LONG DURATION EXPOSURE FACILITY
M0003-5
Thermal Control Coatings
on
DoD Flight Experiment

Charles J. Hurley
University of Dayton Research Institute
Dayton, OH

William Lehn
Nichols Research Corporation
Dayton, OH

INTRODUCTION

The M0003-5 thermal control coatings and materials orbited on the LDEF M0003 Space Environment Effects on Spacecraft Materials were a part of a Wright Laboratories Materials Directorate larger experiment. They were selected from new materials which emerged from development programs during the 1978-1982 time frame. Included were materials described in the technical literature which were being considered or had been applied to satellites. Materials that had been exposed on previous satellite materials experiments were also included to provide data correlation with earlier space flight experiments. The objective was to determine the effects of the LDEF environment on the physical and optical properties of thermal control coatings and materials. One hundred and two specimens of various pigmented organic and inorganic coatings, metallized polymer thin films, optical solar reflectors and mirrors were orbited on LDEF. The materials were exposed in four separate locations on the vehicle. The first set was exposed on the direct leading edge of the satellite. The second set was exposed on the direct trailing edge of the vehicle. The third and fourth sets were exposed in environmental exposure control canisters (EECC) located 30 degrees off normal to the leading and trailing edges.

The purpose of the experiment was to understand the changes in the properties of materials before and after exposure to the space environment and to compare the changes with predictions based on laboratory experiments. The basic approach was to measure the optical and physical properties of materials before and after long-term exposure to a low earth orbital environment comprised of UV, VUV, electrons, protons, atomic oxygen, thermal cycling, vacuum,debris and micrometeoroids. Due to the unanticipated extended orbital flight of LDEF, the thermal control coatings and materials in the direct leading and trailing edge were exposed for a full five years and ten months to the space environment and the canister materials were exposed for approximately one year to the full environment.

LDEF M0003 SUB-EXPERIMENTS

The individual experiments listed below were supplied by the organization named and integrated into the flight hardware trays by Aerospace Corporation. Deintegration was accomplished by the same organization.

#	NAME	ORGANIZATION
1	RADAR CAMOUFLAGE MATERIALS & EO SIGNATURE COATINGS	AVIONICS LAB
2	LASER OPTICS	WEAPONS LAB
3	STRUCTURAL MATERIALS	WEAPONS LAB
4	SOLAR POWER COMPONENTS	PROPULSION LAB
5	THERMAL CONTROL MATERIALS	MATERIALS LAB
6	LASER COMMUNICATION COMPONENTS	SPACE DIVISION/ McD-D ASTRONAUTICS
7	LASER MIRROR COATING	NAVAL WEAPONS CTR
8	COMPOSITE MATERIALS, ELECTRONIC PIECE PARTS, FIBER OPTICS	BOEING AEROSPACE
9	THERMAL CONTROL, ANTENNA, COMPOSITE MATERIALS, COLD WELDING	LOCKHEED MISSILE & SPACE CORP.
10	ADVANCED COMPOSITE MATERIALS	FLIGHT DYNAMICS LAB AEROSPACE CORP.
11	CONTAMINATION MONITORING	AEROSPACE CORP.
12	RADIATION DOSIMETRY	AEROSPACE CORP.
13	LASER HARDENED MATERIALS	McD-D ASTRONAUTICS
14	QUARTZ CRYSTAL MICROBALANCE	BERKLEY INDUSTRY
15	THERMAL CONTROL MATERIALS	AEROSPACE CORP.
16	ADVANCED COMPOSITE MATERIALS	AEROSPACE CORP.
17	RADIATION DOSIMETRY	AEROSPACE CORP.
18	THERMAL CONTROL COATINGS	AEROSPACE CORP.
19	ELECTRONIC DEVICES	AEROSPACE CORP.

LDEF IN THE ORBITER PROCESSING FACILITY

Fifty seven experiments were placed in a low earth orbit aboard LDEF on April 7, 1984 for a planned one year mission. The LDEF vehicle was recovered on January 12, 1990 from a degrading orbit by the Space Shuttle Columbia. After a landing at Edwards Air Force Base, California, the Space Shuttle, with LDEF still contained inside, was transported to Kennedy Space Center, Florida. LDEF was removed from the shuttle bay in the Orbiter Processing Facility (OPF) in late January 1990.

The photograph in figure 1 shows the extensive damage done to some of the experiments on the leading edge side and the space end of the vehicle. The M0003 experiment is located near the center of the vehicle at the scuff plate.

Figure 1. LDEF in Orbital Processing Facility

LDEF in SAEF II

After completion of activities in the Orbiter Processing Facility, LDEF was transported to the Spacecraft Assembly and Experiment Facility II (SAEFII). This facility provided a controlled, clean working environment for the principal investigators and other observers to examine the various experiments. The photograph in figure 2 shows only a portion of the leading edge side of LDEF. The M0003 experiment is located to the far left of the photograph near the scuff plate.

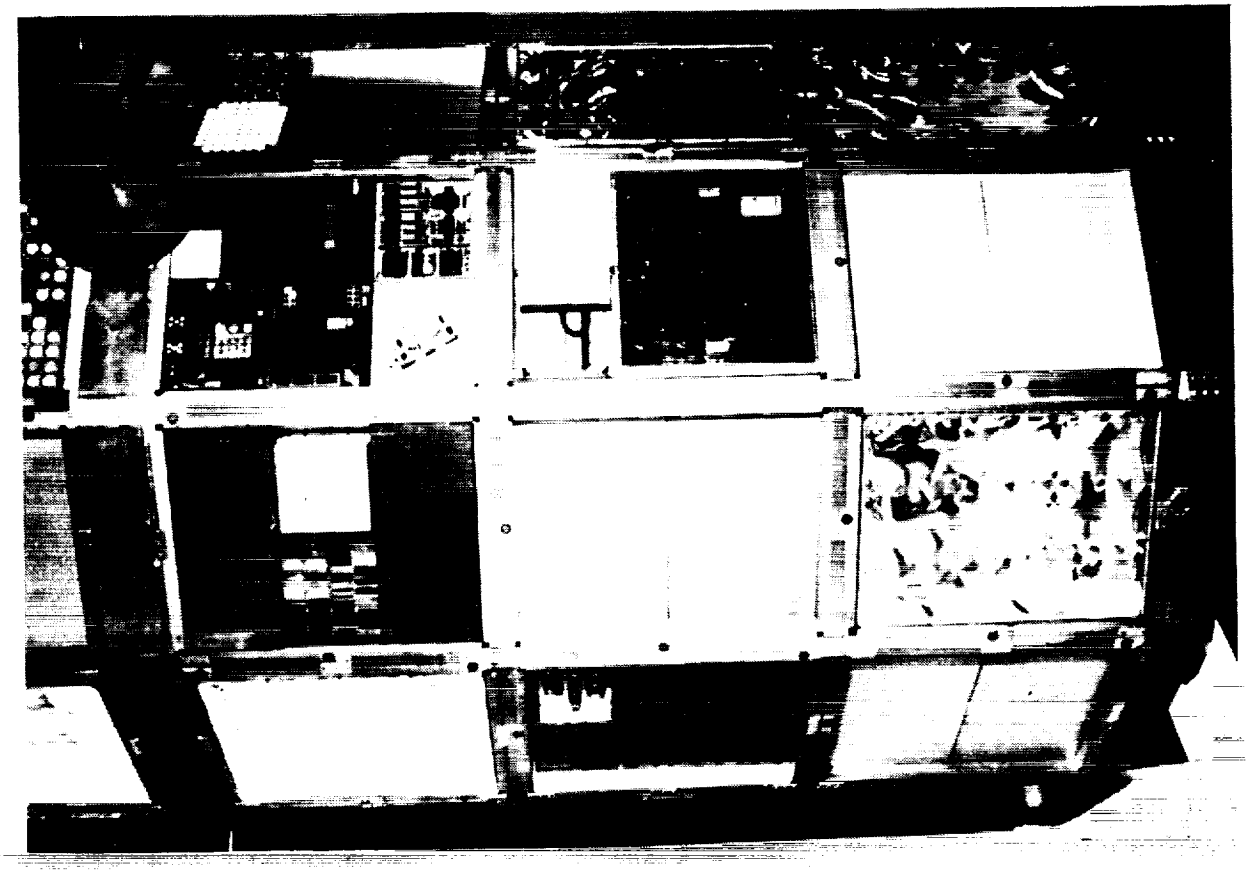

Figure 2. LDEF in SAEF II

LDEF/WL/MD EXPERIMENT
THERMAL CONTROL MATERIALS
M0003-5

THERMAL CONTROL MATERIALS

A SERIES

Pigmented Coatings	44
Metallized Polymer Films	28
Quartz Fabrics	8

B Series

Optical Solar Reflectors (second surface)	8
Gold Mirrors (first surface)	4
Silver Mirrors (first surface)	6
Aluminum Mirrors (first surface)	4

C Series

Metallized Polymeric Films	8
Metallized Bonded Films	14
Clear Films	10
Total	134

M0003-5 LEADING EDGE EXPERIMENT

The M0003-5 experiment was located in a 3 inch deep leading edge tray designated as D9. It contained a variety of thermal control pigmented coatings, metallized polymer films, clear films and mirrors. The photograph in figure 3 shows the preflight layout of the materials. The thermal control coatings discs and mirrors are located on the right hand side of the tray.

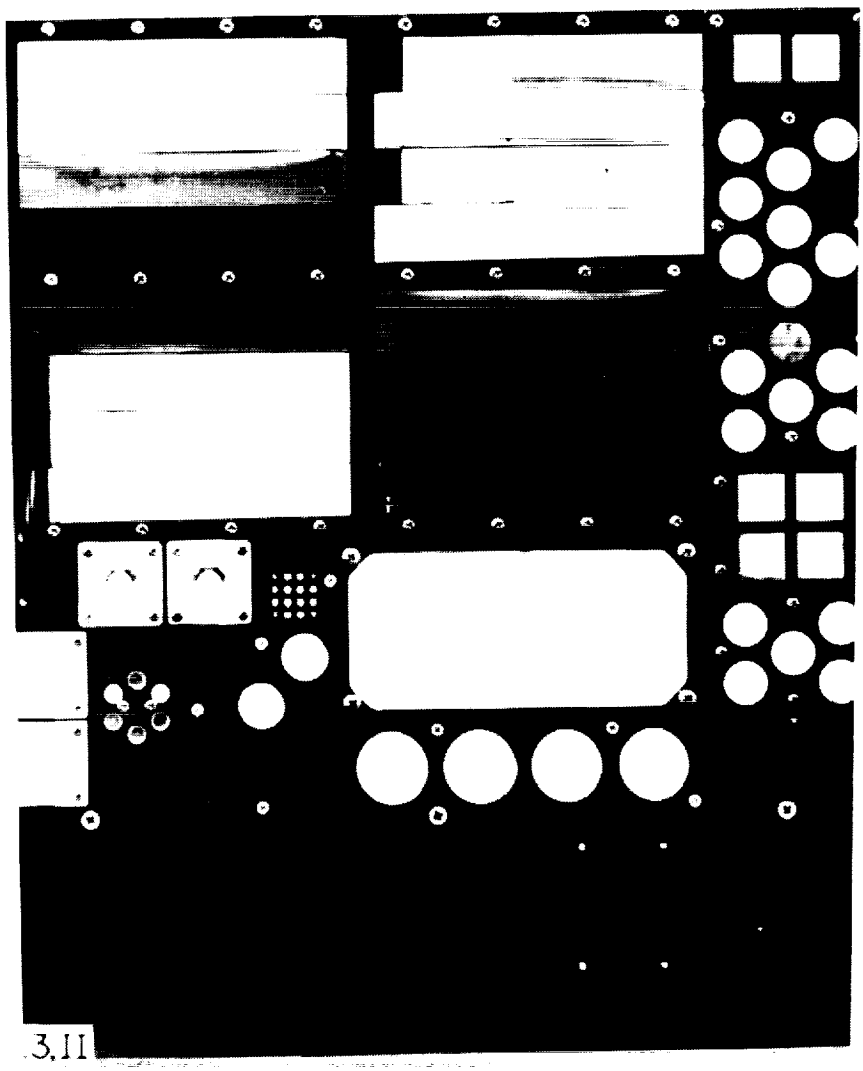

Figure 3. M0003-5 Pre flight Leading Edge Tray Experiment

RECOVERED LEADING EDGE M0003 TRAY

A photograph of the recovered M0003 leading edge tray originally located in the D9 position is shown in figure 4. Among the various areas of visible damage, note the condition of the polymeric films portion of the M0003-5 experiment located in the lower left quadrant of the tray. The thermal control material discs and squares are located in the far lower left quadrant. Atomic oxygen contributed some physical damage to the materials,especially the front surface. Silver mirrors and radiation contributed some color changes .

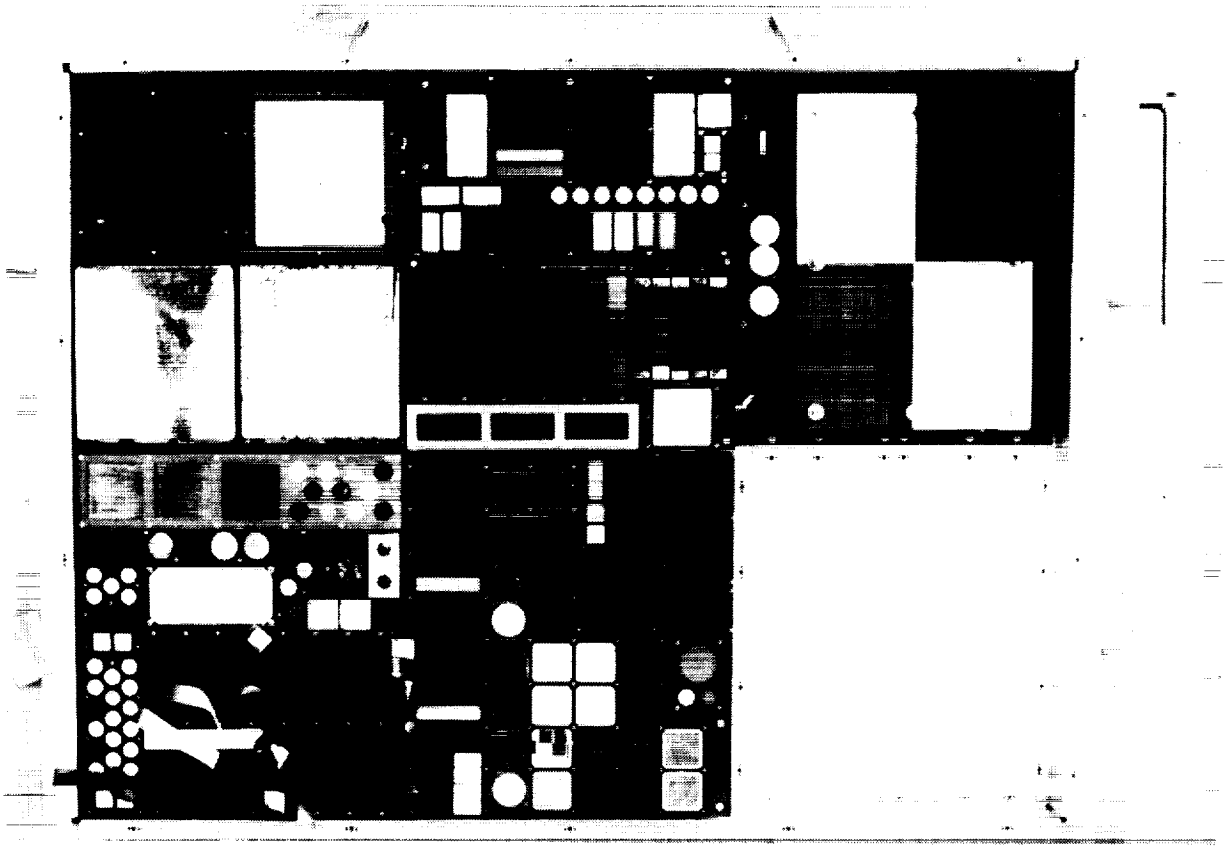

Figure 4. M0003 Post Flight Leading Edge Tray

The photograph in figure 5 shows the M0003 experiment and the surrounding trays. Note the extensive damage to the experiment located in tray D10 immediately above tray D9 M0003 experiment tray. Also observe the serious damage that occurred to the M0003-1 experiment located in the lower right quadrant of the tray. Damage is also evident to the M0003-5 polymer film materials. The thermal control discs are partially obscured by the scuff plate.

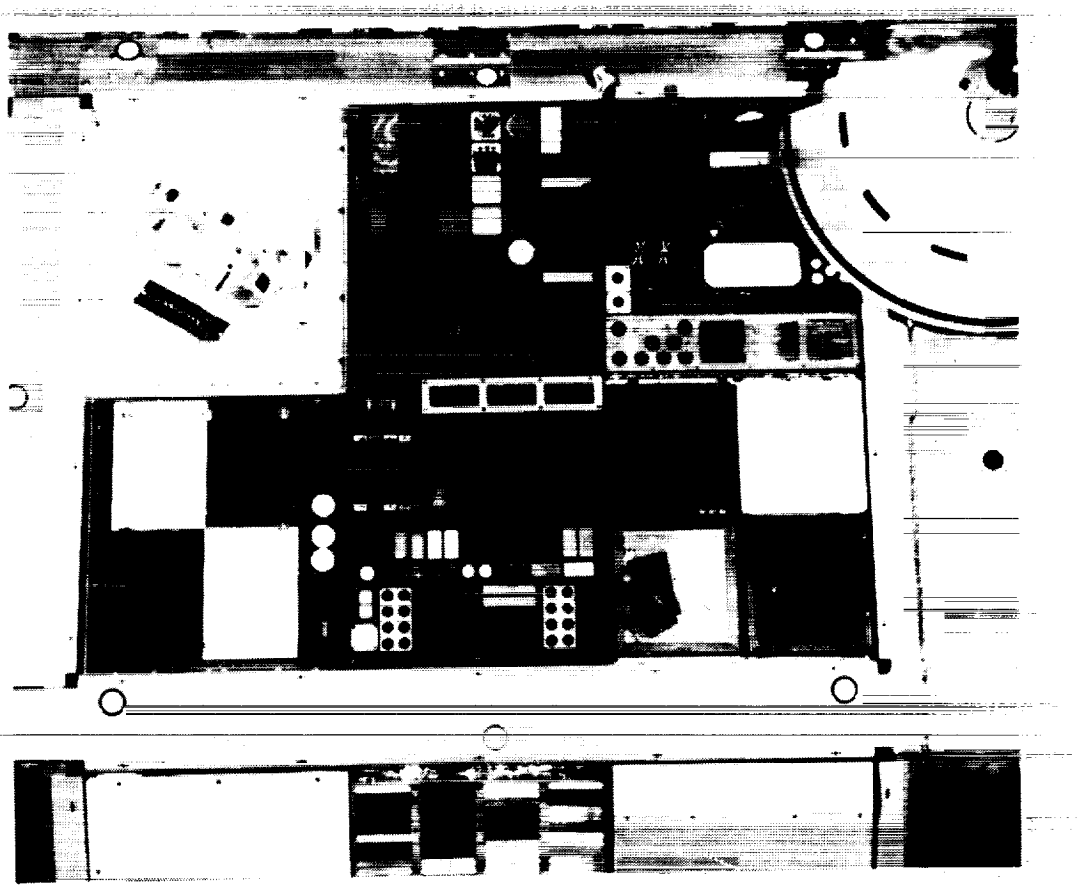

Figure 5. LDEF/M0003 IN SAEF II

M0003-5 POST FLIGHT LEADING EDGE TRAY CLOSEUP

The photograph in figure 6 below shows a closeup of the M0003-5 experiment materials. Note the extensive damage to the polymeric film strips. There is obvious physical damage, discoloration and debonding of the materials. The thermal control materials discs are located on the right hand side of the photograph. The most evident damage are the two front surface silver mirrors which were destroyed by atomic oxygen.

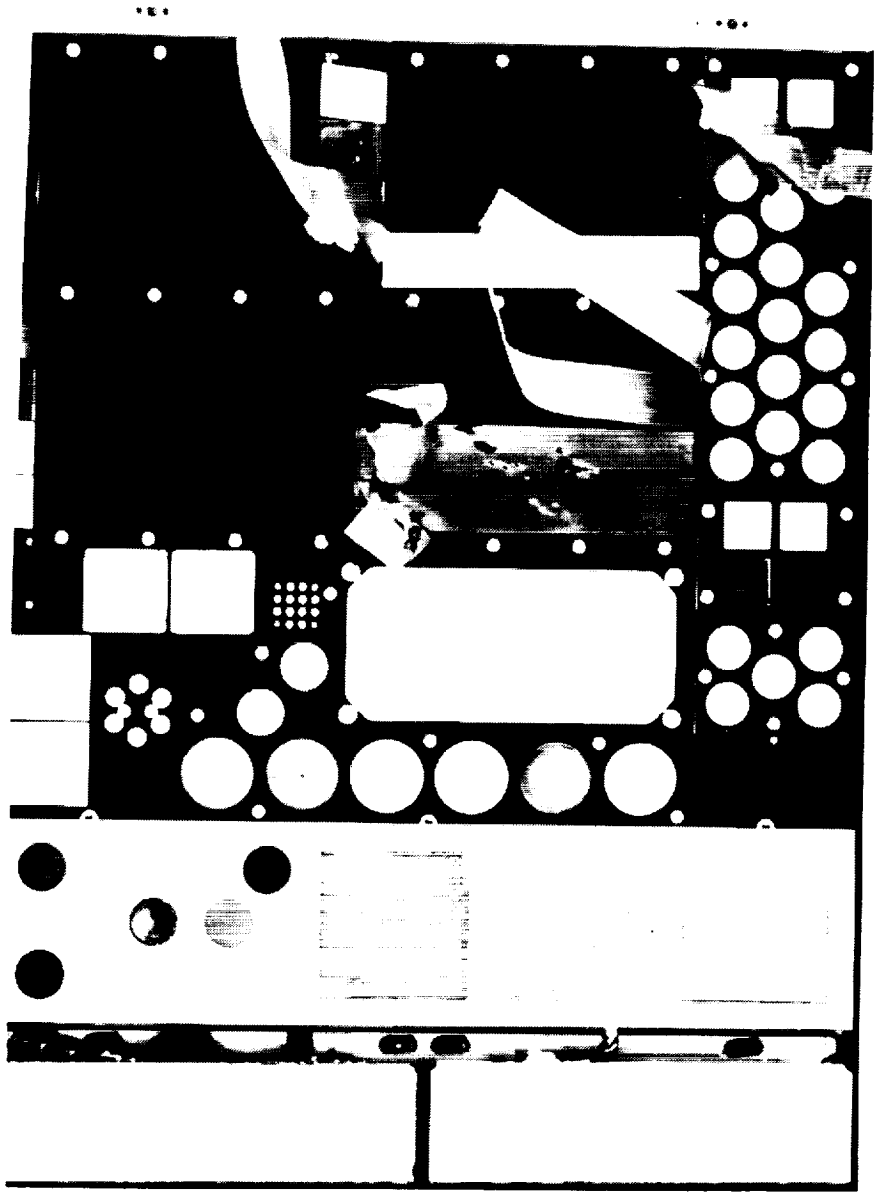

Figure 6. M0003-5 Post Flight Leading Edge Tray Closeup

M0003-5 PREFLIGHT TRAILING EDGE EXPERIMENT

The photograph in figure 7 shows the preflight thermal control coating discs and mirrors on the right side of the tray.

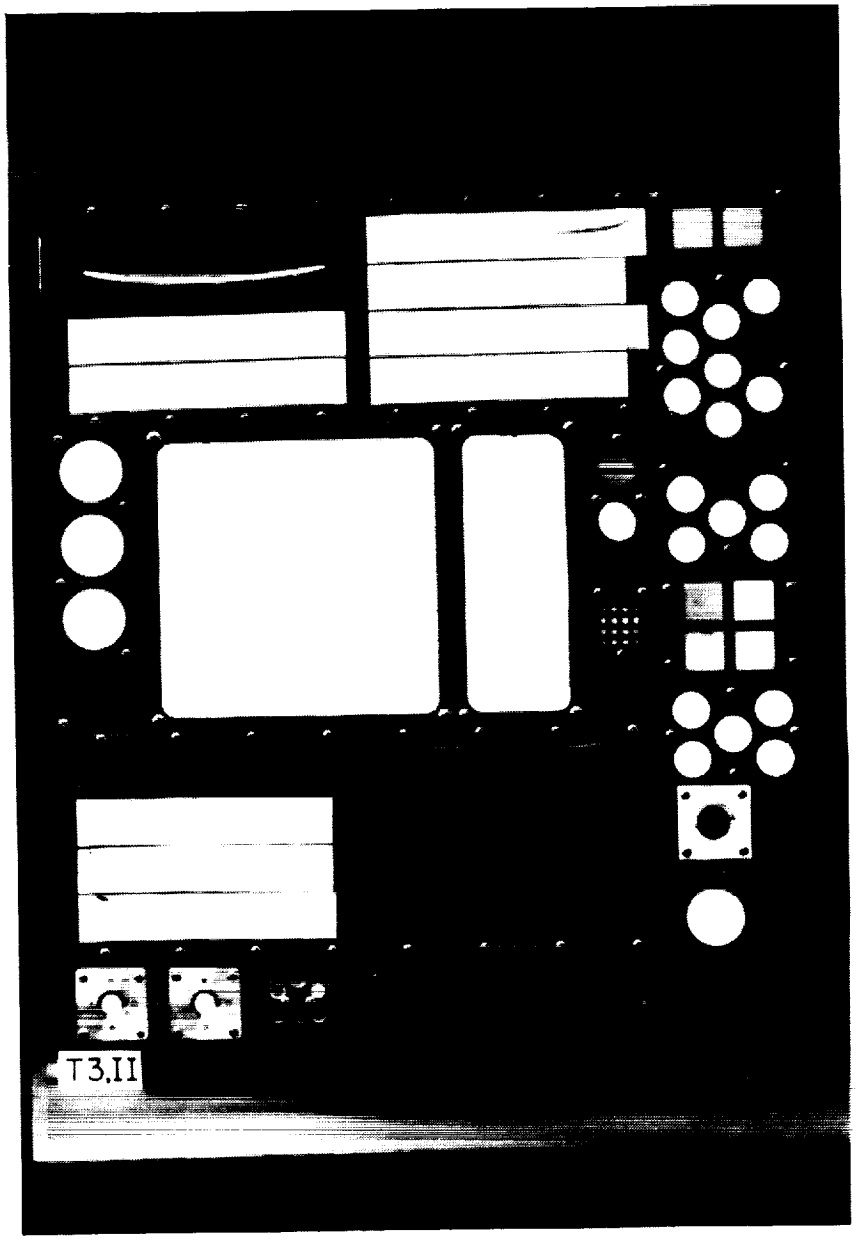

Figure 7. M0003-5 Preflight Trailing Edge Experiment

RECOVERED POST FLIGHT TRAILING EDGE M0003 TRAY

The photograph in figure 8 shows the post flight materials in the recovered trailing edge tray. Among the various areas of visible damage, note the condition of the M0003-5 polymeric film strips located in the upper right quadrant of the tray. The thermal control materials discs are located on the right side of the photograph. Contamination has discolored many of the specimens.

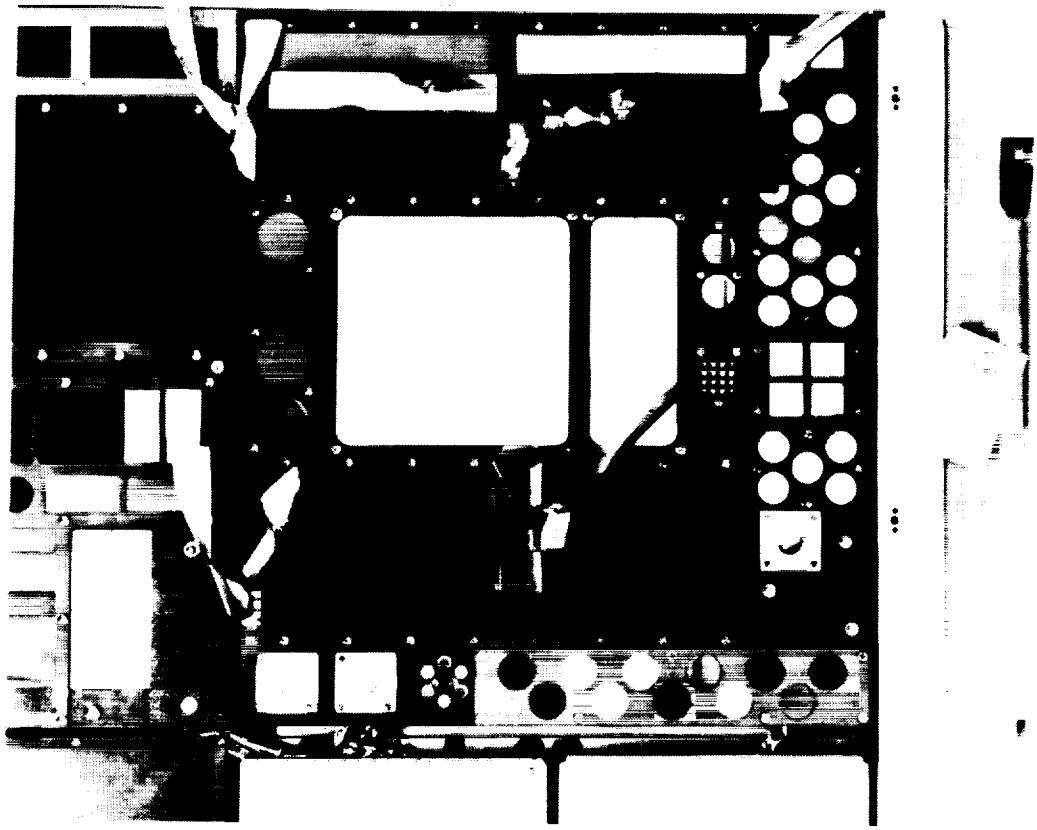

Figure 8. M0003 Post Flight Trailing Edge tray

M0003-5 POST FLIGHT TRAILING EDGE TRAY CLOSEUP

The photograph in figure 9 below shows a closeup of the M0003-5 experiment materials. Note the extensive damage to the polymeric film strips. The thermal control materials discs are located on the right side of the photograph. Contamination and radiation are responsible for the color changes in the materials.

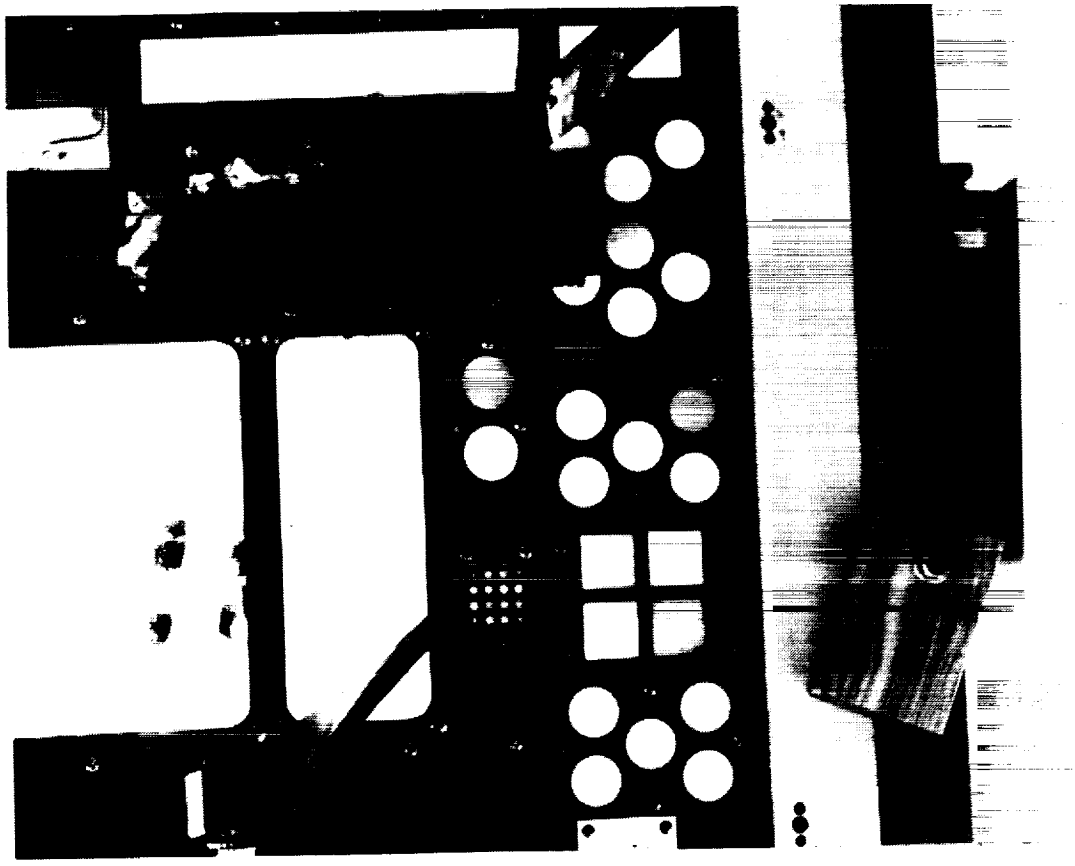

Figure 9. M0003-5 Post Flight Trailing Edge Tray Closeup

M0003-5 THERMO-OPTICAL DATA

Tables 1 through 5 provide a brief description of the materials in the M0003-5 experiment. The pre test and post test intergrated IR emittance values from 2-20 microns are shown. UV-Vis-NIR reflectance values from 0.25 to 2.5 microns are also provided the for pretest and post test measurements.

Table 1. Thermo-Optical Data of M0003-5 Specimens A1 Through A6

SAMPLE ID	Material Description	Gier-Dunkle DB-100 2-20 μ pretest ε	Gier-Dunkle DB-100 2-20 μ post test ε	Bomem DA3 FTIR 2-12.5 μ post test ε	Beckman DK-2A 0.25-2.50 μ pretest α	Perkin-Elmer Lambda 9 0.25-2.50 μ post test α
C1-A1	Quartz fabric 581/FEP/Al		0.854	0.862	0.143	0.211
L3II-5-19-A1	Quartz fabric 581/FEP/Al	0.852	0.856	0.870	0.154	0.251
L6VI-5-7-A1	Quartz fabric 581/FEP/Al		0.855	0.867	0.149	0.215
T3II-5-19-A1	Quartz fabric 581/FEP/Al	0.850	0.854	0.863	0.142	0.289
T6VI-5-8-A1	Quartz fabric 581/FEP/Al		0.853	0.862	0.145	0.279
C1-A2	ITO/FEP/Ag/Inconel 5 mil		0.808	0.840	0.108	0.109
L3II-5-20-A2	ITO/FEP/Ag/Inconel 5 mil	0.812	0.811	0.848	0.104	0.109
L6VI-5-8-A2	ITO/FEP/Ag/Inconel 5 mil		0.810	0.842	0.114	0.096
T3II-5-20-A2	ITO/FEP/Ag/Inconel 5 mil	0.812	0.811	0.839	0.106	0.212
C1-A3	Porcelain Enamel	0.872	0.832	0.917	0.237	0.273
L3II-5-21-A3	Porcelain Enamel	0.869	0.832	0.920	0.249	0.327
L6VI-5-11-A3	Porcelain Enamel	0.871	0.830	0.916	0.248	0.285
T3II-5-21-A3	Porcelain Enamel	0.871	0.834	0.920	0.245	0.363
C1-A4	ITO/FEP/Ag/Inconel 2 mil		0.692	0.681	0.111	0.099
L3II-5-22-A4	ITO/FEP/Ag/Inconel 2 mil	0.696	0.698	0.684	0.119	0.113
L6VI-5-12-A4	ITO/FEP/Ag/Inconel 2 mil		0.696	0.684	0.126	0.098
T3II-5-22-A4	ITO/FEP/Ag/Inconel 2 mil	0.691	0.697	0.684	0.122	0.142
C1-A5	Black Inorganic Coating D111		0.912	0.942	0.965	0.975
L3II-5-23-A5	Black Inorganic Coating D111	0.910	0.921	0.955	0.974	0.979
L6VI-5-13-A5	Black Inorganic Coating D111		0.922	0.958	0.972	0.981
T3II-5-23-A5	Black Inorganic Coating D111	0.909	0.918	0.952	0.971	0.982
C1-A6	Quartz Fabric 7 micron		0.855	0.856	0.239	0.307
L3II-5-24-A6	Quartz Fabric 7 micron	0.849	0.866	0.868	0.250	0.339
L6VI-5-16-A6	Quartz Fabric 7 micron		0.861	0.860	0.234	0.334
T3II-5-24-A6	Quartz Fabric 7 micron	0.851	0.863	0.868	0.239	0.426
T6VI-5-15-A6	Quartz Fabric 7 micron		0.860	0.859	0.224	0.354

M0003-5 THERMO-OPTICAL DATA

Table 2. Thermo-Optical Data of M0003-5 Specimens A7 Through A12

SAMPLE ID	Material Description	Gier-Dunkle DB-100 2-20 μ pretest ε	Gier-Dunkle DB-100 2-20 μ post test ε	Bomem DA3 FTIR 2-12.5 μ post test ε	Beckman DK-2A 0.25-2.50 μ pretest α	Perkin-Elmer Lambda 9 0.25-2.50 μ post test α
C1-A7	FEP/Ag/Inconel 2 mil		0.669	0.655	0.112	0.080
L3II-5-25-A7	FEP/Ag/Inconel 2 mil	0.667	0.640	0.616	0.104	0.092
L6VI-5-17-A7	FEP/Ag/Inconel 2 mil		0.658	0.637	0.108	0.085
T3II-5-25-A7	FEP/Ag/Inconel 2 mil	0.657	0.670	0.657	0.104	0.137
T6VI-5-7-A7	FEP/Ag/Inconel 2 mil		0.670	0.653	0.115	0.094
C1-A8	FEP/Ag/Inconel 5 mil		0.804	0.830	0.098	0.096
L3II-5-26-A8	FEP/Ag/Inconel 5 mil	0.798	0.801	0.829	0.104	0.117
L6VI-5-29-A8	FEP/Ag/Inconel 5 mil		0.802		0.104	0.084
T3II-5-26-A8	FEP/Ag/Inconel 5 mil	0.796	0.808		0.103	0.180
T6VI-5-14-A8	FEP/Ag/Inconel 5 mil		0.806		0.105	0.093
C1-A9	In2O3/FEP/Ag/Inconel 5 mil		0.811	0.843	0.149	0.129
L3II-5-27-A9	In2O3/FEP/Ag/Inconel 5 mil	0.808	0.814	0.844	0.139	0.126
L6VI-5-30-A9	In2O3/FEP/Ag/Inconel 5 mil		0.812	0.840	0.158	0.135
T3II-5-27-A9	In2O3/FEP/Ag/Inconel 5 mil	0.808	0.814	0.844	0.160	0.177
C1-A10	Kapton/Al 1 mil		0.672		0.319	0.356
L3II-5-28-A10	Kapton/Al 1 mil	0.649	0.677		0.299	0.390
L6VI-5-31-A10	Kapton/Al 1 mil		0.631		0.333	0.485
T3II-5-28-A10	Kapton/Al 1 mil	0.643	0.671		0.313	0.399
C1-A11	Kapton/Al 5 mil		0.864	0.902	0.456	0.486
L3II-5-29-A11	Kapton/Al 5 mil	0.850	0.863	0.901	0.453	0.499
L6VI-5-32-A11	Kapton/Al 5 mil		0.894	0.946	0.467	0.620
T3II-5-29-A11	Kapton/Al 5 mil	0.850	0.864	0.900	0.456	0.477
T6VI-5-6-A11	Kapton/Al 5 mil		0.865	0.901	0.458	0.480
C1-A12	In2O3/Kapton/Al 5 mil		0.780		0.370	0.407
L3II-5-30-A12	In2O3/Kapton/Al 5 mil	0.749	0.776		0.361	0.410
L6VI-5-33-A12	In2O3/Kapton/Al 5 mil		0.784		0.366	0.402
T3II-5-30-A12	In2O3/Kapton/Al 5 mil	0.750	0.776	0.835	0.357	0.417

Table 3. Thermo-Optical Data of M0003-5 Specimens A13 Through A17

SAMPLE ID	Material Description	Gier-Dunkle DB-100 2-20 μ pretest ε	Gier-Dunkle DB-100 2-20 μ post test ε	Bomem DA3 FTIR 2-12.5 μ post test ε	Beckman DK-2A 0.25-2.50 μ pretest α	Perkin-Elmer Lambda 9 0.25-2.50 μ post test α
C1-A13	White Inorganic Coating Z93		0.904	0.966	0.143	0.226
L3II-5-31-A13	White Inorganic Coating Z93	0.914	0.921	0.965	0.145	0.177
L6VI-5-34-A13	White Inorganic Coating Z93		0.920	0.966	0.151	0.161
T3II-5-31-A13	White Inorganic Coating Z93	0.903	0.921	0.966	0.149	0.166
T6VI-5-13-A13	White Inorganic Coating Z93		0.921	0.967	0.155	0.170
C1-A14	White Silicone Coating S13 GLO		0.897	0.953	0.161	0.213
L3II-5-32-A14	White Silicone Coating S13 GLO	0.894	0.893	0.945	0.148	0.266
L6VI-5-35-A14	White Silicone Coating S13 GLO		0.893	0.945	0.158	0.233
T3II-5-32-A14	White Silicone Coating S13 GLO	0.892	0.905	0.938	0.150	0.475
T6VI-5-5-A14	White Silicone Coating S13 GLO		0.910	0.950	0.154	0.238
C1-A15	White Inorganic Coating Zn2T1O4		0.909	0.962	0.094	0.152
L3II-5-33-A15	White Inorganic Coating Zn2T1O4	0.909	0.904	0.969	0.093	0.145
L6VI-5-36-A15	White Inorganic Coating Zn2T1O4		0.911	0.967	0.090	0.153
T3II-5-33-A15	White Inorganic Coating Zn2T1O4	0.910	0.904	0.966	0.087	0.152
T6VI-5-12-A15	White Inorganic Coating Zn2T1O4		0.911	0.968	0.089	0.150
C1-A16	White Inorganic Coating NS43G		0.910		0.259	0.301
L3II-5-34-A16	White Inorganic Coating NS43G	0.908	0.910		0.266	0.328
L6VI-5-37-A16	White Inorganic Coating NS43G		0.906		0.260	0.316
T3II-5-34-A16	White Inorganic Coating NS43G	0.908	0.909		0.257	0.301
T6VI-5-3-A16	White Inorganic Coating NS43G		0.908		0.262	0.303
C1-A17	White Silicone Coating Eu2O3 MeSi		0.928		0.131	0.170
L3II-5-35-A17	White Silicone Coating Eu2O3 MeSi	0.924	0.929		0.127	0.198
L6VI-5-38-A17	White Silicone Coating Eu2O3 MeSi		0.930		0.139	0.201
T3II-5-35-A17	White Silicone Coating Eu2O3 MeSi	0.924	0.930		0.133	0.328
T6VI-5-11-A17	White Silicone Coating Eu2O3 MeSi		0.929		0.140	0.228

M0003-5 THERMO-OPTICAL DATA

Table 4. Thermo-Optical Data of M0003-5 Specimens A18 Through A22

SAMPLE ID	Material Description	Gier-Dunkle DB-100 2-20 μ pretest ε	Gier-Dunkle DB-100 2-20 μ post test ε	Bomem DA3 FTIR 2-12.5 μ post test ε	Beckman DK-2A 0.25-2.50 μ pretest α	Perkin-Elmer Lambda 9 0.25-2.50 μ post test α
C1-A18	White Silicone Coating aAl2O3 MeSi		0.880		0.093	0.134
L3II-5-40-A18	White Silicone Coating aAl2O3 MeSi	0.869	0.870		0.090	0.296
L6VI-5-39-A18	White Silicone Coating aAl2O3 MeSi		0.882		0.097	0.227
T3II-5-40-A18	White Silicone Coating aAl2O3 MeSi	0.868	0.867		0.091	0.341
T6VI-5-2-A18	White Silicone Coating aAl2O3 MeSi		0.901		0.089	0.224
C1-A19	White Silicone Coating PV100		0.862		0.196	0.236
L3II-5-41-A19	White Silicone Coating PV100	0.858	0.870		0.198	0.270
L6VI-5-40-A19	White Silicone Coating PV100		0.865		0.198	0.249
T3II-5-41-A19	White Silicone Coating PV100	0.859	0.858		0.196	0.395
T6VI-5-10-A19	White Silicone Coating PV100		0.859		0.193	0.270
C1-A20	WhiteSilicone Coating TiO2 MeSi		0.863		0.158	0.196
L3II-5-42-A20	WhiteSilicone Coating TiO2 MeSi	0.862	0.862		0.157	0.205
L6VI-5-41-A20	WhiteSilicone Coating TiO2 MeSi		0.866		0.154	0.238
T3II-5-42-A20	WhiteSilicone Coating TiO2 MeSi	0.862	0.862		0.156	0.372
T6VI-5-1-A20	WhiteSilicone Coating TiO2 MeSi		0.860		0.155	0.224
C1-A21	White Silicone Coating DC92-007		0.888		0.225	0.260
L3II-5-43-A21	White Silicone Coating DC92-007	0.878	0.869		0.218	0.405
L6VI-5-42-A21	White Silicone Coating DC92-007		0.878		0.235	0.341
T3II-5-43-A21	White Silicone Coating DC92-007	0.885	0.876		0.209	0.383
T6VI-5-9-A21	White Silicone Coating DC92-007		0.881		0.214	0.305
C1-A22	White Silicone Coating DC92-007		0.887		0.222	0.267
L3II-5-44-A22	White Silicone Coating DC92-007	0.887	0.880		0.202	0.377
L6VI-5-43-A22	White Silicone Coating DC92-007		0.878		0.226	0.335
T3II-5-44-A22	White Silicone Coating DC92-007	0.887	0.872		0.229	0.412

Table 5. Thermo-Optical Data of M0003-5 Specimens B1 Through B6

SAMPLE ID	Material Description	Gier-Dunkle DB-100 2-20 μ pretest ε	Gier-Dunkle DB-100 2-20 μ post test ε	Bomem DA3 FTIR 2-12.5 μ post test ε	Beckman DK-2A 0.25-2.50 μ pretest α	Perkin-Elmer Lambda 9 0.25-2.50 μ post test α
C1-B1	OSR OCLI S1-100					
L3II-5-17-B1	OSR OCLI S1-100	0.801	0.804		0.078	0.060
L6VI-5-23-B1	OSR OCLI S1-100		0.804		0.078	0.053
T3II-5-17-B1	OSR OCLI S1-100	0.801	0.807		0.074	0.113
T6VI-5-18-B1	OSR OCLI S1-100		0.805		0.081	0.056
C1-B2	OSR OCLI S1-100 w/conductive coating		0.783		0.090	0.133
L3II-5-18-B2	OSR OCLI S1-100 w/conductive coating	0.778	0.787		0.089	0.076
L6VI-5-28-B2	OSR OCLI S1-100 w/conductive coating		0.787		0.089	0.078
T3II-5-18-B2	OSR OCLI S1-100 w/conductive coating	0.778	0.782		0.089	0.120
T6VI-5-17-B2	OSR OCLI S1-100 w/conductive coating		0.783		0.090	0.066
C1-B3	OSR Au Mirror		0.022		0.276	0.292
L3II-5-36-B3	OSR Au Mirror	0.015	0.024		0.237	0.258
L6VI-5-26-B3	OSR Au Mirror		0.026		0.245	0.258
T3II-5-36-B3	OSR Au Mirror	0.018	0.027		0.247	0.279
T6VI-5-19-B3	OSR Au Mirror		0.030		0.247	0.248
C1-B4	OSR Al Mirror		0.040		0.143	0.132
L3II-5-37-B4	OSR Al Mirror	0.027	0.061		0.158	0.134
L6VI-5-24-B4	OSR Al Mirror		0.044		0.151	0.111
T3II-5-37-B4	OSR Al Mirror	0.027	0.044		0.159	0.171
T6VI-5-16-B4	OSR Al Mirror		0.044		0.153	0.139
C1-B5	OSR Ag Mirror		0.030			0.253
L3II-5-38-B5	OSR Ag Mirror	0.012	0.687		0.105	0.864
L6VI-5-25-B5	OSR Ag Mirror		0.037		0.120	0.861
T3II-5-38-B5	OSR Ag Mirror	0.012	0.494		0.101	0.270
T6VI-5-4-B5	OSR Ag Mirror		0.031		0.094	0.246
C1-B6	OSR Ag Mirror		0.024			0.206
L3II-5-39-B6	OSR Ag Mirror	0.011	0.703		0.095	0.903
T3II-5-39-B6	OSR Ag Mirror	0.012	0.025		0.095	0.384

SELECTED THERMO-OPTICAL DATA

The selected data listed in table 6 below is from the preceding thermo-optical data tables and is displayed in chart form in figures 10 and 11.

Table 6. Selected Thermo-optical Data

MATERIAL	LEADING-EDGE PRE	POST	DELTA	TRAILING-EDGE PRE	POST	DELTA
AQ/581/FEP/Al	0.154	0.251	0.097	0.142	0.289	0.147
ITO/FEP/Ag 5mil	0.104	0.109	0.005	0.106	0.212	0.106
Porcelain Enamel	0.249	0.327	0.078	0.252	0.363	0.111
ITO/FEP/Ag 2mil	0.119	0.113	-.006	0.122	0.142	0.020
Quatrz Fabric 7u	0.250	0.339	0.089	0.239	0.426	0.187
FEP/Ag 2mil	0.104	0.092	-.012	0.104	0.137	0.033
FEP/Ag 5mil	0.104	0.117	0.013	0.103	0.180	0.077
In_2O_3/FEP/Ag 5mil	0.139	0.126	-.013	0.160	0.177	0.017
Kapton 1mil	0.299	0.396	0.097	0.313	0.399	0.086
Kapton 5mil	0.453	0.499	0.046	0.456	0.477	0.021
ITO/Kapton/Al 5mil	0.361	0.410	0.049	0.357	0.417	0.060
Z-93	0.145	0.177	0.032	0.149	0.166	0.017
S13GLO	0.148	0.266	0.118	0.150	0.475	0.325
$ZnTiO_4$ ZOT	0.093	0.145	0.092	0.087	0.162	0.075
GFSC NS43G Yellow	0.266	0.326	0.060	0.257	0.310	0.044
Eu_2O_3 MeSi	0.127	0.198	0.071	0.133	0.328	0.195
PV 100	0.090	0.296	0.206	0.091	0.341	0.250
TiO_2 MeSi	0.157	0.205	0.048	0.156	0.372	0.216
DC92-007	0.218	0.405	0.187	0.209	0.383	0.174
OSR S1-100	0.078	0.060	-.018	0.074	0.113	0.039
OSR S1-100 ITO	0.089	0.076	-.013	0.089	0.120	0.031
OSR Au Mirror	0.237	0.258	0.021	0.247	0.279	0.032
OSR Al Mirror	0.158	0.171	0.013	0.159	0.171	0.012
OSR Ag Mirror	0.105	0.864	0.759	0.101	0.270	0.169
OSR Ag Mirror	0.095	0.903	0.808	0.095	0.384	0.289

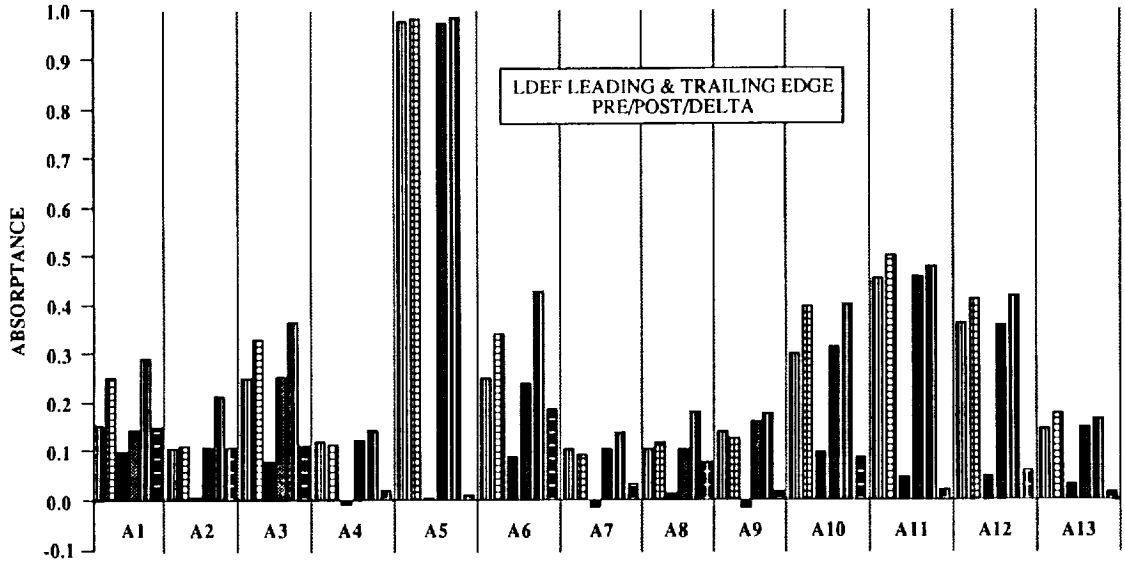

Figure 10. Absorptance Comparison Chart for Specimens A1 Through A13

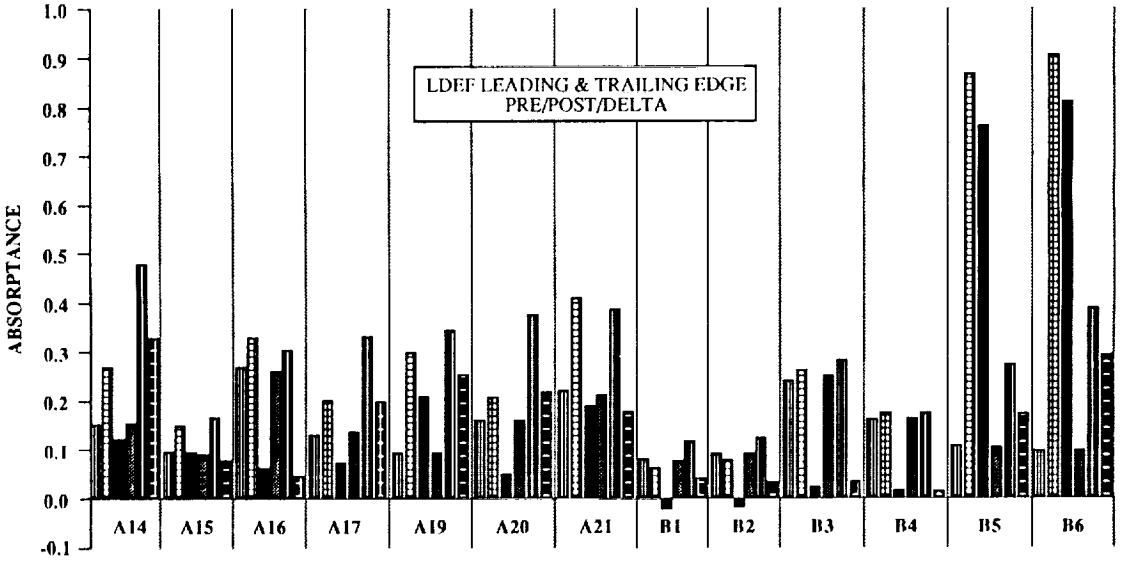

Figure 11. Absorptance Comparison Chart for Specimens A14 Through B6

QUARTZ FABRIC 7 micron

C1-A6 (Laboratory Specimen)
Some fabric fraying is present at the rim of the specimen. The adhesive bond between the Quartz fabric and the substrate appears to be intact.

A6-L3 (Leading Edge Specimen)
The exposed surface of the specimen exhibits a non-uniform distribution of a light-tan discoloration. The cloth weave shows no evidence of damage. The perimeter of the specimen is not discolored but the edges are frayed. The adhesive bond between the quartz fabric 7 micron and Al mounting disc appears intact.

A6-T3 (Trailing Edge Specimen)
The exposed surface of the specimen is discolored a yellowish tan. There is debris on the surface of the specimen. The weave pattern shows no evidence of damage. The perimeter of the specimen is not discolored, but the edges are frayed. The adhesive bond between the Quartz fabric 7 micron and the aluminum mounting disc appears intact.

A6-T6 (EECC Trailing Edge Specimen)
The exposed area of the specimen is nonuniformly discolored a light brown. The weave pattern is undisturbed except for one small localized area. The perimeter of the specimen is clean and white with frayed edges. The adhesive bond between the Quartz fabric 7 micron and the aluminum mounting disc appears intact.

A comparison photograph of the specimens is illustrated in figure 12; figure 13 compares the UV-Vis-NIR reflectance changes and figure 14 compares FTIR reflectance changes.

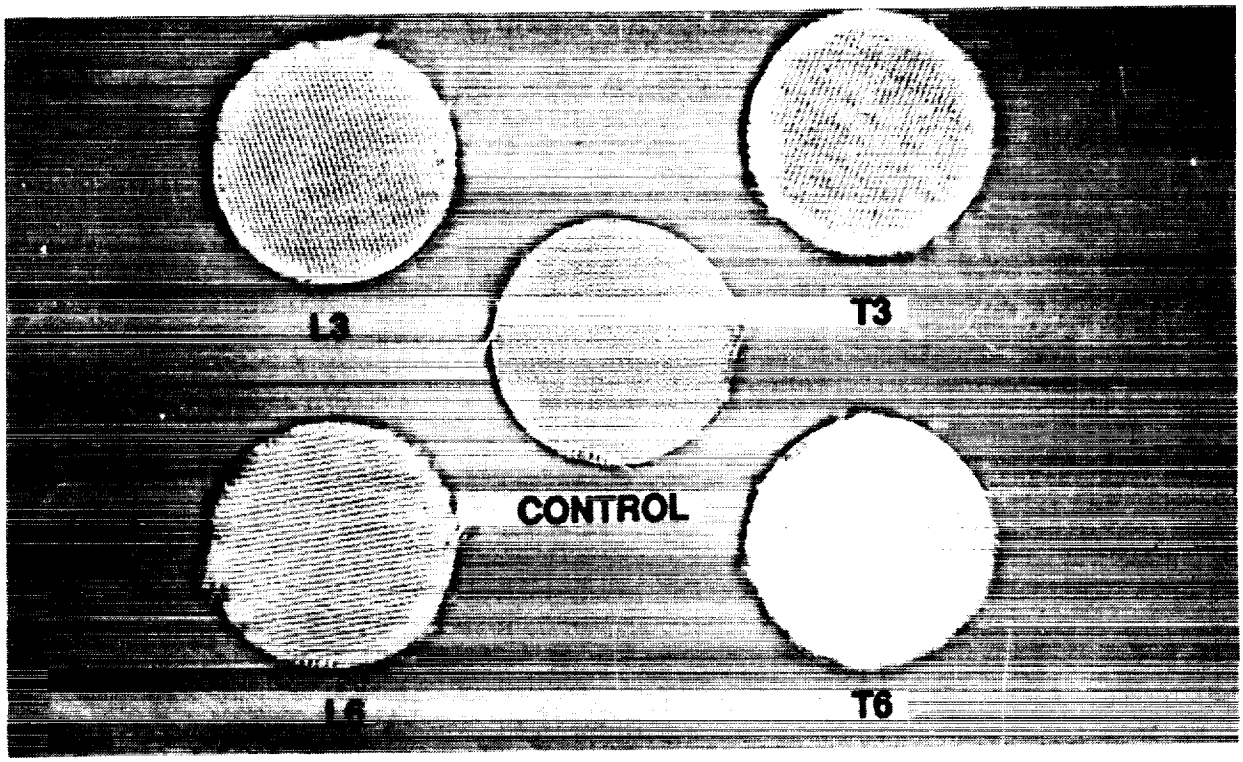

Figure 12. Comparison of Quartz Fabric 7 micron Specimens

QUARTZ FABRIC 7 micron

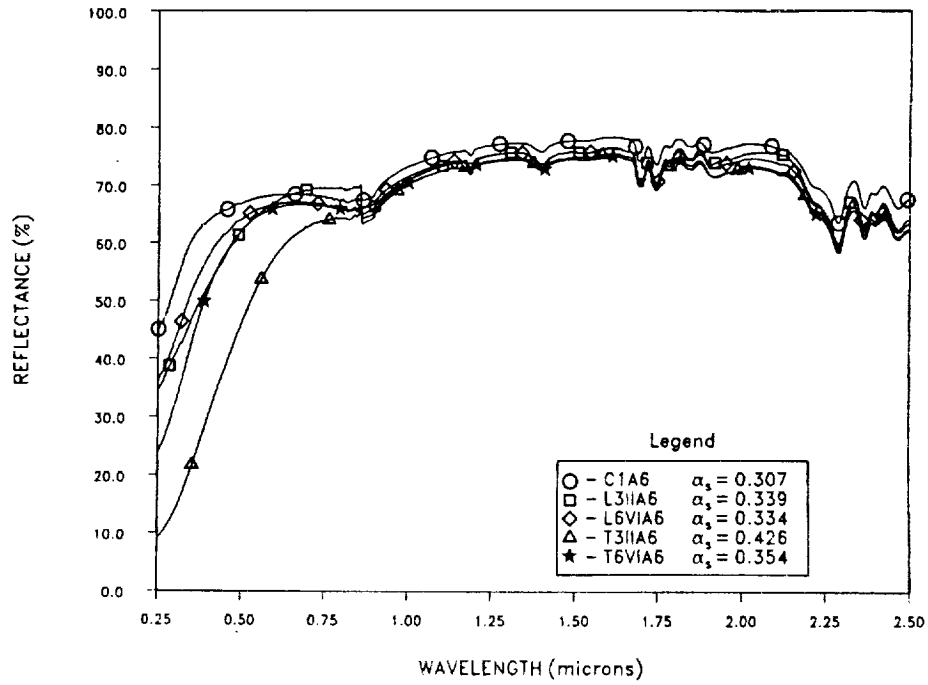

Figure 13. Comparison UV-Vis-NIR Reflectance Curves of Quartz Fabric 7 micron

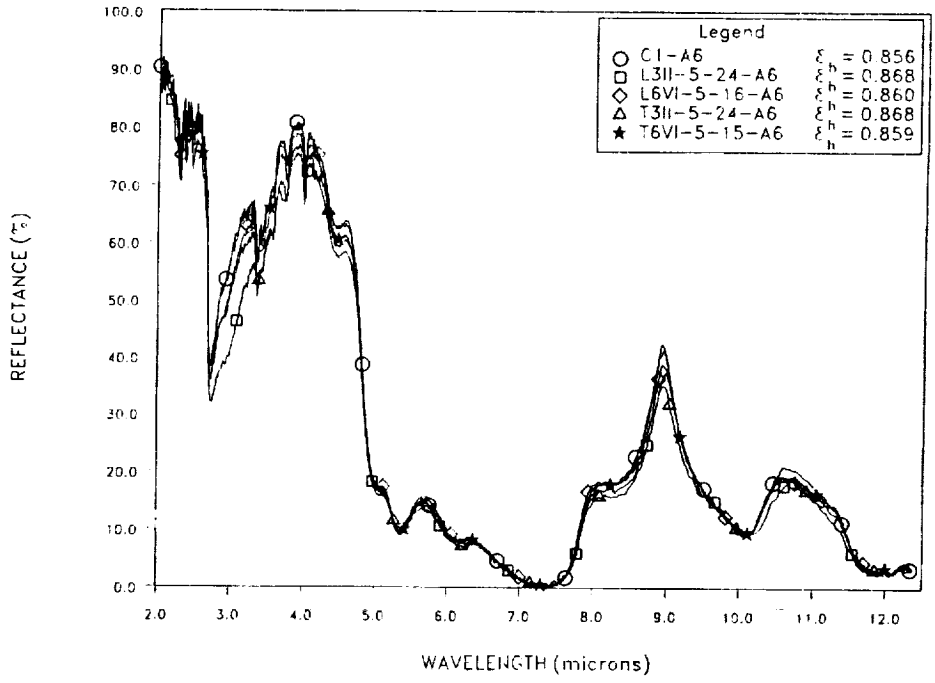

Figure 14. Comparison FTIR Reflectance Curves of Quartz Fabric 7 micron

In_2O_3/FEP/Ag/ INCONEL 5 mil

C1-A9 (Laboratory Specimen)
Specimen has surface scratches. There are small areas of yellow discoloration near the bond area. The metallized coating has pinholes. Some pinholes have tarnish rings surrounding the pinhole site. The adhesive bond between the In_2O_3 / F E P/Ag / Inconel / and Al mounting disc appears intact.

L3-A9 (Leading Edge Specimen)
The exposed surface area of the specimen is bright, shiny and reflective and has a slight haze. Fibers and particles are present on the exposed surface area. The exposed surface appears pitted or eroded. The weave pattern on the cloth used in preflight storage is embossed on the surface. There is a grayish black residue present in several areas near the perimeter covered by the mounting plate. The adhesive bond between the In_2O_3 / F E P/Ag / Inconel / and Al mounting disc appears intact.

T3-A9 (Trailing Edge Specimen)
The exposed surface area of the specimen is bright, shiny and reflective with a surface haze. Scuff marks are present on the surface as well as the imprint of the weave pattern from the cloth used in preflight storage. The adhesive bond between the In $_2O_3$/ FEP/ Ag/ Inconel and the aluminum mounting disc appears intact.

L6-A9 (EECC Leading Edge Specimen)
The exposed surface of the specimen is shiny and reflective with a slight haze. There is a weave pattern embossed on the surface from the protective cloth used during preflight storage. Surface scratches are present. The adhesive bond between the In $_2O_3$ / FEP / Ag / Inconel and the aluminum mounting disc appears intact.

A comparison photograph of the specimens is illustrated in figure 15; figure 16 compares the UV-Vis-NIR reflectance changes and figure 17 compares FTIR reflectance changes.

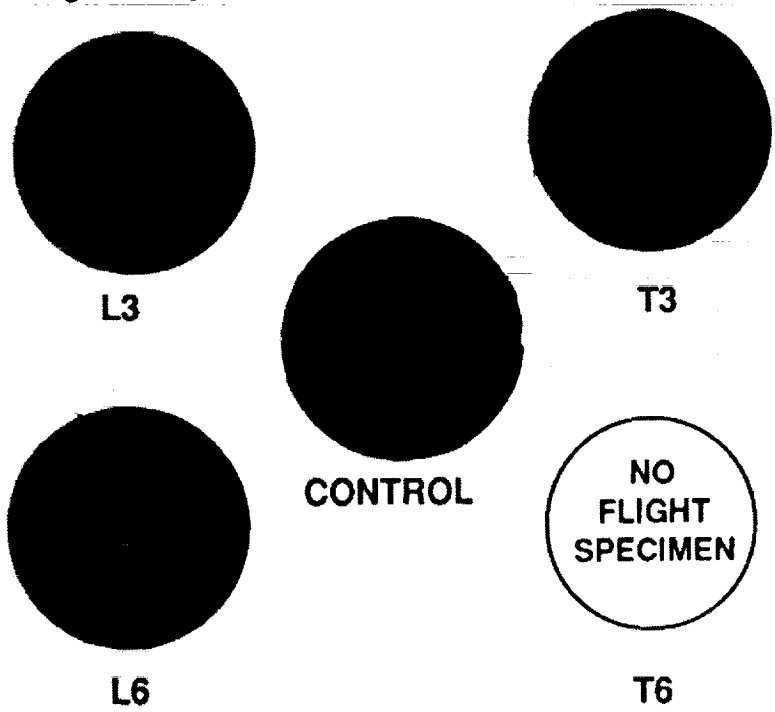

Figure 15. Comparison of In_2O_3/FEP/Ag/Inconel Specimens

In_2O_3/FEP/Ag/ INCONEL 5 mil

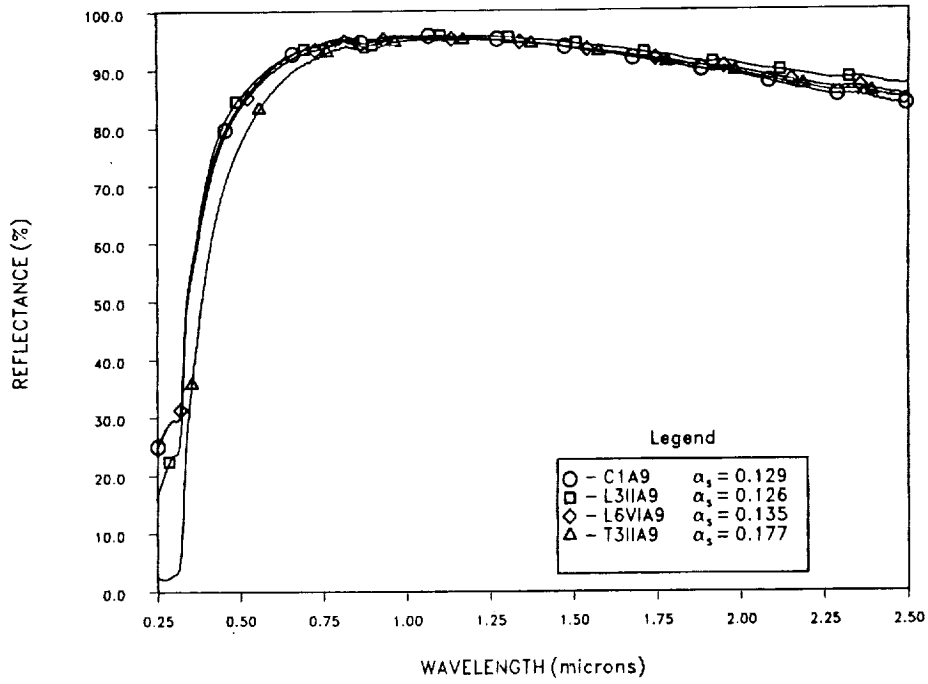

Figure 16. Comparison UV-Vis NIR Reflectance Curves of In_2O_3/FEP/Ag/ INCONEL 5 mil

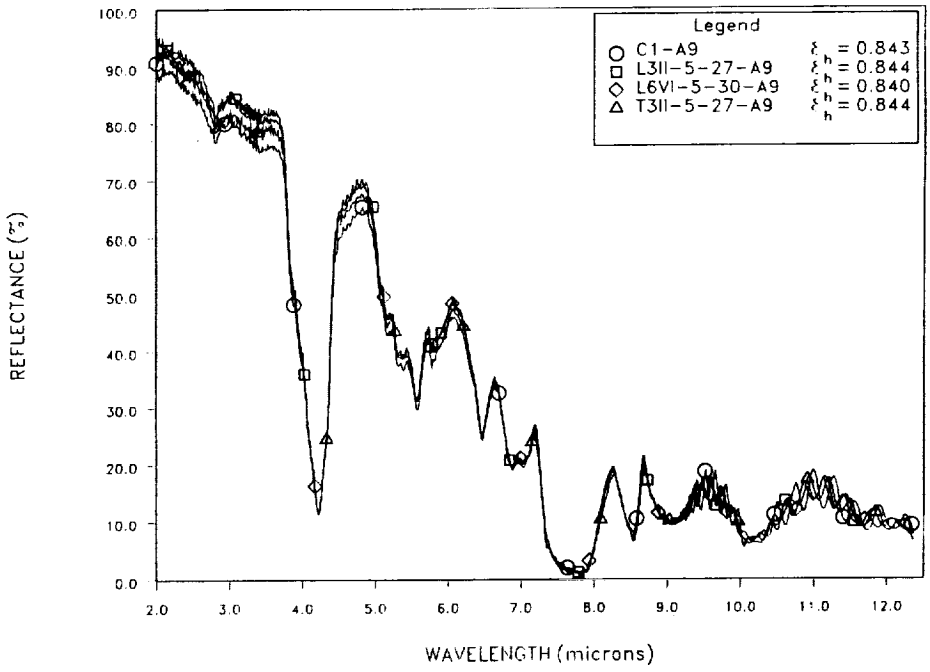

Figure 17. Comparison FTIR Reflectance Curves of In_2O_3/FEP/Ag/ INCONEL 5 mil

C-A11 (Laboratory Specimen)
Specimen appears to be in good condition. No apparent damage from long term storage.

L3-A11 (Leading Edge Specimen)
The exposed surface exhibits a hazy and discolored appearance. Surface scratches are present. A non uniform texture or weave pattern is present on the surface. Surface abrasion or pitting is indicated. Fibers and particles are present on the surface. The perimeter of the specimen covered by the mounting plate is undamaged and reflective, although some discoloration is present.

T3-A11 (Trailing Edge Specimen)
The exposed surface appears bright,shiny, reflective and is lighter in color than the perimeter area. There are thin lines or tracks abruptly beginning and ending on the surface. Fibers and particles are present on the surface. There is a yellowish discoloration in the form of a halo at the intersection of the exposed surface and the perimeter covering the specimen mounting plate. The perimeter is bright, shiny and reflective.

L6-A11 (EECC Leading Edge Specimen)
The exposed surface of the specimen is dull, nonspecular and orange red in color. Surface abrasion or erosion is apparent. There are bright colored particles present on the surface. The specimen appears to have shifted in the mounting plate at an early stage. The perimeter of the specimen appears undamaged, bright and reflective. There is debris around the perimeter.

T6-A11 (EECC Trailing Edge Specimen)
The exposed surface of the specimen is bright, shiny and reflective with a copper red color. A slight haze may be present. A smear is present near the edge of the specimen. Particles are present on the surface. The perimeter of the specimen is undamaged, shiny and reflective.

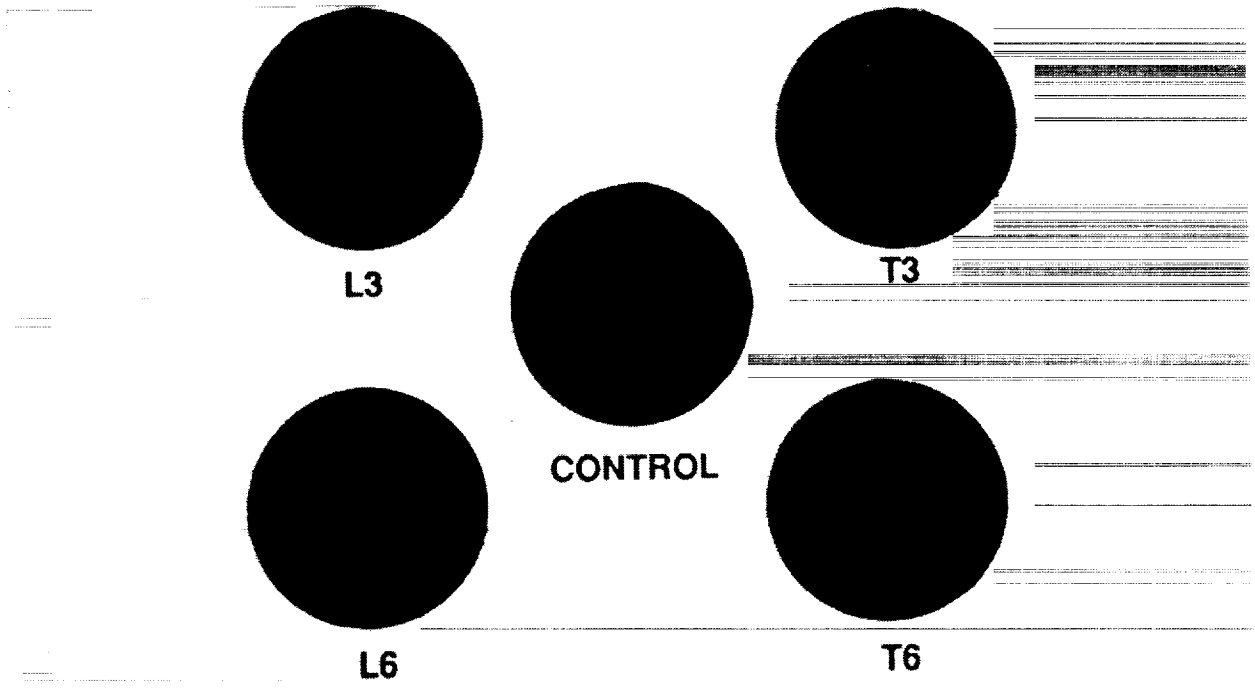

Figure 18. Comparison of Kapton/Al 5 mil Specimens

KAPTON/Al 5 mil

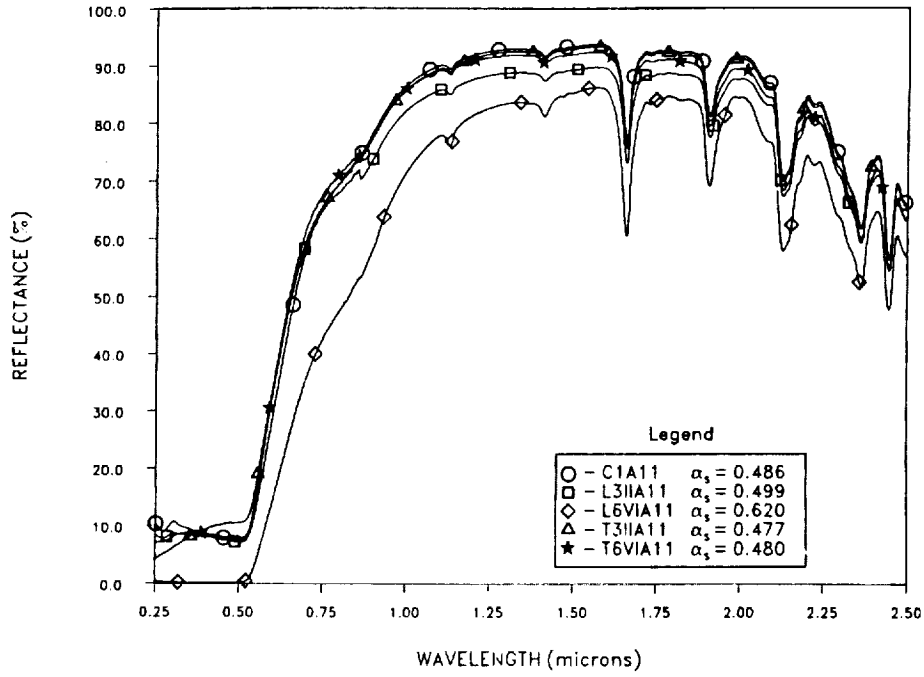

Figure 19. Comparison UV-Vis-NIR Curves of Kapton/Al 5 mil

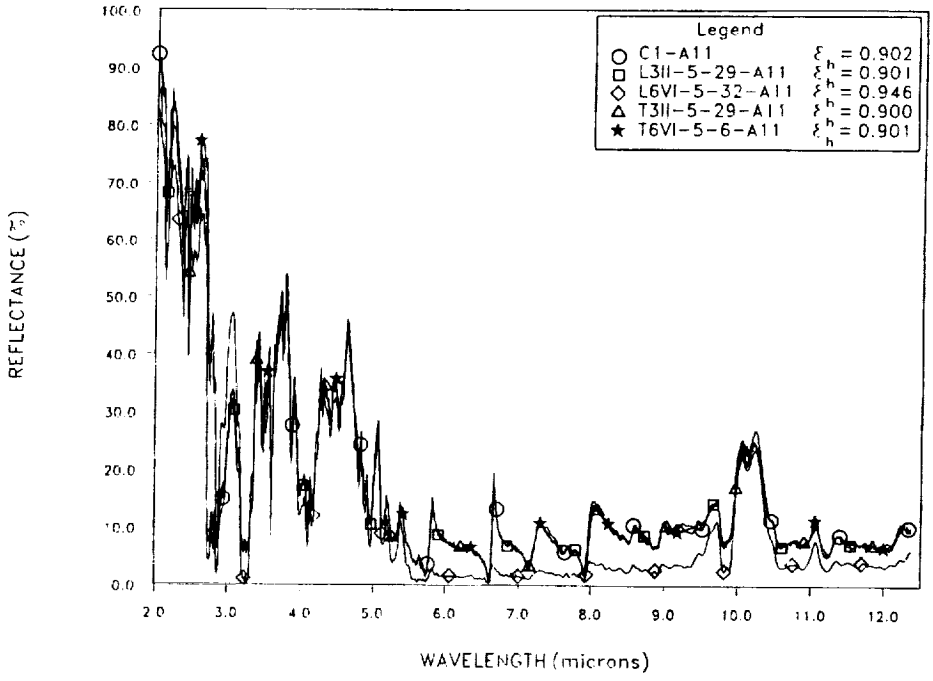

Figure 20. Comparison FTIR Curves of Kapton/Al 5 mil

In_2O_3/KAPTON/Al 5 mil

C1-A12 (Laboratory Specimen)
Specimen appears to be in good condition. No apparent damage from long term storage. The adhesive bond between the In_2O_3/Kapton/Al and the substrate appears to be intact.

L3-A12 (Leading Edge Specimen)
The entire specimen appears bright, shiny and reflective. Some surface scratches are present. Particles are present on the surface. The adhesive bond between the In_2O_3 /Kapton/Al and the aluminum mounting disc appears intact.

T3-A12 (Trailing Edge Specimen)
The exposed surface appears darker than the perimeter area covered by the specimen mounting plate. There is a halo of dark yellow discoloration around the perimeter of the exposed surface. The specimen is bright, shiny and reflective. Surface scratches are present. Fibers and particles are present on the surface. The adhesive bond between the In_2O_3/Kapton/Al and the aluminum mounting disc appears intact.

L6-A12 (EECC Leading Edge Specimen)
Specimen is intact. The surface is bright yellow and reflective. There are some surface scratches present as well as a large amount of particles on the surface. There is a darker yellow halo near the perimeter of the specimen. The perimeter appears undamaged, bright and reflective . The adhesive bond the In_2O_3/ Kapton/Al and the aluminum mounting disc appears intact.

A comparison photograph of the specimens is illustrated in figure 21; figure 22 compares the UV-Vis-NIR reflectance changes.

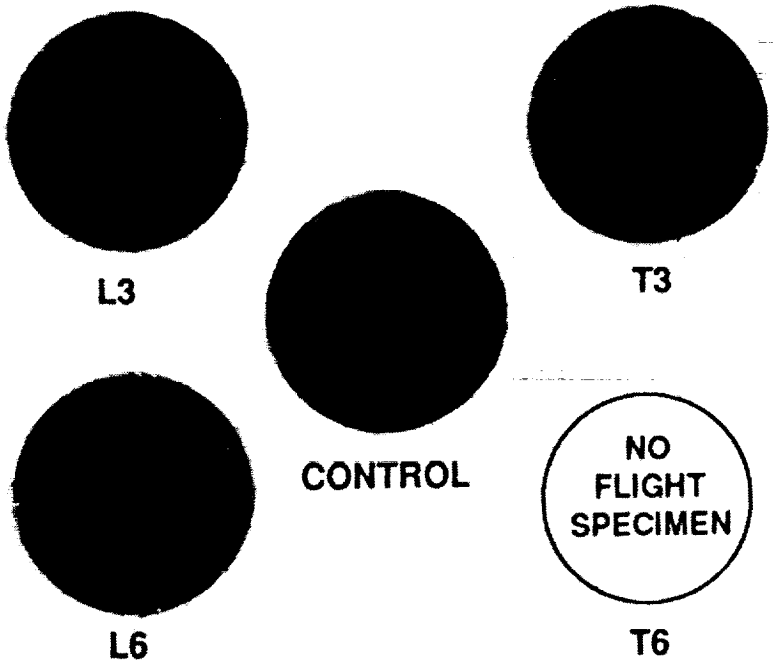

Figure 21. Comparison of In $_2O_3$ /Kapton/Al Specimens

In_2O_3/KAPTON/Al 5 mil

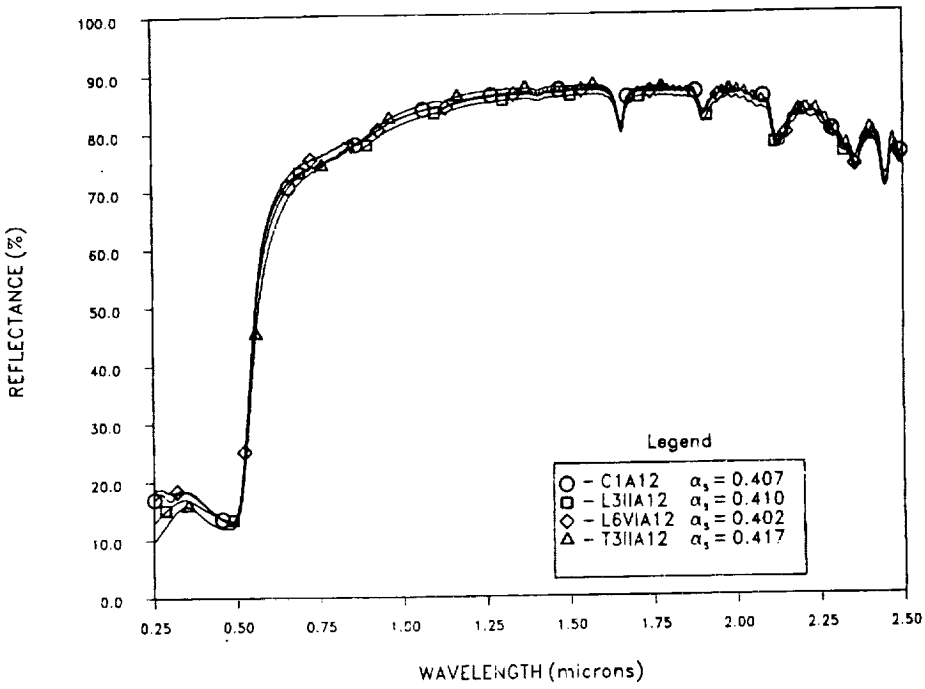

Figure 22. Comparison Curves of In_2O_3 /Kapton/Al 5 mil

FTIR Unavailable

C1-A14 (Laboratory Specimen)
Specimen appears to be in good condition. No apparent damage from long term storage.

L3-A14 (Leading Edge Specimen)
The exposed surface of the specimen is bright yellow in color, nonspecular and has a slight sheen. The surface is rough and pebbled. A large piece of white debris (possibly Teflon) is present near the center of the specimen, as well as several metallic flakes. Other types of surface debris are also present. Several black marks are present at the periphery of the exposed area. Coating at the perimeter of the specimen is white, nonspecular and apparently undamaged.

T3-A14 (Trailing Edge Specimen)
The exposed surface of the specimen is discolored a dark tan-brown and is nonspecular. The surface is rough and pebbled with a localized area of a lighter tan color. Some debris is present on the exposed area. Coating at the perimeter of the specimen is white, nonspecular and apparently undamaged.

L6-A14 (EECC Leading Edge Specimen)
The exposed surface of the specimen is discolored a pale yellow and is rough in texture. Surface debris is present. The perimeter of the specimen is white with dark smears probably from the mounting plate.

T6-A14 (EECC Trailing Edge Specimen)
The exposed surface area of the specimen is discolored a light yellow. The surface has a slightly rough texture. Debris is present on the surface. The perimeter of the specimen is white and undamaged.

A comparison photograph of the specimens is illustrated in figure 23; figure 24 compares the UV-Vis-NIR reflectance changes.

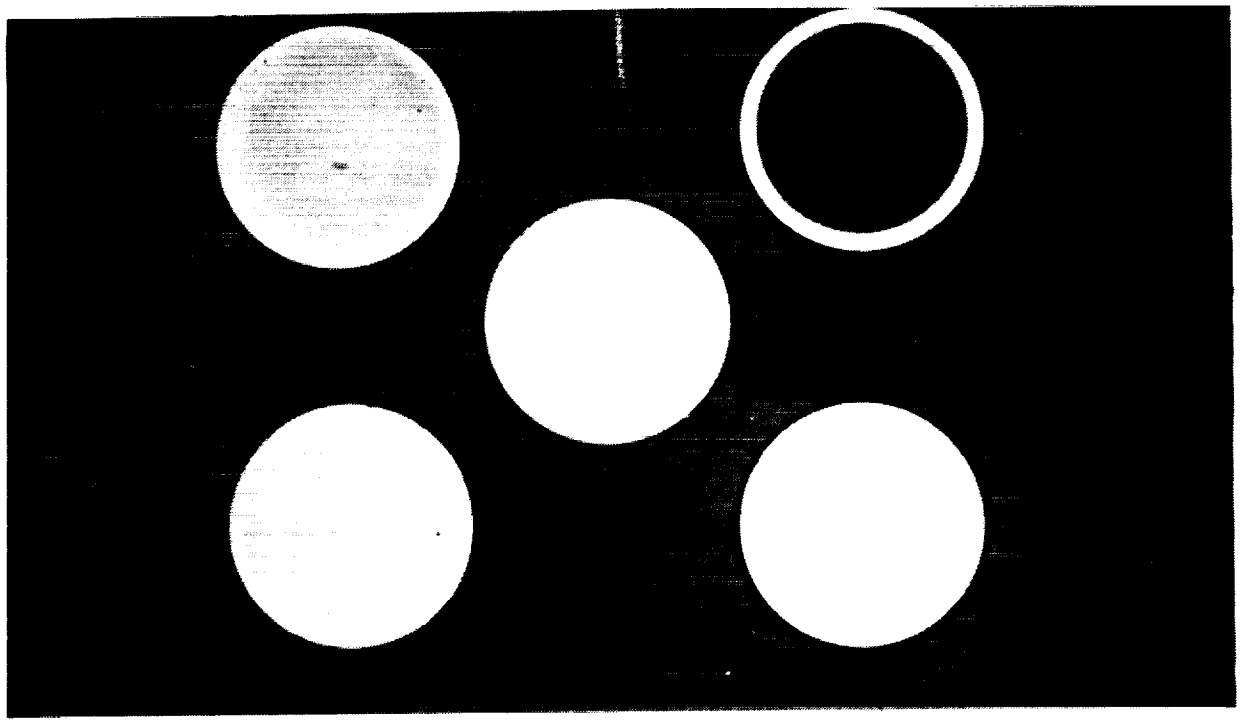

Figure 23. Comparison of S-13 GLO White Silicone Coating Specimens

S-13 GLO WHITE SILICONE COATING

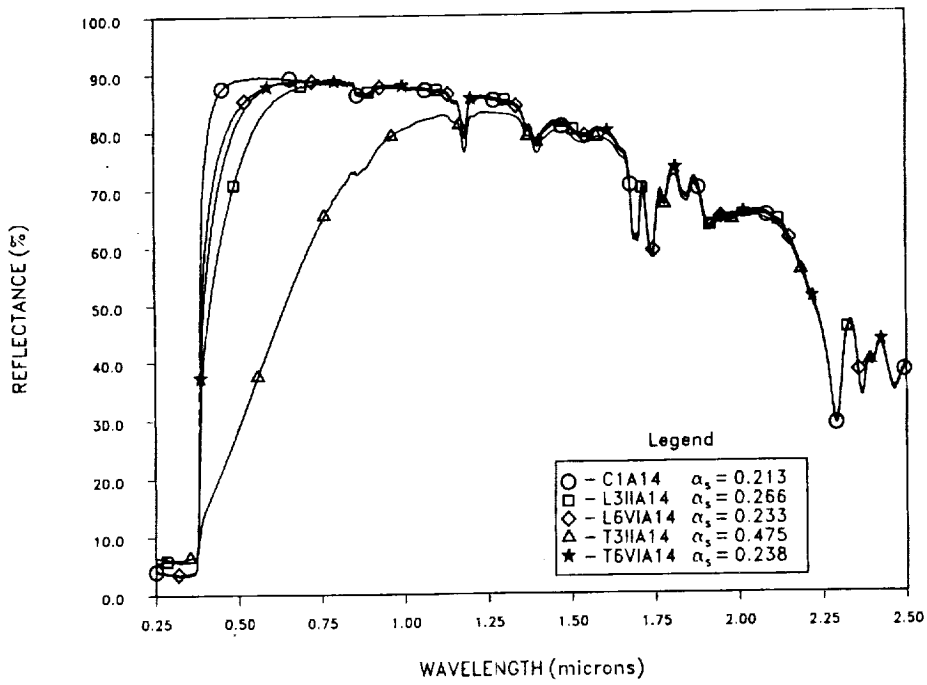

Figure 24. Comparison UV-Vis-NIR Reflectance Curves of S-13 GLO White Silicone Coatings

FTIR Unavailable

C1-A15 (Laboratory Specimen)
Chipping is present in three areas of the specimen rim. One chipped area is large. One long scratch is also present on the rim.

L3-A15 (Leading Edge Specimen)
The exposed surface area of specimen is white and non-reflective. Several large cracks and a rough surface area are present on the exposed area. Black particles are present on the surface and there may be a slight discoloration. Approximately 30% of coating around perimeter is chipped and missing. Two cracks in coating are visible at the perimeter. A dark circular streak is present near the perimeter.

T3-A15 (Trailing Edge Specimen)
The exposed surface of the specimen is discolored a slight yellow. The surface is moderately rough and debris is present on the surface. The perimeter of the specimen is white with areas containing some dark particles or spots.

L6-A15 (EECC Leading Edge Specimen)
The exposed surface of the specimen is white and rough in texture. The surface appears crazed. The perimeter of the specimen has grayish smears, probably from the mounting plate. Chipping near the rim of the specimen is also evident.

T6-A15 (EECC Trailing Edge Specimen)
The exposed surface area of the specimen appears slightly discolored with a large area of rough texture. Debris is present on the surface. The perimeter of the specimen is chipped and remains white in color.

A comparison photograph of the specimens is illustrated in figure 25; figure 26 compares the UV-Vis-NIR reflectance changes and figure 27 compares FTIR reflectance changes.

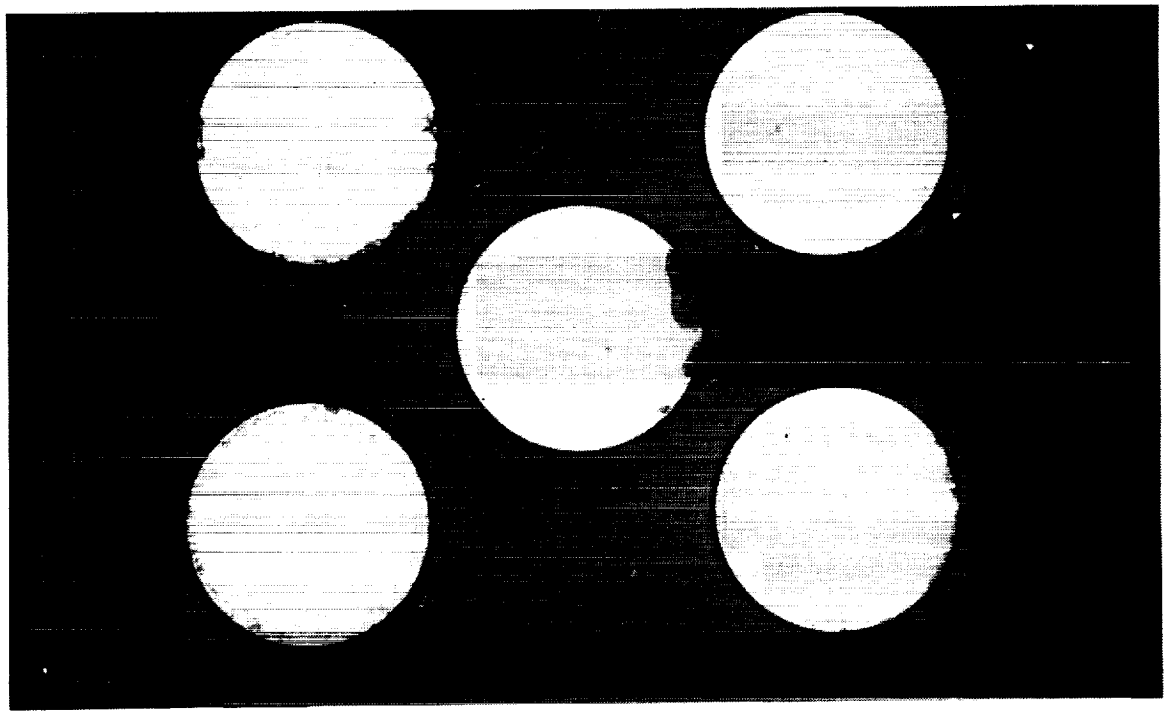

Figure 25. Comparison of Zn_2TiO_4 White Inorganic Coating Specimens

Zn_2TiO_4 WHITE INORGANIC COATING

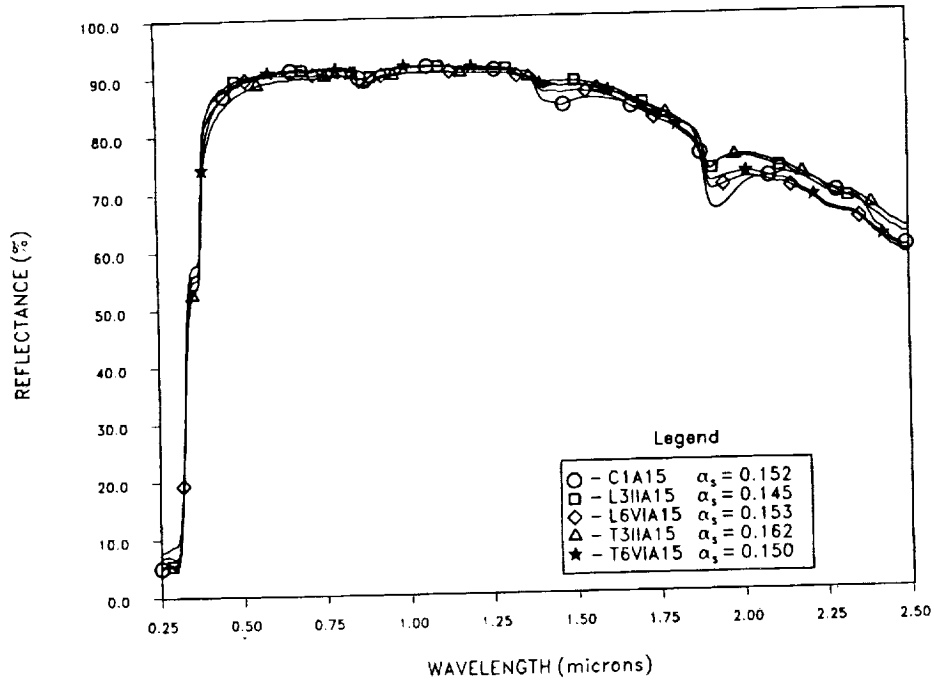

Figure 26. Comparison UV-Vis-NIR Reflectance Curves of Zn_2TiO_4 White Inorganic Coating

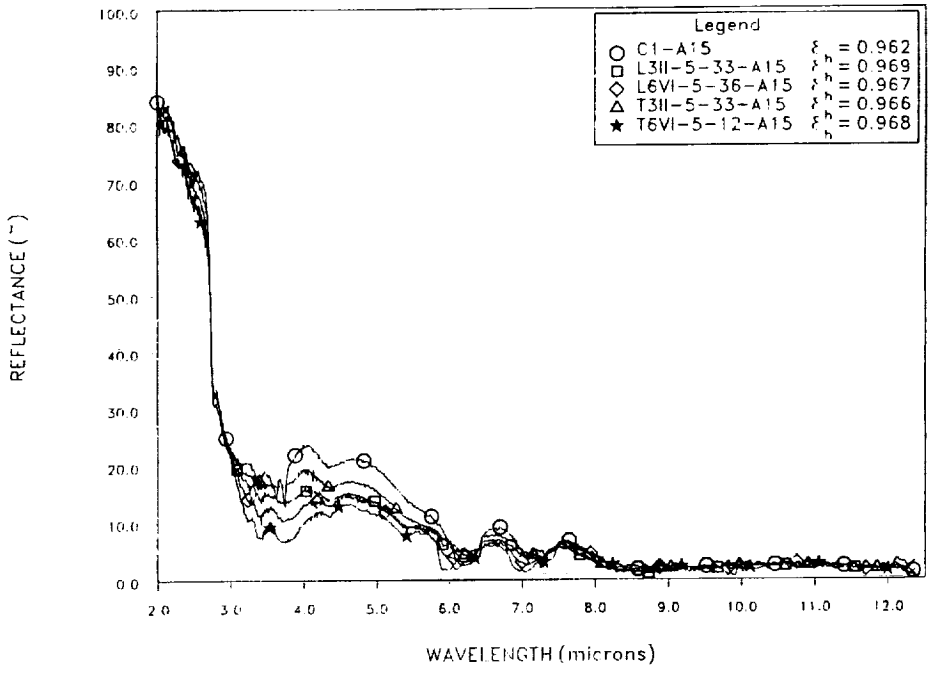

Figure 27. Comparison FTIR Reflectance Curves of Zn_2TiO_4 White Inorganic Coating

NS 43G WHITE INORGANIC COATING

C1-A16 (Laboratory Specimen)
Coating is yellow in color. Pinholes and bubbles are present in the coating. There is slight chipping on the rim of the specimen.

L3-A16 (Leading Edge Specimen)
The exposed surface of specimen is discolored to a light yellow, as well as the periphery of the specimen under the mounting plate. The surface of the entire specimen has a rough texture. Black particles are present in both exposed and unexposed surface area of specimen.

T3-A16 (Trailing Edge Specimen)
The entire surface area of the specimen is discolored a light yellow. The surface is moderately rough and contains considerable surface debris . There is a darker halo near the perimeter of the mounting plate.

L6-A16 (EECC Leading Edge Specimen)
The entire surface of the specimen is pale yellow in color and has a rough texture. Debris is present on the surface.

T6-A16 (EECC Trailing Edge Specimen)
The coating is discolored a light yellow over the entire specimen. A large amount of debris is present on the surface. Overall, the texture of the specimen is very rough.

A comparison photograph of the specimens is illustrated in figure 28; figure 29 compares the UV-Vis-NIR reflectance changes.

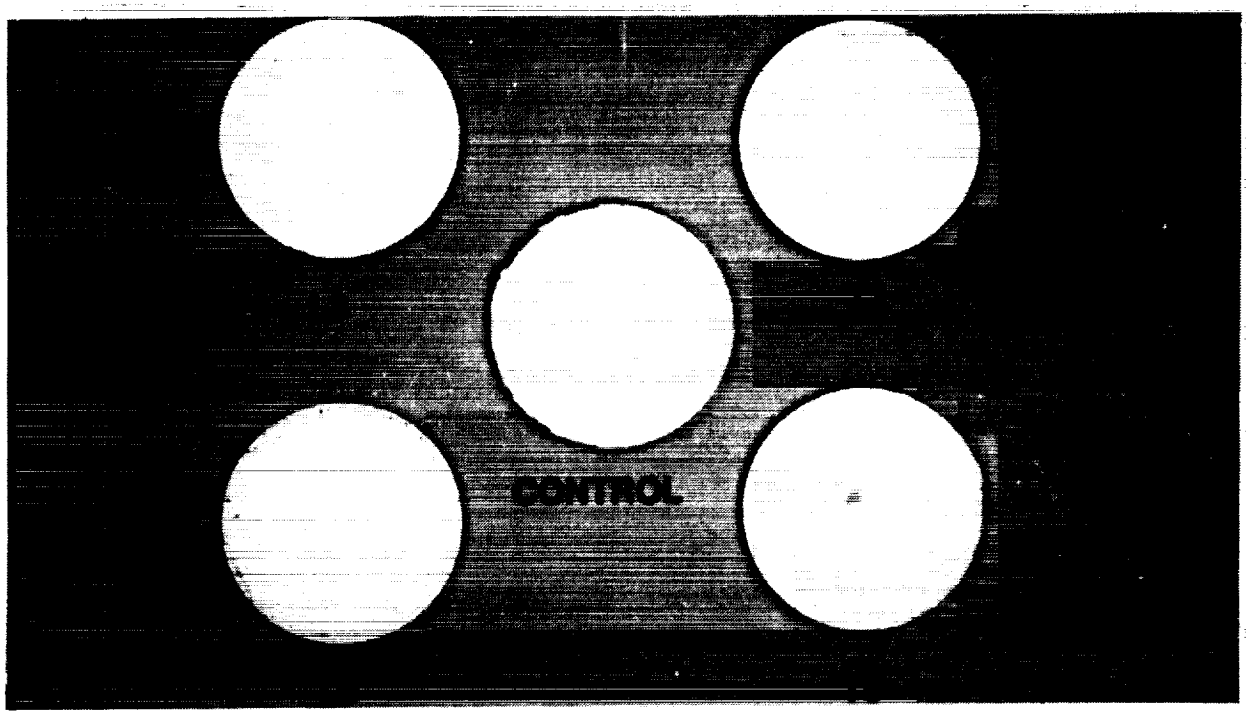

Figure 28. Comparison of NS 43G White Inorganic Coating

NS 43G WHITE INORGANIC COATING

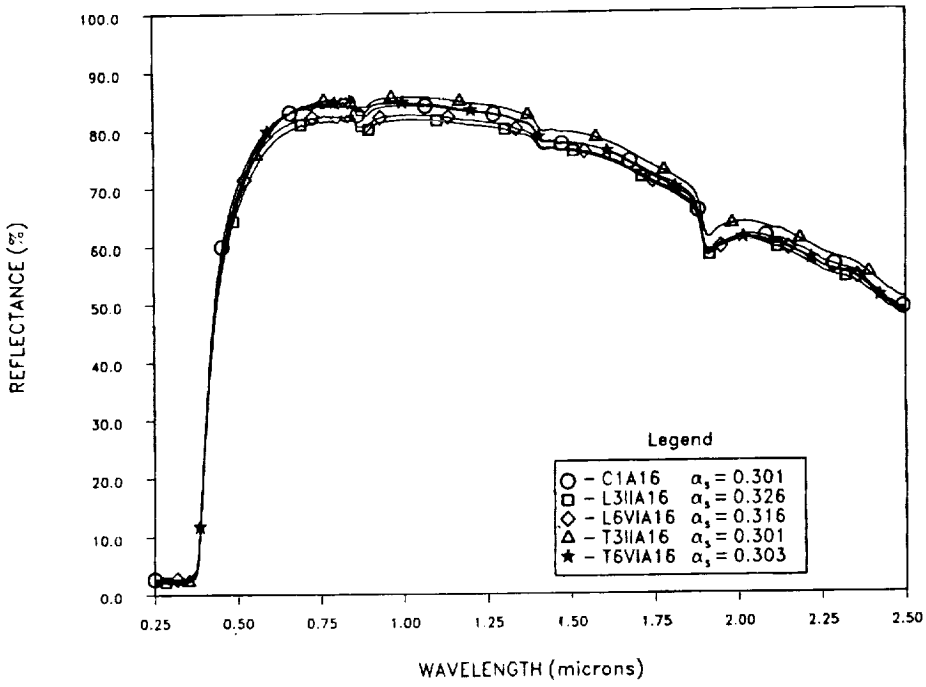

Figure 29. Comparison of UV-Vis-NIR Reflectance Curves of NS 43G White Inorganic Coating

FTIR Unavailable

C-4

C1-A22 (Laboratory Specimen)
A fingerprint is present on the surface. The surface is glossy and has some surface dust.

L3-A22 (Leading Edge Specimen)
The exposed surface area of specimen is discolored a dark yellow, is moderately reflective and has extensive cracks in the coating. There are dark particles and fibers present on the exposed surface area. The coating perimeter of the specimen is white, reflective and slightly damaged.

T3-A22 (Trailing Edge Specimen)
The exposed surface area of the specimen is discolored a deep yellow-gold. There is an extensive network of cracks and fractures in the exposed area. There is a sheen or glazed appearance to the surface. Scuff marks and black particle debris are on the surface. The perimeter of the specimen is white, shiny, reflective and undamaged.

L6-A22 (EECC Leading Edge Specimen)
The exposed surface area of the specimen is yellow and slightly specular. The surface is rough in texture. A large amount of fibers and particles are present on the surface .The perimeter of the specimen is white and specular with debris.

A comparison photograph of the specimens is illustrated in figure 30; figure 31 compares the UV-Vis-NIR reflectance changes.

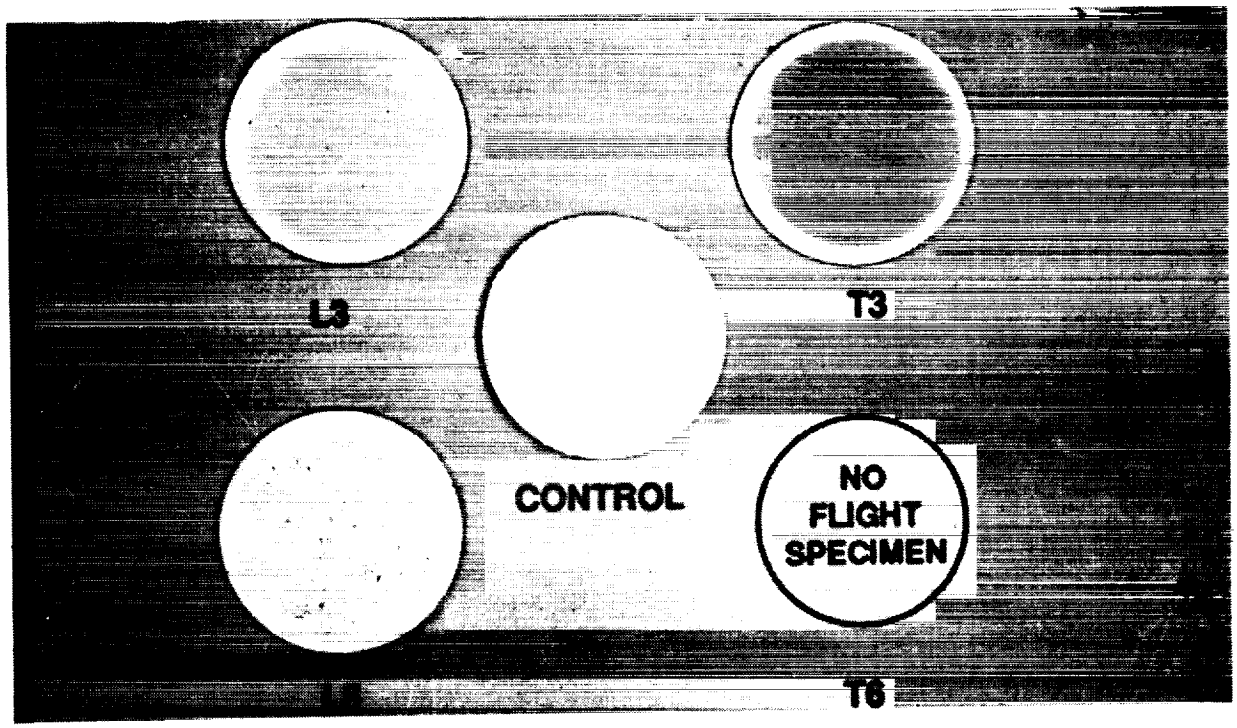

Figure 30. Comparison of DC92-007 White Silicone Coating Specimens

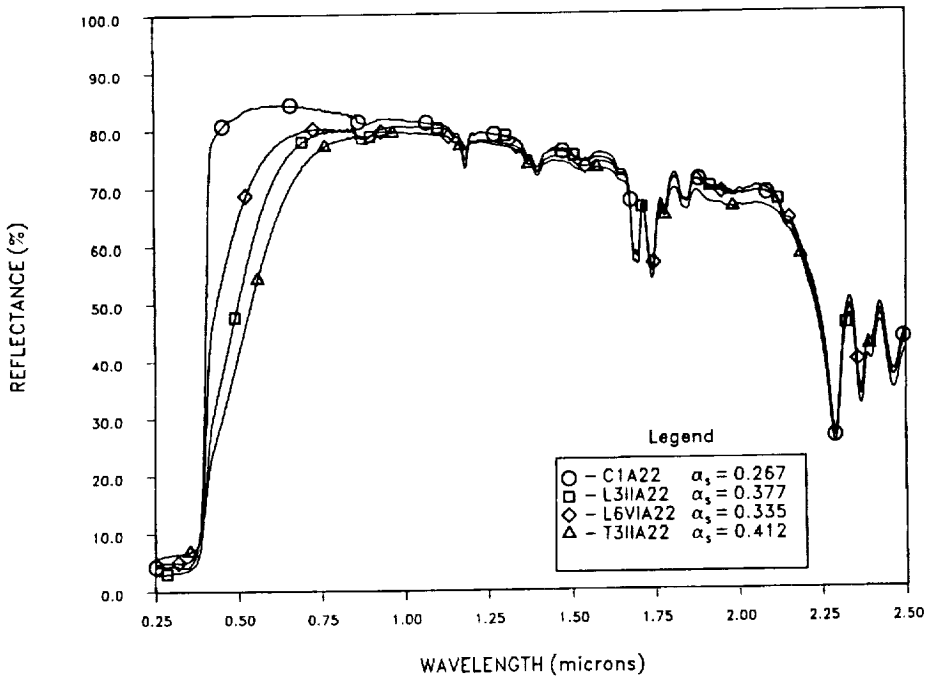

Figure 31 Comparison UV-Vis-NIR Reflectance Curves of DC92-007 White Silicone Coating

FTIR Unavailable

C1-B6 (Laboratory Specimen)
Specimen is tarnished and has a fingerprint on the surface. Stains are also present.

L3-B6 (Leading Edge Specimen)
The exposed surface area of the specimen has been uniformly eroded, except at the perimeter of the specimen mounting plate. The edges of the specimen at the perimeter of the mounting plate are rough, distorted and eroded. The center of the surface has three circular indented areas, as well as several crater sites. The perimeter of the specimen is tarnished and shows evidence of fingerprints. The adhesive bond between the silver and aluminum mounting square appears intact.

T3-B6 (Trailing Edge Specimen)
The exposed surface area of the specimen is discolored a dark brown . The perimeter of the exposed area shows a darker brown discoloration. The perimeter of the specimen is discolored or tarnished. There is evidence of a fingerprint on one side of the specimen. A triangular shaped dark spot with a light center is present near the center of the specimen.

A comparison photograph of the specimens is illustrated in figure 32; figure 33 compares the UV-Vis-NIR reflectance changes.

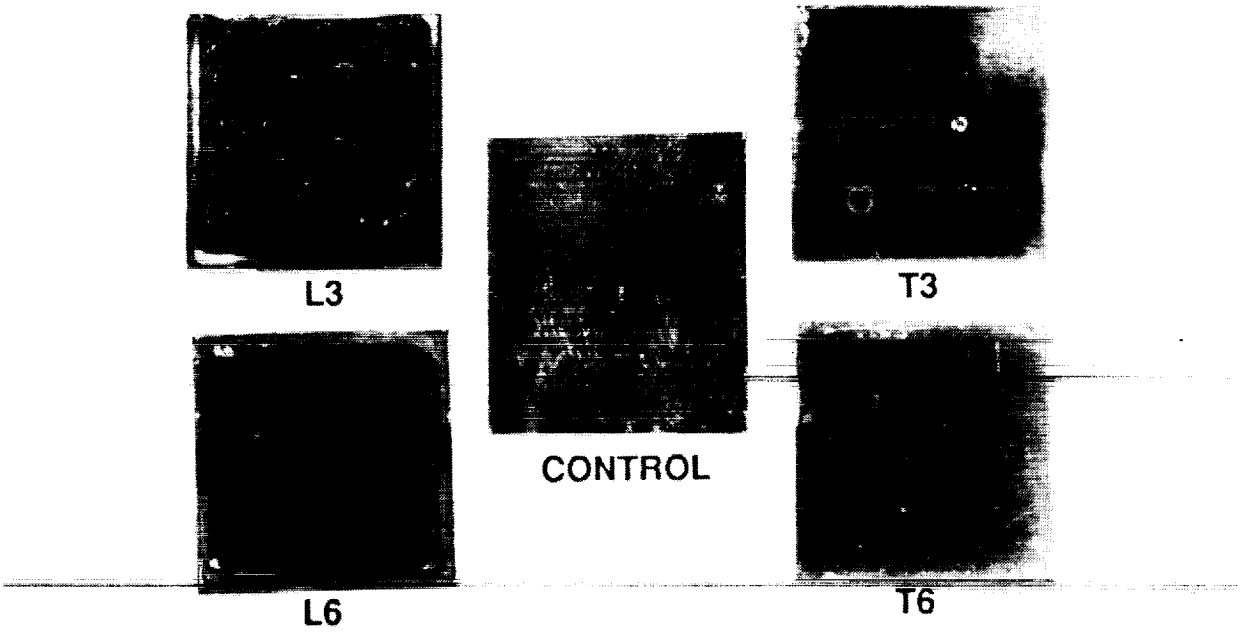

Figure 32. Comparison of Ag Mirror Specimens

Ag MIRROR

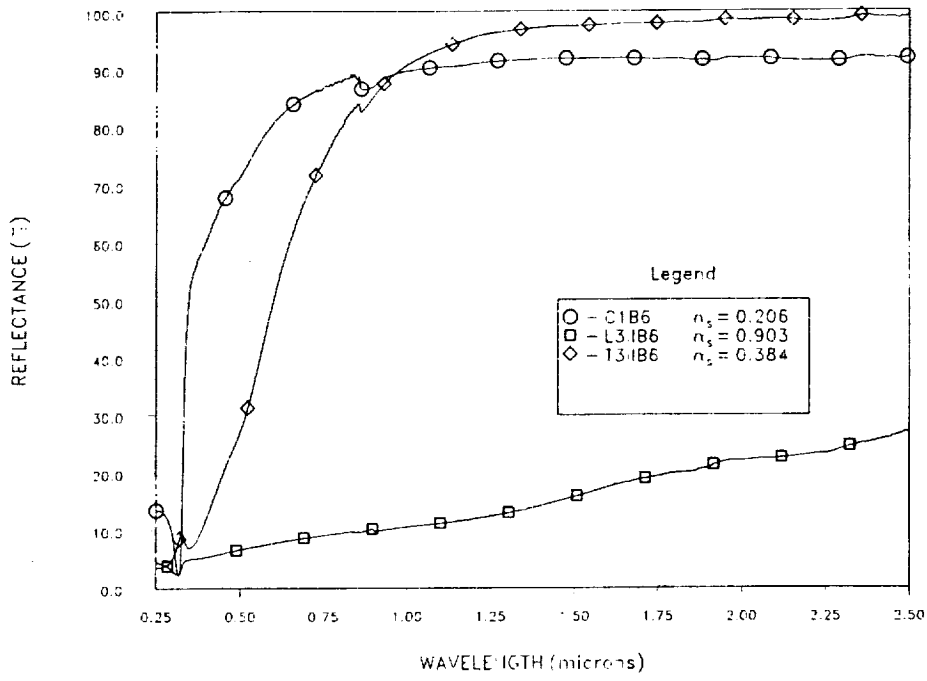

Figure 33. Comparison UV-Vis-NIR Reflectance Curves of Ag MIRROR

FTIR Unavailable

C1-B5 (Laboratory Specimen)
Specimen is badly tarnished and has fingerprints as well as surface scratches.

L3-B5 (Leading Edge Specimen)
The exposed surface area of the specimen has been essentially eroded away leaving a black oxidized residue adhered to the adhesive. The remaining surface is rough and distorted. The perimeter of the specimen is intact, but tarnished. Localized areas of the aluminum mounting plate and adhesive bond are visible.

T3-B5 (Trailing Edge Specimen)
The exposed surface area of the specimen is nonuniformly discolored a light yellow.There is a significant micrometeoroid crater near the center. There are stains, smears and a possible fingerprint visible in the exposed area. There is a lighter band of discoloration around the perimeter of the exposed area. Surface debris is present. One edge of the specimen appears to be tarnished. The other three edges are shiny and reflective.

L6-B5 (EECC Leading Edge Specimen)
The exposed surface area of the specimen is heavily eroded and oxidized. Minute cracks are present on the surface. One spot is metallic in appearance and may be eroded through to the adhesive layer. The perimeter, at the mounting plate, is also severely eroded and oxidized. The perimeter is metallic in color and is heavily tarnished.

T6-B5 (EECC Trailing Edge Specimen)
The exposed surface area of the specimen is non-uniformly tarnished or contaminated a light tan color. Several spots or stains are present on the surface. Particles are present on the surface. The perimeter of the specimen appears tarnished a light grey color.

A comparison photograph of the specimens is illustrated in figure 34; figure 35 compares the UV-Vis-NIR reflectance changes.

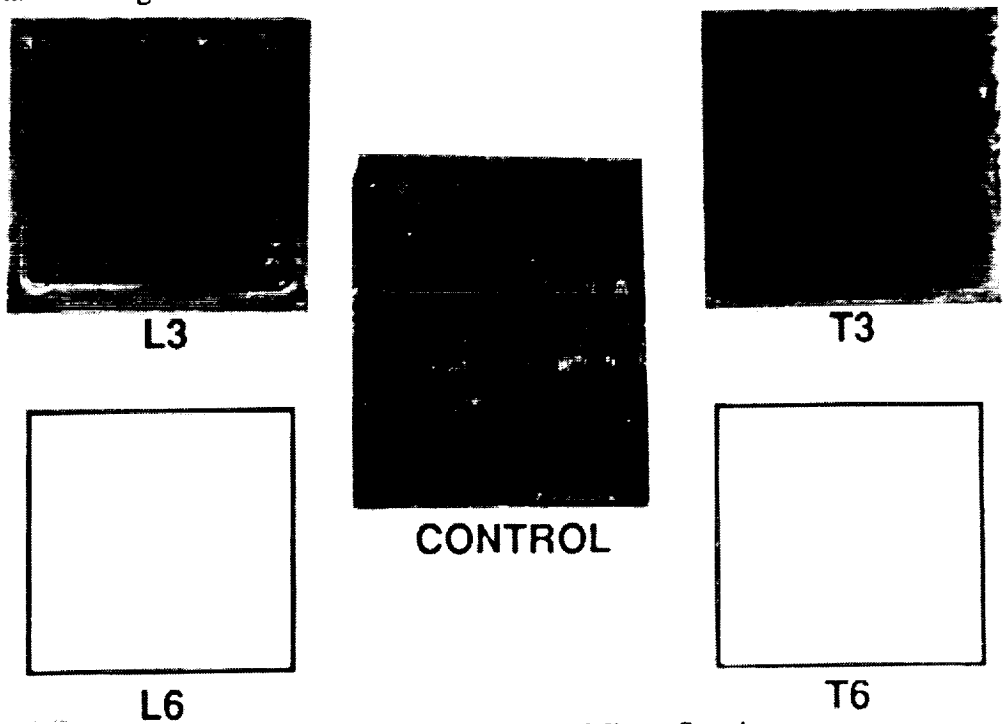

Figure 34. Comparison of Ag Mirror Specimens

Ag MIRROR

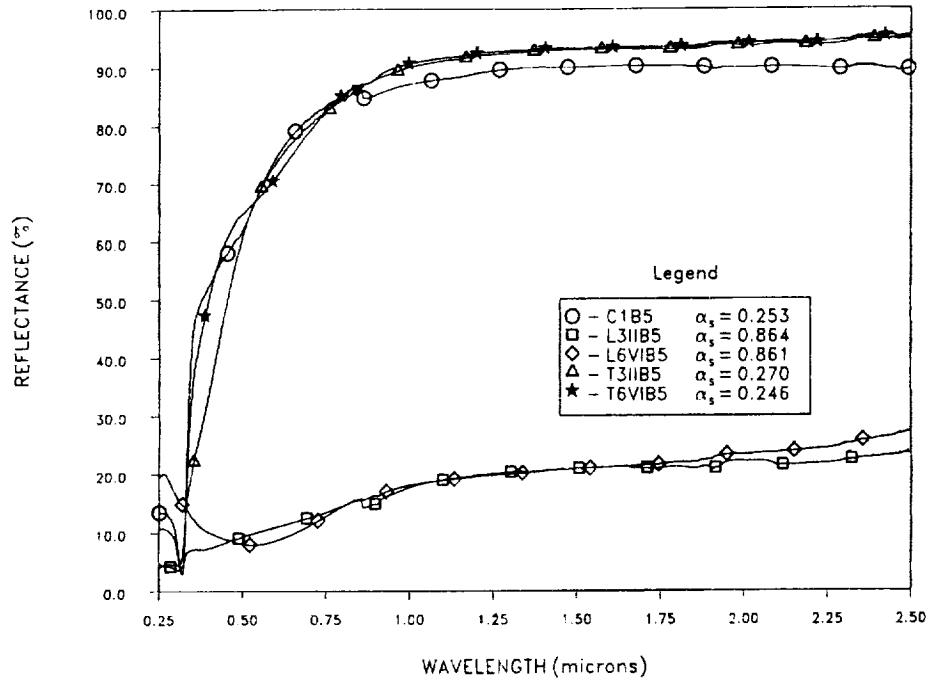

Figure 35. Comparison UV-Vis-NIR Reflectance Curves of Ag Mirror

FTIR Unavailable

LDEF M0003-5
WL/ML THERMAL CONTROL MATERIALS EXPERIMENT
PRELIMINARY OBSERVATIONS

- Solar absorptance changes were greater for trailing edge than leading edge materials.
- White coatings in organic binders exhibited more degradation than coatings in inorganic binders.
- Contamination effects were most pronounced on the trailing edge.
- Front surface silver mirrors were severely attacked by atomic oxygen.
- Polymeric leading edge materials displayed evidence of atomic oxygen attack.
- In_20_3 coatings on Kapton and FEP reduced effects of atomic oxygen exposure.
- DC92-007 (Ti02) and aAl_20_3 coatings exhibited large changes in absorptance.
- Effects of scuff plate shadowing on leading edge samples have not been defined.