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ENVIRONMENT ON SPACECRAFT  
ENGINEERING MATERIALS Final Report  
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**Final Report**

**submitted to**

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
GEORGE C. MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812**

**April 30, 1993**

**for Contract NAS8 - 38609**

**Delivery Order 37**

**entitled**

**Combined Space Environment on Spacecraft  
Engineering Materials**

**by**

**Gary L. Workman Ph.D.**

**Principal Investigator**

**and**

**Guy A. Smith  
Research Associate**

**Susan Kosten  
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## 1. INTRODUCTION

Spacecraft structures and surface materials exposed to the space environment for extended periods, up to thirty years, have increased potential for damage from long term exposure to the combined space environment including solar ultraviolet radiation, electrons, and protons and orbiting space debris. The space environment in which the Space Station Freedom and other space platforms will orbit is truly a hostile environment. For example[1], the currently estimated integral fluence for electrons above 1 Mev at 2000 nautical miles is above  $2 \times 10^{10}$  electrons/cm<sup>2</sup>/day and the proton integral fluence is above  $1 \times 10^9$  protons/cm<sup>2</sup>/day. At the 200 - 400 nautical miles, which is more representative of the altitude which will provide the environment for the Space Station, each of these fluences will be proportionately less; however, the data indicates that the radiation environment will obviously have an effect on structural materials exposed to the environment for long durations.

The effects of ultraviolet radiation, particularly in the vacuum ultraviolet (less than 200 nm wavelength) is more difficult to characterize at this time. Very little data is available in the literature which can be used for determining the life cycle of a material placed in space for extended durations of time. In order to obtain critical data for planning and designing of spacecraft systems, we have made use of a small vacuum system at the Environmental Effects Facility at MSFC, which can be used for these purposes. A special effort has been made to build up this capability during the course of this research effort and perform a variety of experiments on materials proposed for the Space Station. Special emphasis on determining both photon fluxes and measures of material degradation is planned at this time. A description of the apparatus and the procedures devised to process potential spacecraft materials is included in this report.

The detrimental effects of ultraviolet radiation on critical surfaces is due to photochemical reaction occurring on the surface or in the near surface layers of the material under study. Data was obtained in the Skylab era with respect to the effect of contamination occurring from leaks around an orbiting platform and the resulting problems, particularly in the case of optical systems. Where critical optical surfaces are not the major emphasis, results from LDEF showed that many detrimental processes can occur within an extended space flight (> 5 years). In the cases of orbiting space platforms, such as Space Station, where the flight is to last beyond the 5 year time frame, we can expect other problems occurring from contamination and solar radiation. In the studies performed in this work, we are

more concerned with the effects of solar radiation in general. hence, we have chosen a fairly stable surface conditioned material, which has been proposed for Space Station outer surfaces, chromic anodized aluminum.

The photochemistry of the degradation processes which alters the optical properties of materials after extended exposure to solar radiation becomes a major research task when one considers the many reactions possible. In general we expect that a major photoactivated chemical species will be responsible for most observed photochemical effects in space. Some discussion of such processes is presented in Reference 2; however, the overall information is still currently quite weak. That assumption may not be valid in the presence of contaminating substances and/or space debris. Each of these situations will provide an alternate pathway for surface degradation to occur.

## **2.0 EXPERIMENTAL**

### **2.1 Introduction**

On order to experimentally determine optical changes in surface characteristics, it has been necessary to construct a vacuum chamber with adequate vacuum to avoid contaminating substances and access to simulated solar radiation. This has been accomplished at the Space Environmental Effects Laboratory in Building 4605 at Marshall Space Flight Center. In addition to the experimental measurements made in this study, we have also performed a preliminary survey of the available information on the various elements of the space environment on the materials of interest for platforms such as the Space Station.

Early information on the effects of solar radiation was generated in the 1960's and 1970's when there was a lot interest in the first solar observing satellites. The work at that time focussed on vacuum ultraviolet radiation from the sun and its effects on optical surfaces. The most useful current information appears to be evolving from the LDEF research team which is currently analyzing the many samples returned from the >5 years space experience. All of the data has not been released, hence we still have an incomplete knowledge at this time.

In order for the LDEF researchers to completely analyze the data and extrapolate to a space platform such as the Space Station, there will still need to be some additional ground-based experiments performed. Once these experimental results are all assimilated, the databases required for complete knowledge of a materials performance in space will become more useful.

2.1.1. Perform a preliminary examination of the available information from the literature for the effects of the various elements of the space environment on the materials of interest for the Space Station.

Currently available databases, such as MAPTIS at MSFC and LDEF at Langley appear to be the only databases which contain the pertinent information about materials which are potentially useful for outer shell structure of the Space Station. As mentioned earlier, these databases are currently being revised due to the extreme time and effort involved in analyzing all the samples returned from space.

These will be the appropriate databases upon final compilation of all the data.

#### 2.1.2. Evaluation of Spacecraft Materials

Evaluate and validate candidate materials for spacecraft structures and surfaces, utilizing combined space environmental ground simulation testing apparatus. Several such systems are located at MSFC in the Environmental Effects Laboratory of the Materials and Processing Laboratory/EH15.

In considering the various types of material which has the highest probability of being used as an outer surface for the Space Station and similar platforms, chromic acid anodized aluminum alloys appear at the top of the list. The data for such a surface is just now beginning to come together. As an initial material for test, this sample provides a number of useful criteria. For example, passive aluminum surfaces are known to be stable in a variety of atmospheres.[3] For that reason, the early work on reflecting surfaces for space-based optical instruments were based on aluminum. Much of the work by Hass (et. al.) centered on that activity.[4,5]. Although their work concentrated on changes observed in the vacuum ultraviolet region of the spectrum, the observations are useful for determining anticipated trends at longer wavelengths.

## 2.2 Experimental Procedures

To begin testing the chromic acid anodized aluminum for the effects of a prolonged space environment a test chamber needed to be developed to simulate a space environment. The required parameters included a high vacuum in the order of  $10^{-7}$  torr and simulated solar ultraviolet energy. The solar UV was provided by an Oriel model 6141 HgXe arc lamp and the intensity adjusted to provide one solar constant to the sample being tested. Approximately 90 percent of the materials needed to construct the test chamber was available in the laboratory from surplus equipment. A Varian model 912-7024 ion pump purchased some 20 years earlier and never used was the starting point for the system. This factory modified 1000 micron-liters/second diode pump weighed 980 pounds and was required to be portable. As a result a pallet was constructed with castors and leveling jacks with the capability of carrying 2000 pounds. Once the pallet was finished work began to build up the vacuum system. With the ion pump located on the pallet the next step involved mounting a 13 inch gate isolation valve to the ion pump. Then a 10 inch four way cross was mounted to the gate valve. This would serve as the test chamber for the various test samples. A UV transmissive window was mounted at one end and a chamber access hatch mounted just opposite. This fused quartz window used for the sample irradiation window was a special UV grade, which allowed greater transmission in the ultraviolet region down to 200 nm.. A reference optical transmission curve is provided in Figure 1. Necessary valves and vacuum gauges were then mounted onto the secondary ports. A rotary feed through was mounted on the top of the cross to which the sample holder was connected to internally. This allowed the sample holder to be rotated 90 degrees and the sample removed as needed.



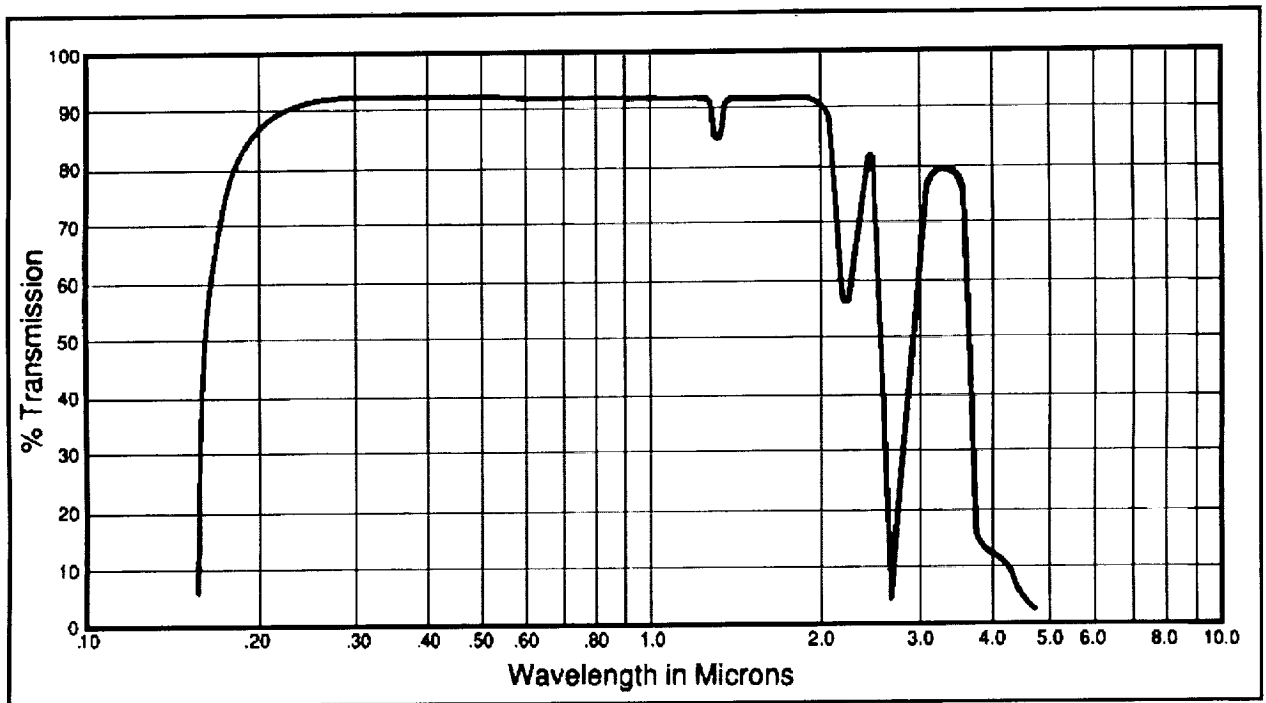


Figure 1: Transmission curve for UV window on vacuum test chamber

With the vacuum UV test chamber completed and operational the next step was to begin exposing samples to the simulated effects of space vacuum ultraviolet. The first sample to be tested was chromic acid anodized 6061-T6 aluminum type II. This sample type was anodized in 10% chromium trioxide/water bath for 45 minutes at 35°C using 15 volts DC. The voltage was ramped up at 5 volts per minute during the start up of the anodizing process. It was then sealed in de ionized water at 73°C for 8 minutes. On December 8, 1992 the initial reflectance vs. wavelength spectra and absorbance ( $\alpha$ ) numbers were recorded using the LPSR-102 system on both sides of the 6 inch square plate. On December 10, 1992 the sample was then loaded into the vacuum UV chamber. When the vacuum level had reached  $10^{-8}$  torr the HgXe arc lamp was turned on.

Following is the procedure for pumping down the vacuum chamber. At this point it is assumed that the ion pump is already on and the 13" gate valve is closed isolating the ion pump from the vacuum test chamber.

1. Connect contamination free roughing pump (CFR) to the vacuum test chamber.
2. Fill CFR Styrofoam tank with  $LN_2$  and continue to top off as needed to keep cold traps covered with liquid nitrogen.
3. Connect 1/4" nitrogen gas line to vacuum test chamber backfill valve.
4. Run CFR blower for 15 seconds and turn off.

5. Back fill vacuum test chamber with nitrogen to ambient pressure.
6. Run CFR blower for 15 to 20 seconds.
7. Repeat steps 5 and 6 twice.
8. With CFR blower now off, open primary cold trap valve (move black handle down to open).
9. Allow the vacuum chamber to pump down to between 10 and 50 millitorr. This will take approximately 10 minutes.
10. Close the primary cold trap valve and open the secondary valve (one with two cold traps attached). Allow chamber to pump down for approximately 30 minutes.
11. Set the two ion pump protect/start switches to the **START** position.
12. Close CFR pump isolation valve located on the vacuum test chamber and immediately open the 13" gate valve.

Current meter on ion pump will quickly increase to as much as 200 milliamps and then begin to decrease. Vacuum level should reach  $10^{-7}$  torr range within 30 minutes. If not then the o-ring seal around the access hatch is leaking.

13. Once vacuum level begins to stabilize, place the two ion protect/start switches back to the **PROTECT** position. This will protect the ion pump power supplies if the vacuum should be lost for what ever reason during unattended periods of time.

14. Activate Varian ion gauge power to monitor vacuum level in the test chamber area.
15. Open bleed valve on CFR isolation valve to back fill CFR vacuum hose up to ambient pressure.
16. Disconnect CFR vacuum hose from vacuum test chamber hose.
17. Pump down procedure is now complete.

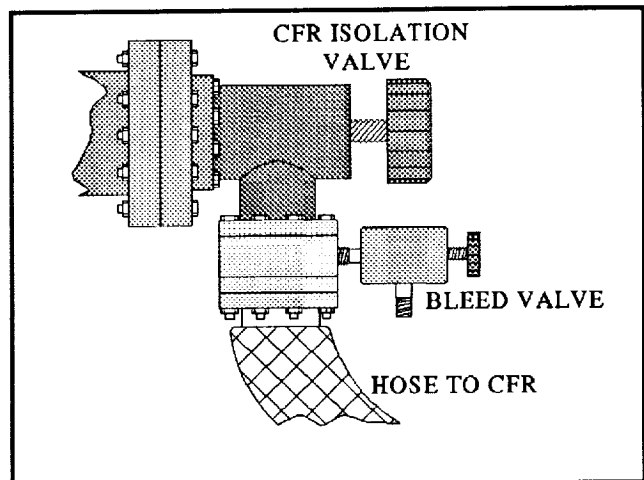


Figure 2: CFR isolation valve diagram

One month later on January 7, 1993 the sample was removed from the vacuum test chamber in preparation for the reflectance scan. Procedure for removing sample from vacuum test chamber follows.

1. Rotate the sample holder 90 degrees to allow the UV energy to shine through to the access hatch window.

2. Using UV intensity sensor and a Keithley model 197 microvolt DVM, measure the UV level by placing the sensor flush to the window at the indexed mark. Expose the sensor for at least 20 seconds and record the reading on the DVM. This measurement will determine the drift of the arc lamp over time and allow adjustments to the lamp power to maintain one solar constant to the sample.

3. Turn off HgXe arc lamp

4. Close 13" gate valve isolating the ion pump from the vacuum test chamber.

5. Back fill vacuum test chamber with nitrogen to ambient pressure level.

6. Open access hatch and using gloves remove sample from holder.

7. Take the necessary LPSR scans. In this case and all subsequent cases five scans were taken on the exposed side and two on the unexposed side of the sample.

8. Replace sample into sample holder in vacuum test chamber. Do not rotate sample back to the normal exposure position at this time.

9. Begin the pump down procedure as described previously.

10. With the vacuum back down to nominal levels turn the HgXe arc lamp on and allow it to run for a least ten minutes.

11. Using the UV sensor measure the UV energy level at the window. Adjust power supply if needed to obtain a reading of 0.355 millivolts DC on the DVM after at least 20 seconds of exposing the sensor to the UV energy. The measurement of 0.355 millivolts on the exterior surface of the access hatch window corresponds to a reading of 6.2 to 6.3 millivolts at the sample face center surface inside the vacuum test chamber.

12. Rotate the sample holder back to the position where the sample face is perpendicular to the UV light.

Using a spectral radiometer a test was performed on the Oriel HgXe arc lamp to provide an accurate spectral output of the lamp. The following graph provides the information.

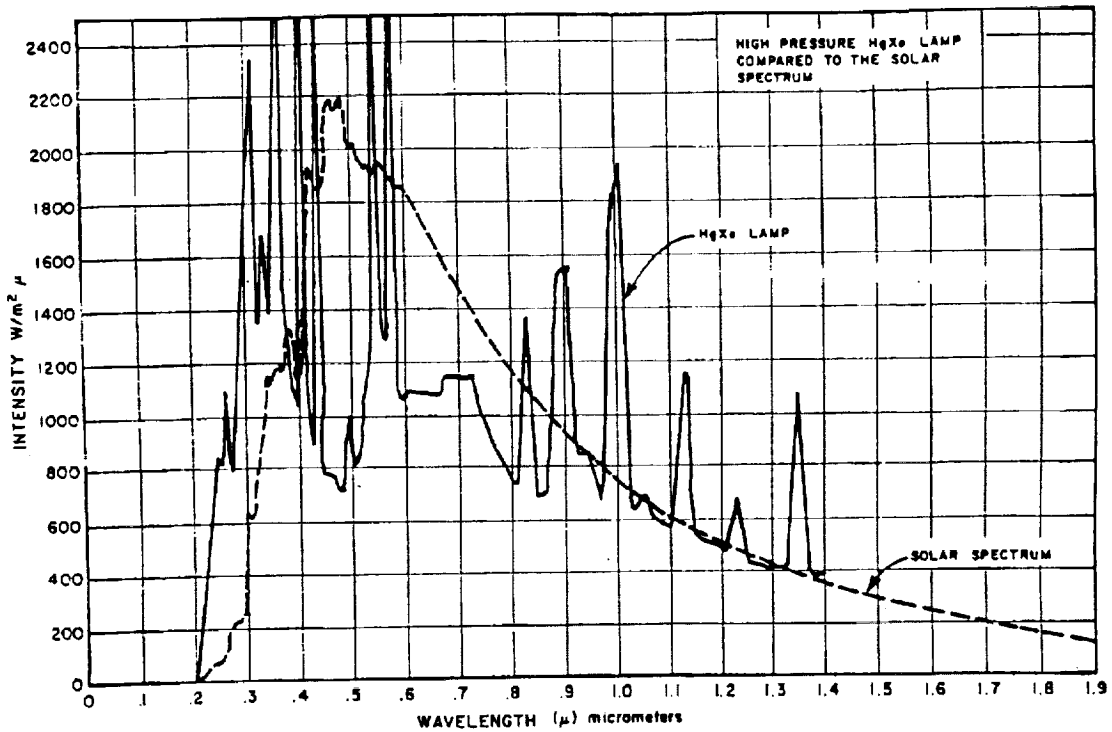


Figure 3. Johnston curve vs. output of high pressure HgXe lamp used for solar simulation.

Since January three additional scans using the LPSR have been completed all of which were approximately one month apart. It is intended that a scan will be performed every month for a least one full year on this one sample. In so doing this it would provide approximately 2 years of simulated on orbit exposure to solar UV for the series II chromic acid anodized aluminum. In reviewing the plotted data some minor shifts in reflectance can already be detected.

### 2.3 Results

The following data tables represent four months of ultraviolet exposure to the chromic anodized aluminum series II sample. It should be pointed out that the 1,2,3, and 4 month reflectance numbers are an average of five sets of data collected over five different areas of the exposed surface - one set from the center of the sample and four from each corner. As for the back side of the sample or the unexposed side only two scans were taken as indicated. The data was then graphed to indicate visually any differences in the exposed and unexposed surface reflectance. The following indicates the approximate location for each of the scans on the sample surfaces.

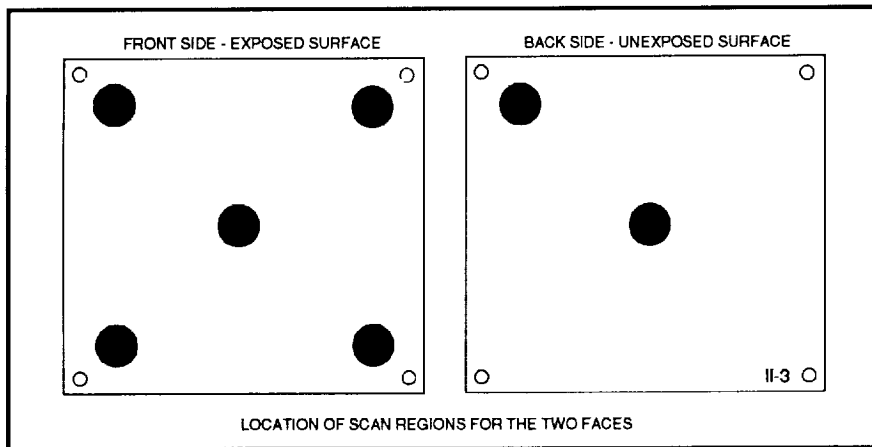


Figure 4: Locations of LPSR scanning regions on aluminum sample

Table 1: Reflectance vs. Wavelength for UV exposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH EXPOSURE	REFLECTANCE 2 MONTH EXPOSURE	REFLECTANCE 3 MONTH EXPOSURE	REFLECTANCE 4 MONTH EXPOSURE
ALPHA =	0.348	0.337	0.331	0.333	0.334
250	0.132	0.142	0.146	0.141	0.140
260	0.132	0.145	0.152	0.145	0.144
270	0.145	0.151	0.159	0.155	0.155
280	0.187	0.175	0.180	0.177	0.175
290	0.257	0.222	0.223	0.216	0.213
300	0.324	0.275	0.268	0.256	0.253
310	0.365	0.308	0.300	0.286	0.283
320	0.352	0.315	0.310	0.298	0.295
330	0.309	0.301	0.303	0.294	0.291
340	0.254	0.280	0.288	0.280	0.280
350	0.205	0.251	0.266	0.263	0.262
360	0.183	0.238	0.254	0.257	0.254
370	0.201	0.247	0.262	0.265	0.263
380	0.234	0.304	0.313	0.321	0.306
390	0.307	0.354	0.359	0.359	0.352
400	0.397	0.407	0.415	0.410	0.401
410	0.480	0.482	0.483	0.478	0.476
420	0.515	0.505	0.505	0.498	0.495
430	0.540	0.525	0.524	0.517	0.514
440	0.564	0.537	0.534	0.528	0.524
450	0.580	0.557	0.551	0.544	0.541
460	0.596	0.569	0.563	0.556	0.553
470	0.609	0.576	0.573	0.567	0.563
480	0.621	0.590	0.585	0.580	0.576
490	0.629	0.600	0.596	0.593	0.589
500	0.627	0.609	0.604	0.599	0.596
510	0.626	0.605	0.602	0.596	0.595
520	0.636	0.603	0.603	0.600	0.597
530	0.643	0.612	0.614	0.613	0.608
540	0.644	0.627	0.627	0.626	0.622
550	0.639	0.634	0.632	0.628	0.627
560	0.636	0.626	0.625	0.619	0.621
570	0.635	0.616	0.618	0.613	0.615
580	0.639	0.614	0.617	0.617	0.614
590	0.647	0.622	0.625	0.626	0.621
600	0.647	0.637	0.638	0.640	0.635
610	0.647	0.644	0.645	0.646	0.642
620	0.636	0.643	0.646	0.643	0.645
640	0.636	0.620	0.628	0.625	0.627
660	0.641	0.619	0.623	0.625	0.623
680	0.639	0.628	0.636	0.639	0.636
700	0.627	0.634	0.641	0.642	0.642
720	0.618	0.616	0.624	0.622	0.627
740	0.616	0.597	0.605	0.604	0.608

Table 1(Cont.): Reflectance vs. Wavelength for UV exposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH EXPOSURE	REFLECTANCE 2 MONTH EXPOSURE	REFLECTANCE 3 MONTH EXPOSURE	REFLECTANCE 4 MONTH EXPOSURE
760	0.621	0.598	0.606	0.608	0.606
780	0.627	0.621	0.625	0.629	0.624
800	0.628	0.642	0.645	0.645	0.643
825	0.636	0.650	0.652	0.651	0.649
850	0.659	0.667	0.668	0.669	0.663
875	0.691	0.695	0.701	0.704	0.695
900	0.718	0.734	0.743	0.746	0.737
925	0.728	0.770	0.782	0.782	0.778
950	0.738	0.767	0.776	0.775	0.775
975	0.751	0.771	0.778	0.776	0.776
1000	0.772	0.766	0.772	0.770	0.772
1033	0.784	0.775	0.780	0.780	0.779
1067	0.798	0.788	0.797	0.797	0.793
1100	0.806	0.810	0.818	0.821	0.817
1133	0.813	0.827	0.835	0.835	0.833
1167	0.822	0.838	0.845	0.846	0.845
1200	0.835	0.845	0.854	0.852	0.853
1233	0.834	0.848	0.857	0.856	0.857
1267	0.841	0.839	0.845	0.844	0.848
1300	0.842	0.831	0.841	0.838	0.841
1333	0.833	0.820	0.830	0.829	0.831
1367	0.828	0.815	0.826	0.825	0.825
1400	0.828	0.818	0.827	0.828	0.826
1433	0.829	0.827	0.837	0.838	0.836
1467	0.838	0.836	0.845	0.847	0.844
1500	0.847	0.850	0.859	0.861	0.859
1533	0.858	0.863	0.872	0.871	0.872
1567	0.868	0.874	0.884	0.884	0.883
1600	0.878	0.882	0.895	0.892	0.894
1633	0.887	0.885	0.899	0.896	0.897
1667	0.888	0.886	0.899	0.896	0.899
1700	0.888	0.883	0.896	0.893	0.897
1733	0.884	0.880	0.892	0.890	0.894
1767	0.882	0.872	0.886	0.881	0.886
1800	0.880	0.865	0.880	0.875	0.879
1833	0.873	0.863	0.877	0.876	0.876
1867	0.867	0.852	0.869	0.867	0.870
1900	0.865	0.847	0.866	0.864	0.868
1933	0.865	0.847	0.865	0.865	0.859
1967	0.862	0.850	0.868	0.868	0.872
2000	0.860	0.849	0.868	0.868	0.867
2033	0.863	0.852	0.871	0.872	0.873
2067	0.863	0.857	0.877	0.878	0.879
2100	0.865	0.859	0.878	0.878	0.882
2133	0.871	0.863	0.881	0.881	0.885

Table 1(Cont.): Reflectance vs. Wavelength for UV exposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH EXPOSURE	REFLECTANCE 2 MONTH EXPOSURE	REFLECTANCE 3 MONTH EXPOSURE	REFLECTANCE 4 MONTH EXPOSURE
2167	0.879	0.872	0.890	0.890	0.894
2200	0.886	0.881	0.901	0.898	0.902
2233	0.895	0.892	0.913	0.910	0.910
2267	0.906	0.900	0.922	0.919	0.923
2300	0.910	0.905	0.930	0.927	0.932
2333	0.917	0.905	0.930	0.927	0.932
2367	0.923	0.911	0.938	0.931	0.937
2400	0.922	0.916	0.945	0.942	0.945
2433	0.929	0.913	0.942	0.939	0.942
2467	0.942	0.918	0.948	0.947	0.948
2500	0.912	0.921	0.956	0.952	0.955



Figure 5. REFLECTANCE CHANGE OF CHROMIC ANODIZED ALUMINUM OVER A 4 MONTH PERIOD

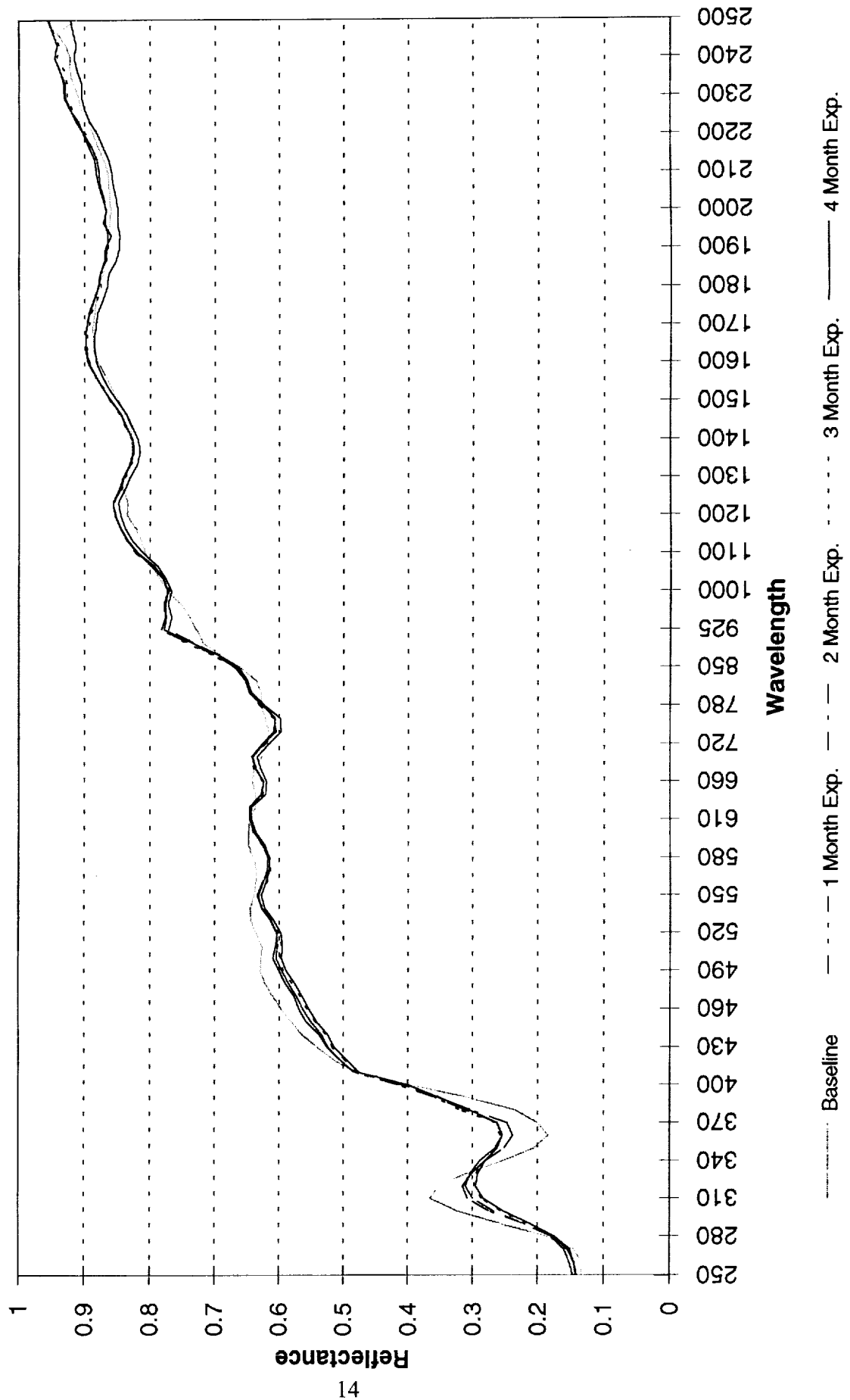


Figure 6. A COMPARISON BETWEEN 1 AND 4 MONTHS OF UV EXPOSURE

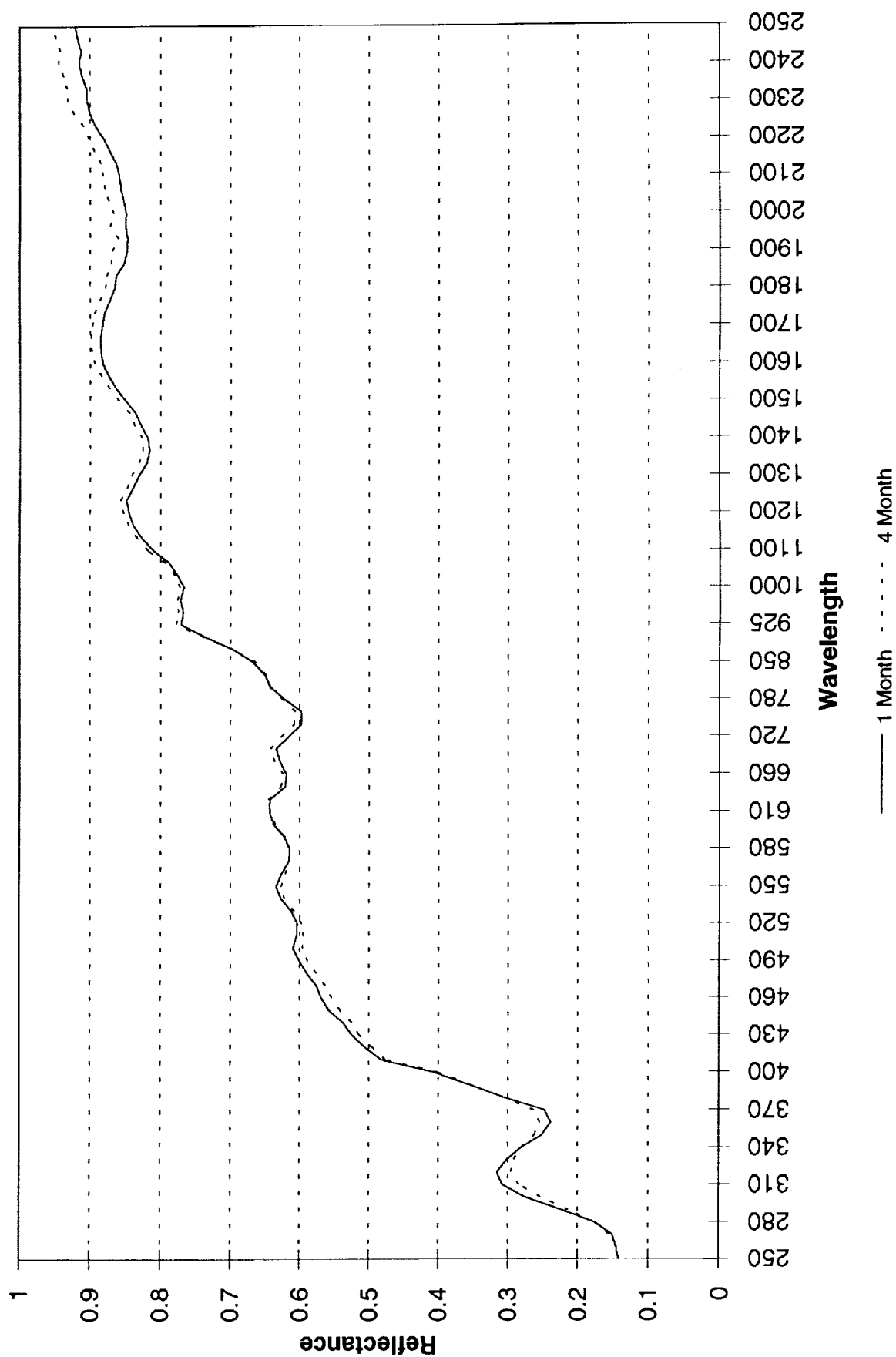


Table 2: Reflectance vs. Wavelength for UV unexposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH UNEXPOSED	REFLECTANCE 2 MONTH UNEXPOSED	REFLECTANCE 3 MONTH UNEXPOSED	REFLECTANCE 4 MONTH UNEXPOSED
ALPHA =	0.348	0.325	0.326	0.326	0.327
250	0.129	0.127	0.136	0.142	0.146
260	0.124	0.126	0.141	0.139	0.143
270	0.122	0.133	0.168	0.144	0.148
280	0.140	0.171	0.234	0.171	0.175
290	0.200	0.249	0.313	0.236	0.237
300	0.292	0.329	0.357	0.312	0.311
310	0.379	0.355	0.351	0.356	0.355
320	0.395	0.330	0.309	0.352	0.353
330	0.355	0.278	0.263	0.314	0.318
340	0.296	0.231	0.212	0.270	0.278
350	0.221	0.186	0.189	0.221	0.230
360	0.177	0.173	0.189	0.197	0.206
370	0.148	0.215	0.253	0.194	0.199
380	0.149	0.287	0.320	0.261	0.268
390	0.216	0.377	0.398	0.321	0.322
400	0.302	0.432	0.492	0.395	0.392
410	0.435	0.510	0.524	0.495	0.498
420	0.480	0.539	0.550	0.525	0.526
430	0.516	0.565	0.564	0.550	0.551
440	0.540	0.583	0.588	0.563	0.563
450	0.558	0.598	0.602	0.587	0.586
460	0.579	0.608	0.613	0.602	0.602
470	0.595	0.619	0.622	0.612	0.611
480	0.612	0.625	0.631	0.621	0.620
490	0.617	0.631	0.641	0.630	0.628
500	0.618	0.624	0.637	0.639	0.637
510	0.621	0.626	0.632	0.636	0.635
520	0.635	0.634	0.637	0.631	0.631
530	0.638	0.644	0.648	0.636	0.635
540	0.634	0.638	0.655	0.647	0.646
550	0.627	0.629	0.651	0.654	0.653
560	0.629	0.630	0.642	0.651	0.650
570	0.636	0.636	0.633	0.642	0.641
580	0.643	0.646	0.635	0.633	0.633
590	0.646	0.646	0.647	0.634	0.634
600	0.639	0.640	0.654	0.646	0.644
610	0.634	0.635	0.660	0.654	0.653
620	0.630	0.625	0.641	0.659	0.659
640	0.642	0.627	0.630	0.640	0.640
660	0.646	0.628	0.637	0.632	0.633
680	0.637	0.618	0.641	0.635	0.633
700	0.625	0.596	0.628	0.640	0.639
720	0.628	0.598	0.607	0.628	0.629
740	0.630	0.616	0.602	0.610	0.612

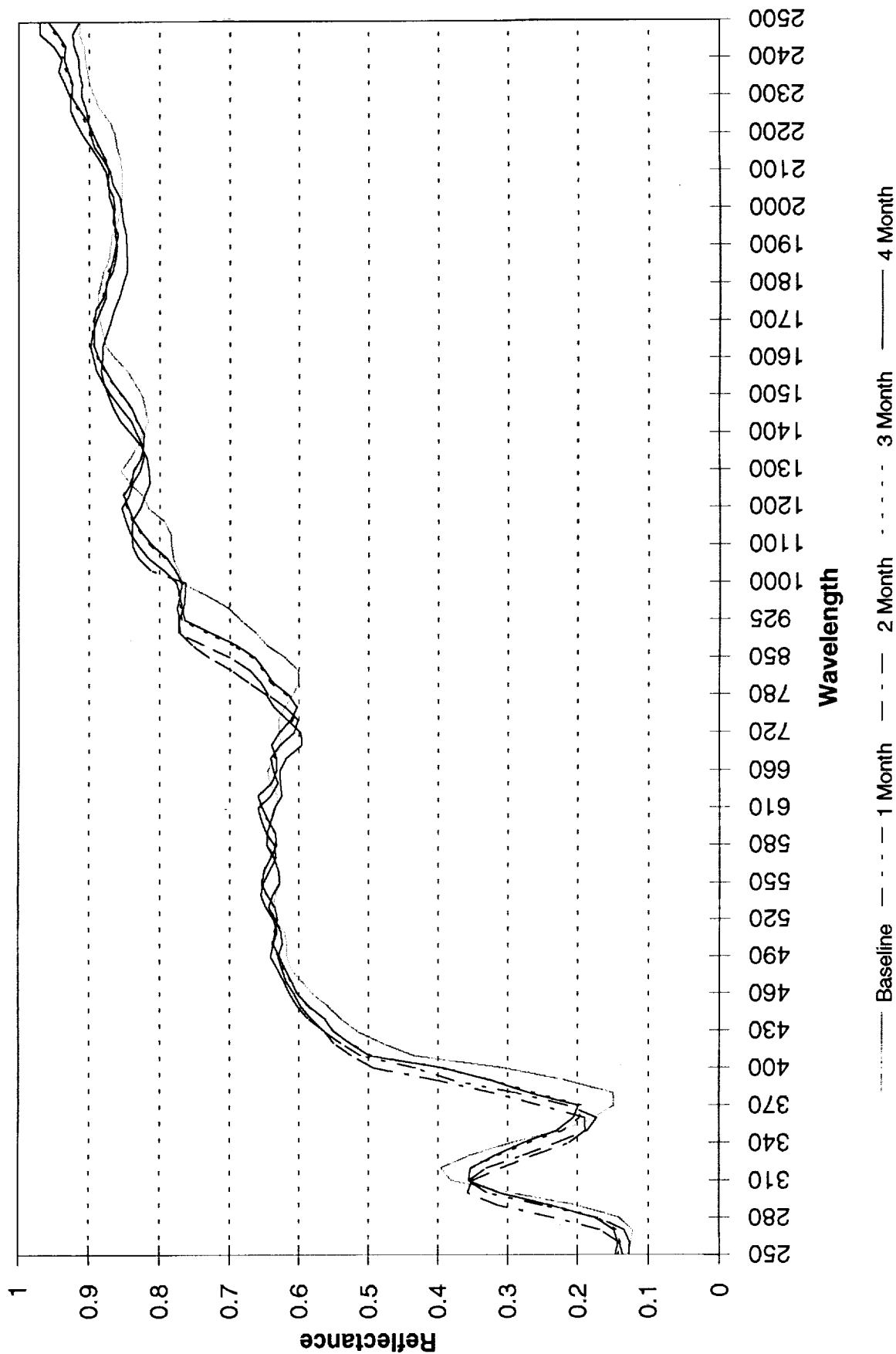
Table 2(Cont.): Reflectance vs. Wavelength for UV unexposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH UNEXPOSED	REFLECTANCE 2 MONTH UNEXPOSED	REFLECTANCE 3 MONTH UNEXPOSED	REFLECTANCE 4 MONTH UNEXPOSED
760	0.622	0.636	0.620	0.602	0.603
780	0.610	0.648	0.644	0.618	0.615
800	0.601	0.672	0.655	0.641	0.638
825	0.602	0.697	0.670	0.652	0.649
850	0.619	0.729	0.699	0.667	0.664
875	0.645	0.754	0.737	0.695	0.690
900	0.662	0.770	0.773	0.732	0.727
925	0.684	0.772	0.772	0.769	0.764
950	0.701	0.766	0.775	0.770	0.768
975	0.732	0.763	0.770	0.773	0.771
1000	0.768	0.763	0.776	0.769	0.768
1033	0.773	0.813	0.794	0.777	0.777
1067	0.780	0.830	0.816	0.792	0.790
1100	0.783	0.838	0.830	0.813	0.810
1133	0.784	0.839	0.842	0.827	0.825
1167	0.795	0.839	0.849	0.840	0.837
1200	0.816	0.827	0.854	0.846	0.844
1233	0.824	0.821	0.844	0.852	0.851
1267	0.842	0.814	0.839	0.842	0.841
1300	0.855	0.816	0.828	0.838	0.837
1333	0.843	0.818	0.823	0.827	0.827
1367	0.832	0.827	0.824	0.823	0.823
1400	0.824	0.841	0.833	0.823	0.822
1433	0.817	0.856	0.841	0.833	0.833
1467	0.821	0.866	0.855	0.840	0.840
1500	0.825	0.873	0.869	0.854	0.853
1533	0.835	0.879	0.880	0.867	0.866
1567	0.846	0.884	0.890	0.878	0.877
1600	0.862	0.882	0.894	0.888	0.886
1633	0.876	0.882	0.898	0.894	0.893
1667	0.880	0.875	0.895	0.896	0.893
1700	0.885	0.870	0.891	0.894	0.894
1733	0.886	0.865	0.883	0.891	0.891
1767	0.888	0.857	0.876	0.881	0.879
1800	0.884	0.852	0.876	0.876	0.875
1833	0.879	0.846	0.867	0.874	0.871
1867	0.872	0.846	0.862	0.866	0.866
1900	0.870	0.847	0.860	0.862	0.863
1933	0.868	0.847	0.863	0.860	0.859
1967	0.860	0.852	0.864	0.865	0.867
2000	0.855	0.854	0.866	0.864	0.864
2033	0.854	0.857	0.872	0.866	0.866
2067	0.854	0.867	0.873	0.873	0.875
2100	0.853	0.870	0.876	0.873	0.872
2133	0.856	0.881	0.886	0.877	0.877

Table 2(Cont.): Reflectance vs. Wavelength for UV unexposed surface over a four month period

WAVELENGTH nm	REFLECTANCE BASELINE	REFLECTANCE 1 MONTH UNEXPOSED	REFLECTANCE 2 MONTH UNEXPOSED	REFLECTANCE 3 MONTH UNEXPOSED	REFLECTANCE 4 MONTH UNEXPOSED
2167	0.861	0.893	0.898	0.886	0.886
2200	0.863	0.898	0.910	0.896	0.894
2233	0.871	0.901	0.919	0.906	0.902
2267	0.885	0.905	0.927	0.916	0.914
2300	0.893	0.911	0.927	0.926	0.925
2333	0.899	0.910	0.935	0.925	0.923
2367	0.903	0.914	0.943	0.932	0.930
2400	0.905	0.915	0.938	0.939	0.935
2433	0.907	0.921	0.950	0.936	0.933
2467	0.914	0.924	0.970	0.947	0.944
2500	0.912	0.914	0.970	0.964	0.958

Figure 7. REFLECTANCE CHANGE OF UNEXPOSED ALUMINUM SIDE



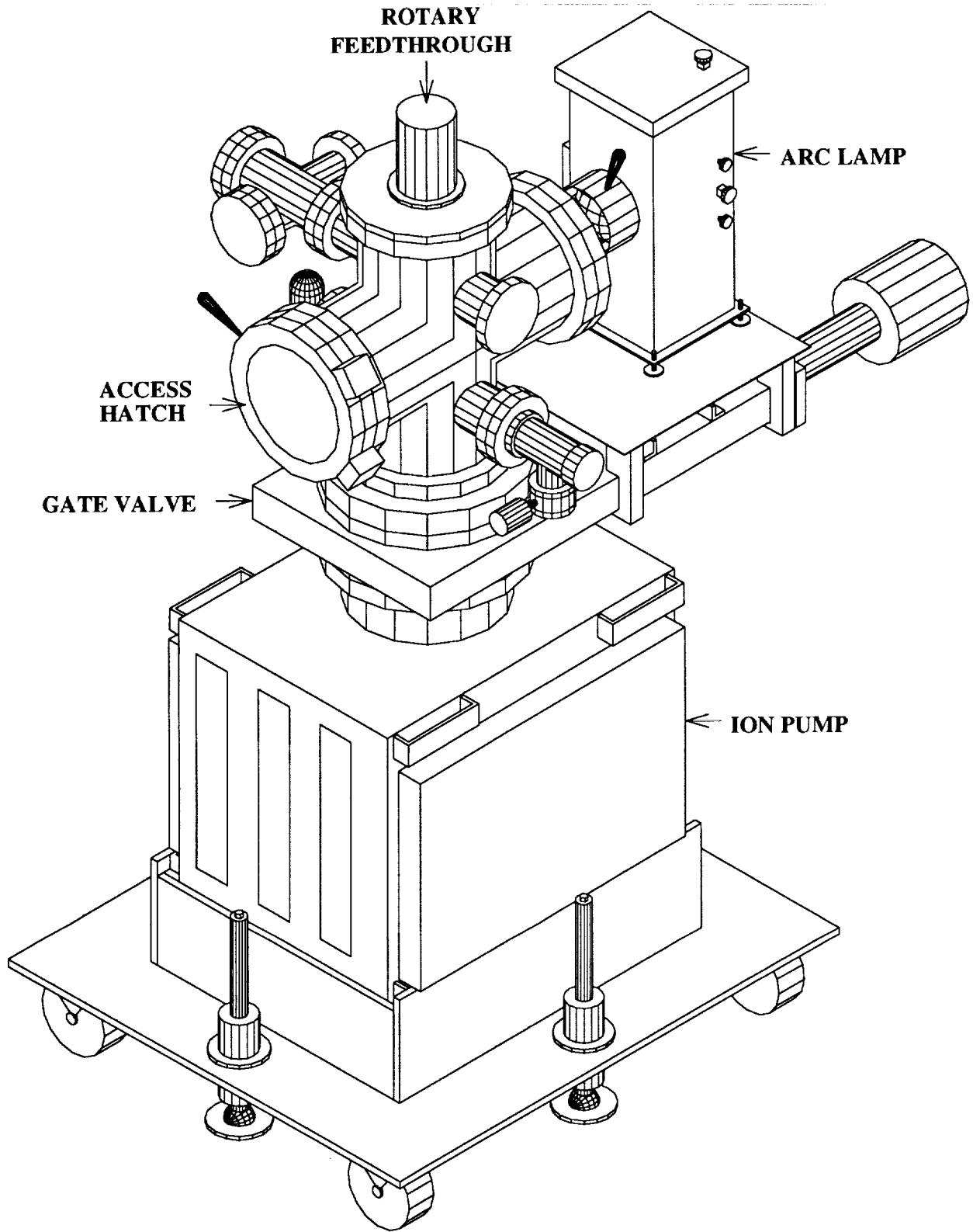


Figure 8. Vacuum Ultra-Violet Test Assembly

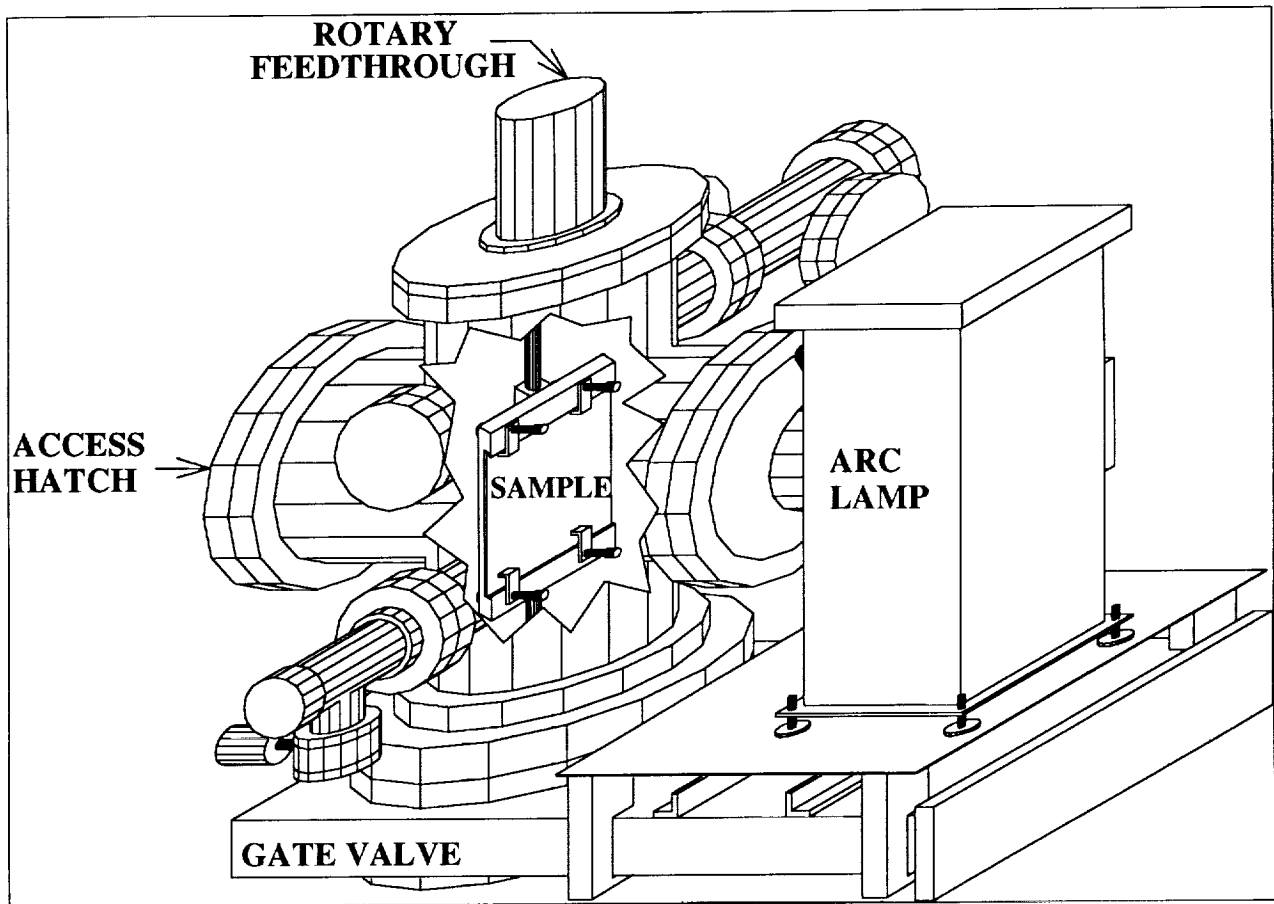


Figure 9. Sample Configuration in Test Assembly

### 3.0 CONCLUSIONS

The results of this study has concentrated on determining the effects of ultraviolet radiation on the optical characteristics of chromic acid anodized aluminum 6061. As shown in the data presented here, the majority of reflectance change occurred over the first one month period. The reason for this is unclear at the moment. The change could be due to a small number of photo-reactive species which are completely used up in that time period or it could be due a "cleaning up" of the surface upon initial exposure to the vacuum chamber. From Month 1 to Month 4 there is only a slight change in reflectance. What little change there is could be due to drift in the LPSR unit, which still needs to be determined or just to the lack of any more photo-reactive substances, as mentioned earlier. At any case, the chromic acid anodized aluminum surface appears to be very stable to solar radiation in the ultraviolet region after several months of exposure.

The procedures so far have required removing the specimen from the irradiation chamber in order to determine its optical characteristics. New studies should include the capability of making optical measurements *in situ*, i.e. without removing the sample from the chamber. Then any ambiguity in atmospheric effects would be omitted from the experiment.



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