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Silver-Teflon Contamination UV Radiation Study

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Technical Report

SILVER-TEFLON CONTAMINATION
UV RADIATION STUDY

FINAL REPORT

Contract NAS9-15436

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Appendix

1.0 INTRODUCTION

1.1 Purpose and Scope - Silver-Teflon (Ag/FEP) is currently being planned to be used as the thermal control material covering the radiator surfaces on the Shuttle Orbiter payload bay doors. These radiators require the use of materials that have a very low solar absorptance (α_S) and a high emittance for heat rejection. However, operationally, materials used on these critical radiator surfaces, such as silver-Teflon, will be exposed to a variety of conditions which include both the natural as well as the induced environments from the Shuttle Orbiter. It is very important to understand the influences of these environments upon these materials because of their impact upon on-orbit operational activities as well as ground operations such as refurbishment.

Although radiator surfaces are selected to be stable when exposed to the natural solar ultraviolet and particulate environment, the deposition of contaminants and the interaction of the contaminants with solar exposure can significantly degrade the performance of such an operational surface. Laboratory test programs and spacecraft experiments have shown that certain contaminants darken significantly when exposed to solar ultraviolet, resulting in an increased α_S.

With the present requirement to maintain changes in reflectance on the Orbiter radiator surfaces to less than 1%, it becomes very important to understand the nature of spacecraft contaminants when exposed to a solar environment and their effect upon silver-Teflon. The purpose of this study is to determine the effects of radiation upon silver-Teflon surfaces after contamination by the CVCM (collected volatile condensible mass) from RTV-560 and MIL-H-83282 hydraulic fluid. The test procedure was to deposit, irradiate, and measure solar absorptance changes (via reflectance measurements) in-situ. Additionally, surfaces that experienced a change in solar absorptance (α_S) greater than 0.03 were cleaned so that the absorptance could be recovered to its original value.

1.2 Summary - A complete test facility was assembled; detailed test procedures and a test matrix were developed; measurements of α_S were taken before and after contamination, at intervals during irradiation, and after sample cleaning to fulfill all the requirements called out in the statement-of-work Task 4.0 Technical Task Requirements.

Task 4.1 Test Planning and Preparation was accomplished by developing a detailed test matrix, test procedures, and assembling the facility to determine the effects of two potential Shuttle contaminants on Ag/FEP. Table 1 summarizes the important parameters of the solar absorptance tests that were performed. A specific gravity (sp.gr.) of 1.2 for the RTV-560 CVCM and 0.85 for the hydraulic fluid CVCM was assumed to convert the TQCM mass density units (g·cm^{-2}) into an equivalent film thickness for the CVCM. Depending on the source lamp, the radiation intensity varied from 0.05 to 2.74 equivalent ultraviolet solar constant. More details can be found in section 2.0 Test Instrumentation and section 3.0 Test Procedures.

Table 1 Test Matrix

CONTAMINANT SOURCE	EQUIVALENT THICKNESS (nm)	RADIATION EXPOSURE			NUMBER OF REFLECTANCE MEASUREMENTS
		XENON (EUVSH)	KRYPTON (EUVSH)	SOLAR (ESH)	
RTV-560	28	134	-	114	5
	32	-	-	-	1
	75	-	-	-	1
	81	177	84	-	5
	113	-	-	-	1
	238	-	-	-	1
	338	370	-	313	9
	372	234	-	198	4
HYDRAULIC FLUID	56	171	81	-	9
	149	-	-	-	1
	320	-	-	-	1
	490	192	112	159	5
	574	471	276	43	10
	522	252	148	-	11

Task 4.2 Silver-Teflon Contamination was accomplished by outgassing contaminants from RTV-560 and hydraulic fluid onto 2.54 cm square discs of Ag/FEP in at least six different equivalent thicknesses of CVCM. Table 1 lists each of the CVCM

thicknesses tested. These thicknesses were monitored by a TQCM kept at the same temperature as the Ag/FEP samples. The Ag/FEP samples were maintained at temperatures below -40°C for the RTV-560 tests and -50°C for the hydraulic fluid tests to inhibit significant reemission of the CVCM. The change in α_s was not a linear function of the amount of RTV-560 CVCM. The major increase in α_s occurs for CVCM at least as small as a 28 nm equivalent film thickness. Increasing the surface density of CVCM by a factor of 13 only increased the change in α_s by about 0.04. Similarly, the change in α_s was not linear for the hydraulic fluid CVCM. The major increase in α_s occurs for CVCM up to an equivalent film thickness of about 200 nm. This increase in α_s appears to level off just below 0.03 for films up to thicknesses of 600 nm. More details can be found in section 4.0 Results.

Task 4.3 Silver-Teflon Irradiation was accomplished by irradiating the contaminated samples with a xenon vacuum ultraviolet lamp (1470 Å, 0.05 to 2.74 EUVS), a krypton lamp (1240 Å, 1.3 EUVS), and a solar simulator (wavelengths greater than 0.25 µm, 0.3 to 2.32 ES). Table 1 lists the various periods of exposure. The α_s of the RTV-560 CVCM was not affected by solar radiation up to 313 ESH nor vacuum ultraviolet radiation up to 370 EUVSH. In only one of the four tests using the hydraulic fluid did the α_s increase with the period of radiation exposure. The highest energy radiation (krypton lamp, 124 nm) had the greatest effect, increasing α_s by 0.1 in 276 EUVSH. This reduction in reflectance by the irradiated contaminant has a spectral character of increasing as the wavelength becomes shorter (toward the ultraviolet). More details can be found in section 4.0 Results.

Task 4.4 Spectral Reflectance Measurements were accomplished in-situ as shown in Table 1. Twenty-seven separate reflectance measurements were performed on Ag/FEP using RTV-560 as the source and thirty-seven separate reflectance measurements were performed using hydraulic fluid.

Task 4.5 Silver-Teflon Cleaning Procedure was accomplished on two contaminated samples (RTV-560 CVCM irradiated up to 370 EUVSH and hydraulic fluid CVCM irradiated up to 148 EUVSH) by wiping the surface with a solution of trichloroethance and methyl alcohol. This technique easily removed the contaminant and restored the clean value of Ag/FEP solar absorptance.

2.0 TEST INSTRUMENTATION

Figure 1 presents a schematic of the test setup and facility. The equipment consists of an ultrahigh vacuum chamber with feedthroughs, manipulators, and LN_2 shroud; contaminant source holder heated by filament lamps; a receptor holder to position nine Ag/FEP samples, a control Ag/FEP sample, and a barium sulfate calibration sample for deposition, irradiation, and measurement; a spectrophotometer with an integrating sphere mounted in the chamber; a solar simulator; two vacuum ultraviolet lamps; and a temperature controlled quartz crystal microbalance (TQCM).

The vacuum chamber normally operated in the low 10^{-6} Torr range. The LN_2 shroud prevented migration of any contaminants to the Ag/FEP except through direct line-of-sight from the test source. The shroud also cooled the Ag/FEP samples by radiation and maintained the contaminated samples below $-40^{\circ}C$ to inhibit any significant reemission. The TQCM was used to monitor the deposition and any reemission. Thermocouples were used to record the temperatures of the source, Ag/FEP samples, TQCM, spectrophotometer detector system, and the shroud.

The RTV-560 source material was painted onto a 32.3 cm^2 aluminum plate which was mounted to the holder frame. The back side of the holder frame was heated by three quartz envelope filament lamps and a thermocouple was embedded into the RTV-560 material. RTV-560 is a two-component room temperature vulcanizing silicone rubber produced by General Electric. RTV-560, a methyl-phenyl compound, was prepared using 0.5% of dibutyl tin dilaurate catalyst which corresponded to the mixture for the TML/CVCM tests referenced by Lyndon B. Johnson Space Center.[1] The RTV-560 samples were cured for seven days at room temperature. Figure 2 is a photograph of the source/target configuration showing the RTV-560 heater frame, the silver-Teflon samples, and the TQCM.

The TRASYS computer program was used to calculate the ratio of each sample/source view factor to the TQCM/source view factor to verify the uniformity of contaminant deposition. Table 2 shows this viewfactor ratio.

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[1] JSC-08962 Rev. P, Compilation of VCM Data of Nonmetallic Materials, March 1978.

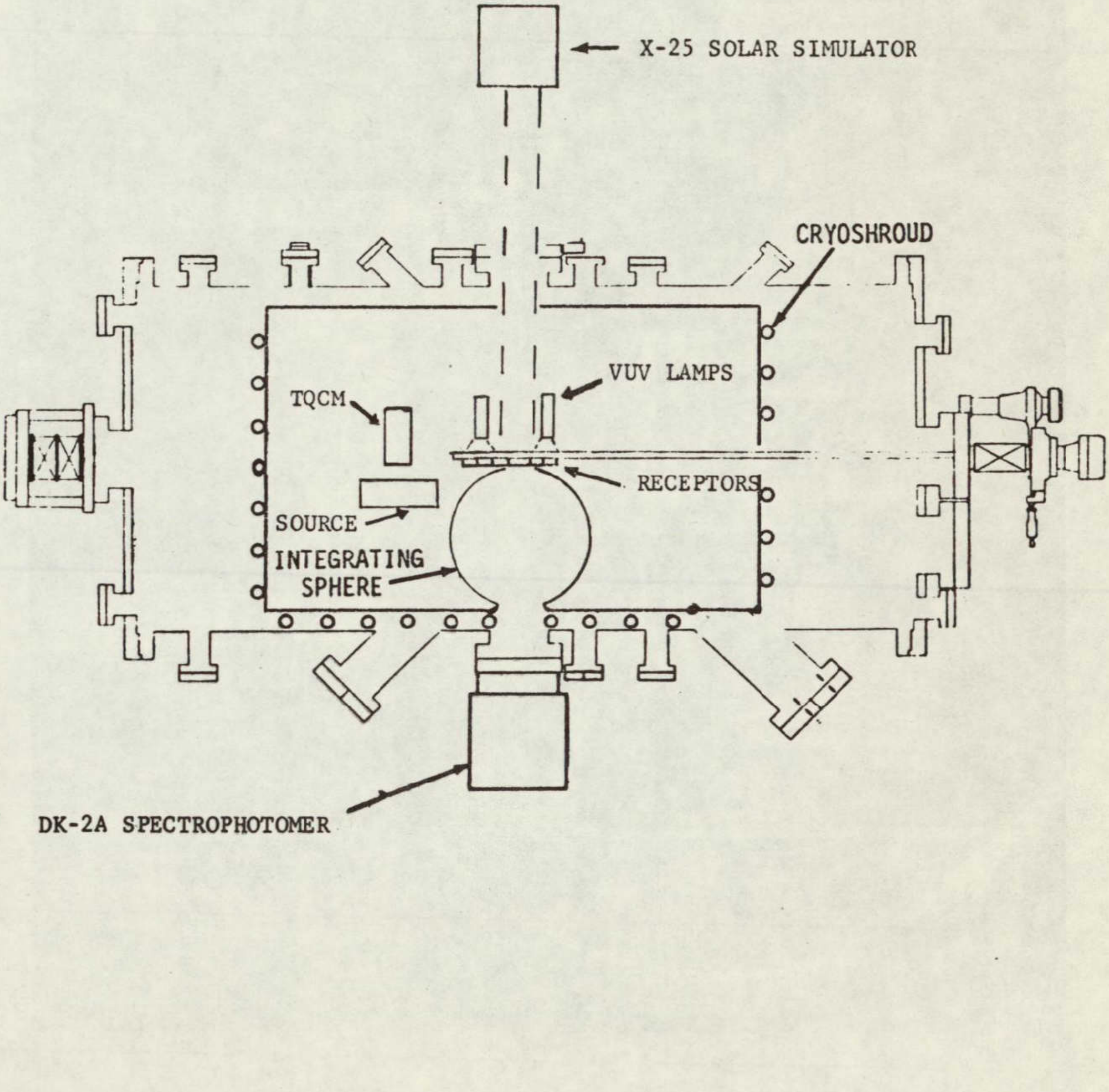

Figure 1 Schematic of the Test Setup and Facility.

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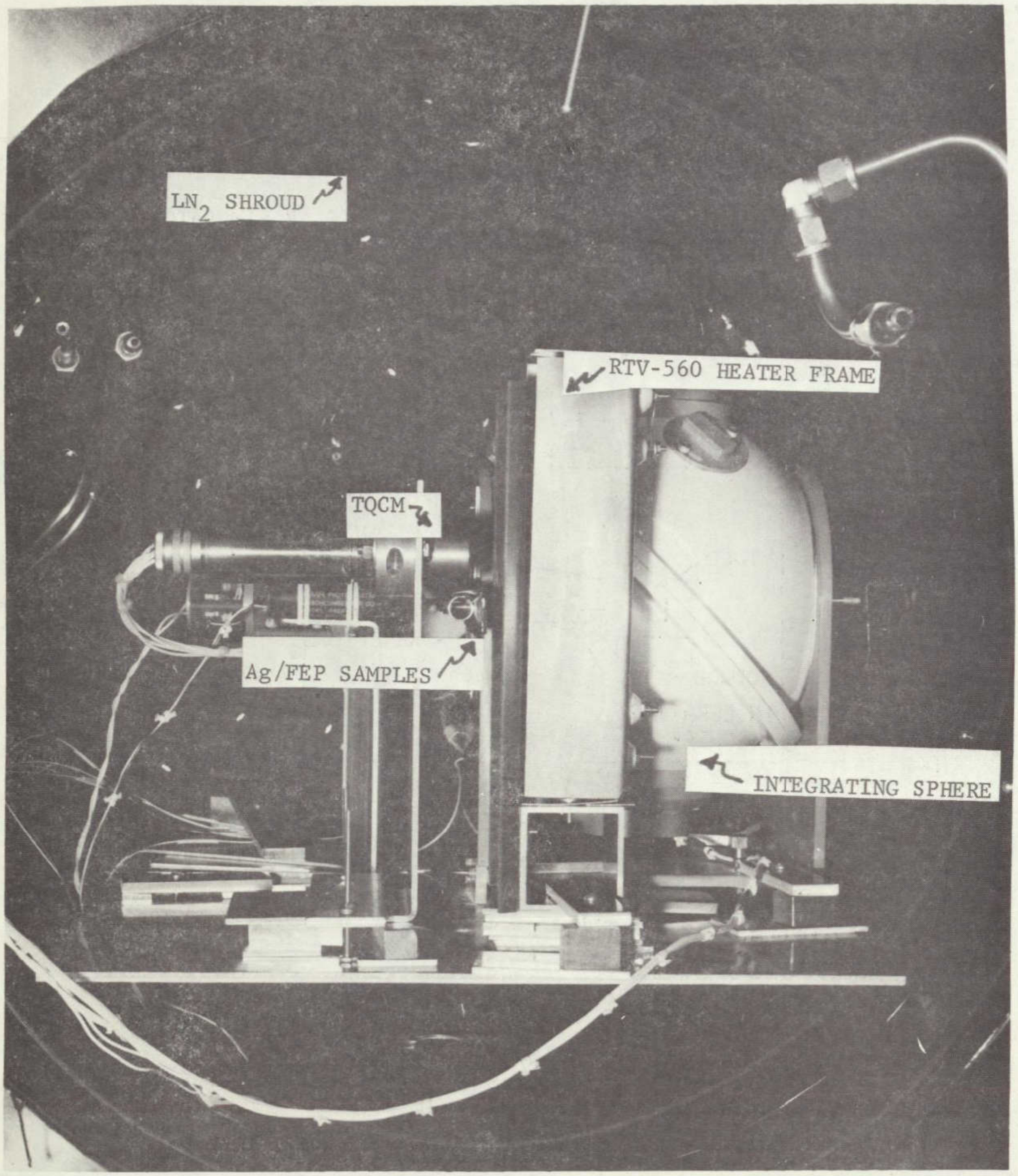

Figure 2 Photograph of the Source/Target Configuration Showing the RTV-560 Heater Frame, the Ag/FEP Samples, and the TQCM.

Table 2 Ratio of Sample/Source Viewfactor to the TQCM/Source Viewfactor

SAMPLE	$(VF_S)/(VF_{TQCM})$
3A	0.94
3B	0.97
3C	0.99
2A	1.00
2B	1.00
2C	1.00
1A	0.99
1B	0.97
1C	0.94

Bray Oil Company hydraulic fluid #83282 (developed to meet specification MIL-H-83282A) was placed into the source reservoir consisting of an "L-shaped" aluminum cylinder with a heater cup at the lower end and a glass capillary disc facing the Ag/FEP samples. The glass capillary disc consists of 1 μm diameter parallel tubes fused together in a uniform and mechanically rigid matrix. The pore size variation is controlled to within 6% or better. With a very high open area ratio (50% or greater) and a length to diameter ratio of 3000, a uniform collimated molecular beam of CVCM from the hydraulic fluid was produced. The aluminum cylinder was wrapped with a heater tape to keep the CVCM from condensing on the walls or the capillary disc. The high vapor pressure of the fluid (0.6 Torr at 37.8°C) required the addition of LN_2 cooling coils around the heater cup to lower the vapor pressure of the fluid. Thermocouples were placed on the capillary disc and inside the fluid cup. The Brayco fluid is a blend of five materials having the following physical properties: specific gravity of 0.850 at 15.6°C and 0.796 at 93.3°C; freezing point of -101°C; vapor pressure of 15.5 Torr at 204°C; and an average molecular weight of 421. Figure 3 is a photograph of the source/target configuration showing the hydraulic fluid molecular generator.

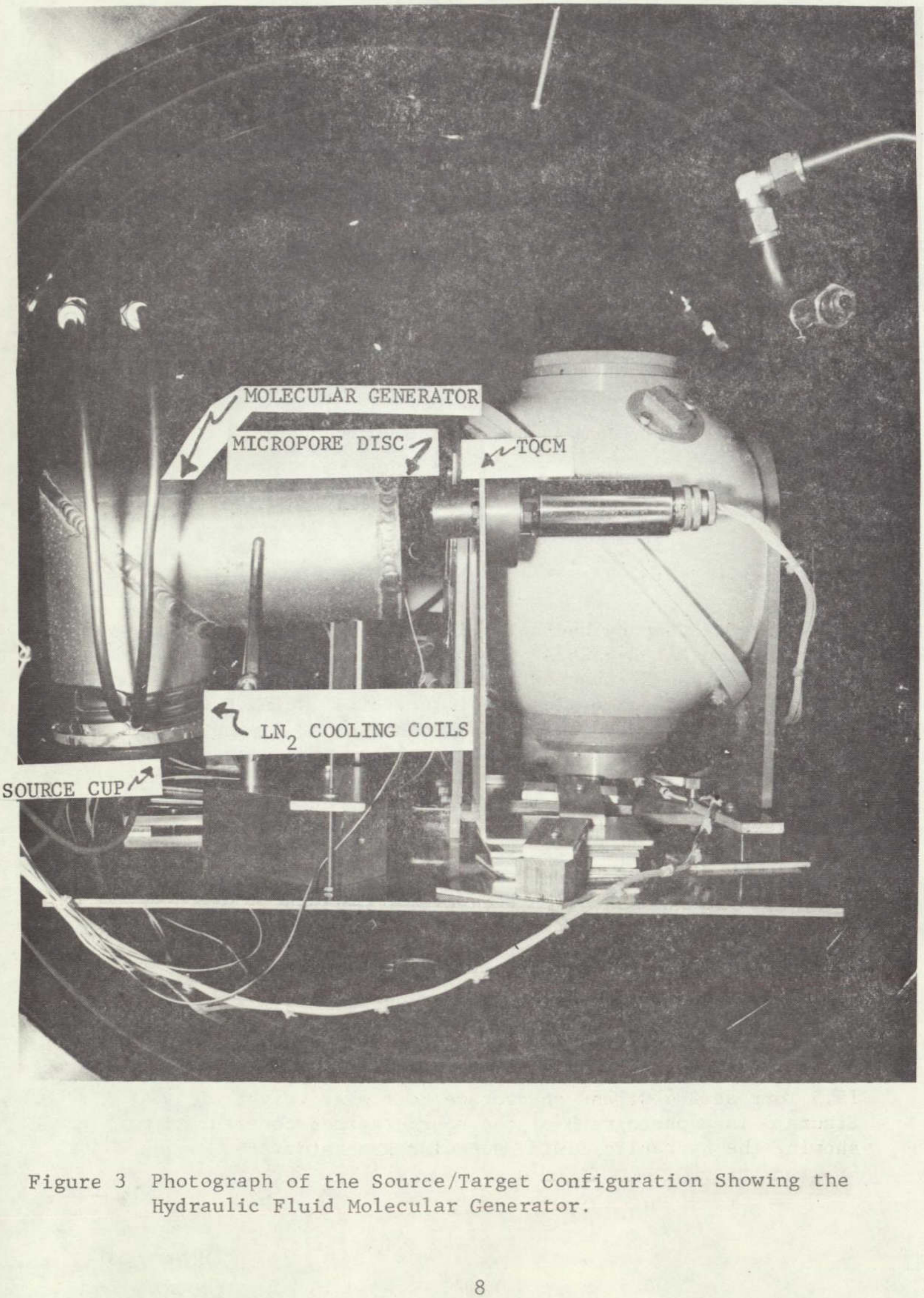

Figure 3 Photograph of the Source/Target Configuration Showing the Hydraulic Fluid Molecular Generator.

The receptor holder positions all nine of the Ag/FEP samples in front of the outgassing source, in front of the exit port in the wall of the integrating sphere. It is then rotated to face the solar simulators. Figure 4 is a sketch of the four Ag/FEP squares (2.54 cm side) showing the area on each square which makes up the nine designated samples. A control sample of Ag/FEP is used to verify sample stability, sphere alignment, and overall system performance. A barium sulfate sample (the walls of the sphere are also coated with barium sulfate) is used to obtain a 100% reading before and after each of measurements. Both the control and the 100% sample are protected from the outgassing source and the solar simulator beams.

A dual beam spectrophotometer sends two light beams through the quartz window of the vacuum chamber into the integrating sphere where the reference beam strikes the diffuse sphere wall and the multireflected light is collected by the detector system. The second beam strikes the sample which is tilted at an angle of four degrees so that the specular scattered light does not exit through the entrance port and is scattered throughout the sphere. The sample and the reference signals are electronically ratioed, displayed on a chart recorder, and converted to digital data for storage on punch cards. The digital data is processed by the use of computer programs. Appendix A shows some examples of the output. A blocking screen covered with barium sulfate prevents the specular Ag/FEP samples from direct line-of-sight to the detectors which would give incorrect signals.

An external X-25 solar simulator provides solar intensities up to 2.5 equivalent suns (ES) at target samples 2A, 2B, and 2C after passing through a quartz vacuum chamber window. However, these standard high-pressure xenon lamps are depleted in the short wavelengths radiation (less than 230 nm) which have been shown to be necessary for changes in certain films.[2] Thus, two in-situ vacuum ultraviolet sources were included to irradiate three samples each. The xenon lamp has 90% of its total radiation (0.621 mW) in the wavelength band of 145 nm to 160 nm. This lamp provides 0.359 $mW\cdot cm^{-2}$ at one Ag/FEP sample and 0.0081 $mW\cdot cm^{-2}$ at two other samples. It was assumed that one equivalent ultraviolet sun (EUVS) is the integrated standard

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[2] P. D. Fleischauer and L. Tolentino, 7th Conf. Space Simulation, NASA SP-336, 645 (1973).

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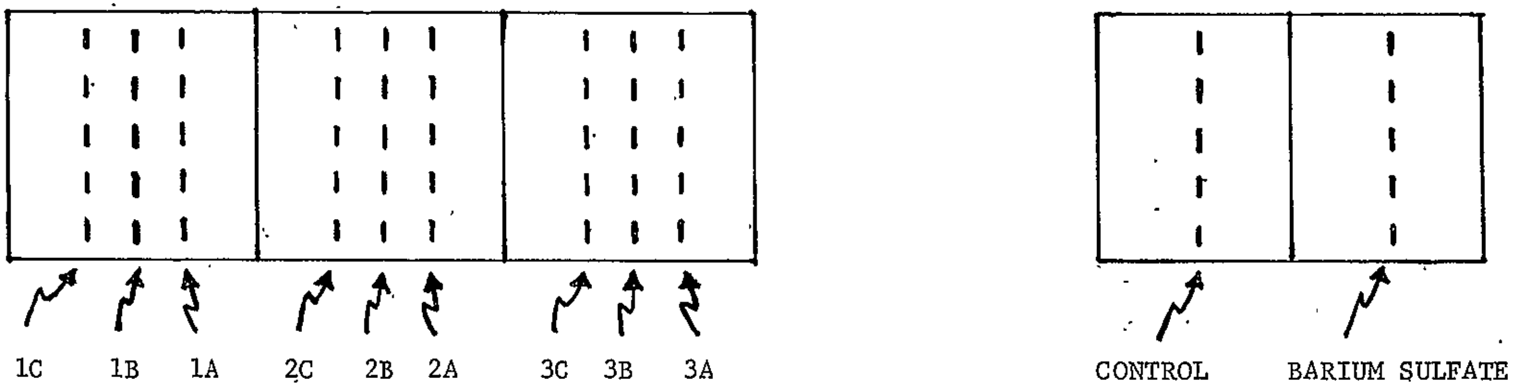

Figure 4 Sketch of the Four Ag/FEP Square Samples (2.54 cm Side) and the Barium Sulfate Sample for Normalizing the Spectrophotometer Signal Showing the Area of Each Designated Sample (Reproducible Position Where Spectrophotometer Light Strikes the Sample).

solar zero air mass intensity for all wavelengths shorter than 230 nm (0.131 $mW\cdot cm^{-2}$)[3]. The xenon lamp irradiated sample 1B with 2.74 EUVS and samples 1A and 1C with 0.062 EUVS. An in-situ hydrogen lamp failed during the testing and was replaced by a krypton resonance line lamp (124 nm; 0.166 $mW\cdot cm^{-2}$) which produces about 1.3 EUVS on samples 3A, 3B, and 3C.

The TQCM, with a mass sensitivity of $3.5x10^{-9}$ $g\cdot cm^{-2}\cdot Hz^{-1}$, was kept at the same temperature as the Ag/FEP samples. The characteristics of the matched set of 10 MHz quartz crystals have been tested previously and are known to be relatively insensitive to temperature changes (+1.5 $Hz\cdot {}^{o}C^{-1}$) and have a low response to thermal radiation from heated sources (-7 Hz for a 125°C source). If it is assumed that the CVCM is a uniform film and its density is 1.2 $g\cdot cm^{-3}$, then a change of 340 Hz is equivalent to a film of 10 nm.

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[3] M. P. Thekaekara, Optical Spectra, 32 (March, 1972).

3.0 TEST PROCEDURES

The stability of Ag/FEP to a vacuum environment and solar radiation, especially vacuum ultraviolet wavelengths, was first verified. Then the effect of the CVCM from RTV-560 and hydraulic fluid for several different CVCM thicknesses were measured. The reflectance measurements were repeated after irradiating with solar radiation for periods of at least 48 hours up to 300 ESH. The 48 hour baseline correlates to near 48 orbits on the average, or a three day exposure for normal incidence during sunlight periods of an orbit. For surfaces not normal to the solar flux, the time to accumulate 48 hours of sunlight is increased by dividing by cos θ where θ is the angle with respect to the surface normal and the incident flux direction. For example, for a surface at 60 degrees, 48 ESH equates to 6 days on orbit and for 45 degrees it is 4.2 days. A current estimate of the expected initial deposition rate on the Ag/FEP surfaces of the Shuttle Orbiter (fixed attitude, flying nose first belly up in a fixed ZLV mode, zero degree beta angle, and at 296 km) is in the range 1.7×10^{-6} $g \cdot cm^{2} \cdot day^{-1}$. Assuming a CVCM density of 1.2 $g \cdot cm^{-3}$ this yields a film thickness of 14 $nm \cdot day^{-1}$.[4] The range of CVCM deposition levels for this program were equivalent to a thickness from 10 nm to 500 nm and thus cover mission durations up to 30 days.

A cleaning technique called out in Vought Corporation Engineering Department Specification #80378 was used to study the restoration of degraded Ag/FEP samples. This technique of wiping the surface with a cloth saturated with a trichloroethane/methanol solution is applicable to very large surfaces. The reflectance was remeasured to verify the original absorptance value or to determine the ineffectiveness of the cleaning solvent.

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[4] R. O. Rantanen and D. A. Strange, Shuttle Orbiter-IUS/DSP Satellite Interface Contamination Study Final Report, MCR-78-512 (January, 1978).

4.0 RESULTS

4.1 Baseline Measurements - After performing the initial tests, it became quite apparent that standard spectrophotometer techniques would not provide the resolution and repeatability necessary for the low solar absorptance of the Ag/FEP samples. With the typical solar absorptance for Ag/FEP of 0.08 and our computed solar intensity of 1310 $W \cdot m^{-2}$ (wavelength region from 0.25 μm to 2.5 μm), a deviation of only 2% in the reflectance would produce a change of 25% in α_s.

Improvements were made in three areas; namely,

a. Replaced the spectrophotometer pen with an electronic analog to digital converter, eliminating the noise from the pen potentiometer and errors in reading the ink traces,

b. Direct digital conversion to computer processing to provide routine machine data handling, and

c. Increased the number of data points to 44 in the spectral range of .25 to 2.5 μm to improve wavelength resolution.

Table 3 presents the solar absorptance values for the clean Ag/FEP samples verifying the stability of the surfaces to solar radiation up to 182 EUVSH.

The values of solar absorptance are only relative due to a sample/instrument geometrical factor. The average standard deviation for all ten runs is ± 0.0063.

Eight repeated runs were performed on the control sample, moving and rotating the rod between measurements. The standard deviation for all eight runs was 0.0043 showing the repeatability of the measuring system.

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Table 3 Solar Absorptance of Ag/FEP Samples When Exposed to a Solar Simulator (2.32 ES, Samples 2A,2B,2C), Xenon Lamp (0.062 EUVS, Samples 1A,1C; 2.74 EUVS, Sample 1B), and No Radiation (Control, 3A,3B,3C).

SAMPLE	SOLAR ABSORPTANCE					
	HOURS OF EXPOSURE				AVERAGE	STANDARD DEVIATION
	0	25.83	44.58	66.58		
CONTROL	0.076	0.054	0.069	0.060	0.065	±0.0097
3A	0.073	0.057	0.070	0.056	0.064	±0.0088
3B	0.071	0.054	0.065	0.052	0.061	±0.0090
3C	0.064	0.053	0.064	0.054	0.059	±0.0061
2A	0.065	0.055	0.064	0.055	0.060	±0.0055
2B	0.068	0.063	0.074	0.057	0.066	±0.0072
2C	0.076	0.075	0.080	0.070	0.075	±0.0041
1A	0.091	0.084	0.096	0.087	0.089	±0.0052
1B	0.100	0.093	0.103	0.095	0.098	±0.0046
1C	0.114	0.110	0.116	0.110	0.112	±0.0030

4.2 RTV-560 Test Results - Table 4 presents the data for the change in α_s for the Ag/FEP samples after they were contaminated by the CVCM from RTV-560 with an initial deposit of 2.54×10^{-5} g·cm^{-2} and allowed to reemit until 3.32×10^{-6} g·cm^{-2} (equivalent to about 28 nm) remained. The samples were then irradiated up to 49 hours. During this period the TQCM slowly lost mass reaching 2.54×10^{-6} g·cm^{-2} after 49 hours. The temperatures of the TQCM and the samples were usually in the -80°C range with short excursions to -10°C. Thus, the data in Table 4 is complicated by the fact that any increases in α_s due to ultraviolet radiation may be masked by the decrease in contaminant thickness. The data up to the first 27.25 hrs of exposure shows no significant change in α_s except for samples 2A, 2B, and 2C. These samples show a decrease in α_s, probably due to the decreasing contaminant thickness. Solar radiation does not appear to affect the RTV-560 CVCM up to 134 EUVSH. The data at 49 hours is shown for completeness, but should not be taken as indicating a trend. The radiation was continued out to 147 hours, however, the TQCM frequency dropped to about 50 Hz when the temperature of the samples accidently reached 0°C. The solar absorptance of the samples returned essentially to the clean values. No discoloration or any other physical defects were observed on the samples after removing them from the vacuum chamber.

Table 4 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of RTV-560 and Exposed to a Solar Simulator (2.32 ES, Samples 2A,2B,2C), Xenon Lamp Radiation 147 nm (0.062 EUVS, Samples 1A,1C; 2.74 EUVS, Sample 1B), and no Radiation (Control, 3A, 3B,3C). The Initial Deposition on the TQCM was 2.54×10^{-5} $g\cdot cm^{-2}$ and was Allowed to Reemit Until 3.32×10^{-6} $g\cdot cm^{-2}$ (Equivalent to 28 nm) Remained.

SAMPLE	CLEAN α_s	CHANGE IN SOLAR ABSORPTANCE			
		HOURS OF EXPOSURE			
		0.0	21.0	27.25	49.0
3A	0.056	0.002	0.006	-0.001	0.012
3B	0.052	0.003	0.008	-0.002	0.022
3C	0.054	0.001	0.008	-0.003	0.026
2A	0.055	0.011	0.015	0.010	0.034
2B	0.057	0.025	0.017	0.012	0.038
2C	0.070	0.024	0.013	0.015	0.034
1A	0.087	0.007	0.008	0.008	0.031
1B	0.095	0.016	0.006	0.009	0.027
1C	0.110	0.017	0.004	-0.006	0.029

Table 5 shows the data for the change in α_s for the samples contaminated with an initial deposit of 4.06×10^{-5} $g \cdot cm^{-2}$ (equivalent to 340 nm), decreasing to 3.45×10^{-5} $g \cdot cm^{-2}$ and remaining relatively constant throughout the 134.98 hour test period ending at 3.12×10^{-5} $g \cdot cm^{-2}$. The number in parenthesis below each exposure time is the frequency of the TQCM above its initial clean value. The temperature control of the LN_2 shroud was improved, resulting in the samples and the TQCM staying at about -46°C ± 5°C. The temperature of samples 2A, 2B, and 2C was continuously monitored during the entire test period. The data in Table 5 incicates that both the solar beam and the vacuum ultraviolet radiation had little effect on the CVCM/FEP/Ag surface and the initial change in α_s decreased as the thickness of the CVCM decreased. Samples 3A, 3B, and 3C which were not exposed to any radiation show the same decrease in α_s as the exposed samples. Also, samples 1A and 1C which were exposed to 8.37 EUVSH show the same change in α_s as 1B which was exposed to 370 EUVSH. Figure 5 presents the change in α_s as a function of time, illustrating the similar decrease in α_s for these example samples. When the TQCM was brought up to room temperature, only a very small residual CVCM remained. The samples were also visibly the same as their initial condition.

Table 6 presents the change in α_s when contaminated by the CVCM deposited sequentially in five steps to a total of 4.46×10^{-5} $g \cdot cm^{-2}$. The data shows an unexpected decrease in α_s from the clean condition. The maximum temperature of the RTV-560 source, T_s, started at 33°C for the first layer and reached 65°C for the last step. The maximum temperature of the Ag/FEP samples during deposition was -10°C, nominal temperature was -51°C.

The samples used in the above test (4.46×10^{-5} $g \cdot cm^{-2}$) were then irradiated up to 85.41 hours and the data is shown in Table 7. Once again, even for this heavier coating of CVCM, radiation exposure up to 234 EUVSH did not significantly affect the contaminated surface α_s. Figure 6 shows a photograph (22x magnification) of the contaminated area (atmospheric pressure, 20°C) for samples 1A, 1B, and 1C; 1C is the area to the left of center, 1B is the area in the center, and 1A is the area to the right of center. It appears that the intense vacuum ultraviolet causes the CVCM to collect in large droplets, effectively clearing the surface around it. The CVCM that remains after removing the samples from the vacuum chamber was not a uniform film but consists of various size droplets. Figure 7 shows a

Table 5 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of RTV-560 and Exposed to a Solar Simulator and Xenon Lamp. The Initial Deposition on the TQCM was $4.06\text{x}10^{-5}$ $\text{g}\cdot\text{cm}^{-2}$ and After 134.98 Hours $3.12\text{x}10^{-5}$ $\text{g}\cdot\text{cm}^{-2}$ Remained. The Number in Parenthesis Below the Hours of Exposure is the Frequency of the TQCM above the Initial Clean Condition

SAMPLE	CHANGE IN SOLAR ABSORPTANCE							
	HOURS OF EXPOSURE							
	0.0 (11602)	17.23 (9855)	22.23 (9507)	38.37 (9427)	60.48 (9288)	65.98 (9265)	84.73 (8943)	134.98 (8926)
3A	0.024	0.011	0.010	0.015	0.017	0.010	0.016	-0.001
3B	0.013	0.018	0.020	0.019	0.045	0.022	0.026	0.020
3C	0.001	0.005	0.008	0.008	0.025	0.010	0.014	0.005
2A	0.011	0.006	0.011	0.011	0.023	0.009	0.010	-0.003
2B	0.025	0.013	0.017	0.018	0.033	0.014	0.018	0.001
2C	0.021	0.012	0.016	0.014	0.033	0.014	0.012	-0.001
1A	0.028	0.030	0.023	0.026	0.045	0.026	0.015	0.011
1B	0.042	0.034	0.022	0.028	0.052	0.030	0.016	0.019
1C	0.046	0.044	0.030	0.022	0.053	0.032	0.026	0.023

Table 6 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of RTV-560 Sequentially in Five Steps to a Total of $4.46\text{x}10^{-5}$ $\text{g}\cdot\text{cm}^{-2}$. The Change in Solar Absorptance is From the Initial Clean Value. The Sensitivity of the TQCM is $3.5\text{x}10^{-9}$ $\text{g}\cdot\text{cm}^{-2}\cdot\text{Hz}^{-1}$

SAMPLE	CHANGE IN SOLAR ABSORPTANCE				
	(TQCM FREQUENCY IN Hz)				
	(1088)	(2558)	(3873)	(8176)	(12742)
3A	-0.014	0.000	-0.004	-0.013	-0.019
3B	-0.009	-0.003	-0.011	-0.029	-0.027
3C	-0.011	-0.006	-0.020	-0.037	-0.036
2A	-0.011	-0.010	-0.021	-0.040	-0.040
2B	-0.006	-0.006	-0.019	-0.039	-0.037
2C	-0.007	-0.007	-0.024	-0.033	-0.033
1A	-0.014	-0.003	-0.020	-0.041	-0.043
1B	-0.031	-0.027	-0.028	-0.049	-0.051
1C	-0.046	-0.036	-0.038	-0.060	-0.070
T_s	33°C	37°C	40°C	57°C	65°C

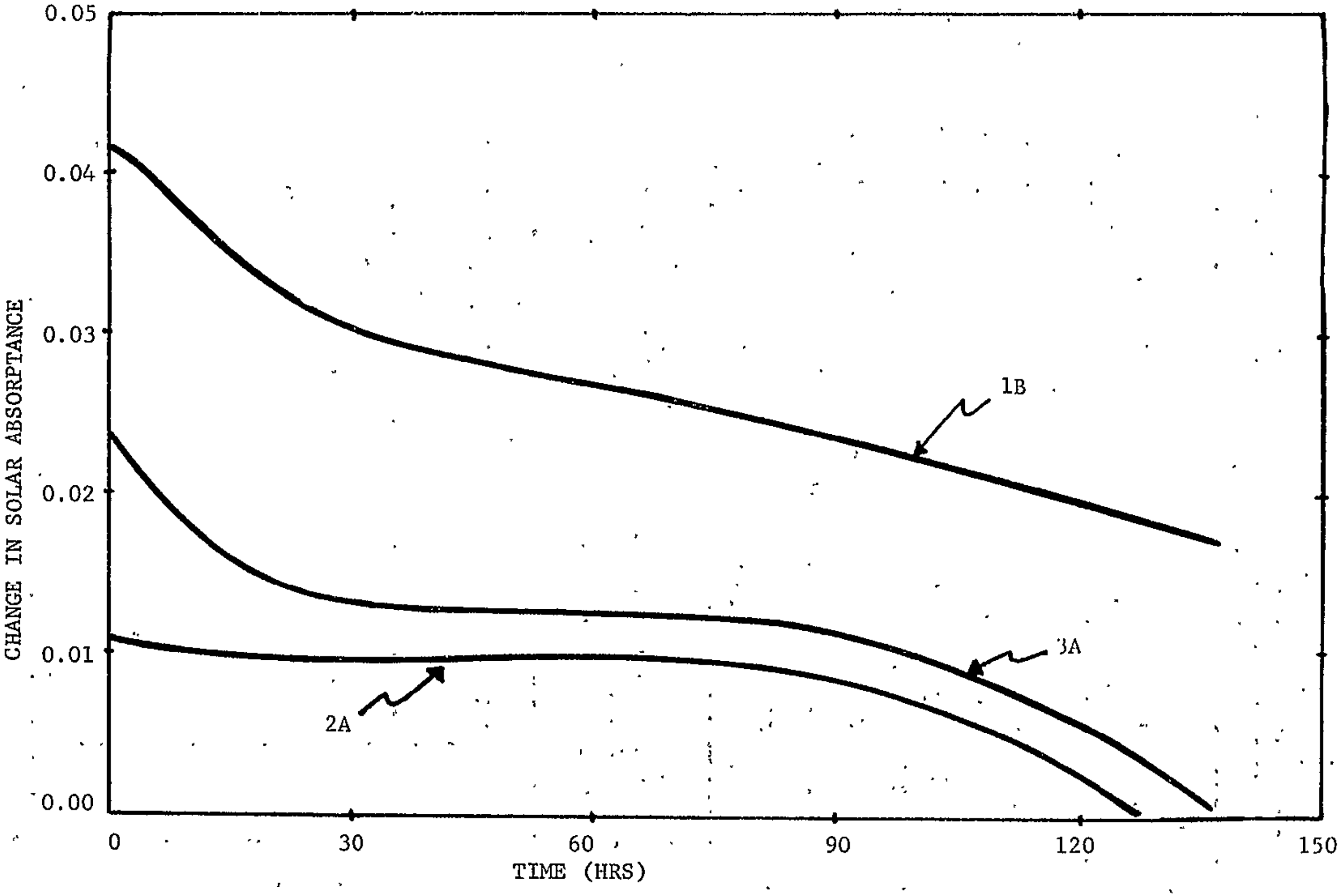

Figure 5 Change in Solar Absorptance of Silver-Teflon Contaminated by CVCM from RTV-560 when Exposed to no Radiation (3A), X-25 Solar Simulator (2A, 2.32 ES), and Vacuum Ultraviolet Radiation (1B, 2.74 EUVS, 147 nm).

Table 7 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of RTV-560 and Exposed to no Radiation (3A,3B,3C), Solar Radiation (2A,2B,2C 2.32 ES), and to a Xenon Lamp 147 nm (1B 2.74 EUVS; 1A,1C 0.062 EUVS). The Initial Deposition on the TQCM was 4.46×10^{-5} $g \cdot cm^{-2}$ and After 85.41 Hours 4.44×10^{-5} $g \cdot cm^{-2}$ Remained. The Change in Solar Absorptance is From the Contaminated Condition Zero Hours Radiation.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE		
	HOURS OF EXPOSURE		
	15.0	65.83	85.41
3A	0.008	0.005	0.015
3B	0.006	0.005	0.009
3C	0.002	0.010	0.020
2A	-0.009	-0.007	-0.006
2B	-0.005	-0.005	-0.008
2C	-0.007	-0.004	-0.009
1A	0.003	-0.005	0.004
1B	-0.001	-0.002	0.001
1C	0.007	0.011	0.009

Figure 6 Photograph of Ag/FEP Sample 1C (Area to the Left of Center), 1B (Center Area), 1A (Area to the Right of Center) Contaminated by the CVCM from RTV-560. Sample 1B was Exposed to Xenon Vacuum Ultraviolet Radiation, 2.74 EUVS, 147 nm; 1A and 1C were Exposed to 0.062 EUVS. Magnification 10x.

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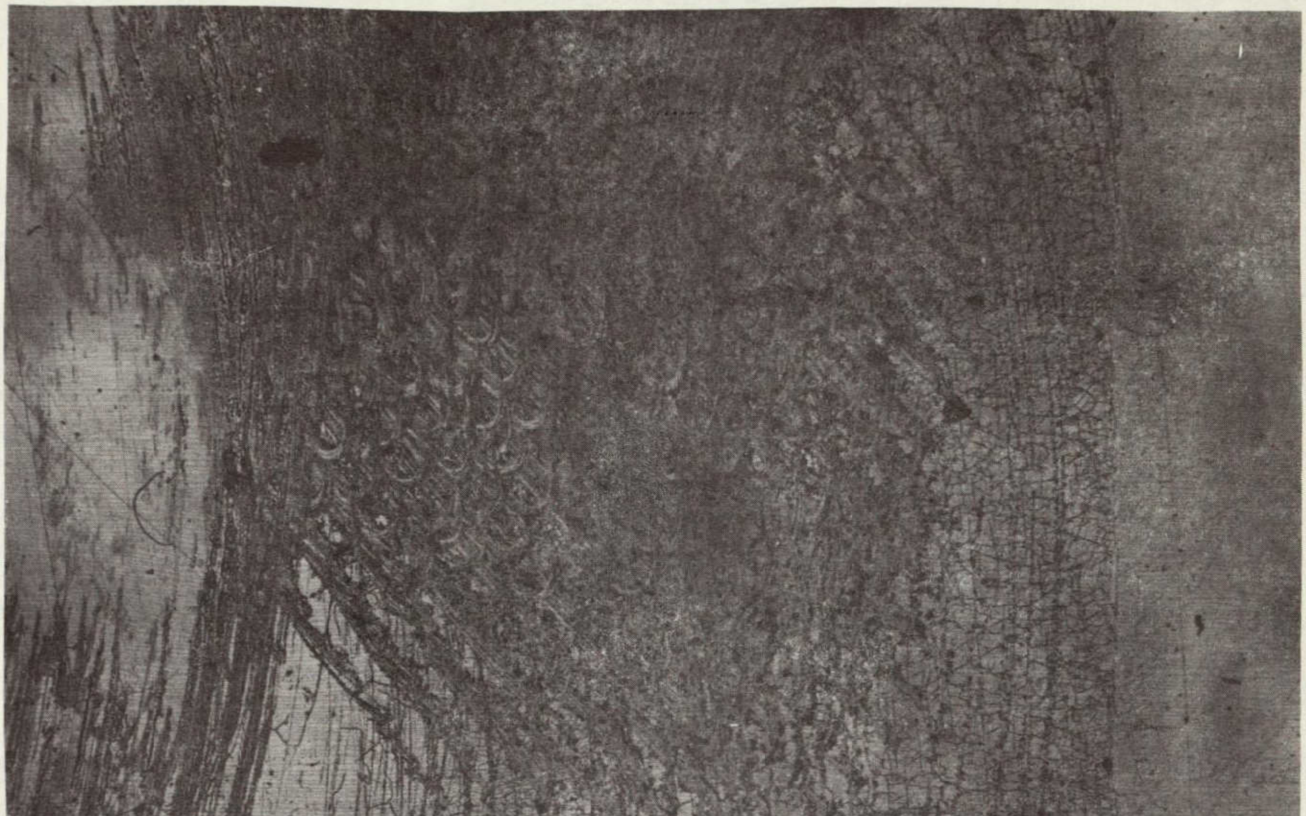

Figure 7 Photograph of Ag/FEP Sample 2C (Area to the Left of Center), 2B (Center Area), 2A (Area to the Right of Center) Contaminated by the CVCM from RTV-560 and Exposed to 2.32 ES. Vertical Streaks are from an Accidental Brush by a Gloved Hand. The Clear Area to the Extreme Right was Covered up by Sample 3C. Magnification 10x.

photograph (22x magnification) of sample 2C (area to the left of center), 2B (center area), and 2A (area to the right of center). These samples were all exposed to the X-25 solar simulator (2.32 ES). The clear area to the extreme right was that part of the sample which was under 3C. The vertical streaks were from an accidental brush by a gloved hand. Notice that the cross hatched area just to the right of center is similar to that found on sample 3A. Figure 8 shows a photograph (22x magnification) of sample 3C (area to the left of center), 3B (center area), and 3A (area to the right of center). No radiation was applied directly to this sample however some of the X-25 light can just strike the extreme left side of sample 3C. The spider web character of the CVCM on these samples differs from the droplets found on the samples irradiated with vacuum ultraviolet. Figure 9 shows a photograph of the control sample.

Table 8 presents the data for the change in α_s for a deposition level of 9.67×10^{-6} g·cm^{-2}, the RTV-560 reached a maximum temperature of 48°C. No reemission of the CVCM was measured and the Ag/FEP samples did not reach a temperature above -40°C for the entire test. Once again, the data does not show any strong trends. The irradiated samples, including 3A, 3B, and 3C which were exposed to the krypton lamp, did not show any different changes in α_s than the samples 2A, 2B, and 2C which were not exposed to any radiation. When the samples were brought back to room temperature, 58% of the CVCM had been reemitted. Visual inspection of the samples did not show any significant characteristic.

Table 8 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of RTV-560 and Exposed to a Krypton Vacuum Ultraviolet Lamp 124 nm (3A,3B3C), no Radiation (2A,2B,2C), and a Xenon Vacuum Ultraviolet Lamp 147 nm (1B, 2.74 EUVS; 1A,1C 0.062 EUVS). The Initial Deposition on the TQCM was 9.67×10^{-6} g·cm^{-2} (81 nm), no Reemission was Measured. All the Columns Show the change in Solar Absorptance from the Initial Clean Value.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE			
	HOURS OF EXPOSURE			
	0.00	3.67	21.17	64.76
3A	0.005	-0.001	-0.001	-0.003
3B	0.010	0.004	0.005	0.004
3B	0.013	-0.001	-0.002	-0.001
2A	-0.001	-0.010	-0.017	0.002
2B	0.008	-0.007	-0.012	0.003
2C	0.007	-0.015	-0.011	-0.005
1A	0.007	-0.012	-0.015	-0.015
1B	0.011	0.002	-0.012	-0.009
1C	0.003	0.004	-0.007	-0.010

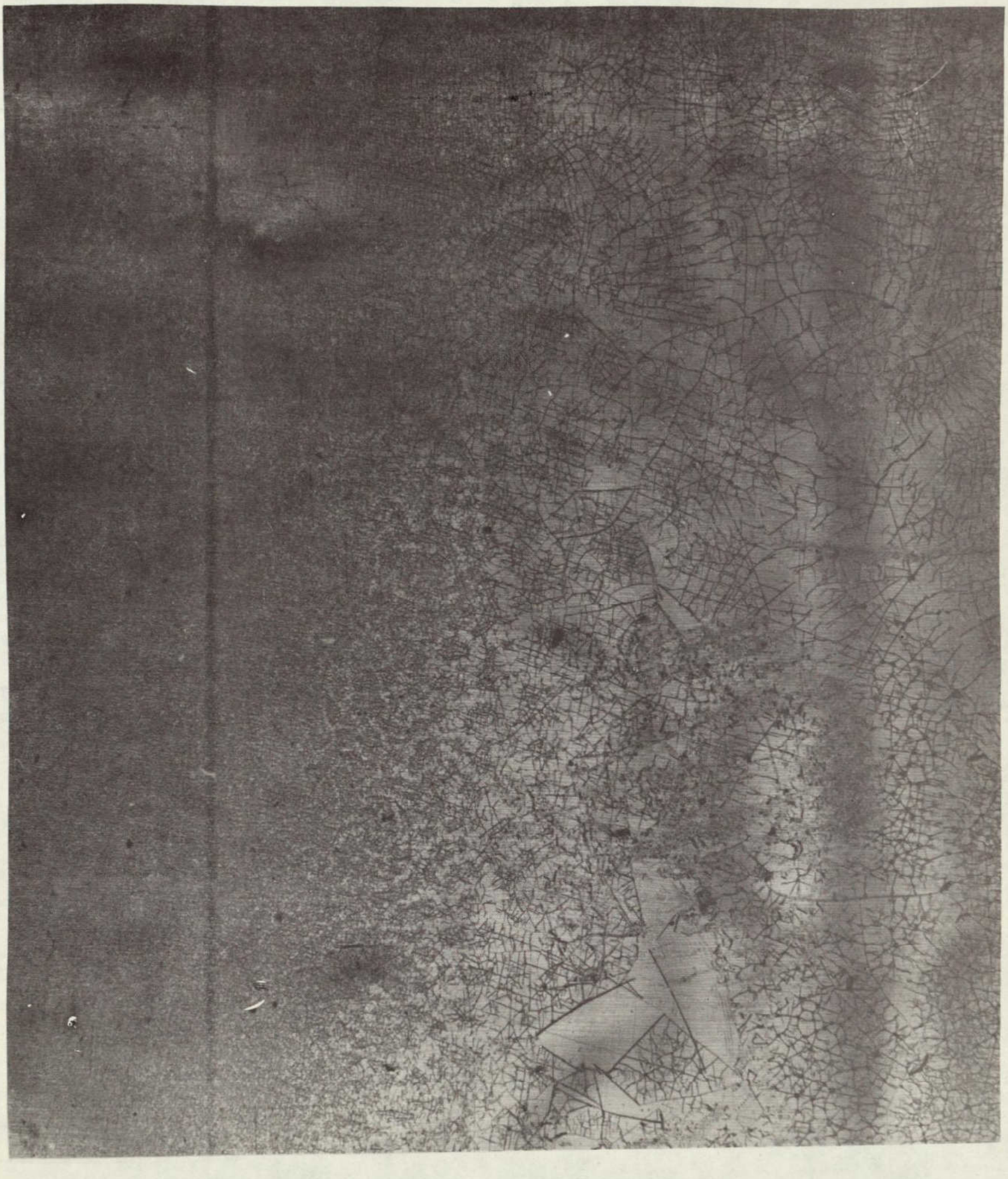

Figure 8 Photograph of Ag/FEP Sample 3C (Area to the Left of Center), 3B (Center Area), 3A (Area to the Right of Center) Contaminated by the CVCM from RTV-560. No Radiation was Applied Directly to this Sample, However some of the Solar (2.32 ES) can just Irradiate the Extreme Left Side of Sample 3C. Magnification 10x.

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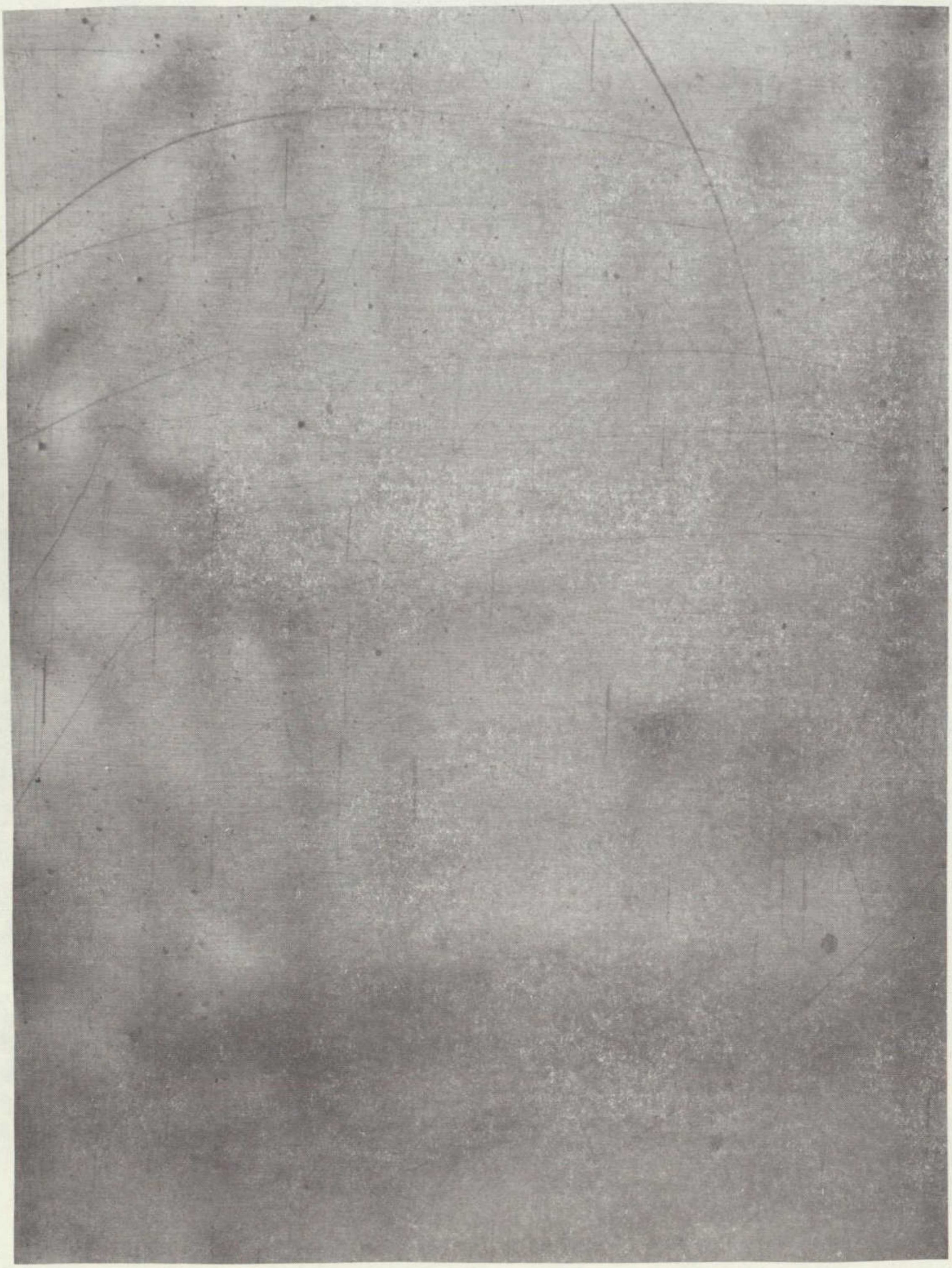

Figure 9 Photograph of Ag/FEP Control Sample. Magnification 10x.

4.3 Hydraulic Fluid Test Results - Table 8 presents the data for the change in solar absorptance for Ag/FEP samples contaminated by the CVCM from MIL-H-83282A hydraulic fluid. The fluid reached a maximum temperature of 15°C and deposited $4.76 \text{x} 10^{-6}$ g$\cdot$cm^{-2} on the TQCM. Although temperature of the TQCM always remained below -34°C, about 62% of the CVCM was reemitted and the TQCM showed $1.8 \text{x} 10^{-6}$ g$\cdot$cm^{-2} after 62.39 hours. The second column shows the change in solar absorptance from when the samples were clean. The remaining columns show the change in solar absorptance from the contaminated state at zero hours of radiation (column 2). Samples 3A, 3B, and 3C were exposed to a krypton vacuum ultraviolet lamp (123.6 nm and about 1.3 EUVS). No radiation was used on samples 2A, 2B, and 2C. Samples 1A, 1B, and 1C were exposed to a xenon vacuum ultraviolet lamp, with its resonance line at 147 nm (1B 2.74 EUVS; 1A,1C 0.062 EUVS). The data does not show any strong trends. During the initial heating of the hydraulic fluid, the heating tape which keeps the source cylinder at a temperature higher than the fluid shorted out. The CVCM from this event collected on the control sample (a visible faint white haze), samples 3, 2, 1, and the TQCM were protected by the upper portion of the cylinder. The solar absorptance of this control sample changed from 0.064 to 0.315, an increase of over 312%. Figure 10 shows this contaminated control sample.

Visual inspection of all the samples of Ag/FEP did not show any significant accumulation nor color variation. However, it should be noted that in order to bring the chamber back to atmosphere it is necessary to allow the shroud to warm up. Thus, the CVCM does reach room temperature in vacuum and can reemit during this interval. The hydraulic fluid in the source container is kept cool during this time using the LN_2 cooling coils. When the shroud is at room temperature, gaseous nitrogen is admitted into the chamber to bring the pressure back to ambient.

Table 10 presents the data for the change in solar absorptance of the silver-Teflon samples contaminated by the hydraulic fluid and then irradiated by the same light sources up to 113.58 hours. During deposition the TQCM overloaded and stopped oscillating, the last frequency output was 12695 Hz which is equivalent to $4.44 \text{x} 10^{-5}$ g$\cdot$cm^{-2}. The fluid reached a maximum temperature of 194°C very quickly and exceeded our planned stopping point. If it is assumed that the specific gravity of

Table 9 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282A Hydraulic Fluid and Exposed to a Krypton Vacuum Ultraviolet Lamp 124 nm (3A,3B,3C), no Radiation (2A,2B,2C), and a Xenon Vacuum Ultraviolet Lamp 147 nm (1B, 2.74 EUVS; 1A,1C 0.062 EUVS). The Initial Deposition on the TQCM was 4.76×10^{-6} $g \cdot cm^{-2}$ and Decreased to 1.8×10^{-6} $g \cdot cm^{-2}$ at the Conclusion of the Test. The Temperature of the Silver-Teflon Samples Varied From -34°C to -54°C. The Sensitivity of the TQCM is 3.5×10^{-9} $g \cdot cm^{-2} \cdot Hz$. Maximum Fluid Temperature 15°C.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE FROM INITIAL DEPOSITION							
	HOURS OF EXPOSURE							
	0	5.18	12.93	18.43	34.83	40.48	56.81	62.39
3A	0.012	0.020	0.012	0.006	-0.005	0.012	0.007	0.010
3B	0.010	0.002	0.003	-0.011	0.001	0.000	-0.005	-0.002
3C	0.003	0.006	0.007	-0.003	0.007	0.000	-0.001	0.000
2A	-0.004	0.006	0.007	0.002	0.008	-0.003	-0.003	0.001
2B	-0.013	0.018	0.016	0.011	0.022	0.004	0.012	0.012
2C	-0.014	0.016	0.031	0.024	0.026	0.012	0.017	0.016
1A	0.006	-0.007	-0.001	-0.008	-0.003	-0.018	-0.017	-0.018
1B	0.007	-0.013	-0.012	-0.027	-0.011	-0.031	-0.003	0.002
1C	0.010	-0.011	0.016	0.021	-0.015	-0.022	-0.009	-0.006
SAMPLE TEMP.°C	-34	-37	-39	-51	-54	-47	-48	-47
TQCM FREQ.Hz	1360	841	772	536	532	529	521	517

Figure 10 Control Sample Contaminated By The CVCM From An Accidental Short Of The Drift Tube Heating Tape. The Solar Absorptance Of This Sample Increased By 312%. Photograph Magnification Was 10x.

Table 10 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282A Hydraulic Fluid and Exposed to a Krypton Vacuum Ultraviolet Lamp 124 nm (3A,3B,3C), no Radiation (2A,2B,2C), and a Xenon Vacuum Ultraviolet Lamp 147 nm (1B, 2.22 EUVS; 1A,1C 0.050 EUVS). The Last Frequency Output from the TQCM was 12695 Hz which is Equivalent to 4.44×10^{-5} g.cm^{-2}. The TQCM Overloaded and Stopped Oscillating. The Sensitivity of the TQCM is 3.5×10^{-9} g.cm^{-2}.Hz. Maximum Fluid Temperature 194°C. Maximum Silver-Teflon Temperature During Deposition -16°C.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE FROM CLEAN VALUE									
	HOURS OF EXPOSURE									
	0	1.92	19.42	24.00	52.50	70.50	75.50	91.75	109.08	113.58
3A	0.003	0.011	-0.011	-0.002	-0.017	0.006	-0.010	-0.023	-0.012	-0.006
3B	0.010	0.018	-0.006	0.003	-0.003	-0.004	0.001	-0.019	0.001	-0.003
3C	0.017	0.018	0.009	0.015	0.015	0.007	0.012	-0.009	0.016	0.011
2A	0.026	0.026	0.013	0.018	0.006	0.008	0.011	-0.008	0.003	0.005
2B	0.019	0.009	0.007	0.016	0.000	0.020	0.002	-0.011	0.000	-0.001
2C	0.005	-0.001	-0.007	-0.007	-0.011	-0.003	-0.009	-0.023	-0.010	-0.008
1A	0.029	0.008	0.011	0.009	0.019	0.005	0.011	0.011	0.010	0.013
1B	0.009	0.008	0.022	0.004	0.013	0.002	0.014	0.000	0.013	0.037
1C	0.016	0.007	0.025	0.016	-0.004	-0.003	0.007	-0.010	0.009	0.016
SAMPLE TEMP. °C	-65	-76	-54	-67	-54	-53	-50	-66	-58	-56

the CVCM is the same as the fluid (at 60°F, the sp.gr. is 0.8498), then 12695 Hz is equivalent to a thickness of 522 nm. Thus, the CVCM was at least this thick and column 2 in Table 10 shows the increase in solar absorptance from the clean value. This initial increase in solar absorptance slowly decreased with time. Thus, again the data does not show any strong trends. Samples 3B, 2B, and 1B were measured ex-situ before and after the test in another spectrophotometer, positioned this time in the center of the integrating sphere. No change in solar absorptance was also found using this instrument.

Even after bringing the system back to ambient temperature, a large amount of CVCM remained on all the samples in the form of clear droplets. Figures 11-13 show the surfaces of the Ag/FEP samples with 10x magnification. Notice that around most of the large droplets there is a clear area, as if the droplet had been formed by smaller drops collecting at a point and leaving the surrounding area clear. Figure 13 shows samples 1A, 1B, and 1C which were irradiated by the intense Xenon lamp. The CVCM has a "baked look" with cracks being formed as the material shrinks.

Table 11 presents the data for the change in solar absorptance of the Ag/FEP samples contaminated by the CVCM from the hydraulic fluid with an initial deposition of 4.88×10^{-5} $g \cdot cm^{-2}$ (equivalent thickness of 574 nm). After 212.36 hours, 3.81×10^{-5} $g \cdot cm^{-2}$ of CVCM remained. The samples were exposed to the vacuum ultraviolet lamps for a total of 212.36 hours. After about 67 hours, the X-25 solar simulator was operable and samples 2A, 2B, and 2C were exposed for a total of 143.53 hours. After the test, visual inspection of the samples 2A, 2B, and 2C and the position of the krypton lamp showed that the vacuum ultraviolet radiation from the krypton lamp was also striking the area of samples 2A, 2B, and 2C. The very small droplets of CVCM had a pale yellowish color where the vacuum ultraviolet radiation was striking the surface. Figure 14 shows the change in solar absorptance for representative samples 3B, 2B, and 1B. Figure 15 shows the reduction in reflectance was inversely proportional to the wavelength as the time of vacuum ultraviolet exposure increased. Figure 16-18 are photographs of these contaminated Ag/FEP surfaces with 25x magnification. Figure 19 is a photograph (10x) of the TQCM.

Table 12 presents the data for the change in solar absorptance of the Ag/FEP samples contaminated by the CVCM from the hydraulic fluid with three successive depositions of 1.27×10^{-5} $g \cdot cm^{-2}$, 2.73×10^{-5} $g \cdot cm^{-2}$, and 4×10^{-5} $g \cdot cm^{-2}$ (149 nm, 321 nm, 500 nm). The third deposition is an estimated value derived from the

Figure 11 Photograph Of Sample 3 (3A,3B,3C) Contaminated By The CVCM From MIL-H-83282 Hydraulic Fluid And Irradiated By A Krypton Vacuum Ultraviolet Lamp (124 nm, about 1.27 EUVS) For 113.58 Hours. Initial Deposit Was Greater Than 4.44×10^{-5} g.cm^{-2}. Significant Reemission Occurs In Bringing Sample Temperature From -56°C To Room Temperature. Magnification 10x.

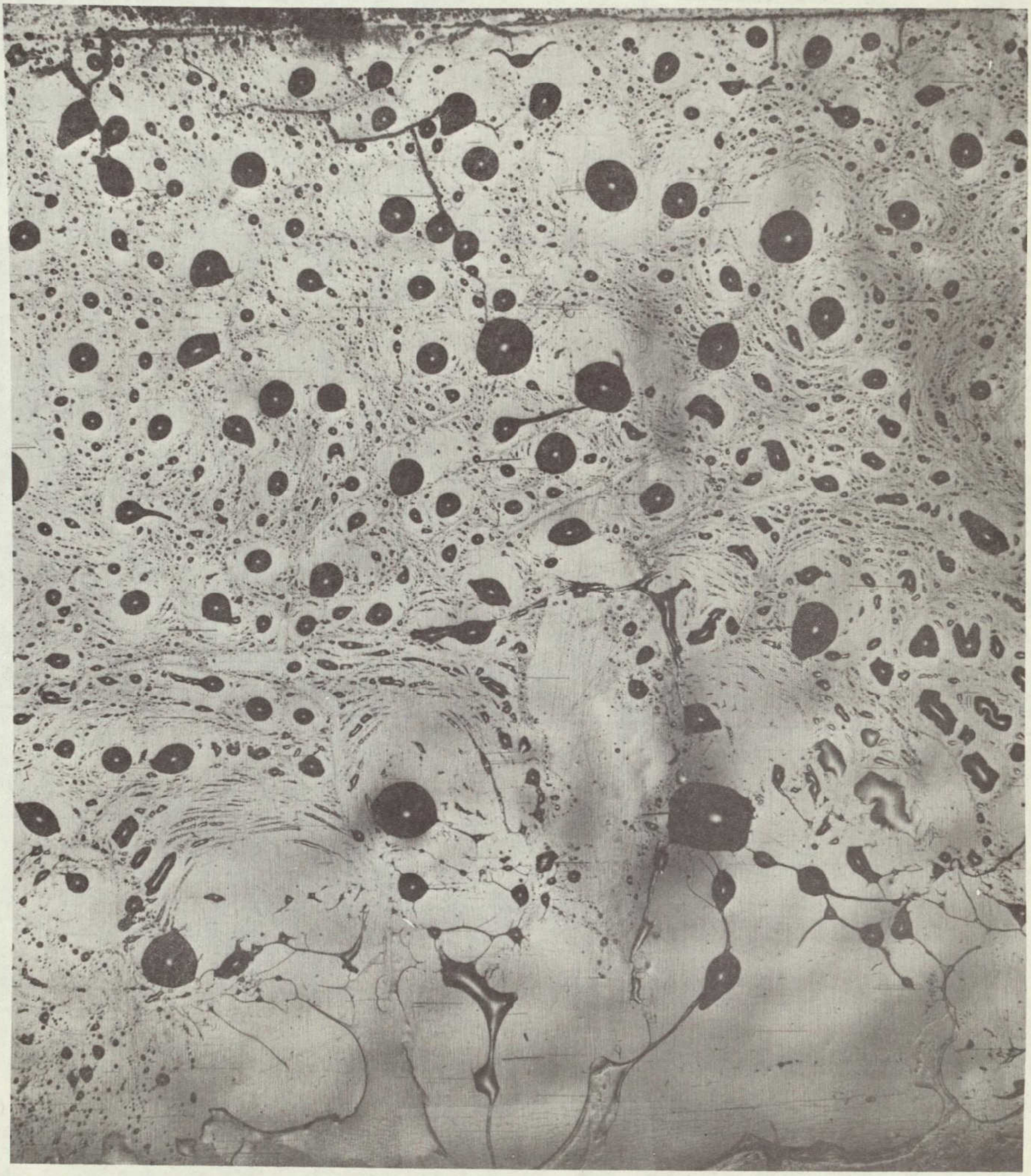

Figure 12 Photograph Of Sample 2 (2A,2B,2C) Contaminated By The CVCM From MIL-H-83282 Hydraulic Fluid To An Initial Deposit Of 4.4×10^{-5} $g\cdot cm^{-2}$. Significant Reemission Occurs In Bringing Sample Temperature From -56°C To Room Temperature. Magnification 10x.

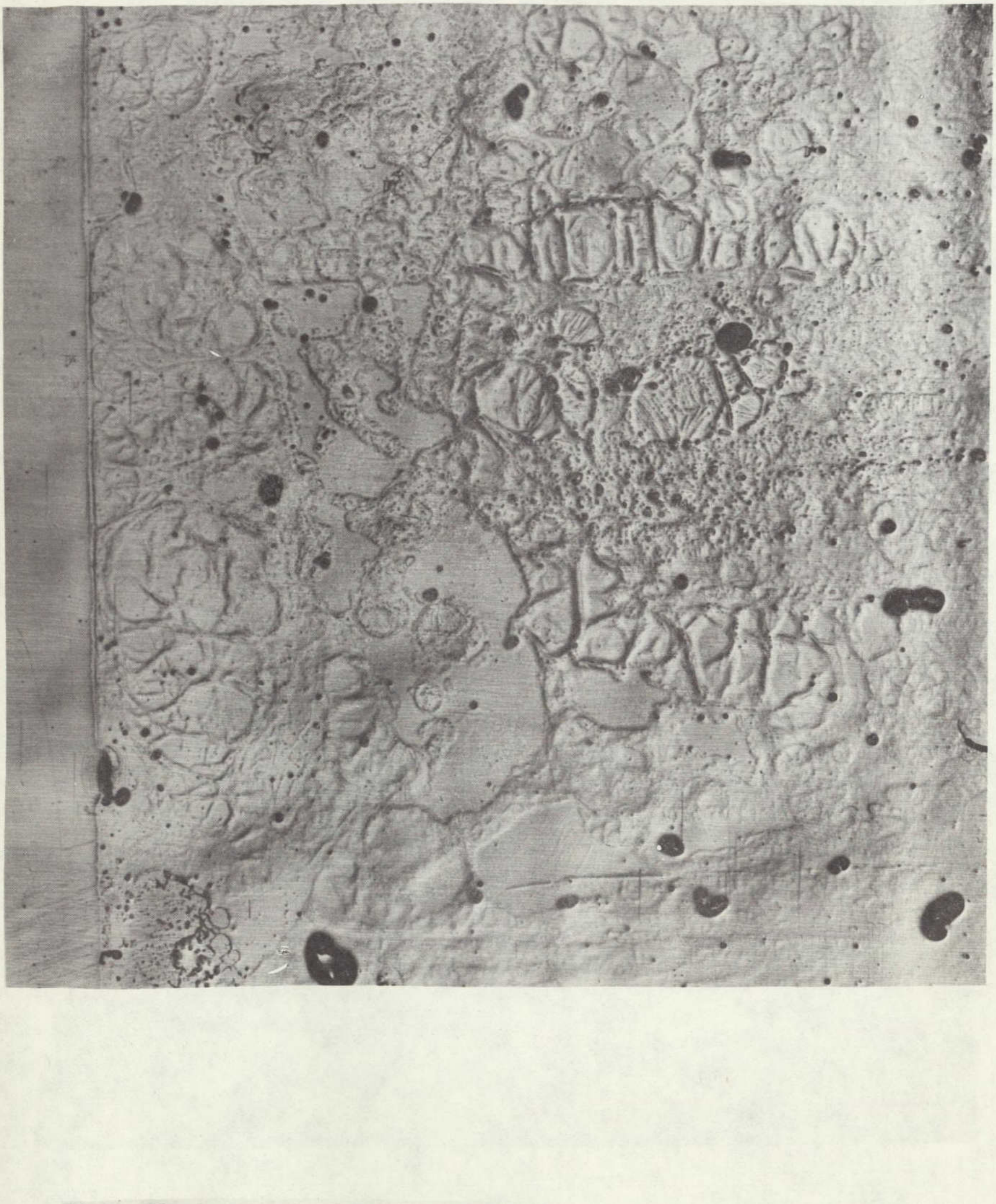

Figure 13 Photograph Of Sample 1 (1A,1B,1C) Contaminated By The CVCM From MIL-H-83282 Hydraulic Fluid And Irradiated By A Xenon Vacuum Ultraviolet Lamp (147 nm, 1B 2.74 EUVS, 1A,1C 0.062 EUVS) For 113.58 Hours. Initial Deposit Was Greater Than 4.4×10^{-5} g·cm^{-2}. Significant Reemission Occurs In Bringing Sample Temperature From -56°C To 25°C. Magnification 10x.

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Table 11 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282A Hydraulic Fluid (Column 2) and the Change After Exposure to a Krypton Vacuum Ultraviolet Lamp 124 nm (3A,3B,3C 1.3 EUVS), Solar Simulator (2A,2B,2C 0.3 ES), and a Xenon Vacuum Ultraviolet Lamp 147 nm (1B, 2.22 EUVS; 1A,1C 0.050 EUVS). Initial Deposition 4.88×10^{-5} $g \cdot cm^{-2}$ and After 212.36 Hrs 3.81×10^{-5} $g \cdot cm^{-2}$ Remained. Maximum Fluid Temperature 158°C. Maximum Silver-Teflon Temperature During Deposition -16°C.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE								
					HOURS OF EXPOSURE				
	0	19.0	42.42	66.75	88.75	138.25	159.08	181.66	212.36
3A	0.008	0.028	0.039	0.048	0.050	0.056	0.079	0.078	0.085
3B	0.009	0.020	0.036	0.052	0.055	0.057	0.085	0.091	0.093
3C	-0.009	0.034	0.060	0.086	0.068	0.078	0.105	0.101	0.114
1A	0.048	-0.046	-0.041	-0.021	-0.046	-0.040	-0.040	-0.023	-0.048
1B	0.021	-0.002	0.005	0.015	-0.007	0.003	0.011	0.013	0.022
1C	0.014	-0.018	-0.001	0.033	-0.006	0.006	0.021	0.029	0.031
					HOURS OF EXPOSURE				
					19.92	69.42	90.25	112.83	143.53
2A	0.028	-0.027	0.004	0.029	0.004	0.012	0.034	0.030	0.034
2B	0.028	-0.010	0.006	0.028	0.006	0.013	0.035	0.031	0.035
2C	0.031	-0.036	-0.005	0.021	0.002	0.001	0.029	0.018	0.027
SAMPLE TEMP. °C	-59.7	-61.7	-59.9	-57.9	-57.9	-56.4	-57.4	-55.2	-55.7

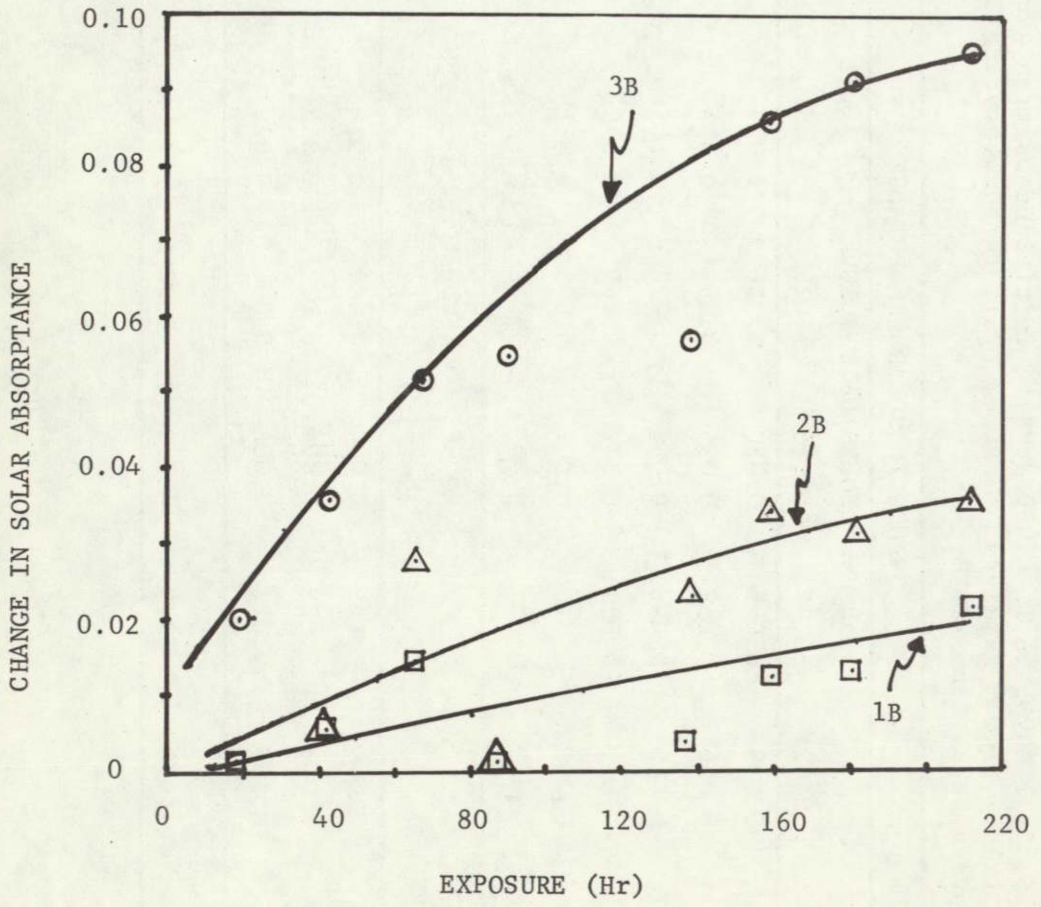

Figure 14 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282 Hydraulic Fluid After Exposure to a Krypton Lamp 124 nm (3B, 1.3 EUVS), Solar Simulator (2B, 0.3 ES) and Accidental Krypton Light, and a Xenon Lamp 147 nm (1B, 2.22 EUVS). Initial Deposition 4.88×10^{-5} $g\cdot cm^{-2}$ and After 212.36 Hrs 3.81×10^{-5} $g\cdot cm^{-2}$ Remained.

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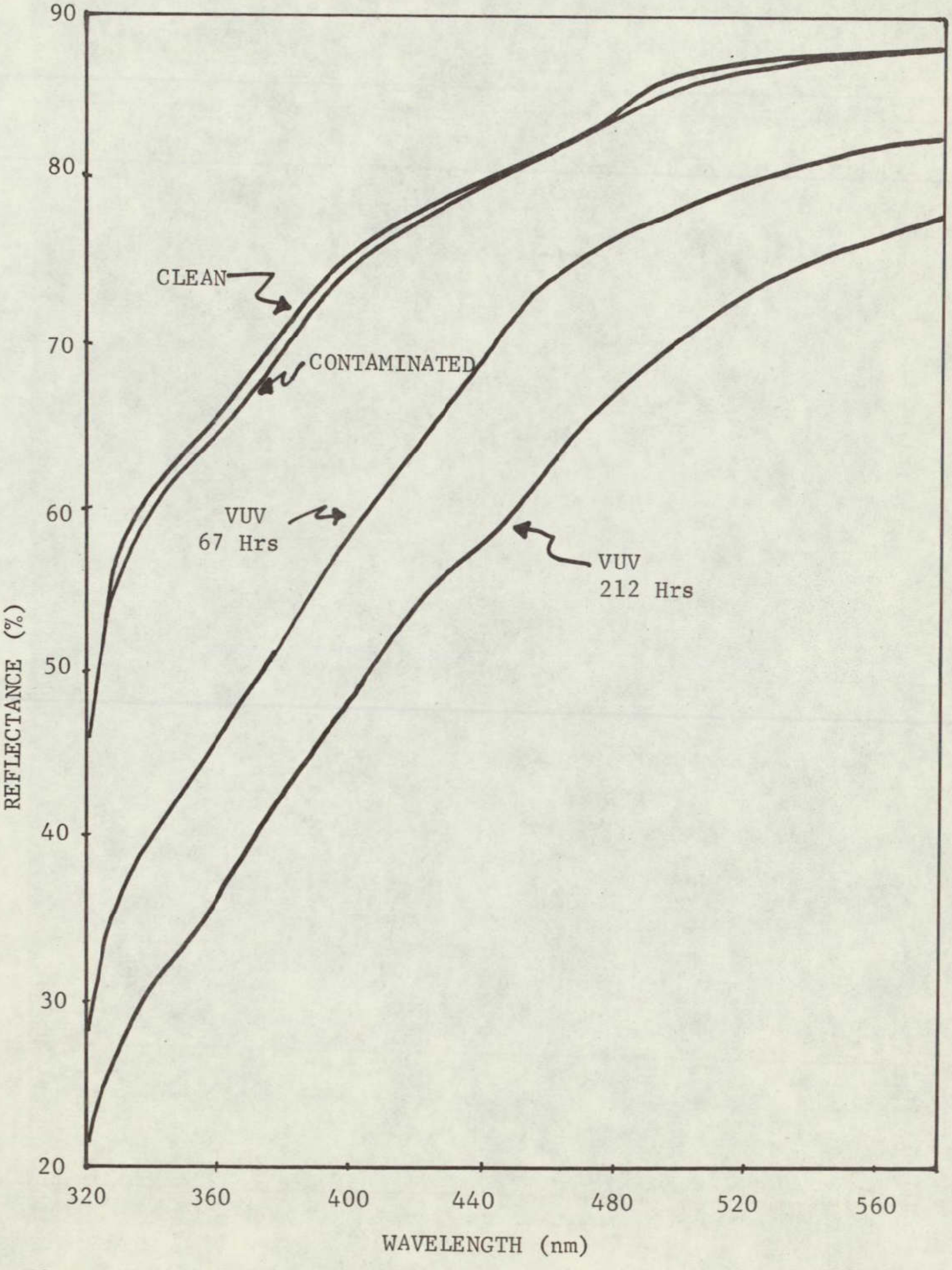

Figure 15 Reflectance versus Wavelength of Ag/FEP Sample 3B Contaminated by the CVCM from Hydraulic Fluid (Relative Thickness of 574 nm) and then Exposed to Vacuum Ultraviolet Radiation 124 nm, 1.3 EUVS.

Figure 16 Photograph of Ag/FEP Sample 3 Contaminated by the CVCM from Hydraulic Fluid (Relative Thickness Under Vacuum 574 nm) and Exposed to Vacuum Ultraviolet Radiation 124 nm for 212 Hrs. 25x.

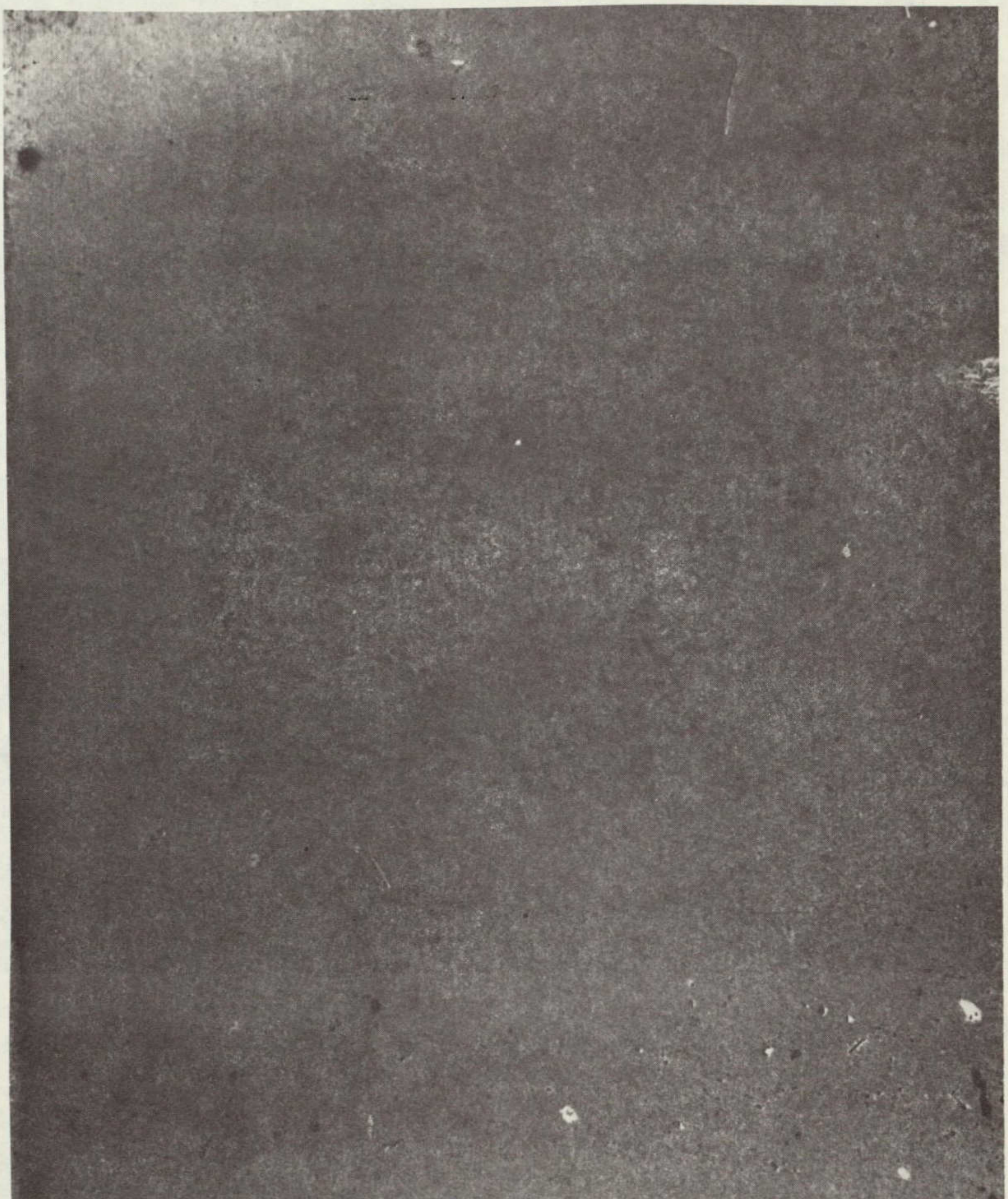

Figure 17 Photograph of Ag/FEP Sample 2 Contaminated by the CVCM from Hydraulic Fluid (Relative Thickness Under Vacuum 574 nm) and Exposed to Solar Simulation and Accidentally Vacuum Ultraviolet Radiation. 25x.

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Figure 18 Photograph of Ag/FEP Sample 1 Contaminated by the CVCM from Hydraulic Fluid (Relative Thickness Under Vacuum 574 nm) and Exposed to Vacuum Ultraviolet Radiation 147 nm for 212 Hrs. 10x.

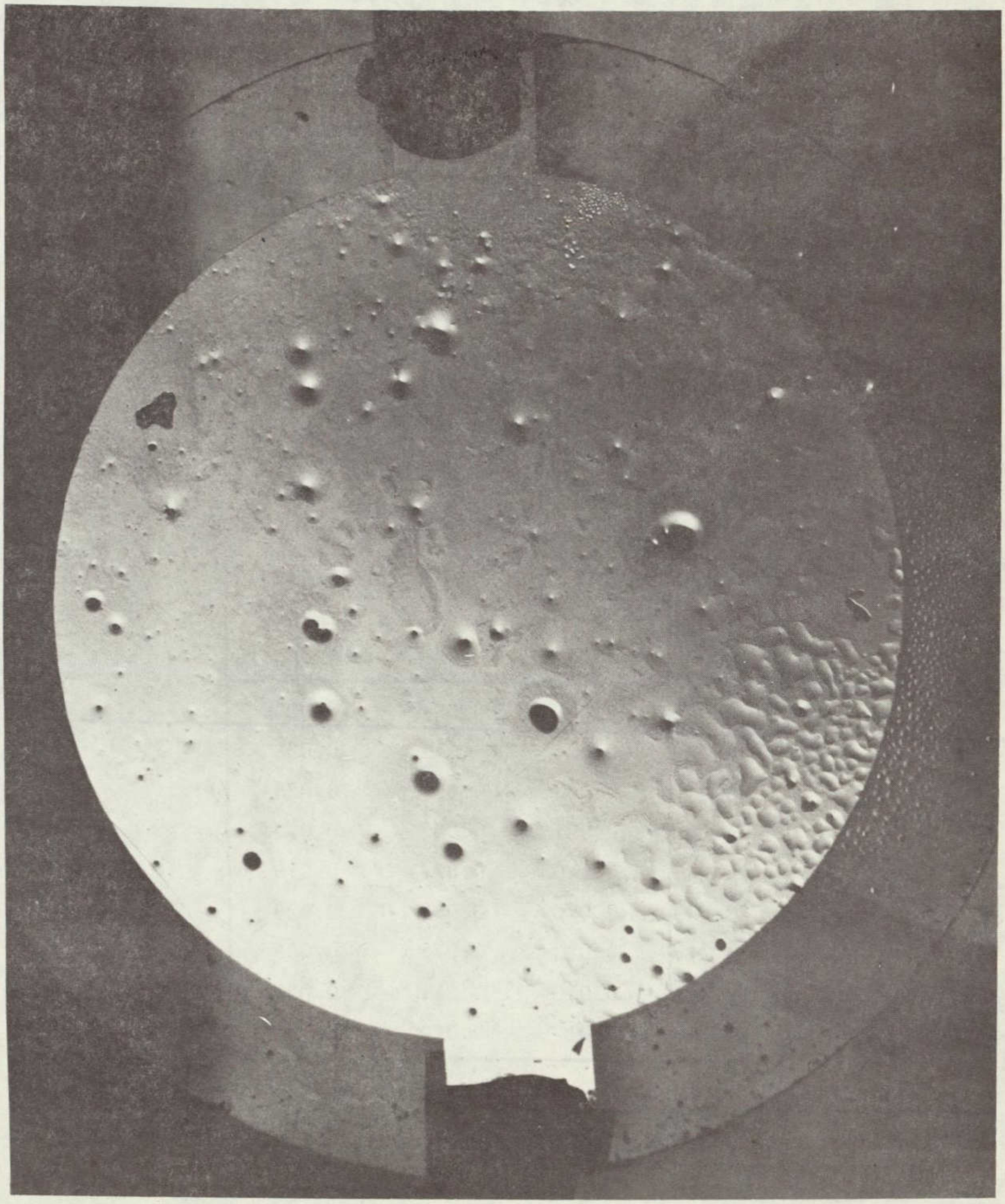

Figure 19 Photograph of the TQCM Crystal Contaminated by the CVCM from Hydraulic Fluid (Relative Thickness Under Vacuum 574 nm), Magnification 10x.

temperature of the fluid and the time of exposure because the TQCM was behaving erratically. The barium sulfate (100%) and the control sample became contaminated making it necessary to use the initial clean 100% values throughout the test. The values for the change in solar absorptance are not affected by the 100%, only the absolute value of α_s is affected.

Table 12 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282A Hydraulic Fluid From the Value of Clean Silver-Teflon. Three Deposition Steps - 1.27×10^{-5} g$\cdot$cm^{-2} (149 nm), 2.73×10^{-5} g$\cdot$cm^{-2} (320 nm), and 4.2×10^{-5} g$\cdot$cm^{-2} (490 nm). Maximum Fluid Temperature 38°C. Maximum Silver-Teflon Temperature During Deposition -46°C.

SAMPLE	CHANGE IN SOLAR ABSORPTANCE		
	(TQCM FREQUENCY IN Hz)		
	3267	7796	12000
3A	-0.040	0.021	-0.009
3B	-0.026	-0.012	-0.032
3C	0.038	0.023	0.028
2A	0.021	0.007	0.043
2B	0.010	0.022	0.016
2C	0.040	0.049	0.029
1A	0.033	0.079	0.065
1B	0.016	0.031	0.033
1C	0.012	0.020	0.040

The wide scatter in the solar absorptance values makes interpretation of the data in Table 12 difficult. However, using the values for solar absorptance in Tables 8-11 does allow a trend to be determined for the average change in α_s versus relative CVCM thickness. Figure 20 shows this increase in α_s leveling out at about 0.03.

The total CVCM of the three deposition steps was then exposed to vacuum ultraviolet radiation and solar simulation up to 86 hrs.

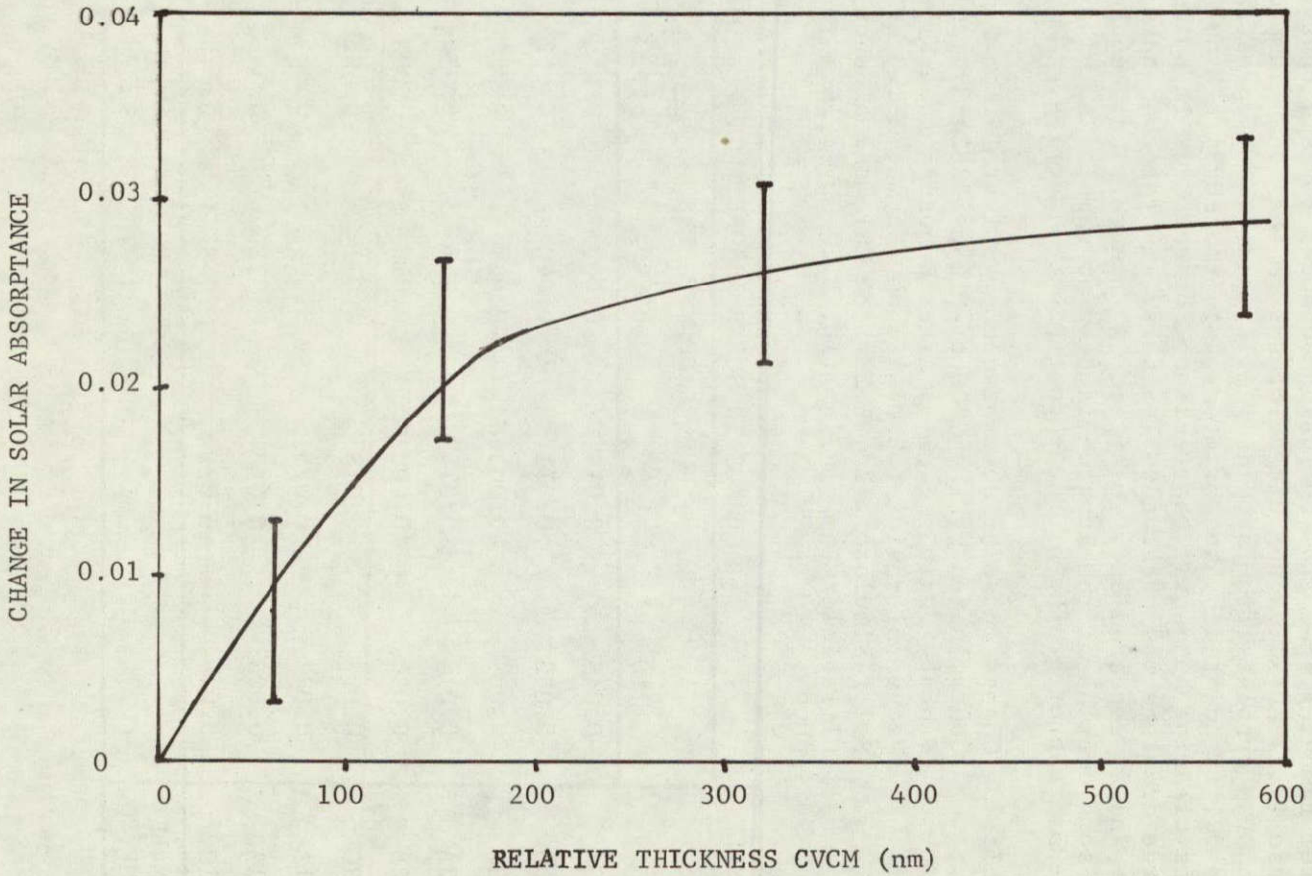

Figure 20 Average Change in Solar Absorptance of Ag/FEP Samples Contaminated by the CVCM From the Hydraulic Fluid Versus Thickness of CVCM Assuming a Specific Gravity of 0.85.

Table 13 presents the data for the change in solar absorptance versus time of exposure to radiation from the contaminated value at the start of the exposure. Once again, the wide scatter in the data makes interpretation difficult. The trend does indicate an overall return to the clean α_s values for the samples having vacuum ultraviolet radiation on them and a smaller decrease for the solar simulator radiation. Visual inspection of the samples after removing them from the vacuum chamber reveals that the intense (2.22 EUVS) vacuum ultraviolet from the xenon lamp cleared the CVCM droplets from samples 1A, 1B, and 1C. Samples 3A, 3B, and 3C, irradiated by the krypton lamp (1.3 EUVS, 124 nm), showed less clearing but still the tendency for the CVCM to collect in large droplets was observed. The solar simulator on samples 2A, 2B, and 2C appeared only to affect 2A; however, this could be due to some overlap of the krypton lamp on to sample 2A. Figures 21-23 are photographs of these contaminated samples.

Table 13 Change in Solar Absorptance of Silver-Teflon Samples Contaminated by the CVCM of MIL-H-83282A Hydraulic Fluid (About 4.2×10^{-5} $g\cdot cm^{-2}$) After Exposure to a Krypton Vacuum Ultraviolet Lamp 124 nm (3A,3B,3C 1.3 EUVS), Solar Simulator (2A,2B,2C 1.84 ES), and a Xenon Vacuum Ultraviolet Lamp 147 nm (1B, 2.22 EUVS; 1A,1C 0.050 EUVS).

SAMPLE	CHANGE IN SOLAR ABSORPTANCE			
	HOURS OF EXPOSURE			
	17.0	41.09	64.09	86.29
3A	-0.015	0.015	-0.003	-0.019
3B	-0.002	0.011	0.000	-0.002
3C	-0.005	-0.007	-0.029	-0.022
2A	0.014	-0.014	-0.011	-0.034
2B	0.028	-0.008	0.016	-0.003
2C	0.023	-0.018	0.011	-0.007
1A	-0.027	-0.025	0.004	-0.061
1B	0.003	-0.013	0.022	-0.045
1C	-0.016	-0.021	0.048	-0.040
SAMPLE TEMP. °C	-42.4	-68.4	-52.7	-53.7

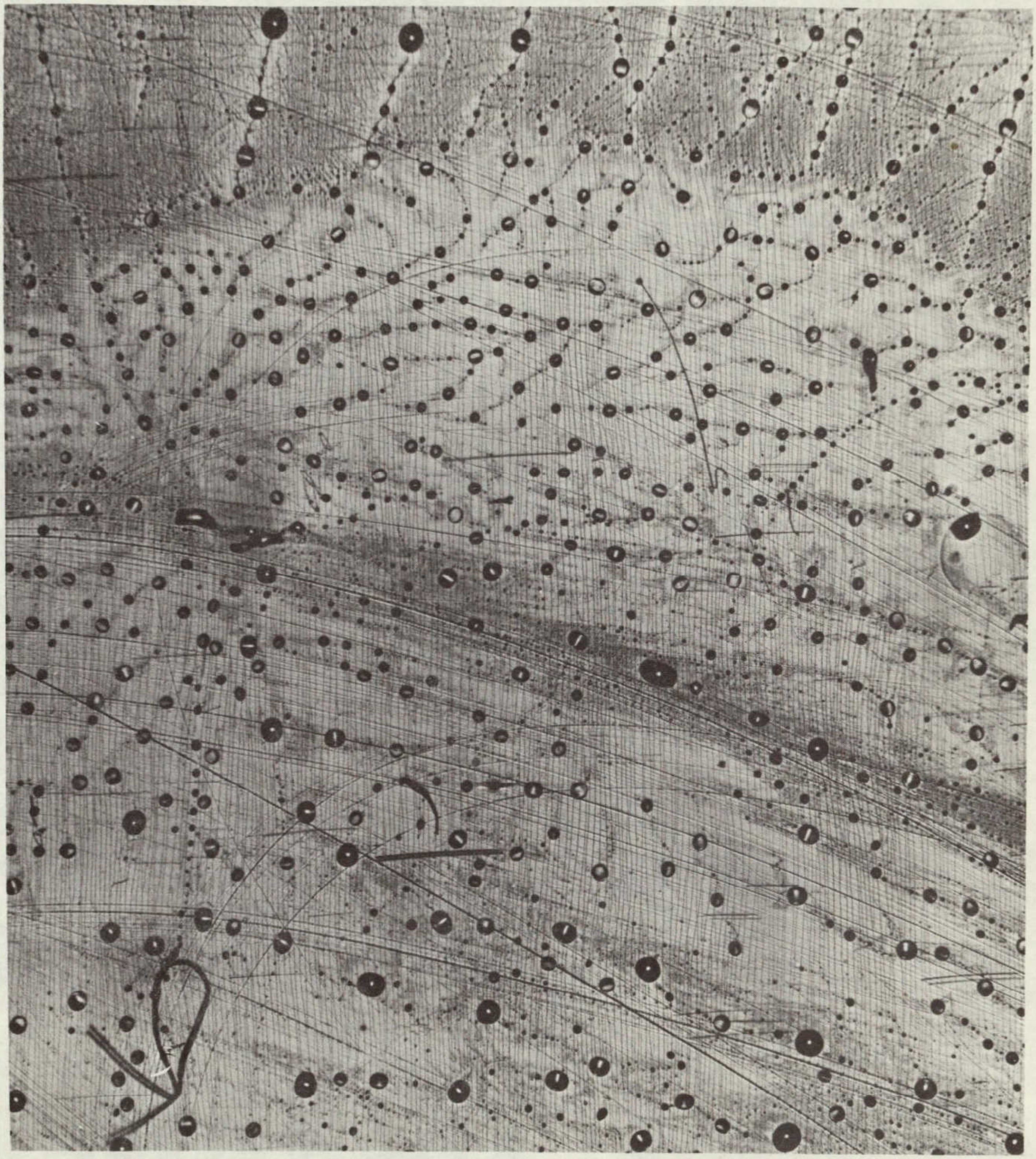

Figure 21 Photograph of Ag/FEP Sample 3 Contaminated by Hydraulic Fluid CVCM (Relative Thickness Under Vacuum 490 nm) and Exposed to Vacuum Ultraviolet Radiation 124 nm for 86 Hours. Magnification 25x.

Figure 22 Photograph of Ag/FEP Sample 2 Contaminated by Hydraulic Fluid CVCM (Relative Thickness Under Vacuum 490 nm) and Exposed to Solar Simulation for 86 Hours. 25x.

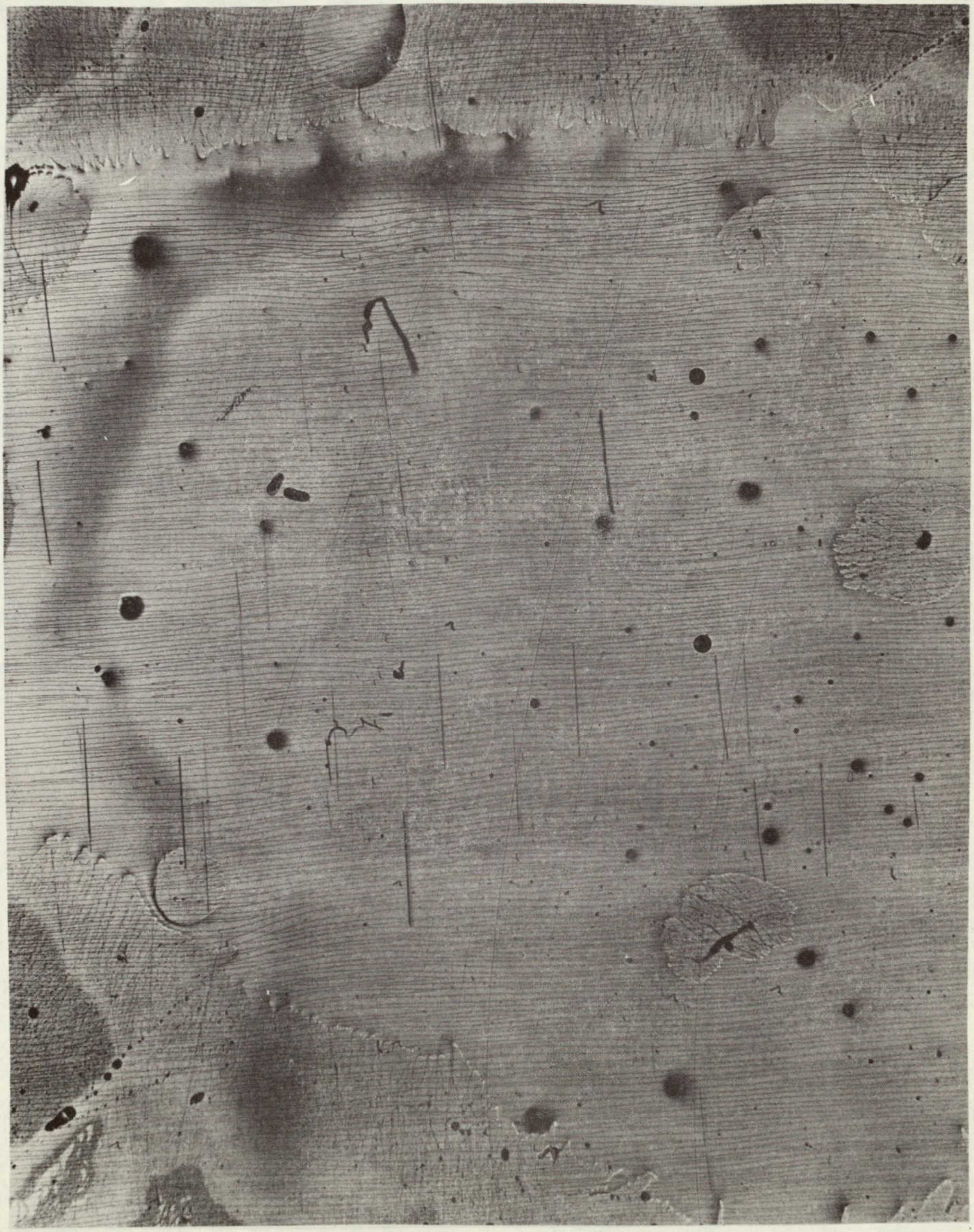

Figure 23 Photograph of Ag/FEP Sample 1 Contaminated by Hydraulic Fluid CVCM (Relative Thickness Under Vacuum 490 nm) and Exposed to Vacuum Ultraviolet Radiation 147 nm for 86 Hours. Magnification 25x.

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4.4 Cleaning Test Results - Sample 1B from Table 5 contaminated by RTV-560 CVCM and exposed to 370 EUVSH and sample 3B from Table 10 contaminated by hydraulic fluid CVCM and exposed to 148 EUVSH were cleaned by wiping the surface with a solution of 80% trichloroethane and 20% methyl alcohol. Excess wiping was avoided to prevent scratching the Teflon surface. The visual contaminant was easily removed by the solution. The solar absorptance was remeasured after cleaning and verified the return to a clean state.

4.5 Additional Test On Fluorocarbon #4334-112 - Samples provided by the Pennwalt Corporation of fluorocarbon #4334-112 were exposed in vacuum to the solar simulator to determine any degradation. The results are shown in appendix B.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This test program shows that for the current estimates of deposition rates on the Ag/FEP (total flux for all sources is $14 \cdot \mathrm{nm} \cdot \mathrm{day}^{-1}$), the fraction that would represent RTV-560 CVCM and hydraulic fluid CVCM depositing and remaining under normal conditions (Ag/FEP temperatures much greater than -40°C) would not seriously degrade the performance of this thermal control surface. Any residual CVCM from RTV-560 or hydraulic fluid can easily be removed from Ag/FEP by wiping with flannel saturated with a solution of trichloroethane and methyl alcohol.

The stability of Ag/FEP to a vacuum environment and solar radiation, especially vacuum ultraviolet wavelengths, up to 370 EUVSH was verified. Although a geometrical factor produced solar absorptance values differing from the nominal 0.08, the sensitivity and repeatability of the instrumentation and analysis techniques were sufficient to determine a change of α_s less than 0.01.

Temperatures below -40°C were necessary to inhibit significant reemission of the RTV-560 CVCM. The CVCM from a fresh RTV-560 source almost entirely reemits when the contaminated Ag/FEP reaches room temperature (20°C). RTV-560 sources that were used repeatedly produce a CVCM that will remain on the surface at 20°C (for one case 42% of the CVCM remained). The RTV-560 CVCM was colorless (RTV-560 is red) and did not darken when exposed to solar radiation up to 2.74 EUVS for 370 EUVSH.

Temperatures below -50°C were necessary to inhibit significant reemission of the hydraulic fluid CVCM. The CVCM did not entirely reemit when reaching 20°C only when very large amounts were deposited or the vacuum ultraviolet radiation affected the contaminant. The hydraulic fluid CVCM was colorless (the basic fluid was red) and turned a very pale yellow for one of the four exposures to vacuum ultraviolet radiation.

The change in α_s was not a linear function of the amount of RTV-560 CVCM. The major increase in α_s occurs for CVCM at least as small as a 28 nm equivalent film thickness. Increasing the surface density of CVCM by a factor of 13 only increased the change in α_s by about 0.04. The α_s of the contaminated Ag/FEP was not affected by solar radiation (wavelengths greater than 250 nm, 313 ESH) nor vacuum ultraviolet radiation (147 nm, 370 EUVSH; 124 nm, 82 EUVSH).

The change in α_s was not a linear function of the amount of hydraulic fluid CVCM. The major increase in α_s occurs for CVCM up to an equivalent film thickness of about 200 nm. This increase in α_s appears to level off just below 0.03 for films up to thicknesses of 600 nm. In only one of the four tests using hydraulic fluid did the α_s increase with the period of radiation exposure. Another test under similar conditions failed to duplicate this effect, however there was an indication that the TQCM frequency was in error and the thickness of the CVCM was much greater than planned. The highest energy radiation (124 nm) for this one test had the greatest effect, increasing α_s by 0.1 in 276 EUVSH. This reduction in reflectance by the irradiated contaminant has a spectral character of increasing as the wavelength becomes shorter (toward the ultraviolet).

The RTV-560 CVCM and the hydraulic fluid CVCM that remains on the Ag/FEP surface at temperatures near 20°C was deposited uniformly in small droplets. The droplets can combine occupying a smaller surface area then the sum of the individual droplets. Thus, an initial increase in α_s can be decreased by both reemission of the CVCM and by large droplet formation. This decrease in α_s was not observed in the accidently contaminated white barium sulfate paint. Since no radiation strikes the paint, only reemission can reduce the measured α_s increase. The large increase in α_s for this paint remained, indicating that solar radiation may be more dominant in reducing the change in α_s.

Vacuum ultraviolet radiation up to 370 EUVSH on the RTV-560 CVCM and 148 EUVSH on the hydraulic fluid CVCM did not prevent easy removal and restoration by a solution of trichloroethane and methyl alcohol. This cleaning technique, wiping with flannel saturated with the solution, is applicable to the Shuttle orbiter bay door Ag/FEP surfaces.

Potential future test programs should include additional tests to determine if the observed single test increase in α_s with vacuum ultraviolet radiation is valid and a critical thickness exists. Potential synergetic effects on α_s by simultaneously depositing two or more contaminants and irradiating with two or more vacuum ultraviolet sources should be studied.

APPENDIX A

DATA OUTPUTS

The data taken during the Ag/FEP program were as follows:

1. Reflectance versus wavelength, analog, chart recording;
2. Detector voltage versus wavelength, digital, computer punch cards;
3. Temperature of RTV-560, analog, chart recording;
4. Temperature of Ag/FEP sample #1 or sample #2 or sample #3 or shroud, analog, chart recording;
5. Temperature of hydraulic fluid, analog, chart recording;
6. Temperature of micropore disc, analog, chart recording;
7. Temperature of TQCM, digital, meter;
8. Frequency of TQCM, digital, paper tape; and
9. Solar simulator on time, analog, chart recording.

The computer punch card data was processed by a computer program to determine the solar absorptance of the sample. Figure A-1 shows an example of the computer processing for the control sample after 44.58 hours of exposure from Table 2. The first column shows the wavelength in μm, the second column shows the solar intensity in $w \cdot m^{-2} \cdot \mu m^{-1}$, the third column presents the absolute reflectance of barium sulfate, the fourth column presents the relative voltage output of the detector with the barium sulfate sample in position, the fifth column shows the relative voltage output of the detector with the test sample (control) in position, the sixth column shows the product of the absolute reflectance of barium sulfate times the ratio of the test sample detector voltage to the barium sulfate detector voltage, and column seven shows the product of the solar intensity times the value in column six. The computer program

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integrates the area under the curve of NSOLAR (seventh column) versus wavelength (first column) and calculates the solar absorptance as shown in Figure A-1. Figure A-2 shows the computer plot of the test sample (control) reflectance versus wavelength. Figure A-3 shows the computer plot of the solar intensity (ELAM) and NSOLAR (product of reflectance times solar intensity) versus wavelength.

```
 ++++ ALPHA SUB S SOLUTION (JSC)  ++++
SILVER-TEFLON TEST (CONTROL) 44.58 HRS 0.0HZ  02/06/78


LAMBA       ELAM       RBASUL     DK100        REFLECT     REFLECT    NSOLAR
  (UM)    W/M-2/U-1    ++++       ++++         (INPUT)      (CAL)     (CAL)
 2.50000    55.00000      .87400          460         517       .98230   54.02650
 1.95000   114.00000      .88900          460         517       .99916  113.90409
 1.87000   136.00000      .89700          564         627       .99720  135.61877
 1.80000   159.00000      .89700          606         675       .99913  158.86225
 1.73000   189.00000      .89700          607         669       .98862  186.84939
 1.65000   223.00000      .89700          611         667       .97921  218.36445
 1.55000   267.00000      .89700          606         661       .97841  261.23571
 1.47000   294.00000      .89700          598         651       .97650  287.09100
 1.38000   345.00000      .89700          596         652       .98128  338.54225
 1.30000   397.00000      .89700          606         658       .97397  386.66621
 1.20000   485.00000      .89500          605         643       .95121  461.33921
 1.12000   570.00000      .89200          582         613       .93951  535.52186
 1.03000   700.00000      .89400          575         600       .93287  653.00870
  .67500  1442.00000      .88900          663         684       .91716 1322.54237
  .64200  1591.00000      .88100          672         681       .89280 1420.44338
  .61000  1635.00000      .88300          661         670       .89502 1463.36210
  .58000  1715.00000      .88300          652         647       .87623 1502.73192
  .55500  1720.00000      .87800          621         621       .87800 1510.16000
  .52000  1833.00000      .87500          619         614       .86793 1590.91963
  .51000  1682.00000      .87500          613         605       .86358 1625.25897
  .49000  1950.00000      .87500          602         596       .86628 1689.24419
  .47400  2042.00000      .87000          626         594       .82553 1685.72645
  .46000  2066.00000      .87000          595         603       .88170 1821.58699
  .44600  1939.00000      .86800          583         560       .83376 1616.65372
  .44300  1653.00000      .86800          608         550       .78520 1297.93125
  .42300  1715.00000      .86600          610         551       .78224 1341.54048
  .41200  1760.00000      .86600          607         544       .77612 1365.96876
  .40400  1601.00000      .86300          611         535       .75565 1209.80312
  .39300  1153.00000      .86000          610         521       .73452  846.90685
  .38500  1098.00000      .85700          606         519       .73397  805.89395
  .37700  1142.00000      .85400          608         493       .69247  790.80119
  .37000  1181.00000      .85100          607         481       .67435  796.40842
  .36300  1170.00000      .84800          611         466       .64676  756.70468
  .35700  1077.00000      .84600          612         455       .62897  677.40132
  .35100  1091.00000      .84300          610         444       .61359  669.43045
  .34500  1069.00000      .84000          609         438       .60414  645.82345
  .34000  1074.00000      .83800          609         430       .59169  635.47645
  .33400  1077.00000      .83200          608         420       .57474  618.99158
  .33000  1059.00000      .83200          611         398       .54196  573.93294
  .32500   975.00000      .82900          605         360       .49329  480.95702
  .32100   859.00000      .82400          598         300       .41338  355.09164
  .31700   790.00000      .82100          600         199       .27230  215.11568
  .31200   719.00000      .81200          594          93       .12713   91.40741
  .25000    70.40000      .75400          594          93       .11805    8.31076

  LAM(I-1) =  .2500E+01 LAM(I) =  .1950E+01 DELLAM=  .5500E+00
  SOL(I-1)=  .5403E+02 SOL(I)=  .1139E+03 TOTSOL = .8397E+02
  DELTA AREA=  .4618E+02 ACCUM AREA=  .4618E+02

  LAM(I-1) =  .1950E+01 LAM(I) =  .1870E+01 DELLAM=  .8000E-01
  SOL(I-1)=  .1139E+03 SOL(I)=  .1356E+03 TOTSOL = .1248E+03
  DELTA AREA=  .9981E+01 ACCUM AREA=  .5616E+02
```

Figure A-1 Computer Tabulation for Solar Absorptance.

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```
LAM(I-1) =  .1870E+01 LAM(I) =  .1800E+01 DELLAM=  .7000E-01
SOL(I-1)=  .1356E+03 SOL(I)=  .1589E+03 TOTSOL = .1472E+03
DELTA AREA=  .1031E+02 ACCUM AREA=  .6647E+02

LAM(I-1) =  .1800E+01 LAM(I) =  .1730E+01 DELLAM=  .7000E-01
SOL(I-1)=  .1589E+03 SOL(I)=  .1868E+03 TOTSOL = .1729E+03
DELTA AREA=  .1210E+02 ACCUM AREA=  .7857E+02

LAM(I-1) =  .1730E+01 LAM(I) =  .1650E+01 DELLAM=  .8000E-01
SOL(I-1)=  .1868E+03 SOL(I)=  .2184E+03 TOTSOL = .2026E+03
DELTA AREA=  .1621E+02 ACCUM AREA=  .9478E+02

LAM(I-1) =  .1650E+01 LAM(I) =  .1550E+01 DELLAM=  .1000E+00
SOL(I-1)=  .2184E+03 SOL(I)=  .2612E+03 TOTSOL = .2398E+03
DELTA AREA=  .2398E+02 ACCUM AREA=  .1188E+03

LAM(I-1) =  .1550E+01 LAM(I) =  .1470E+01 DELLAM=  .8000E-01
SOL(I-1)=  .2612E+03 SOL(I)=  .2871E+03 TOTSOL = .2742E+03
DELTA AREA=  .2193E+02 ACCUM AREA=  .1407E+03

LAM(I-1) =  .1470E+01 LAM(I) =  .1380E+01 DELLAM=  .9000E-01
SOL(I-1)=  .2871E+03 SOL(I)=  .3385E+03 TOTSOL = .3128E+03
DELTA AREA=  .2815E+02 ACCUM AREA=  .1688E+03

LAM(I-1) =  .1380E+01 LAM(I) =  .1300E+01 DELLAM=  .8000E-01
SOL(I-1)=  .3385E+03 SOL(I)=  .3867E+03 TOTSOL = .3626E+03
DELTA AREA=  .2901E+02 ACCUM AREA=  .1979E+03

LAM(I-1) =  .1300E+01 LAM(I) =  .1200E+01 DELLAM=  .1000E+00
SOL(I-1)=  .3867E+03 SOL(I)=  .4613E+03 TOTSOL = .4240E+03
DELTA AREA=  .4240E+02 ACCUM AREA=  .2403E+03

LAM(I-1) =  .1200E+01 LAM(I) =  .1120E+01 DELLAM=  .8000E-01
SOL(I-1)=  .4613E+03 SOL(I)=  .5355E+03 TOTSOL = .4984E+03
DELTA AREA=  .3987E+02 ACCUM AREA=  .2801E+03

LAM(I-1) =  .1120E+01 LAM(I) =  .1030E+01 DELLAM=  .9000E-01
SOL(I-1)=  .5355E+03 SOL(I)=  .6530E+03 TOTSOL = .5943E+03
DELTA AREA=  .5348E+02 ACCUM AREA=  .3336E+03

LAM(I-1) =  .1030E+01 LAM(I) =  .6750E+00 DELLAM=  .3550E+00
SOL(I-1)=  .6530E+03 SOL(I)=  .1323E+04 TOTSOL = .9878E+03
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LAM(I-1) =  .6750E+00 LAM(I) =  .6420E+00 DELLAM=  .3300E-01
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DELTA AREA=  .4526E+02 ACCUM AREA=  .7295E+03

LAM(I-1) =  .6420E+00 LAM(I) =  .6100E+00 DELLAM=  .3200E-01
SOL(I-1)=  .1420E+04 SOL(I)=  .1463E+04 TOTSOL = .1442E+04
DELTA AREA=  .4614E+02 ACCUM AREA=  .7757E+03

LAM(I-1) =  .6100E+00 LAM(I) =  .5800E+00 DELLAM=  .3000E-01
SOL(I-1)=  .1463E+04 SOL(I)=  .1503E+04 TOTSOL = .1483E+04
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LAM(I-1) =  .5800E+00 LAM(I) =  .5550E+00 DELLAM=  .2500E-01
SOL(I-1)=  .1503E+04 SOL(I)=  .1510E+04 TOTSOL = .1506E+04
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LAM(I-1) =  .5550E+00 LAM(I) =  .5200E+00 DELLAM=  .3500E-01
SOL(I-1)=  .1510E+04 SOL(I)=  .1591E+04 TOTSOL = .1551E+04
```

Figure A-1 Computer Tabulation for Solar Absorptance - Continued.

```
DELTA AREA=  .5427E+02 ACCUM AREA=  .9121E+03

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SOL(I-1)=  .1591E+04 SOL(I)=  .1625E+04 TOTSOL = .1608E+04
DELTA AREA=  .1608E+02 ACCUM AREA=  .9282E+03

LAM(I-1) =  .5100E+00 LAM(I) =  .4900E+00 DELLAM=  .2000E-01
SOL(I-1)=  .1625E+04 SOL(I)=  .1689E+04 TOTSOL = .1657E+04
DELTA AREA=  .3315E+02 ACCUM AREA=  .9613E+03

LAM(I-1) =  .4900E+00 LAM(I) =  .4740E+00 DELLAM=  .1600E-01
SOL(I-1)=  .1689E+04 SOL(I)=  .1686E+04 TOTSOL = .1687E+04
DELTA AREA=  .2700E+02 ACCUM AREA=  .9883E+03

LAM(I-1) =  .4740E+00 LAM(I) =  .4600E+00 DELLAM=  .1400E-01
SOL(I-1)=  .1686E+04 SOL(I)=  .1822E+04 TOTSOL = .1754E+04
DELTA AREA=  .2455E+02 ACCUM AREA=  .1013E+04

LAM(I-1) =  .4600E+00 LAM(I) =  .4460E+00 DELLAM=  .1400E-01
SOL(I-1)=  .1822E+04 SOL(I)=  .1617E+04 TOTSOL = .1719E+04
DELTA AREA=  .2407E+02 ACCUM AREA=  .1037E+04

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LAM(I-1) =  .4430E+00 LAM(I) =  .4230E+00 DELLAM=  .2000E-01
SOL(I-1)=  .1298E+04 SOL(I)=  .1342E+04 TOTSOL = .1320E+04
DELTA AREA=  .2639E+02 ACCUM AREA=  .1068E+04

LAM(I-1) =  .4230E+00 LAM(I) =  .4120E+00 DELLAM=  .1100E-01
SOL(I-1)=  .1342E+04 SOL(I)=  .1366E+04 TOTSOL = .1354E+04
DELTA AREA=  .1489E+02 ACCUM AREA=  .1083E+04

LAM(I-1) =  .4120E+00 LAM(I) =  .4040E+00 DELLAM=  .8000E-02
SOL(I-1)=  .1366E+04 SOL(I)=  .1210E+04 TOTSOL = .1288E+04
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SOL(I-1)=  .1210E+04 SOL(I)=  .8469E+03 TOTSOL = .1028E+04
DELTA AREA=  .1131E+02 ACCUM AREA=  .1104E+04

LAM(I-1) =  .3930E+00 LAM(I) =  .3850E+00 DELLAM=  .8000E-02
SOL(I-1)=  .8469E+03 SOL(I)=  .8059E+03 TOTSOL = .8264E+03
DELTA AREA=  .6611E+01 ACCUM AREA=  .1111E+04

LAM(I-1) =  .3850E+00 LAM(I) =  .3770E+00 DELLAM=  .8000E-02
SOL(I-1)=  .8059E+03 SOL(I)=  .7908E+03 TOTSOL = .7983E+03
DELTA AREA=  .6387E+01 ACCUM AREA=  .1117E+04

LAM(I-1) =  .3770E+00 LAM(I) =  .3700E+00 DELLAM=  .7000E-02
SOL(I-1)=  .7908E+03 SOL(I)=  .7964E+03 TOTSOL = .7936E+03
DELTA AREA=  .5555E+01 ACCUM AREA=  .1123E+04

LAM(I-1) =  .3700E+00 LAM(I) =  .3630E+00 DELLAM=  .7000E-02
SOL(I-1)=  .7964E+03 SOL(I)=  .7567E+03 TOTSOL = .7766E+03
DELTA AREA=  .5436E+01 ACCUM AREA=  .1128E+04

LAM(I-1) =  .3630E+00 LAM(I) =  .3570E+00 DELLAM=  .6000E-02
SOL(I-1)=  .7567E+03 SOL(I)=  .6774E+03 TOTSOL = .7171E+03
DELTA AREA=  .4302E+01 ACCUM AREA=  .1133E+04

LAM(I-1) =  .3570E+00 LAM(I) =  .3510E+00 DELLAM=  .6000E-02
```

Figure A-1 Computer Tabulation for Solar Absorptance - Continued.

```
SOL(I-1)=  .6774E+03 SOL(I)=  .6694E+03 TOTSOL = .6734E+03
DELTA AREA=  .4040E+01 ACCUM AREA=  .1137E+04

LAM(I-1) =  .3510E+00 LAM(I) =  .3450E+00 DELLAM=  .6000E-02
SOL(I-1)=  .6694E+03 SOL(I)=  .6458E+03 TOTSOL = .6576E+03
DELTA AREA=  .3946E+01 ACCUM AREA=  .1140E+04

LAM(I-1) =  .3450E+00 LAM(I) =  .3400E+00 DELLAM=  .5000E-02
SOL(I-1)=  .6458E+03 SOL(I)=  .6355E+03 TOTSOL = .6406E+03
DELTA AREA=  .3203E+01 ACCUM AREA=  .1144E+04

LAM(I-1) =  .3400E+00 LAM(I) =  .3340E+00 DELLAM=  .6000E-02
SOL(I-1)=  .6355E+03 SOL(I)=  .6190E+03 TOTSOL = .6272E+03
DELTA AREA=  .3763E+01 ACCUM AREA=  .1147E+04

LAM(I-1) =  .3340E+00 LAM(I) =  .3300E+00 DELLAM=  .4000E-02
SOL(I-1)=  .6190E+03 SOL(I)=  .5739E+03 TOTSOL = .5965E+03
DELTA AREA=  .2386E+01 ACCUM AREA=  .1150E+04

LAM(I-1) =  .3300E+00 LAM(I) =  .3250E+00 DELLAM=  .5000E-02
SOL(I-1)=  .5739E+03 SOL(I)=  .4810E+03 TOTSOL = .5274E+03
DELTA AREA=  .2637E+01 ACCUM AREA=  .1152E+04

LAM(I-1) =  .3250E+00 LAM(I) =  .3210E+00 DELLAM=  .4000E-02
SOL(I-1)=  .4810E+03 SOL(I)=  .3551E+03 TOTSOL = .4180E+03
DELTA AREA=  .1672E+01 ACCUM AREA=  .1154E+04

LAM(I-1) =  .3210E+00 LAM(I) =  .3170E+00 DELLAM=  .4000E-02
SOL(I-1)=  .3551E+03 SOL(I)=  .2151E+03 TOTSOL = .2851E+03
DELTA AREA=  .1140E+01 ACCUM AREA=  .1155E+04

LAM(I-1) =  .3170E+00 LAM(I) =  .3120E+00 DELLAM=  .5000E-02
SOL(I-1)=  .2151E+03 SOL(I)=  .9141E+02 TOTSOL = .1533E+03
DELTA AREA=  .7663E+00 ACCUM AREA=  .1156E+04

LAM(I-1) =  .3120E+00 LAM(I) =  .2500E+00 DELLAM=  .6200E-01
SOL(I-1)=  .9141E+02 SOL(I)=  .8311E+01 TOTSOL = .4986E+02
DELTA AREA=  .3091E+01 ACCUM AREA=  .1159E+04


 INTEGRATED ALPHA SUB S =     .06914
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Figure A-1 Computer Tabulation for Solar Absorptance - Continued.

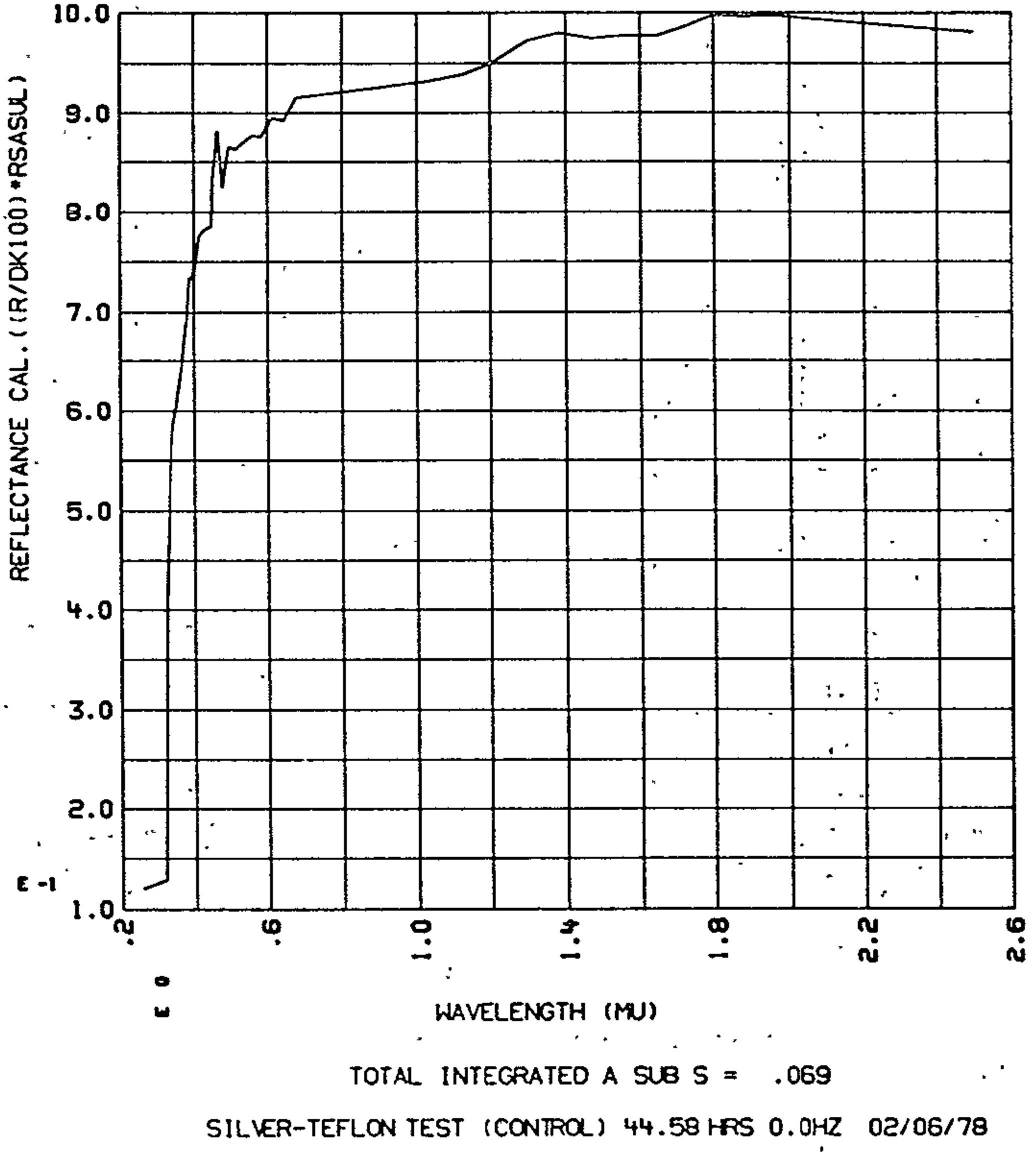

Figure A-2 Computer Plot Reflectance Versus Wavelength.

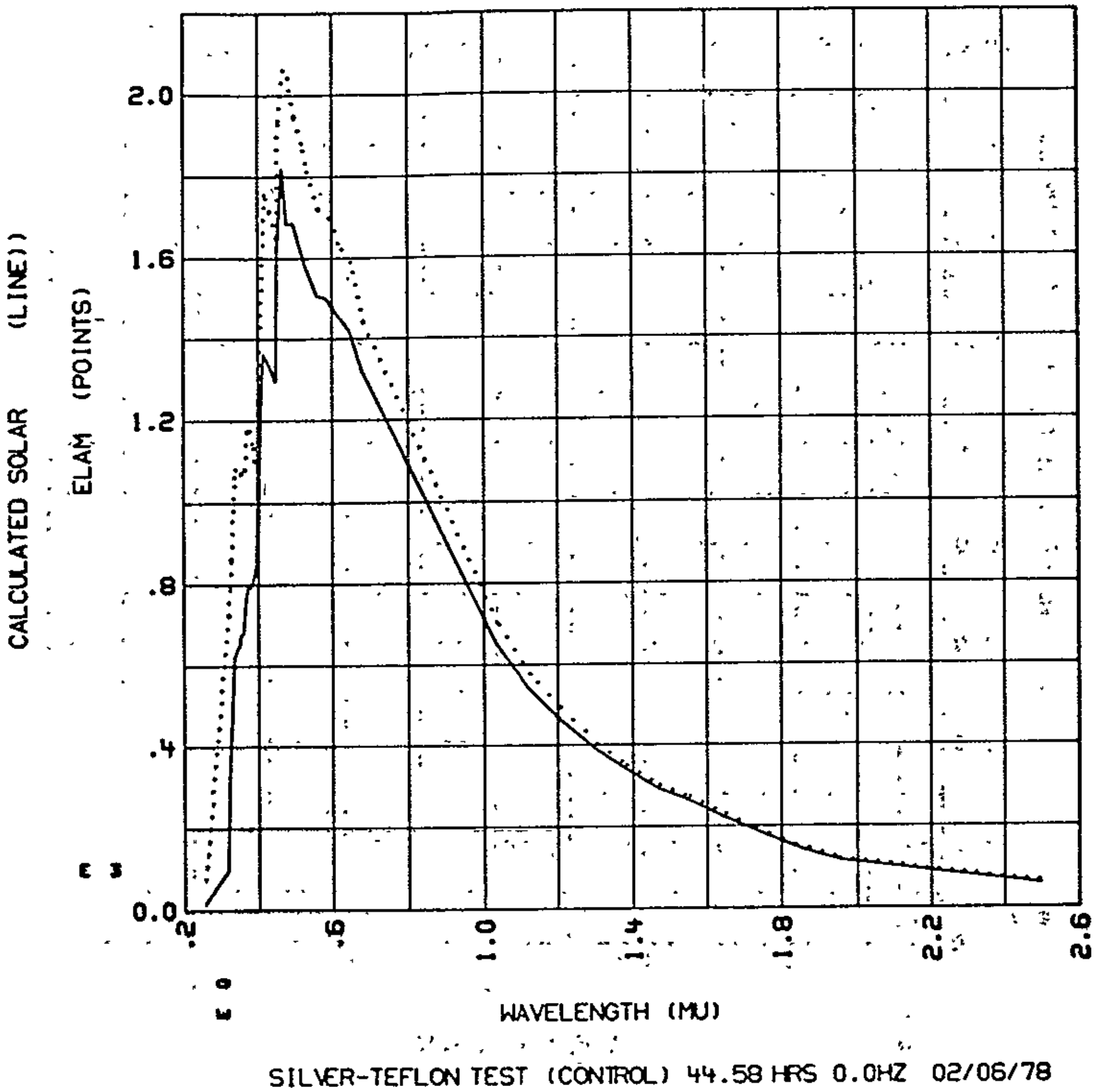

Figure A-3 Computer Plot of Solar Intensity (ELAM) and NSOLAR Versus Wavelength.

APPENDIX B

FLUOROCARBON 4334-112 TEST

Four disks coated with Pennwalt Corp. fluorocarbon #4334-112 were selected (pigment TiO_2/ZnO in 9/1 ratio) to measure any change in solar absorptance (α_s) when exposed in vacuum to a simulated solar beam (X-25 Solar Simulator). The white surface of the samples appeared mottled and subsequent discussions determined that the paint was sprayed on with an air brush in a single pass. The reflectance of the four discs was measured in-situ at several intervals during the solar beam exposure (2.5 ES) of 47.95 hrs. Only three of the discs were exposed to the solar beam, the fourth was kept as a control sample. This control sample showed changes of α_s of ±5%. Figure B-1 illustrates the reflectance spectrum of sample 3 after 120 ESH. Figure B-2 shows the plot of the product, reflectance times the normalized solar spectrum, as a function of wavelength. Table B-1 shows the increase in α_s for this coating versus solar exposure.

Table B-1 Average Solar Absorptance Versus Hours of Solar Exposure for Fluorocarbon 4334-112

ESH	SOLAR ABSORPTANCE	PERCENT CHANGE SOLAR ABSORPTANCE PER UNIT TIME (%/Hr)
0	0.216	
5.8	0.219	0.00239
7.6	0.228	0.00731
50.2	0.270	0.00498
79.0	0.288	0.00422
120.	0.317	0.00390

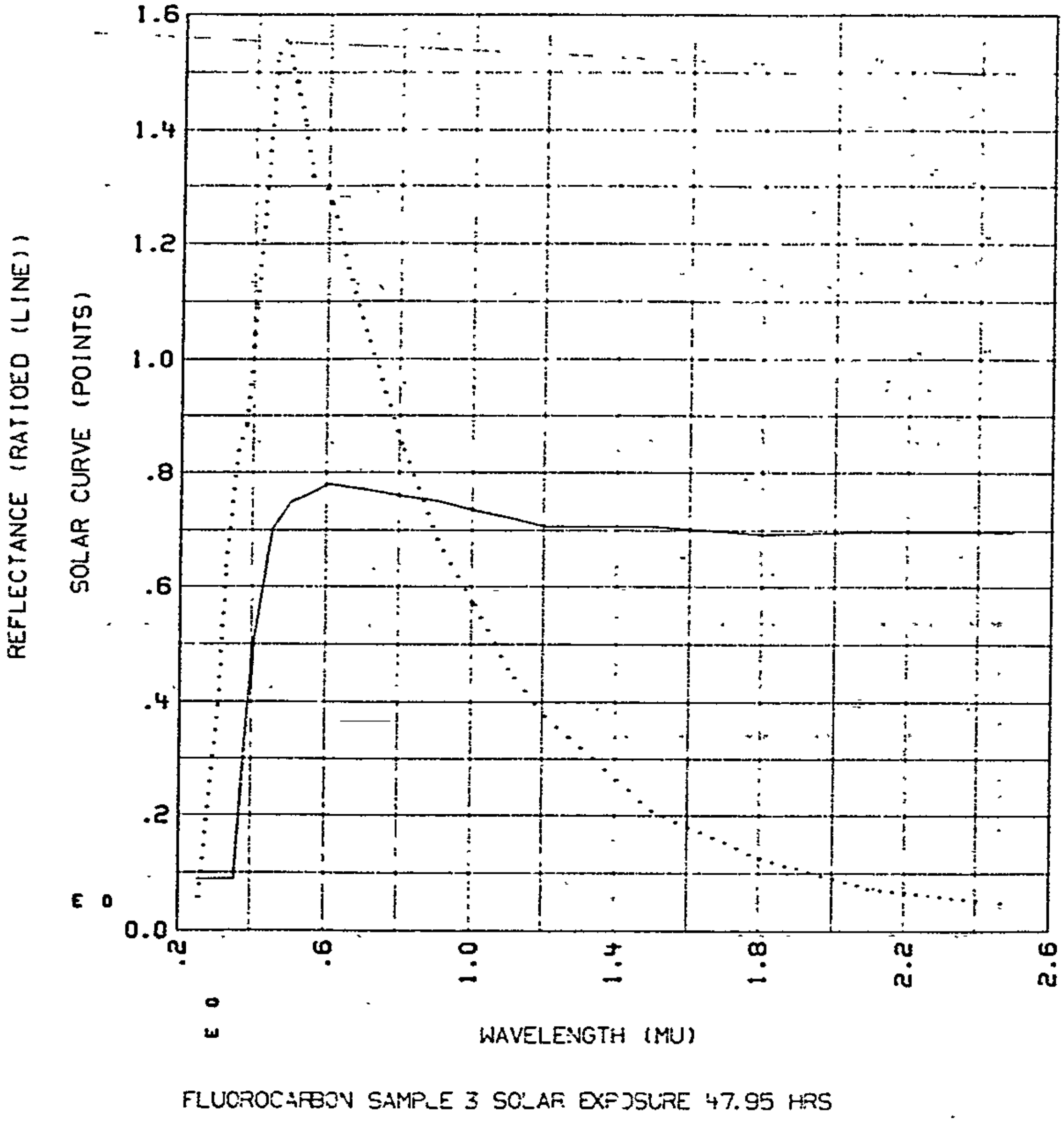

Figure B-1 Reflectance Versus Wavelength for Fluorocarbon Sample 3 Exposed for 47.95 Hrs to 2.5 ES. Normalized Solar Spectrum Versus Wavelength in the Dashed Line.

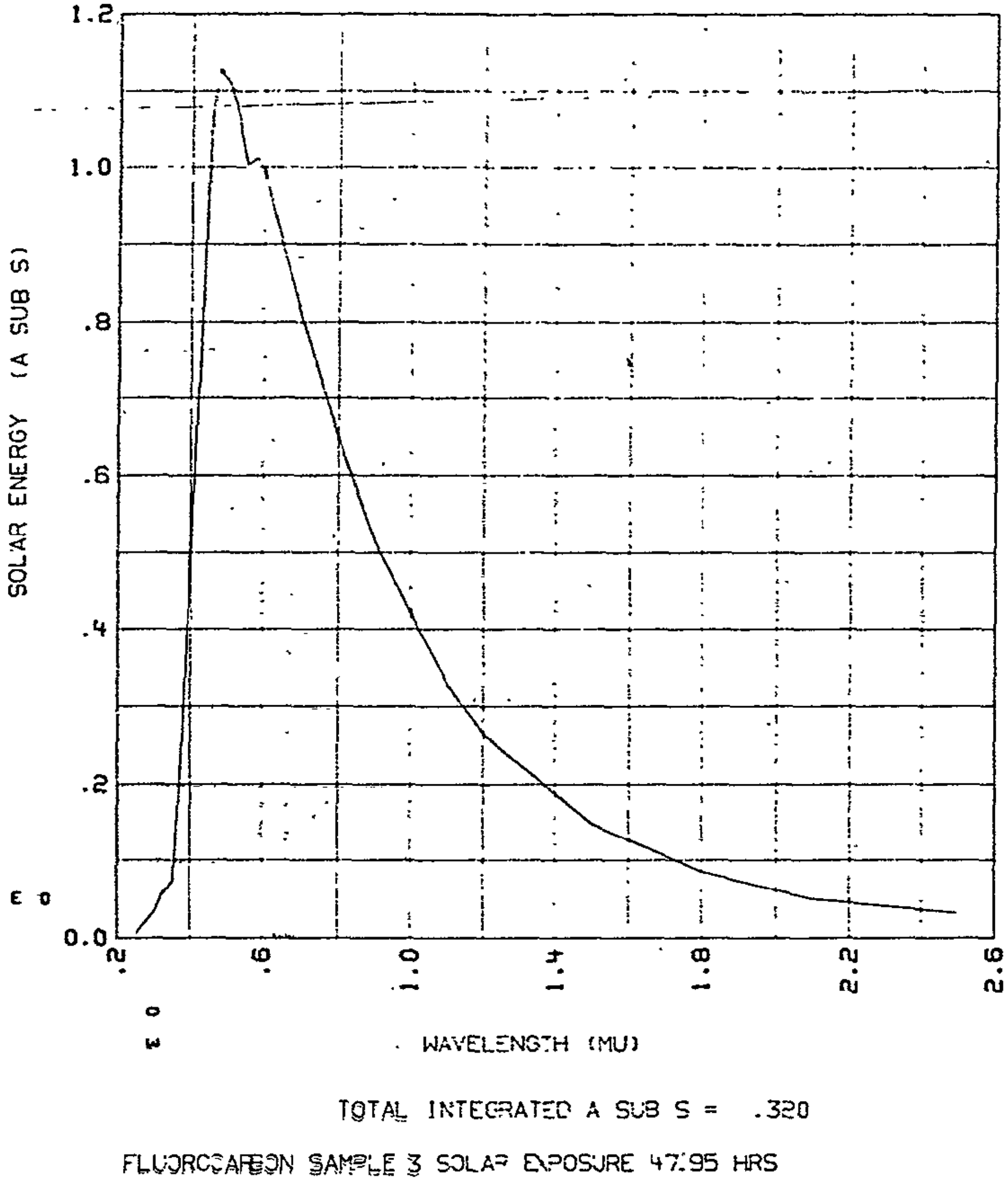

Figure B-2 Product of Reflectance and Normalized Solar Irradiance Versus Wavelength for Fluorocarbon 4334-112 Exposed for 47.95 Hrs to 2.5 ES.

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