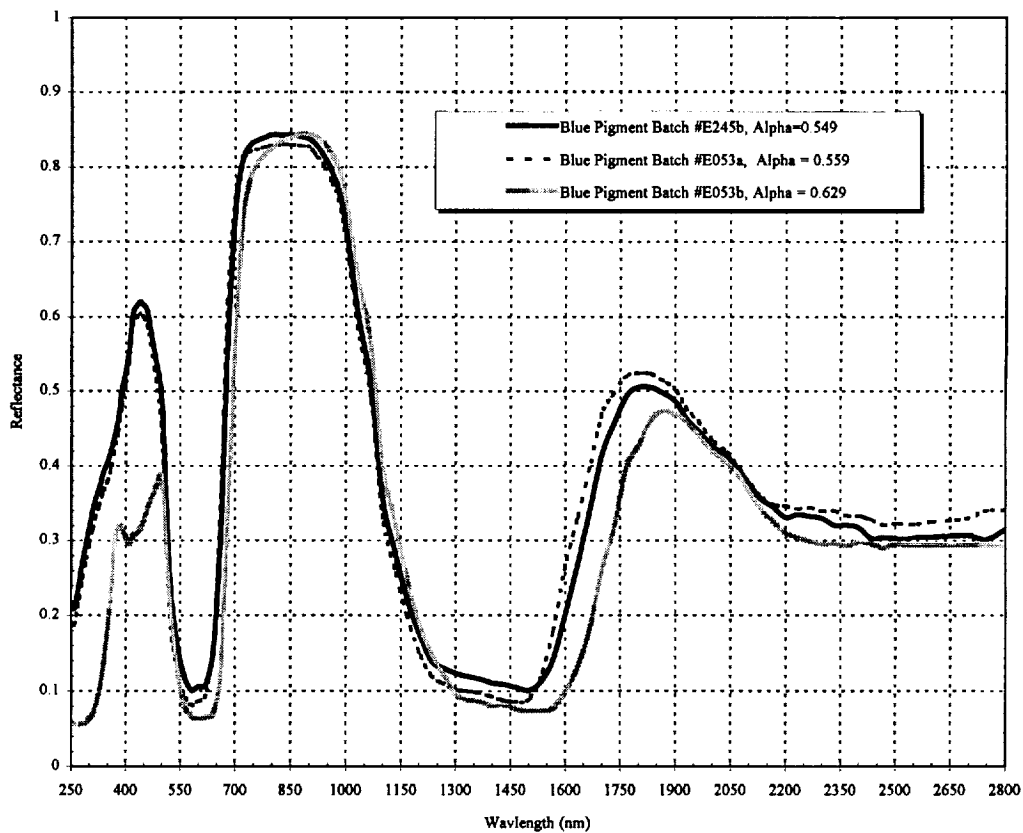

Fgure A-23. Comparison of Blue Pigment Batch #E245b, #E053a & #E053b
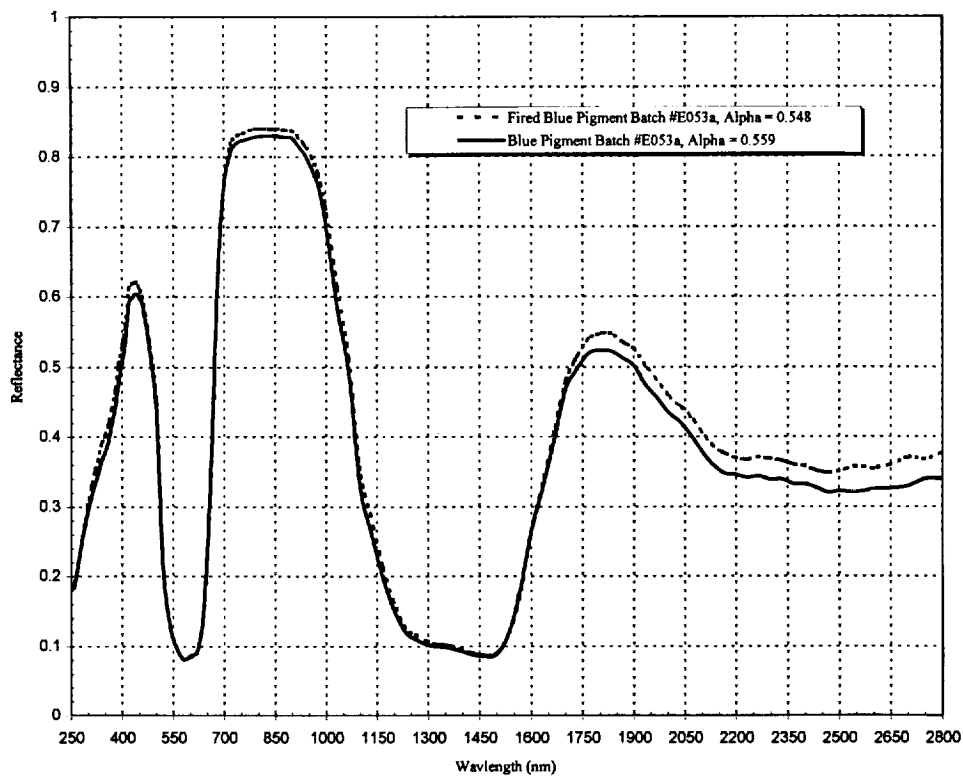
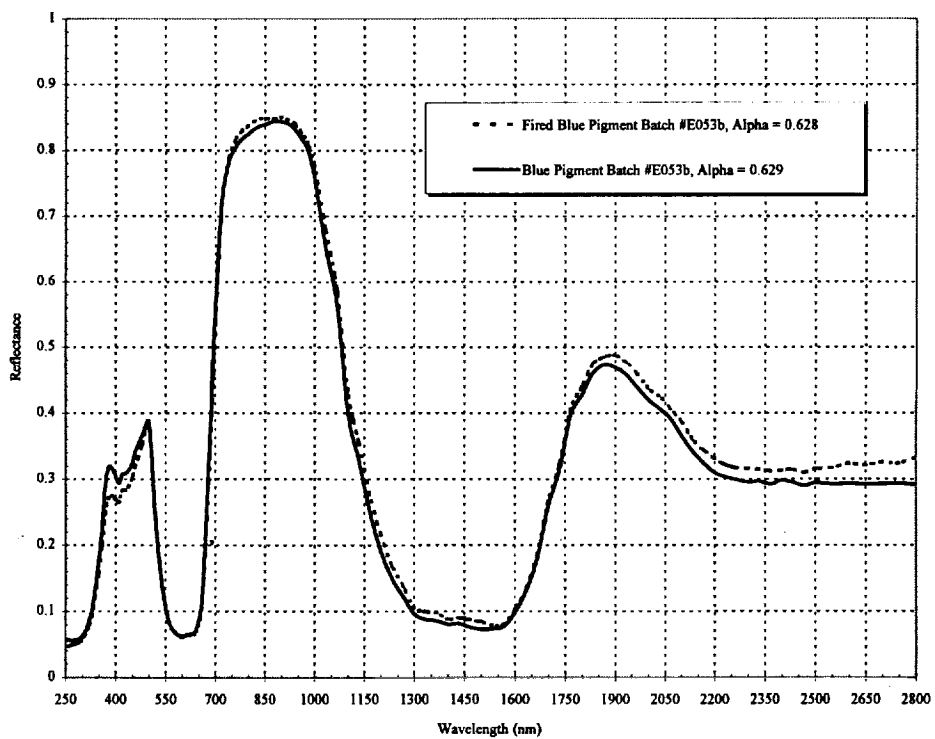Figure A-24.   Comparison of Pigment Batch #E053a (Fired and Unfired)

Figure A-25.   Comparison of Pigment Batch #E053b (Fired and Unfired)
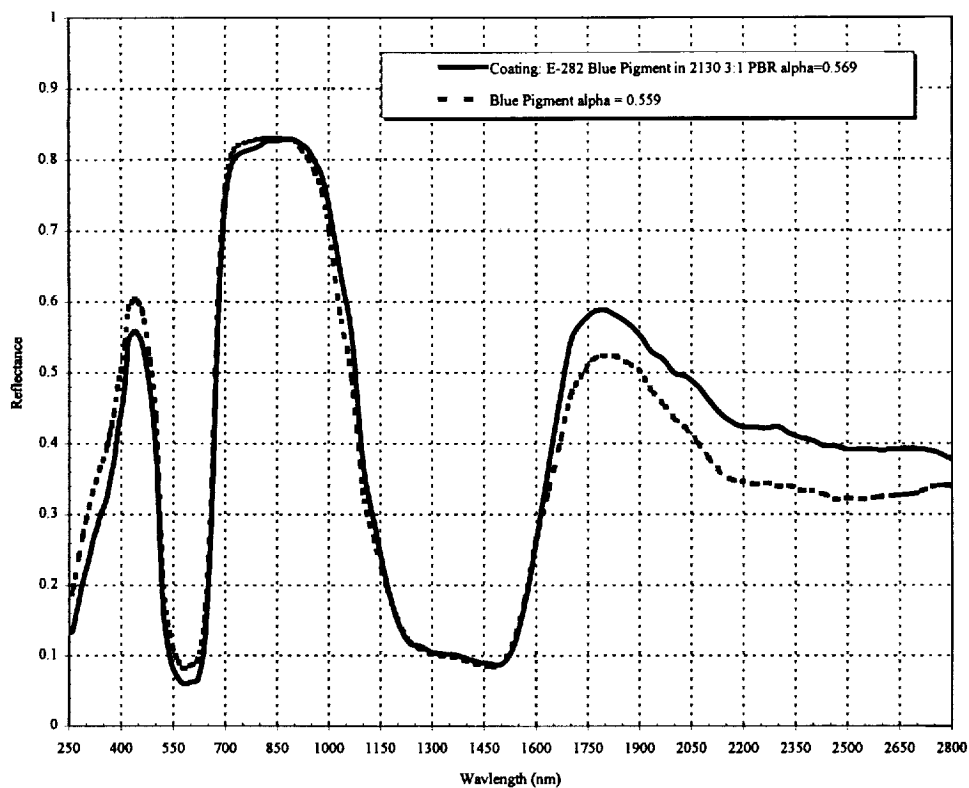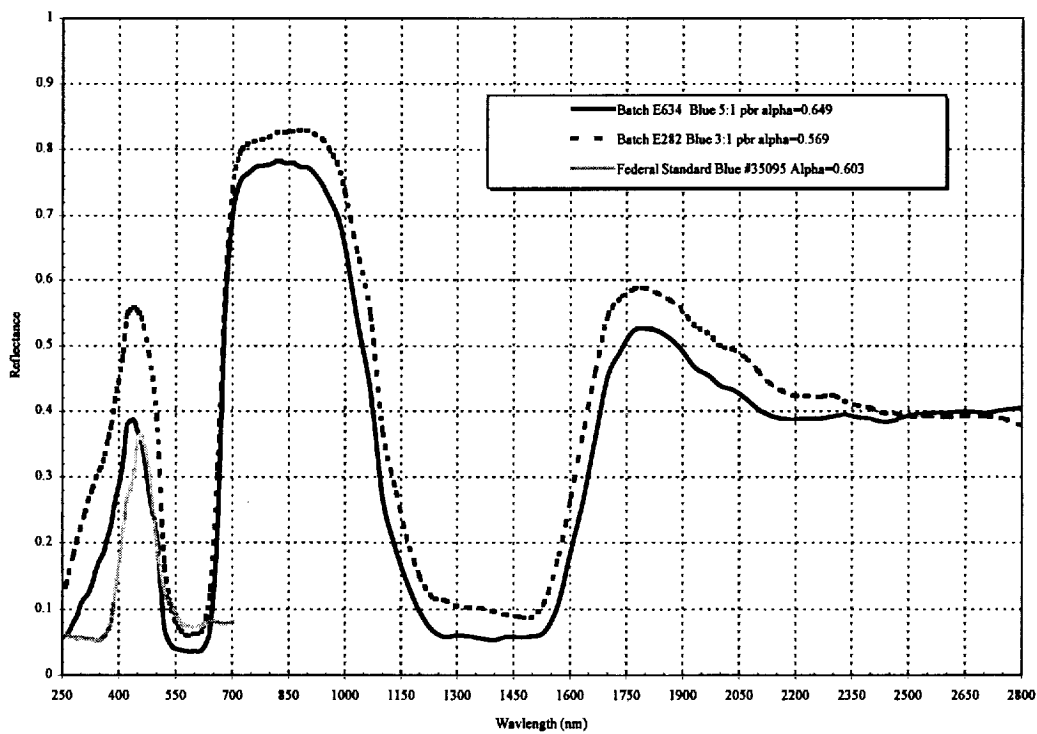
A- 13

Figure A-26. Pigments Vs. Coating

Figure A-27. Comparison of Blue Pigments with Federal Standards
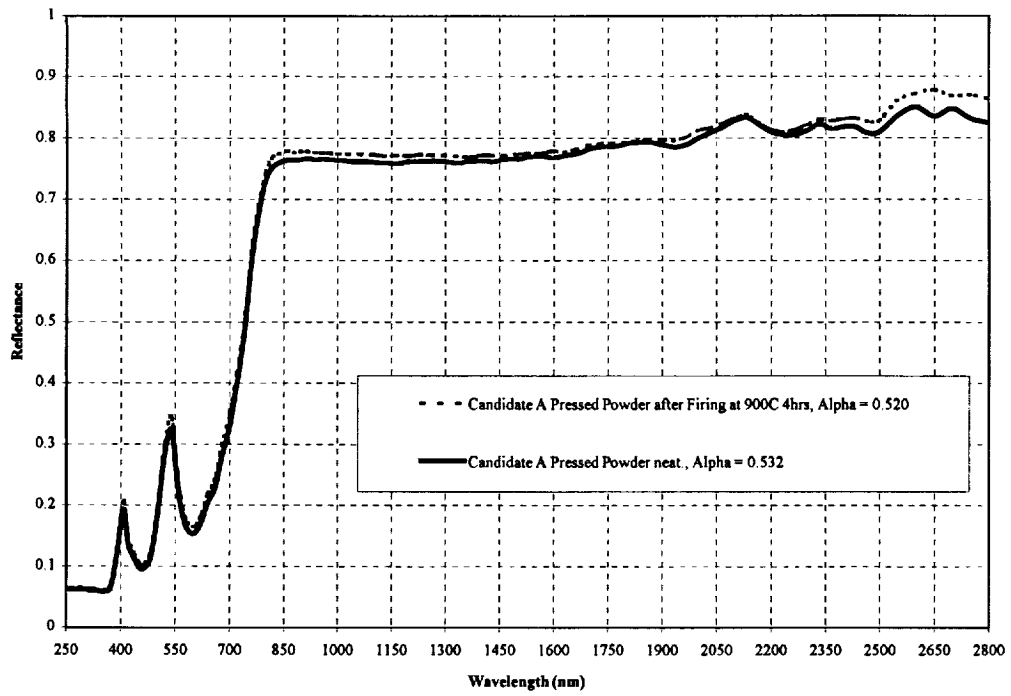
A-14

Figure A-28 Pre and Post Test Reflectance of Green Candidate A
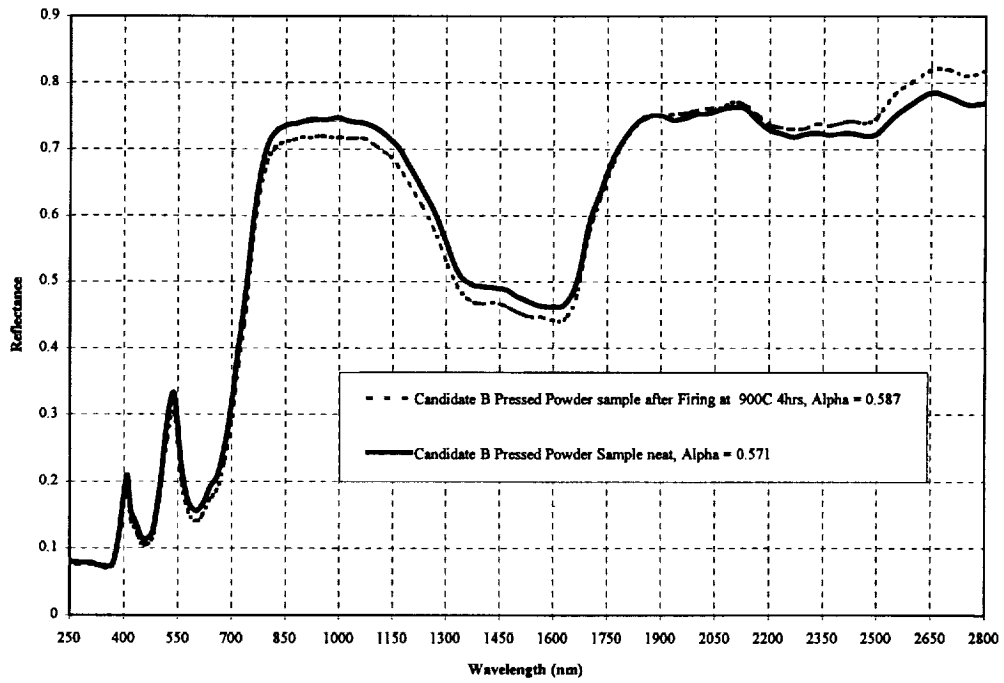

Figure A-29 Pre and Post Test Reflectance of Green Candidate B

APPENDIX B.   PROTECTIVE OVERCOAT DATA

Table B-1. Sample Composition and Properties of Fluorocarbon Polymer (FP) on AZ-93 Samples

Sample Ident.	Type of FP Overcoat	Coating Materials	Coating Thickness	Intended Thickness (Mils)	FP Thickness	Total Thickness	Solar absorptance	Relative Emittance
D135 #8	AF	AZ93/MLP-300	6.68	0.50	0.70	7.38	0.144	0.905
D135 #9	AF	AZ93/MLP-300	6.95	0.25	0.37	7.32	0.140	0.906
D135 #10	AF	AZ93/MLP-300	7.60	0.25	0.27	7.87	0.141	0.904
D135 #12	AF	AZ93/MLP-300	6.66	0.50	0.63	7.29	0.145	0.899
D135 #16	AF	AZ93/MLP-300	7.53	0.25	0.26	7.79	0.149	0.905
D135 #17	AF	AZ93/MLP-300	7.43	0.50	0.55	7.98	0.150	0.905
D135 #19	AF	AZ93/MLP-300	7.75	0.25	0.47	8.22	0.151	0.908
D135 #20	AF	AZ93/MLP-300	6.94	0.25	0.37	7.31	0.141	0.906
D161 #9	AF	AZ93	6.75	0.50	0.59	7.34	0.147	0.899
D161 #10	AF	AZ93	4.66	0.50	0.50	5.16	0.158	0.901
D161 #15	AF	AZ93	6.19	0.50	0.51	6.70	0.150	0.904
D161 #16	AF	AZ93	5.70	0.25	0.23	5.93	0.153	0.901
D161 #17	AF	AZ93	5.17	0.25	0.22	5.39	0.150	0.900
D161 #19	AF	AZ93	4.37	0.50	0.53	4.90	0.155	0.900
D135 #1	SF	AZ93/MLP-300	6.80	0.25	0.33	7.13	0.145	0.904
D135 #3	SF	AZ93/MLP-300	7.00	0.50	0.59	7.59	0.144	0.902
D135 #4	SF	AZ93/MLP-300	7.51	0.50	0.49	8.00	0.145	0.901
D135 #6	SF	AZ93/MLP-300	7.00	0.25	0.41	7.41	0.152	0.904
D135 #11	SF	AZ93/MLP-300	6.62	0.50	0.56	7.18	0.148	0.903
D135 #14	SF	AZ93/MLP-300	7.38	0.50	0.59	7.97	0.144	0.904
D135 #15	SF	AZ93/MLP-300	7.49	0.50	0.57	8.06	0.146	0.904
D135 #18	SF	AZ93/MLP-300	7.75	0.25	0.32	8.07	0.158	0.899
D161 #1	SF	AZ93	5.73	0.25	0.38	6.11	0.159	0.902
D161 #2	SF	AZ93	5.02	0.25	0.37	5.39	0.160	0.901
D161 #3	SF	AZ93	4.80	0.25	0.42	5.22	0.160	0.902
D161 #4	SF	AZ93	5.28	0.50	0.42	5.70	0.151	0.905
D161 #11	SF	AZ93	4.37	0.50	0.49	4.86	0.156	0.900
D161 #12	SF	AZ93	4.27	0.25	0.41	4.68	0.154	0.900

Listing of AZT prepared fluorocarbon polymer protective overcoated samples of AZ93 (Z93) tested in the MSFC atomic oxygen beam facility (AOBF).

TABLE B-2. Sample Description

Coating Designation	Thermal Control Coatings	TFE Type Overcoat	TFE Thickness (Mil)	# of Samples
Z.25.A	AZ93	Amorphous	0.25	2
Z.50.A	AZ93	Amorphous	0.50	1
Z.25.C	AZ93	Partially Crystalline	0.25	1
Z.50.C	AZ93	Partially Crystalline	0.50	2
ZP.25.A	AZ93+Primer	Amorphous	0.25	1
ZP.50.A	AZ93+Primer	Amorphous	0.50	3
ZP.25.C	AZ93+Primer	Partially Crystalline	0.25	4

TABLE B-3. Test Environments and Thermal Properties Data

Coating - Sample #	AO Fluence x 10^{21} (atoms/cm^2)	VUV (ESH) @ 130nm	$\Delta\alpha$	$\Delta\varepsilon$
Z.25.A - 9	0.58	6202	-0.001	-0.002
Z.25.A -10	0.54	12303	0.001	0.001
Z.50.A - 9	0.87	12303	0.005	0.002
Z.25.C -2	0.79	12303	0.001	-0.001
Z.50.C - 15	0.96	12303	0.004	-0.002
Z.50.C - 3	0.44	6202	0.000	0.006
ZP.25.A - 16	0.48	6202	0.001	0.003
ZP.50.A - 8	0.42	6202	-0.004	0.002
ZP.50.A - 17	0.30	6202	-0.001	0.008
ZP.50.A - 19	1.06	12303	0.000	0.002
ZP.25.C-1	0.53	6202	-0.007	0.004
ZP.50.A - 6	0.62	6202	-0.004	0.004
ZP.50.A -11	1.13	12303	0.002	0.000
ZP.50.A -15	0.77	12303	0.000	0.014

APPENDIX C. TYPICAL COATING DATA SHEET

ISS Coatings Data Sheet Compilation

Figure C-1provides an example of a prototype material data sheet. This format is for the coatings developed primary for use on ISS. In addition to this data sheet we are intending to provide UV-NIR spectrum for each coating and a one inch diameter coating sample with each data sheet. We are also considering of providing spectral thermal emittance data in addition to total emittance valued provided in the properties table of the data sheet but have not had the resources to undertake this task.

AZ Tek

AZ TECHNOLOGY

PRODUCT DATA SHEET

MATERIAL DESIGNATION: TMS-800IY

PRODUCT DESCRIPTION:

TMS-800IY is an inorganic non-specular yellow coating developed for use as a marker coating for spacecraft. TMS-800IY is a bendable inorganic marker coating that can be spray deposited with an air brush or high-volume low-pressure system with ease. The coating was developed for possible use on EVA handrails and for a marking material on Beta cloth utilized in the manufacture of MLI blankets. If used on Beta cloth that is Teflon coated, the side to be coated should be prepared with a suitable etchant prior to coating application for best results. This material has good to excellent adhesion to most substrate materials including hard anodized aluminum. TMS-800IY has been tested to NHB 8060.1C and meets flammability, toxicity and outgassing requirements. This coating has also been tested in MSFC UV/AO and combined environmental effects test chamber resulting in only small changes in optical properties. TMS-800IY is also being exposed to the space environment on both POSA (Passive Optical Sample Assembly) and OPM (Optical Properties Monitor) flight experiments, there no change in the coatings yellow color discernible from shuttle photographs (POSA) or spectral reflectance data from OPM.

The table below lists the optical and application parameters of cured TMS-800IY.

NOMINAL DRY THICKNESS	4.0 ± 1.0mils (over 85% of coated area)
APPEARANCE/COLOR	Nonspecular optical yellow
THERMAL EMITTANCE (ϵ_t)	≥ 0.80
SOLAR ABSORPTANCE (α_S)	0.370 ± 0.01 at ≥ 4.0 mils thickness
ADHESION GRADE	Not less than 3A (when tested according to ASTM D3359, Method A)

AZ Technology has provided specialized coatings to many major aerospace corporations and to NASA. We have also consulted with spacecraft manufacturers in the development and application of thermal control coatings for flight hardware. AZ Technology personnel have the background and experience to provide all your spacecraft coating needs. For more information or to place an order, call Richard Mell at: (205) 837-9877, extension 131, 8 AM to 5 PM Central Time, Monday through Friday.

AZ Technology
7047 Old Madison Pike, Suite 300
Huntsville, Alabama 35806
Telephone: (205)837-9877   Fax: (205)837-1155

APPENDIX D.   PARTIAL LISTING OF SAMPLES DELIVERED TO MSFC FOR EVALUATION

Table D-1 lists the coating systems that have been completed at this time and for each coating 50 samples or two inch square Kapton substrate samples were produced. These coatings were deposited on 6061 aluminum sample buttons which were chosen to make these samples compatible with most common analytical equipment.

Table D-1 Finished Space Station Coating Samples

Coating Designation	Substrate Type	Color or Type	Batch Number
AZ-93 / MLP-300[1]	Aluminum Buttons	White Inorganic / TCC[2] / Rigid	E-182
AZ-93 .	Aluminum Buttons	White Inorganic / TCC / Rigid	E-182
TMS 800IY	Aluminum Buttons	Yellow Inorganic / Marker / Rigid	E-254
TMJ-850LSY	Aluminum Buttons	Yellow Silicone / Marker / Rigid	E-255
AZ-400LSW	Aluminum Buttons	White Silicone / Marker / Rigid	E-265
ML-210IB	Aluminum Buttons	Black Inorganic / Optical / Rigid	E-245
TMJ-20LSB	Aluminum Buttons	Black Silicone/ Marker / Rigid	E-264
	Aluminum Buttons	White E. Conductive / TCC	E-365
	Aluminum Buttons	Black E. Conductive / TCC	E-366
MLS-85SB	Aluminum Buttons	Black Silicone / Optical / Rigid	E-243
AZ-93 / MLP-300	Kapton/Al foil	White Inorganic / TCC. / Flexible	
ML-210 / MLP-300	Kapton/Al foil	Black Inorganic / Optical / Flexible	
TMS 800IY / MLP-300	Kapton/Al foil	Yellow Inorganic / Marker / Flexible	
	Aluminum Buttons	Yellow E. Conductive / Marker	
	Aluminum Buttons	Red Coating / Marker	
	Aluminum Buttons	Blue Coating / Marker	

High Contrast Coatings For ISS

A sample using an arrow symbol was prepared with the inorganic black coating, RM5501B as the arrow and AZ-93 as the background. This first attempt at making an inorganic marker was fairly successful and the sample was submitted to NASA for review and evaluation.

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[1] AP = Adhesion Promoter

[2] TCC = Thermal Control Coating

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13. ABSTRACT *(Maximum 200 words)*

This final report is concerned with the tasks performed during the contract period which included spacecraft coating development, testing, and applications. Five marker coatings consisting of a bright yellow handrail coating, protective overcoat for ceramic coatings, and specialized primers for composites (or polymer) surfaces were developed and commercialized by AZ Technology during this program. Most of the coatings have passed space environmental stability requirements via ground tests and/or flight verification. Marker coatings and protective overcoats were successfully flown on the Passive Optical Sample Assembly (POSA) and the Optical Properties Monitor (OPM) experiments flown on the Russian space station MIR. To date, most of the coatings developed and/or modified during this program have been utilized on the International Space Station and other spacecraft. For ISS, AZ Technology manufactured the "UNITY" emblem now being flown on the NASA UNITY node (Node 1) that is docked to the Russian Zarya (FGB) utilizing the colored marker coatings (white, blue, red) developed by AZ Technology. The UNITY emblem included the USA American flag, the Unity logo, and NASA logo on a white background, applied to a Beta cloth substrate.

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