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RESEARCH CORPORATION

LABORATORIES IN BOULDER, COLORADO AND MUNCIE, INDIANA

FINAL REPORT

TEST PROGRAM ON THE CONTAMINATION OF ULTRAVIOLET-REGION MIRRORS BY APOLLO TELESCOPE MOUNT MATERIALS

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Section 1
INTRODUCTION

This final report summarizes the testing performed for Marshall Space Flight Center (MSFC) of Huntsville, Alabama, to measure the effects of material outgas products on the reflectances of ultraviolet-region mirrors. The testing was done by the Materials and Processes Section of Ball Brothers Research Corporation (BBRC) in accordance with contract NAS8-27996, modifications 1 through 3, covering the time period 14 October 1971 to 15 December 1973. Mr. J. C. Horton of MSFC's R-P & VE Materials Laboratory was the Technical Monitor for this program.

The purpose of these tests was to provide MSFC with data on changes of ultraviolet reflectances of first-surface mirrors which had been exposed to the outgas products of selected materials under specific time and thermal-vacuum conditions. The requirement for such data was based on the extreme sensitivity of the sophisticated optical instruments in the Skylab mission's Apollo Telescope Mount (ATM) to condensed outgas products from materials, and on the desire by MSFC to insure that no serious hazard of contaminating these instruments existed.

Sixteen materials samples were supplied by MSFC. The data obtained in the testing of these samples included:

- Weight loss of each sample during thermal-vacuum conditions
- Changes of reflectance of first-surface platinum mirrors at the ultraviolet wavelengths of 304, 584, and 1216Å as a result of their exposure to the selected materials during thermal-vacuum conditions.

A modification to the contract authorized further investigation of an apparent anomaly which was evident in the mirror reflectance data. This anomalous condition was characterized by significantly greater reflectance changes occurring at 1216Å, than at the other two wavelengths in several of the tests. This condition did not agree with the previous expectations that the shorter wavelengths, those in the extreme ultraviolet at less than 1000Å, probably would be more sensitive to adsorbed contaminants than would the longer wavelengths. Thus, the condition was considered anomalous pending further investigation. Part of the study that was made of the apparent anomaly was concerned with the stability of mirrors and the precision of reflectance measurements since, in order to determine the significance of small, indicated changes of reflectance of the mirrors, it is necessary to know the precision with which each measurement is made and the uncertainty of the calculated reflectance-change values.

Section 2
MEASUREMENT EQUIPMENT AND PROCEDURES

2.1 VACUUM EXPOSURE TESTS

2.1.1 Equipment

The exposure of the platinum mirrors to the materials samples was done in BBRC's contamination screening test thermal-vacuum chambers. Figure 2-1 shows a diagram of such a system. The system consists of: a stainless steel vacuum chamber, a 20 liter per second ion pump, a temperature-controlled collector platen, a chamber heater, and a cryo-sorption roughing pump. An orifice plate divides the vacuum chamber into a heated sample cavity and a collector cavity. The opening of the sample cavity points directly at the collector platen, which is in the collector cavity, and through which a temperature-controlled fluid circulates. The vacuum system is designed to maximize the probability that the outgas products leaving the sample cavity will first contact the contaminant collector. All system gaskets are copper except for the fluoro-elastomer (Viton) seals on the roughing and bleed-up valves. Pump-down from atmospheric pressure is accomplished using the cryo-sorption pump, filled with molecular sieve, which together with the ion pump provides a clean, contamination-free system. Temperature control of the sample is provided by individual adjustable temperature controllers for each system. Temperature control of the collector platen is provided by a refrigerated circulating bath which circulates fluid to all systems through flow meters. Power for the ion pumps is provided from a single power supply through a multiple-station switching unit. Pressure of the individual system vacuum chambers is determined by the ion pump current for that chamber pump as read on the switching unit. The master control console containing the power supply and the switching unit also

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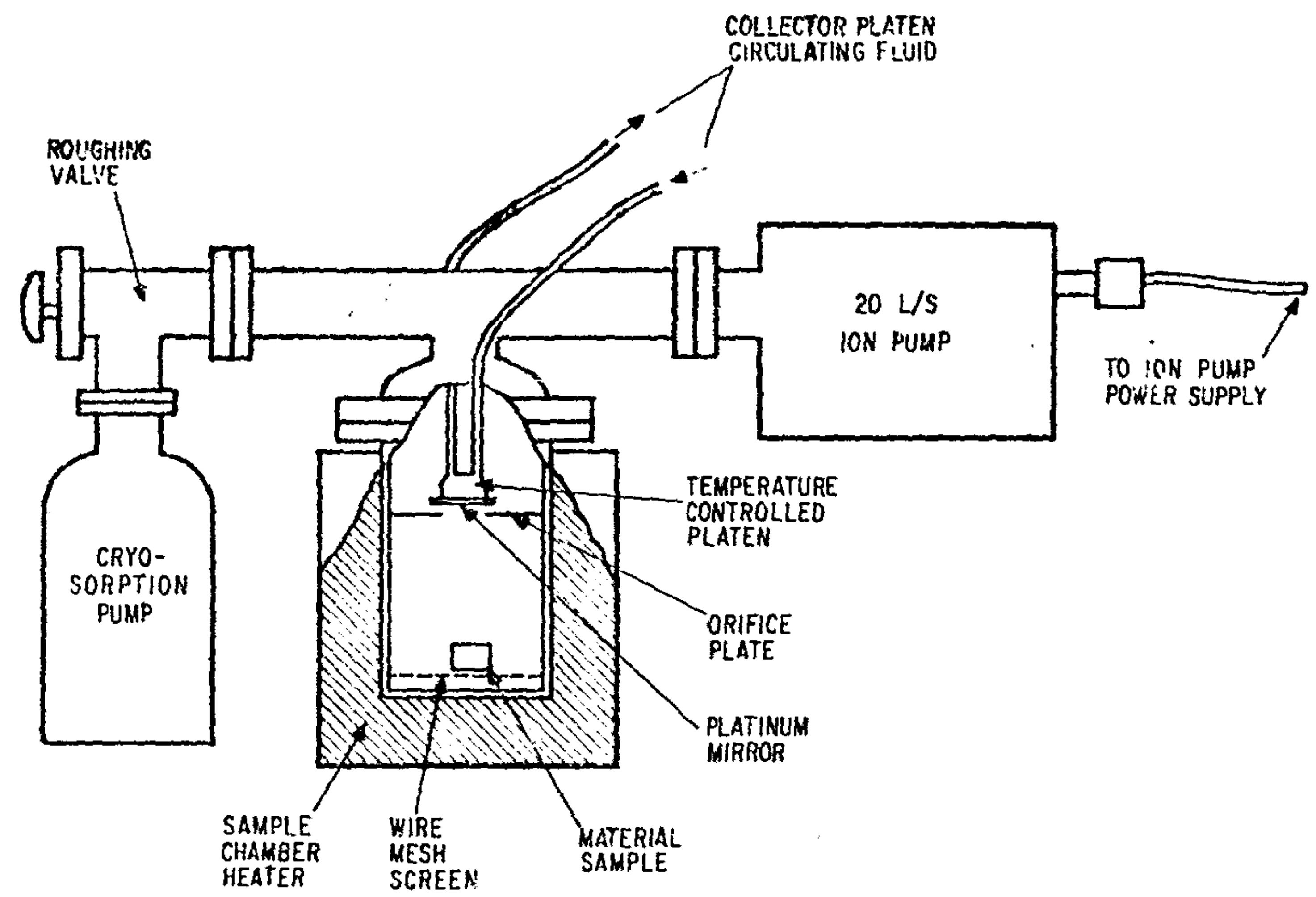

Figure 2-1 Contamination Screening Test Vacuum System

includes individual elapsed time indicators and the adjustable temperature controllers for each system.

The weight of samples is measured using an Ainsworth Model 24N semi-microbalance which reads to 0.01 milligrams and features reproducibility of ± 0.02 milligrams. The balance can be used to weigh samples weighing up to 80 grams.

The test systems and the screening test procedure are similar to those used in a previous materials test program done for MSFC and are described in detail in Reference 1.

2.1.2 Procedure

The general steps of the test procedure are as follows:

- The vacuum chamber is prepared by solvent cleaning the interior surfaces and then vacuum-baking the chamber at approximately 250 to 300°C for a minimum of 100 hours.
- The reflectance of the platinum mirror is measured in accordance with paragraph 2.2.
- The sample is prepared by cutting or trimming it to a standard size, generally such that the exposed surface area is about 25 cm^2, and then the surface area of the sample is measured to ± 0.1 cm^2. All reasonable precautions are taken during sample preparation and handling to prevent contaminating it so that the sample can be tested in the "as received" condition.

- The sample and the mirror are then placed in a desiccator and allowed to stabilize at the temperature of the balance for a minimum of one hour (generally overnight). The sample is then weighed to the nearest 0.01 milligram.

- The sample is then placed in the sample cavity of the test chamber and the mirror is attached to the cooled platen using a specially prepared, low vapor pressure vacuum grease as the attachment and thermal transfer medium.

- The chamber is evacuated, the elapsed time indicator is started, and the chamber heater and the cooling fluid flow rate are adjusted as needed.

- The test is conducted for 72 hours at a chamber pressure of less than 10^{-5} Torr with the sample at 55°C and the mirror at 25°C. These conditions had been previously chosen by BBRC to provide acceleration of sample outgassing and a convenient test duration while permitting testing for a reasonable time and at a temperature close to the maximum generally expected during ATM flight operation at points inside the ATM cannister. For some tests, noted in Section 4, the conditions were changed to 24 hours with the sample at 100°C. This was done at the request of MSFC for samples of paints intended for use on the exterior of the ATM cannister.

- Immediately after the thermal vacuum exposure is completed, the sample is again placed in a desiccator and allowed to stabilize at the temperature of the balance for a minimum of one hour and then it is reweighed.

- The reflectance of the mirror is measured again.

2.2 ULTRAVIOLET-REGION REFLECTANCE MEASUREMENTS

2.2.1 Equipment

The system used for making the ultraviolet-region reflectance measurements consists of a monochromator, a reflectometer, an ultraviolet source and appropriate gas supply system, a signal detector and amplifier, and a strip chart recorder.

The monochromator is a McPherson Model 247 which is a 2.2 meter, grazing incidence, vacuum-ultraviolet-region monochromator/spectrograph. It uses a Rowland Circle type optical mounting for concave gratings. The entire optical system, stainless steel ways, main vacuum chamber, bellows, slit isolation valves, and wavelength drive mechanism are mounted on a granite base plate. The grating assembly is kinematically mounted and may be removed for ease of grating removal and replacement. The half-width resolution at all wavelengths and with 10 micron slits is better than 0.3Å with a 300 line per millimeter grating and better than 0.15Å with a 600 line per millimeter grating. The theoretical wavelength range of the monochromator is from 10 to 2500Å and it has been used to produce monochromatic lines in the soft X-ray and ultraviolet range from 44 to 2000Å. The major components of the vacuum pumping system of the monochromator consist of a 15 cubic feet-per-minute mechanical pump and a four-inch oil diffusion pump with a liquid nitrogen cold trap.

The vacuum chamber of the reflectometer attaches at the exit slit of the monochromator. It has its own vacuum pumping system including a 15 cubic-feet-per-minute mechanical pump and a two-inch oil diffusion pump equipped with a liquid nitrogen cold trap. The reflectometer can be used for both reflectance and transmittance measurements and can accommodate up to three small mirrors at a time. Both translation and rotation of the mirror mount can be achieved to properly position the mirrors. The reflectance measurements for this program were made at an angle of incidence of 7-1/2 $\pm$1/2 degrees. The detector is mounted on a rotation arm allowing both measurement of the beam from the monochromator's exit slit and of the reflected beam from the mirrors. The detector is an EMI multiplier phototube and uses a sodium salicylate coating on the end window.

The ultraviolet sources, the amplifier and the recorder are all made by McPherson and are designed to match the characteristics and performance of the monochromator.

2.2.2 Procedure

The first step in the procedure is to mount and align the mirrors. For alignment purposes the gas discharge lamp is replaced by a white light source and the monochromator is set for central image at the exit slit. The mirrors are individually positioned in the mirror mount such that the light beam falls on the central portion of each of the mirrors in turn. If necessary, the beam size is adjusted using aperture plates, and the angle indicators for the detector and the mirror mount are reset.

Then the vacuum chambers of both the reflectometer and the monochromator are evacuated to a pressure of less than 10^{-5} Torr. Generally, a time period of about 45 minutes is allowed for the pump-down and pressure stabilization. The ultraviolet source is then started and an additional 30 minutes are allowed for its stabilization.

At each of three wavelengths, 1216, 584, and 304Å, the detector is rotated into the beam from the exit slit of the monochromator and adjusted for peak signal. This direct signal is recorded for approximately 30 seconds. The first mirror is then moved into the beam and the detector is rotated to intercept the reflected beam where it is again adjusted for peak signal. This reflected signal is recorded also for approximately 30 seconds. The other mirrors in the mount are then positioned, in turn, in the beam and again the reflected signals are recorded as with the first mirror. The direct signal is once again recorded for 30 seconds, and is followed by a 30-second recording of the base line signal with the slit closed. The reflectance measurements are repeated three times at each wavelength for all mirrors. During the reflectance measurements the mirrors remain at room temperature.

Following completion of the measurements, the reflectometer is isolated from the monochromator and the reflectometer is brought to atmospheric pressure using nitrogen gas. The mirrors are removed from the mount and are returned to their individual containers.

A Gerber variable scale is used to measure the recorded signal levels on the chart paper and the reflectance at each wavelength is calculated for each mirror as follows:

$$R(\text{percent}) = (100)\,\frac{D - Z}{r - Z}$$

where

R = the reflectance (in percent)

D = the direct beam intensity

Z = the base line or zero signal intensity
r = the reflected beam intensity

The three reflectance values obtained at each wavelength for each mirror are averaged. These averaged values are the ones shown on the individual test data sheets, which have been supplied to MSFC in the monthly reports for this program.

2.3 MIRROR HANDLING AND STORAGE

In all cases the mirrors were handled by the edges and corners using either cleaned nonporous gloves or solvent-cleaned metal tweezers. At all times when they were neither in tests nor in the reflectometer, they were stored in cleaned tin-plated steel cans with tight-fitting lids.

Section 3
PRECISION OF ULTRAVIOLET-REGION REFLECTANCE MEASUREMENTS

3.1 DISCUSSION OF ERRORS AND PRECISION

Error in measurements is normally thought of as the deviation from a true or exact value and generally presupposes knowledge of the exact value[2]. However, since the exact values of the ultraviolet-region reflectances of the mirrors are not known, for purposes of this analysis error is used to denote the deviation from the mean value of a small sample of measurements.

All measurements are subject to three basic types of errors; systematic (those errors related to equipment, etc.), human, and random. If repeated measurements are free of systematic and human errors, they can be treated statistically to evaluate the random errors. Precision is defined here as the clustering of individual measured values of a property about the arithmetic mean of a set of measured values of the property[3]. It is not to be confused with accuracy, which applies to the difference between measured values of a property and its true or absolute value. For normal distributions of measured values the degree of clustering is given in terms of various measures of precision such as standard deviation, average error, and probable error. The measure of precision used here is the probable error, r, which is the error such that one-half of the deviations of individual measurements from the mean value of a set will be less than r and one-half will be greater than r[4]. Thus, for a given measurement, the measured value will have a 50 percent probability of being within r of the mean value. The probable error is calculated for a set of measured values using the following formula:

$$\text{Probable error} = r + \pm 0.6745 \left[\frac{\Sigma (x_j)^2}{n - 1}\right]^{1/2} \quad \text{(Reference 5)}$$

where

$x_j = (\bar{x} - x_i)$ residuals

$\bar{x} = \frac{\Sigma x_i}{n}$ mean

$x_i =$ individual measurements

$n =$ total number of measurements

The uncertainty of the probable error is inversely proportional to the square of the number of measurements according to

$$r_r = \frac{0.4769}{n^{1/2}} \quad \text{(Reference 6)}$$

which yields the probable error of the probable error of the sample of n measurements.

When two or more measured values are used in calculations to derive another value, the errors of the measured values are propagated to the derived value. Calculation of the uncertainty (propagated probable error) is based on the equation

$$r_Z = \left[\left(r_x \frac{\partial Z}{\partial x}\right)^2 + \left(r_y \frac{\partial Z}{\partial y}\right)^2 + \ldots\right]^{1/2} \quad \text{(Reference 7)}$$

where the derived value is Z which is a function of the measured values x, y, ...

The value of interest in the present ultraviolet test data is the change in reflectance, which is a derived value:

$\Delta R = R_1 - R_2$ reflectance change

where

$R_1 =$ reflectance before exposure

$R_2 =$ reflectance after exposure

For the reflectance change values, the equation for uncertainty reduces to

$$r_{\Delta R} = [(r_{R_1})^2 + (r_{R_2})^2]^{1/2}$$

or simply

$$r_{\Delta R} = \sqrt{2}\, r_R$$

where

$$r_R = r_{R_1} = r_{R_2}$$

For routine contamination tests and contamination monitoring measurements of ultraviolet reflectance, the costs would be prohibitive to make sufficient repeated measurements to calculate the measurement precision at each wavelength for each set of measurements for each mirror. Thus the accepted practice at BBRC has been to periodically perform a precision analysis on one or two mirrors, making twelve or more measurements at each wavelength of interest. The probable errors at each wavelength, r_R, were calculated and it was then assumed that the precision of subsequent measurements would be essentially the same if no other errors were made and the measurement procedure remained consistent. Then the uncertainty (propagated probable error) of the reflectance change values at each wavelength, $r_{\Delta R}$, would be the square-root-of-two times the probable errors of the individual measurement sets at each wavelength or $\sqrt{2}\, r_R$. The uncertainty values obtained for the one or two mirrors would then be used as estimated uncertainties of reflectance change values for other, similar mirrors when the same measurement equipment and procedure were employed. This technique has been used at BBRC for approximately ten years and applied to about 1000 magnesium-fluoride-overcoated-aluminum mirrors, which were measured using different equipment than that used in this program. In that case the technique has proved quite acceptable. The technique has been used only for a little over three years with platinum mirrors and the equipment used on this program.

The estimated uncertainty values obtained in the manner described above are those values of reflectance change which have approximately a 50 percent probability of occurring because of randomness. A single value of reflectance change between two and three times the estimated uncertainty value has a low probability (between about 4 and 20 percent) of occurring randomly. However, in this program we have generally considered such a change to be real and significant only if substantiating evidence, such as significant changes at other wavelengths has existed. Reflectance change values exceeding about four times the estimated uncertainty values have very low probabilities (less than about four percent) of occurring randomly and we have considered these indicated changes to be definitely real and significant.

3.2 PRECISION OF MEASUREMENTS AND UNCERTAINTY OF CHANGE VALUES

At the beginning of this program the uncertainty of the ultraviolet reflectance change values was estimated based on a previous error analysis using platinum mirrors and the same equipment and procedure described in section 2.2. The estimated uncertainty of reflectance change values was approximately ± 0.2 percent* at 304 and 584Å and ± 0.4 percent at 1216Å. During the repeated measurements discussed in Section 5, a new error analysis was made using twelve measurements at each of the three wavelengths on mirrors 25-11 and 25-23. The results of the analysis are given in Table 3-1.

*Percent, as used throughout this report in connection with reflectance, reflectance changes (as well as probable errors and uncertainties) refers to the units of the reflectance measurements and not to the ratio of reflectance change to initial reflectance (i.e., not $\Delta R/R_1$).

The uncertainty values shown in the table were averaged and then rounded to one figure giving uncertainties of approximately ±0.1 percent at 304 and 584Å and ±0.4 percent at 1216Å. The values were rounded to one figure because the formula for probable error of probable error indicates that calculations based on only twelve measurements are only precise to about 14 percent, which is not adequate for two figure values.

Table 3-1

RESULTS OF PRECISION ANALYSIS

	304Å Percent	584Å Percent	1216Å Percent
Probable error; r, Mirror 25-11	± 0.102	± 0.021	± 0.22
Probable error; r, Mirror 25-23	± 0.100	± 0.133	± 0.26
Uncertainty of ΔR; $r_{\Delta R}$, Mirror 25-11	± 0.144	± 0.03	± 0.31
Uncertainty of ΔR; $r_{\Delta R}$, Mirror 25-23	± 0.141	± 0.19	± 0.37

NOTE: Values above are only precise in the first figure shown. More figures are shown here only for comparison and calculation purposes

Average uncertainty of ΔR; $\bar{r}_{\Delta R}$, for estimates applied to other mirrors	Approx. ± 0.1	Approx. ± 0.1	Approx. ± 0.3

The results of the precision analysis allow us to make the following statements:

- Reflectance change values less than about ±0.2 percent at 304 and 584Å and less than about ±0.4

percent at 1216Å will randomly occur about one-half of the time and do not signify real changes.

- Reflectance change values between about ±0.2 and ±0.6 percent at 304 and 584Å and those between about ±0.4 and ±1.2 percent at 1216Å have chances varying from even to as low as 1 in 20 of being due to random measurement errors. Such values, though suggestive of real reflectance changes, do not indicate strongly that the changes are not random. Borderline change values of this type are the hardest to interpret.

- The chances are high (greater than about 19 in 20) that reflectance change values which exceed about ±0.6 percent at 304 and 584Å and those which exceed about ±1.2 percent at 1216Å are real changes, and thus they are considered significant.

The statements above cannot be considered exact; they are only intended as general guides for determining the importance of small indicated reflectance changes. In the following sections of this report, the words insignificant, borderline, and significant are used without further elaboration to describe reflectance changes of mirrors. The reader should recall that these are somewhat qualitative descriptions based on an approximation technique. Nevertheless we feel that they are generally valid interpretations of the test data.

Section 4
TEST RESULTS

4.1 BACKGROUND TESTS

There was a total of five background tests completed during the program. These tests were like the materials tests with the exception that there were no samples in the vacuum chambers during the thermal-vacuum exposures of the mirrors. Thus any significant reflectance changes of the mirrors used in these tests would be attributable to causes other than contamination directly by outgas products from materials samples. The reflectance change data from these background tests are summarized in Table 4-1, and Appendix A includes copies of the individual test data sheets.

Table 4-1
BACKGROUND TEST RESULTS

		Reflectance Changes - Percent		
Test No.	Mirror No.	at 304Å	at 584Å	at 1216Å
1835	H-3	+ 0.1	+ 0.4	- 0.9
1836	H-4	+ 0.1	+ 0.5	- 1.5
1849	25-4	+ 0.3	+ 1.1	+ 0.7
1859*	25-8	+ 0.3	+ 0.6	- 1.7
1905	25-12	- 0.4	- 0.2	0

* For Test No. 1859 the thermal vacuum test conditions were 24-hour test duration with the sample cavity at 100°C, rather than the 72 hours at 55°C which was normal for these ultraviolet-region contamination screening tests.

Of the six results obtained from the mirrors of test numbers 1835 and 1836, only one showed a significant reflectance change, while three showed borderline changes. The remaining two changes were insignificant. The mirrors used in these two tests were together in the reflectometer both for the ultraviolet measurements before and those after the thermal-vacuum exposures*.

In the results obtained from the mirrors of text numbers 1849 and 1859, all changes were at least borderline with two of the changes being significant. These two mirrors were in the reflectometer for ultraviolet reflectance measurements with other, new mirrors before they were used in the background tests. However, both were in the reflectometer for the "after-exposure" measurements with other mirrors which had been in materials tests and may have been somewhat contaminated.

The mirror used in test number 1905 had no significant reflectance changes and only one borderline change at 304Å. This mirror, however, was in the reflectometer both before and after its background test with possibly contaminated mirrors.

The results of the background tests are discussed further in Section 6 along with a general discussion of the results of all of the tests on the program.

4.2 MATERIALS TESTS

Sixteen samples of materials were submitted by MSFC for testing under this program. All of the tests on these samples were reported in detail, both by telephone as soon as the test data were

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* Table B-1 of Appendix B lists all of the mirrors which were together in the reflectometer during their reflectance measurements.

available, and in the periodic progress reports which included test data sheets on the individual samples tested*. The data from these materials tests are summarized in Table 4-2 and copies of the data sheets are included in Appendix A.

During three of the tests, 1820, 1841, and 1941, readily visible contaminant deposits had been adsorbed on the mirror surfaces and significant reflectance changes had occurred at all measured wavelengths for these mirrors. The materials in these tests were the first sample of S-13G white paint**, the ATM door seal, and the silicone impregnated glass cloth. From a contamination-potential viewpoint, all three of these materials, when in the "as-tested" condition, are considered to be a serious threat and unacceptable in proximity to ultraviolet optical surfaces in vacuum.

In an additional two tests, 1860 and 1863 on two more S-13G white paint samples, the reflectance changes at all three wavelengths were significant although visible deposits were not produced on the mirrors. Another material, the Beta Cloth run in test 1924, caused significant reflectance changes at 584 and 1216Å and a borderline change at 304Å. Again from a contamination-potential viewpoint, these materials, when used in the "as-tested" condition, are considered to be undesirable and their use would be highly questionable in proximity to ultraviolet optical surfaces in vacuum.

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* Progress Reports numbered 1 through 21 covering the time period 9 November 1971 through 31 July 1973.

** At the request of MSFC all three tests of the S-13G white paint were run with a test duration of 24 hours and the sample at 100°C rather than the 72 hours at 55°C which is normal for the ultraviolet contamination screening tests. The intended use of the S-13G was on the exterior of the ATM cannister as well as other exterior surfaces of the Skylab where the operating temperatures would likely be on the order of 100°C.

Table 4-2

MATERIALS TEST RESULTS

Test No.	Mirror No.	Material	Reflectance Changes, Percent at 304Å	at 584Å	at 1216Å	Sample Weight Loss g/cm^2 *	Visible Deposit On Mirror
1820	Pr013	S-13G White Paint	-2.2	-18.2	---	----	Yes
1837	H-5	Cat-A-Lac Black Paint	+0.2	+ 0.1	- 1.3	1.2×10^{-5}	No
1838	H-6	Tedlar PVF Film, Black	+0.2	0	- 1.6	1.2×10^{-5}	No
1840	25-1	Mylar Polyester Film, Aluminized	-0.2	+ 0.2	- 0.9	(0.8×10^{-6})	No
1841	25-2	ATM Door Seal	-3.3	-19.1	-14.5	4.1×10^{-4}	Yes
1845	25-3	Fiberglass Stand-off	-0.2	- 0.1	- 0.9	2.7×10^{-4}	No
[illegible]53	25-5	ATM Flight Cable Bundle	0	- 0.5	- 1.0	2.3×10^{-4}	No
1857	25-6	ATM Insulation Button	-0.1	- 0.4	- 1.1	5.9×10^{-6}	No
1860	25-9	S-13G White Paint	-0.7	- 0.7	- 5.0	1.2×10^{-4}	No
1863	25-10	S-13G White Paint	-1.1	- 2.5	- 7.4	3.7×10^{-5}	No
1909	25-13	Viton PLV 1000S	-0.5	- 0.5	- 1.8	2.0×10^{-4}	No
1916	25-14	Viton PLV 1006A	+0.3	+ 0.3	- 1.0	1.5×10^{-4}	No
1924	25-16	Beta Cloth, Fluorel Coated	-0.5	- 5.5	- 8.8	(1.7×10^{-6})	No
1925	25-17	Lacing Tape, Nomex	+0.4	- 0.6	- 2.1	5.6×10^{-5}	No
1932	25-18	O-Ring Compound, V-747-75	+0.4	- 0.5	- 1.5	1.3×10^{-4}	No
1941	25-19	Glass Cloth, Silicone Impreg	-1.9	10.0	- 5.5	3.3×10^{-5}	Yes

*Weight loss values in parentheses indicate that the value is less than the reproducibility limits for weighing.

The Viton PLV 1000B in test number 1909, the Nomex lacing tape in test number 1925, and the V-747-75 o-ring compound in test number 1932 all caused significant reflectance changes at 1216Å and borderline changes at the other two wavelengths. The Viton PLV 1000A in test number 1916 caused borderline changes at all three wavelengths. These four materials, though not as bad as those already discussed above, perhaps are still borderline materials and their use near ultraviolet optical surfaces in vacuum should be strictly controlled to prevent line-of-light conditions between the materials and the optics, to prevent use of large quantities of the materials and to prevent use of the materials where they might be heated above the temperature of the optics.

The Cat-A-Lac black paint in test number 1837 and the black Tedlar in test number 1838 caused reflectance changes at 1216Å which were apparently significant but which were not at all substantiated by even borderline changes at the other two wavelengths. The remaining four materials; the aluminized Mylar in test number 1840, the fiberglass standoff in test number 1845, the ATM flight cable in test number 1853, and the ATM insulation button in test number 1857 produced no significant reflectance changes and only one or two borderline reflectance changes each for their respective test mirrors. These six materials, appear to have sufficiently low potentials for contaminating ultraviolet optics that they do not represent a serious threat.

Section 5
ANALYSIS OF "1216Å ANOMALY"

5.1 ANOMALY DISCUSSION

Many of the progress reports made note of the fact that the reflectance changes generally were greater at 1216Å than at 304 and 584Å and that repeated measurements were being made in an attempt to explain the data. Progress Report No. 11 (1 September 1972 through 30 September 1972) also indicated that preliminary study of the data showed perhaps some reflectance changes during storage of the mirrors and that cross-contamination between mirrors was possibly occurring in a few hours in vacuum at room temperature.

The assumptions in the past regarding the absorption of ultraviolet-region radiation by adsorbed contaminants led us to expect greater reflectance losses at the shorter wavelengths, at least down to the X-ray region. Our prior extensive experience in the wavelength region between 1100 and 3800Å had indicated the shorter wavelengths in this region to be appreciably more sensitive to outgas products from plastics and hydrocarbons than the longer wavelengths. We were well aware of the transmission bands of metals at wavelengths below 1000Å with transmission increasing down to their X-ray absorption bands. Probably the most well known of these is aluminum with a transmission onset at about 800Å. In fact, most pure metals do transmit to various degrees in the extreme ultraviolet(8); however, we had not expected similar characteristics from the much more varied outer electron clouds of complex plastic and hydrocarbon molecules. Thus the initial observations of much greater changes at 1216Å than at 304Å, and to some degree than at 584Å, led us to question the data as irregular or anomalous.

5.2 BACKGROUND-TEST AND CONTROL MIRROR ANALYSES

As part of an attempt to explain the "anomalous" data obtained in this program, some mirrors were measured repeatedly at various time intervals during the program. The results obtained from these control mirrors (numbered H-4, 25-4, 25-11, and 25-23) are discussed in Sections 5.2.1 through 5.2.4.

5.2.1 Mirror H-4

Table 5-1 lists the individual reflectance values obtained at each wavelength for each date on which mirror H-4 was measured. The reflectance averages for each date and wavelength are plotted in Figure 5-1. This mirror was initially measured with two other new mirrors (12-6-71) and then it was used in background test number 1836. In the second set of measurements on this mirror (12-30-71), it was in the reflectometer with mirror H-3 from background test number 1835. Examination of the data in Table 4-1 and Figure 5-1 indicates the possibility of slight contamination of these mirrors with H-4 having a significant reflectance change and H-3 having a borderline change at 1216Å. Both mirrors had borderline changes at 584Å and both had insignificant changes at 304Å. Mirror H-4 was then stored until it was remeasured on February 22, 1972 by itself. This set of reflectance measurements made after storage indicated borderline changes at 1216 and 584Å and an insignificant change at 304Å. After almost 22 more months of storage, the mirror was remeasured along with mirror 25-4 (12-12-73). This time the reflectance changes were significant at all three wavelengths. It appears that this mirror, H-4, may well have been contaminated during this mearurement by mirror 25-4. (See the following discussion.)

Table 5-1
REFLECTANCE VALUES OF MIRROR H-4

Date	REFLECTANCE, PERCENT Wavelength at 304Å	at 584Å	at 1216Å
12-6-71	3.3	17.6	23.2
	3.2	17.5	23.4
	3.0	17.5	23.2
12-30-71	3.3	18.0	21.9
	3.4	18.0	21.8
	3.3	18.0	21.7
2-22-72	3.2	18.7	20.9
	3.4	18.3	21.2
	3.1	18.3	20.8
12-12-73	2.1	15.0	12.4
(Order of reflectance measurements was 304, 584, 1216)	2.2	15.0	12.5
	2.2	15.5	13.0

5.2.2 Mirror 25-4

Table 5-2 lists the individual reflectance values obtained at each wavelength for each date on which mirror 25-4 was measured. The reflectance averages for each date and wavelength are plotted in Figure 5-2. Mirror 25-4 was initially measured with two other new mirrors (1-4-72) after which it was used in background test number 1849. It was remeasured after the background test (2-21-72) along with mirrors 25-5 and 25-6 which had been used in the tests of the ATM flight cable (test number 1853) and the ATM insulation button (test number 1857), respectively (see Section 4.2). Mirror 25-4 had positive reflectance changes at all three wavelengths with the change at 584Å being significant and those at 304 and 1216Å being borderline. The other two mirrors with which it was measured had no significant reflectance changes and only borderline changes at 584 and 1216Å.

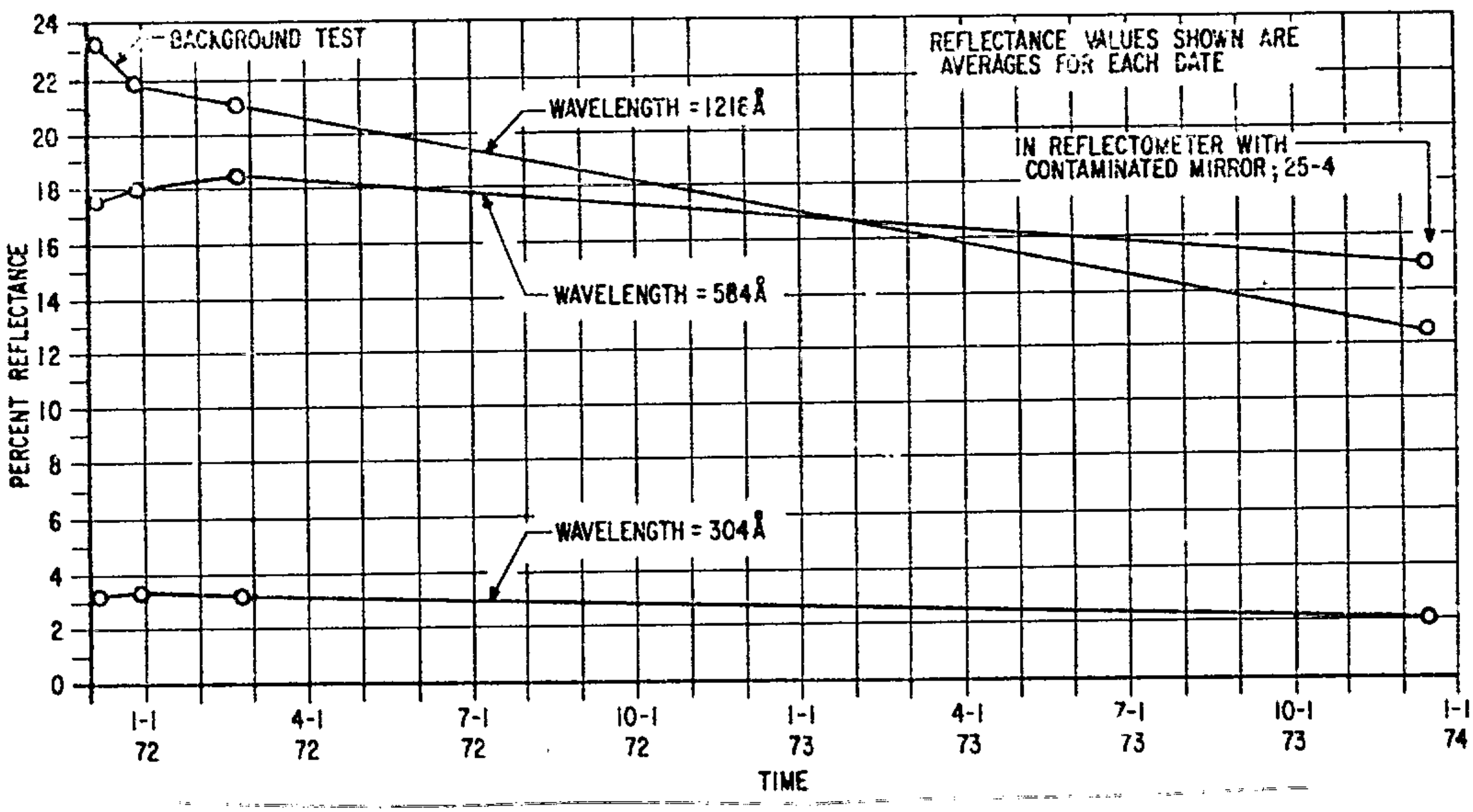


Figure 5-1 Long Term Changes of the Reflectance of Mirror II-4

Table 5-2
REFLECTANCE VALUES OF MIRROR 25-4

Date	REFLECTANCE, PERCENT Wavelength at 304Å	at 584Å	at 1216Å
1-4-72	3.4	20.5	19.3
	3.3	20.5	19.3
	3.3	20.2	19.5
2-21-72	3.8	21.6	19.8
	3.5	21.7	20.0
	3.4	21.2	20.5
3-23-72	3.9	21.1	19.5
	3.8	21.0	19.2
	3.6	21.3	19.0
8-11-72	3.5	20.6	18.4
	3.5	20.4	18.5
	3.5	20.6	18.0
10-12-72	3.0	18.8	16.8
	3.0	19.0	16.5
	3.0	18.8	16.8
12-12-73	3.6	11.5	9.0
	3.5	11.5	8.8
	3.3	11.3	8.6

Mirror 25-4 was stored for approximately one month and then it was remeasured (3-23-72) with one new mirror and one (Mirror 25-11) which had not yet been exposed to any significant contaminant source. The reflectance changes at 584 and 1216Å were borderline again. It was subsequently stored for four and one-half months and was remeasured (8-11-72) along with mirror 25-14 from materials test number 1916 on the Viton PLV 1006A. Mirror 25-4 had borderline reflectance changes at all three wavelengths, as did mirror 25-14. Following two more months in storage the mirror was again remeasured (10-12-72), this time with mirrors 25-11 and 25-19. The results of Mirror 25-11 are discussed in Section 5.2.3.

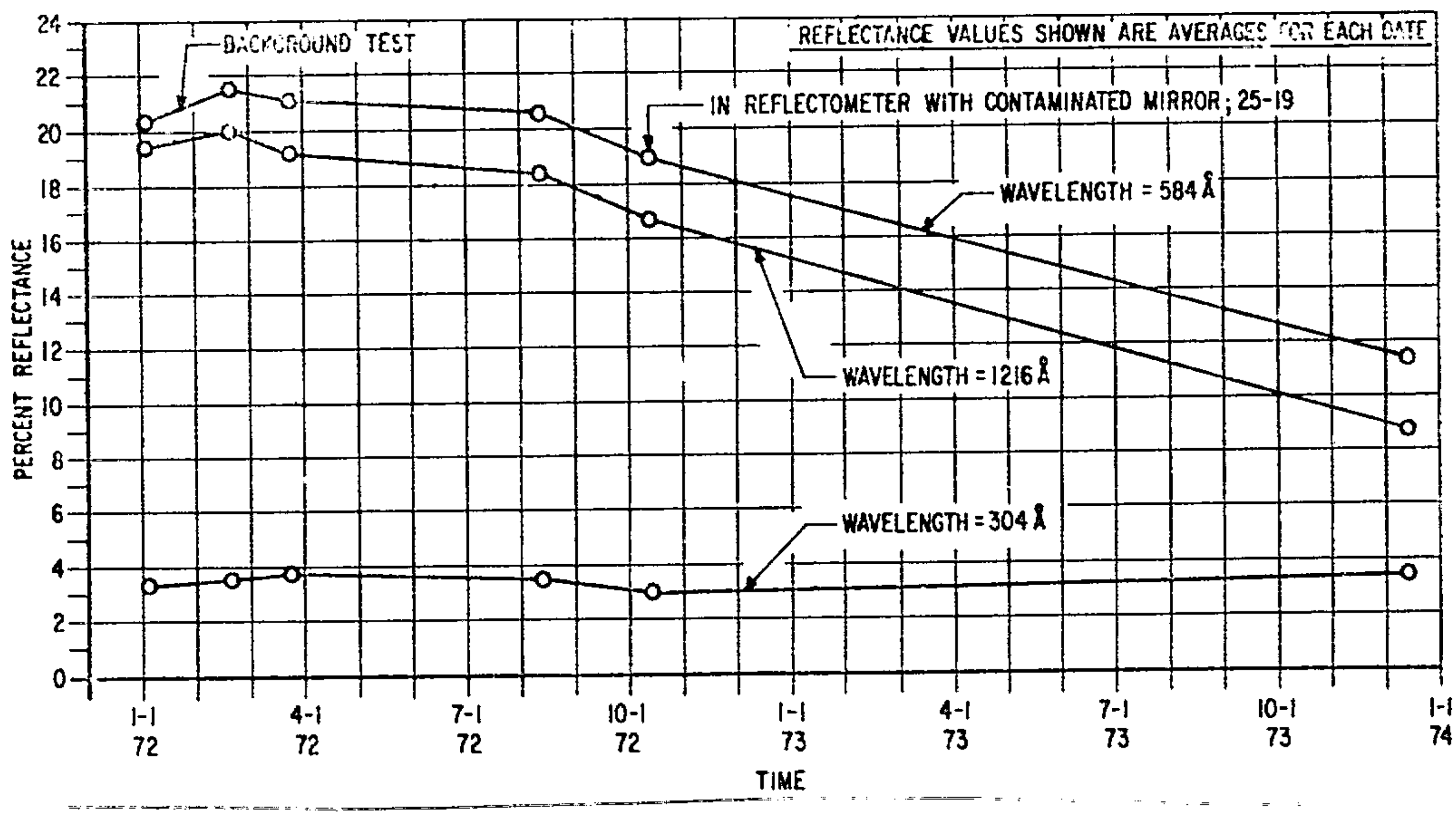


Figure 5-2 Long Term Changes of the Reflectance of Mirror 25-4

Mirror 25-19 had been used in materials test number 1941 on the sample of silicone impregnated glass cloth which had definitely contaminated the mirror, producing a visible deposit and significant reflectance changes at all three wavelengths (see Table 4-2). Following its exposure in the reflectometer to the other two mirrors on 10-12-72, mirror 25-4 had a visible deposit adsorbed on its front surface. Presumably the contaminant had come from mirror 25-19. Compared to the previous set of reflectance measurements, the reflectance changes for mirror 25-4 were significant at 584 and 1216Å. However, (very surprisingly because of the visible deposit on the mirror's surface) the reflectance change at 304Å was only borderline and was within 0.5 percent of the average of all previous reflectance measurements at 304Å for this mirror.

Subsequent remeasurement of mirror 25-4 after 14 additional months of storage (12-12-73) showed drastic reflectance changes at 584 and 1216Å while the change at 304Å was again only borderline. In fact, the reflectance at 304Å had returned to the average of previous reflectance values at 304Å prior to contamination of the mirror. The visible deposit was still evident at this time. At the present time we are unable to explain why the reflectances at 584 and 1216Å continued to drop during this last storage period when, to the best of our knowledge, the mirror was not contaminated further after its exposure to mirror 25-19. Possible reasons for the surprisingly small changes in reflectances at 304Å are discussed in Section 6.1.3.

5.2.3 Mirror 25-11

The reflectance on mirror 25-11 was measured on nine different days over a twenty-two month period. It was not used in background or other tests and the only environments to which it was exposed were its storage container and the reflectometer. The reflectance data for this control mirror are listed in Table 5-3 and the averaged reflectances for each date are plotted in Figure 5-3. In its first set of reflectance measurements (1-17-72), mirror 25-11 was in the reflectometer with one new mirror and mirror 25-3 which had been used in test number 1845 on the fiberglass standoff. The next set of measurements on 25-11 was two months later (3-23-72) when it was in the reflectometer with one new mirror and mirror 25-4 (see Section 5.2.2). The reflectance changes at all three wavelengths were insignificant for mirror 25-11. It was then stored for four and one-half months after which it was in the reflectometer for reflectance measurements (8-11-72) along with mirrors 25-12 and 25-13 which were used in background test number 1905 and in material test number 1909 (Viton PLV 10008), respectively. (Tables 4-1 and 4-2 show no indication of significant contamination of mirrors 25-12 and 25-13.) This set of reflectance measurements for mirror 25-11 differed from the previous set only by borderline changes at 584 and 304Å and an insignificant change at 1216Å. On September 20, 1972, after about six weeks more in storage, the reflectance of mirror 25-11 was measured along with mirrors 25-15 and 25-16, both of which had been definitely contaminated. (Mirror 25-16 was used in test number 1924 on Beta Cloth and 25-15 was used in an unnumbered repeat test on the same material.) As can be seen in Figure 5-3, the reflectance changes at 1216 and 584Å were significant, perhaps due to cross-contamination from the other two mirrors, yet the change at 304Å was insignificant. The next reflectance measurement set, three weeks later (10-72-72), was made with mirror 25-4 and a contaminated mirror (25-19) in the reflectometer with mirror 25-11. The reflectance change was insignificant at 304Å and those at 584 and 1216Å were borderline.

Table 5-3
REFLECTANCE VALUES OF MIRROR 25-11

Date	REFLECTANCE, PERCENT Wavelength at 304Å	at 584Å	at 1216Å
1-17-72	3.1	20.9	18.5
	3.2	20.6	18.5
	3.5	21.0	18.4
3-23-72	3.6	20.6	18.4
	3.2	20.8	18.2
	3.4	21.0	18.3
8-11-72	3.0	21.0	18.1
	2.9	21.2	17.9
	2.8	21.3	18.1
9-20-72	3.0	18.2	15.7
	3.0	18.8	16.0
	2.9	18.5	16.0
10-12-72	2.7	18.0	15.2
	2.9	18.1	15.2
	2.8	18.2	15.5
10-12-73	2.9	18.0	14.0
	3.0	17.9	13.7
	3.0	18.0	13.1
	3.0	18.0	13.0
	2.6	18.0	13.0
	2.8	18.0	13.0
	2.6	18.0	13.0
	2.7	18.0	13.0
	2.7	18.0	13.0
	2.8	17.9	13.1
	2.7	18.0	13.0
	2.7	18.0	13.1
10-30-73*	2.7	18.4	14.6
	3.0	18.3	14.5
	2.9	18.5	14.6
11-8-73	3.0	19.4	15.5
	2.9	19.4	15.0
	2.8	19.5	15.0
11-21-73	3.5	18.8	15.4
	3.5	18.5	15.1
	3.4	19.0	15.2

*The data obtained on 10-30-73 was in the following order: 304, 584, 1216Å. In all other measurements of mirror 25-11, 1216Å was measured first, followed by 584 and then 304Å last.

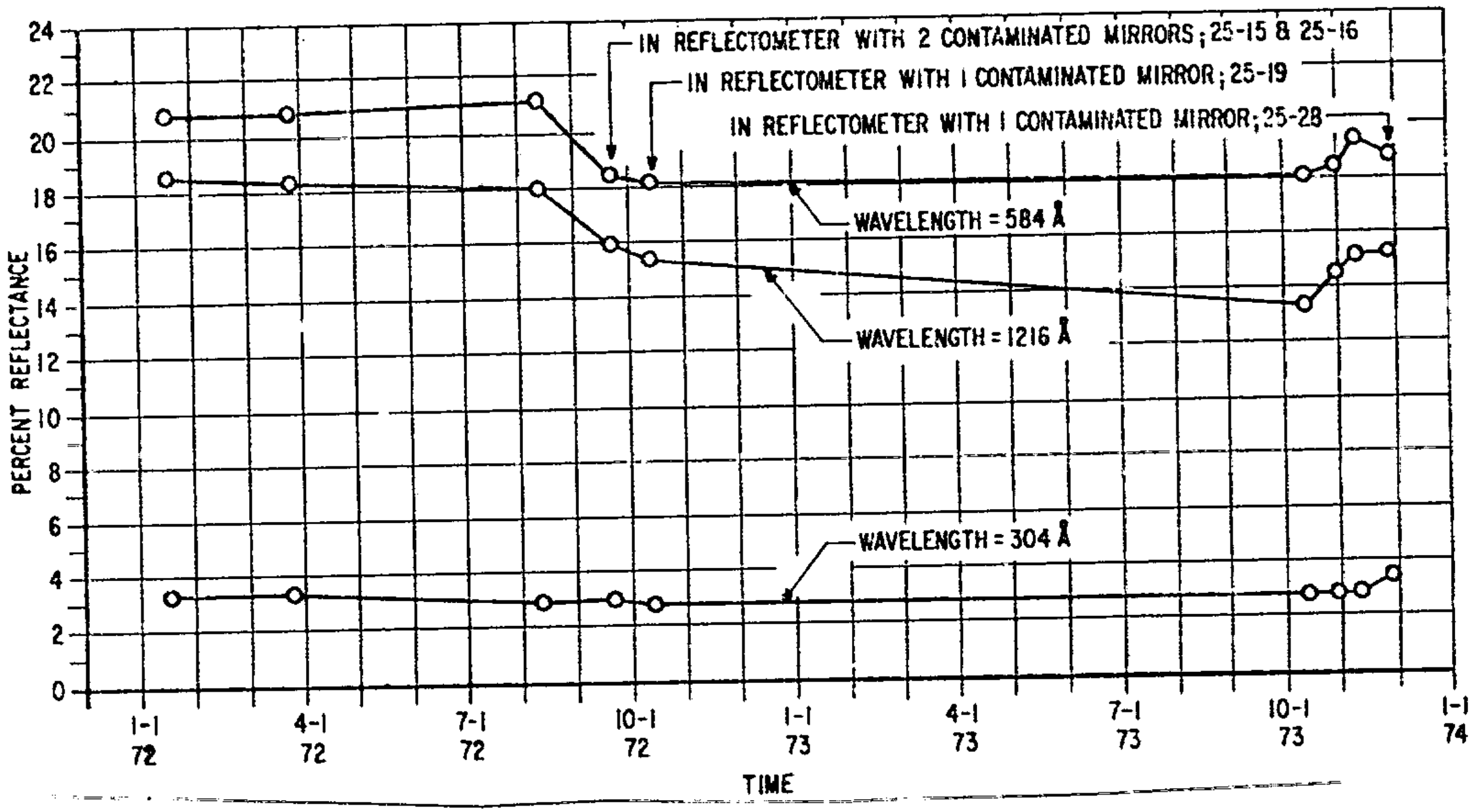


Figure 5-3 Long Term Changes of the Reflectance of Control Mirror 25-11

Then mirror 25-11 was stored for one year after which time its reflectance was remeasured (10-12-73) along with one new mirror, 25-23. Individual reflectance measurements were made twelve times at each wavelength. The reflectance changes from the previous measurements were insignificant at 584 and 304Å while that at 1216Å was significant. Figure 5-4 shows the individual reflectance values as a function of approximate time in the reflectometer. It is interesting to note that early in the measurement period the reflectance at 1216Å showed an apparent drop whereas the measurements made over the next several hours appeared reasonably stable. The reflectances at 584 and 304Å were stable throughout the measurement period. About two and one-half weeks later (10-30-73) mirror 25-11 was again in the reflectometer, this time with mirror 25-23 (see Section 5.2.4) and with mirror 25-24 which had been used in test number 2192 (see Section 5.3.1). Again the reflectance change at 1216Å was significant while that at 584Å was borderline, yet 304Å showed an insignificant change. Nine days later (11-8-73) mirrors 25-11 and 25-23 were together again in the reflectometer for measurements. Mirror 25-11 had a borderline change at 1216Å, a significant change at 584Å, and no change at 304Å. The final set of reflectance measurements on mirror 25-11 was made some two weeks later (11-21-73) when a borderline change (an increase in reflectance) occurred at 304Å for this mirror. A significant change at 584Å was also observed. However, for the first time, the reflectance at 1216Å appeared not to have changed from the previous measurements. During these final measurements, the other two mirrors in the reflectometer with mirror 25-11 were 25-23 and 25-28. Mirror 25-28 had been used in test number 2218 on Beta Cloth in which it had been contaminated (see Section 5.3.3).

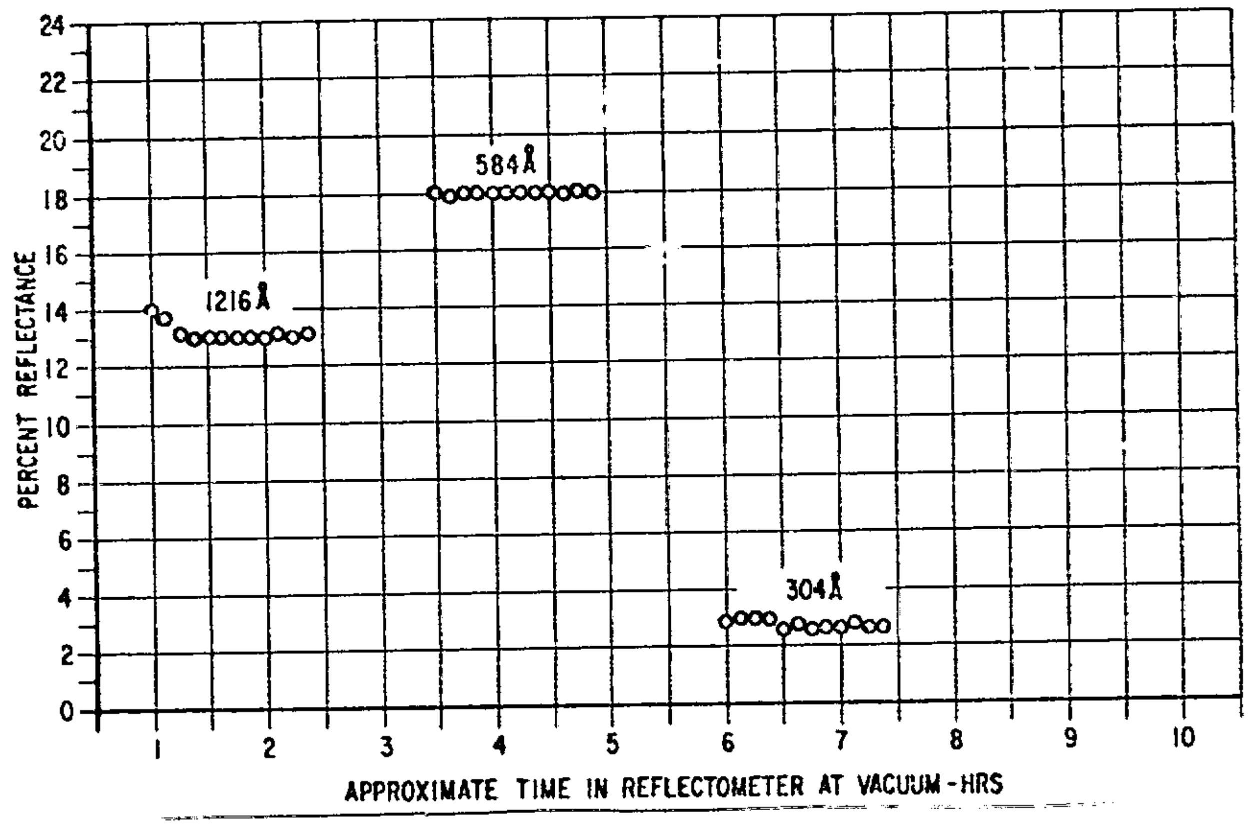


Figure 5-4 Reflectance of Mirror 25-11 on 10-12-73

5.2.4 Mirror 25-23

Mirror 25-23, like 25-11 (see Section 5.2.3), was used only as a control mirror and was not used in any tests. Its reflectance data are given in Table 5-4 and the reflectance averages for each measurement date are plotted in Figure 5-5. The reflectance measurements on this mirror covered a time period of only about six weeks. All four of the measurement sets on this mirror were made in the reflectometer along with the last four sets on mirror 25-11. In two cases another mirror was also present in the reflectometer during these measurements.

Table 5-4
REFLECTANCE VALUES OF MIRROR 25-23

Date	REFLECTANCE, PERCENT Wavelength at 304Å	at 584Å	at 1216Å
10-12-73	2.9	18.0	15.0
	3.0	17.8	14.7
	3.0	18.0	14.0
	3.0	18.0	14.9
	2.8	17.9	14.0
	2.6	17.5	14.0
	2.6	18.0	14.0
	2.7	17.9	14.0
	2.7	17.9	14.0
	2.8	17.5	14.0
	2.8	17.6	14.4
	2.8	18.0	14.2
10-30-73*	2.5	16.6	13.5
	2.5	16.9	13.5
	2.3	16.7	13.5
11-8-73	2.9	20.0	16.4
	2.9	20.2	16.4
	2.8	19.8	16.4
11-21-73	3.4	18.5	16.0
	3.4	18.5	15.7
	3.3	18.5	15.4

*The data obtained on 10-30-73 was in the following order: 304, 584, 1216Å. In all other measurements of mirror 25-23, 1216Å was measured first, followed by 584 then 304Å last.

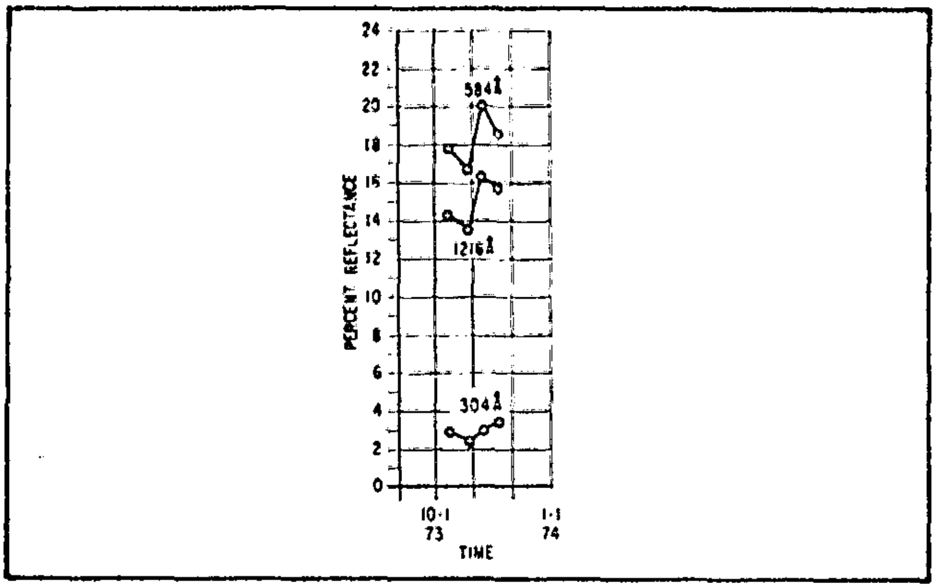


Figure 5-5 Long-Term Changes of the Reflectance of Control Mirror No. 25-23

In the first set of reflectance measurements on mirror 25-23, it was in the reflectometer with mirror 25-11 when the reflectance was measured twelve times at each wavelength (10-12-73). The individual measurements from this first set are plotted in Figure 5-6 as a function of approximate time in the reflectometer. This mirror, like 25-11, showed an apparent reflectance decrease early in the measurement period at 1216Å. However the subsequent measurements in a several hour time period appear reasonably stable as did all measurements of 584 and 304Å. In the second set of reflectance measurements (10-30-73), mirror 25-23 was in the reflectometer with mirror 25-11 and 25-24 (see Section 5.3.1). The reflectances at all three wavelengths decreased for mirror 25-23 with the reflectance changes being borderline at 1216 and 304Å while the change at 584Å was significant. (As discussed in Section 5.2.3, the reflectance measurements made at the same time on mirror 25-11 had shown apparent increases at all three wavelengths with a significant change at 1216Å and a borderline change at 584Å. The changes at all three wavelengths for mirror 25-24 were insignificant.)

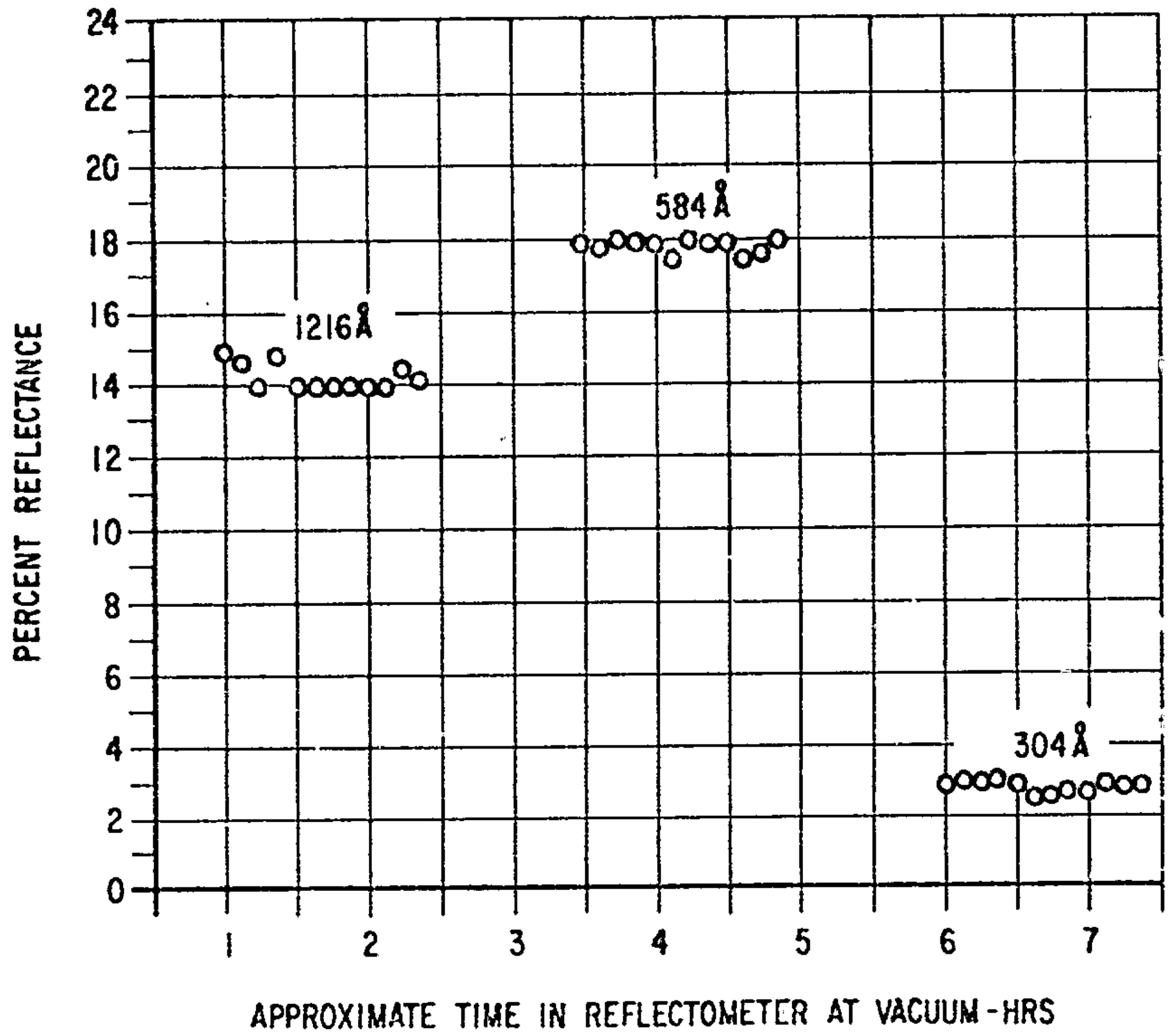


Figure 5-6 Reflectance of Mirror 25-23 on 10-12-73

The reflectance measurements made on mirror 25-23 nine days later (11-8-73), along with mirror 25-11, showed increased reflectances to values greater than the initial values. The changes were significant at 1216 and 584Å with a borderline change at 304Å. (Mirror 25-11 had also shown a borderline reflectance increase at 1216 and a significant increase at 584Å on this date.) In the last set of reflectance measurements on mirror 25-23 (11-21-73), borderline changes were noted at 1216 and 304Å and the change at 584Å was significant. At this time mirror 25-23 was in the reflectometer with mirror 25-11 and mirror 25-28 which had been contaminated (see Section 5.3.3).

5.3 REPEAT TESTS

In addition to the repeated measurements and analyses of all of the data on the control mirrors discussed above, two repeat tests were run on samples of each of three materials* which had been tested earlier in the program. These repeat tests were run to try to determine if the "anomalous" results of 1216Å were reproducible, and if perhaps the mirrors might be "cleaning-up" in the relatively clean vacuum environment of the reflectometer**.

The normal reflectance procedure had been to first measure the reflectance of mirrors at 1216Å followed by measurements at 584 and then at 304Å. The purpose of running two tests on similar samples was to run after-test reflectance measurements in this order on one mirror and on the other mirror to reverse the order with measurements at 304Å being made first. The hypothesis of

*Copies of all six test data sheets are contained in Appendix B.

**We have experienced just this type of situation many times with adsorbed contaminant deposits on magnesium-fluoride-overcoated aluminum first-surface mirrors measured in the wavelength range of 5330 to 1100Å, even to the extent that a visible deposit evaporated essentially completely within less than one hour at room temperature in vacuum.

of the "clean up" effect was that if a mirror were contaminated with a rather volatile adsorbed contaminant, the contaminant may evaporate over a short period of time in the reflectometer. Since we normally measured reflectance at 1216Å first, perhaps the reflectance measurements at that wavelength showed the effects of the as-yet-unevaporated portion of the contaminant. Then the additional time required to measure the reflectances at 584 and 304Å (normally about one to two hours at vacuum in the reflectometer) might be sufficient for most of the remaining contaminant to have evaporated from the mirror's surface such that the reflectance measurements at 304Å, normally measured last, would show no serious effects.

This testing was very brief because of very limited time, funds, and material samples left over from the other tests of the program. The only materials which we had remaining on hand in the as-received condition and in sufficient size to test were black Tedlar and two samples of S-13G paint like those two used in tests 1860 and 1863. Even so the S-13G samples were only approximately one-half the size of the previously tested samples. For lack of other materials which had shown anomalous results, we also reused the Beta Cloth sample that had been used in test number 1924. We cut it into two pieces for two tests and then ran the tests 20°C hotter to compensate for the smaller sample sizes and the 55°C, 72 hr vacuum bake the material had gotten in test number 1924. The results for all six tests are listed in Table 5-5.

5.3.1 S-13G Paint

Test numbers 2192 and 2193 were run on the small samples of S-13G paint using mirrors 25-24 and 25-25, respectively. These two tests of the S-13G samples were run with the normal ultraviolet screening test conditions of 72 hours with a sample temperature of 55°C

Table 5-5

Repeat Test Results

Test No.	Mirror No.	Material	Reflectance Changes, Percent at 304Å	at 584Å	at 1216Å	Sample Weight Loss g/cm^2	Visible Deposit On Mirror
2192	25-24	S-13C White Paint	-0.1	+0.1	-0.2	3.2×10^{-5}	No
2193	25-25	S-13G White Paint	0	+0.6	-0.7	4.4×10^{-5}	No
2210	25-26	Tedlar PVF Film, Black	+0.6	+2.1	+1.7	3.6×10^{-6}	No
2211	25-27	Tedlar PVF Film, Black	+0.7	+1.8	+0.4	4.4×10^{-6}	No
2218	25-28	Beta Cloth, Fluorel Coated	-1.1	-6.4	-7.9	1.8×10^{-5}	Yes
2219	25-29	Beta Cloth, Fluorel Coated	-0.6	-5.0	-7.4	2.0×10^{-5}	Yes

(rather than the conditions of 24 hours at 100°C which had been used for the previous tests of S-13G). At the reduced sample temperature and with the smaller sample size, the samples failed to produce significant contamination of the mirrors. Thus we were unable to determine in this case if clean-up were occurring.

5.3.2 Black Tedlar

Test numbers 2210 and 2211 were run on two samples of black Tedlar using mirrors 25-26 and 25-27. These tests were run with the normal ultraviolet screening test conditions of 72 hours with the samples at 55°C. Unfortunately, in this pair of tests, instead of starting the reflectance measurements at 1216Å on one mirror and at 304Å on the other mirror, the measurements of both mirrors were inadvertently begun at 304Å preventing us from determining in this case if clean-up in the spectrometer were occurring.

In both of these tests the mirrors showed reflectance increases at all three wavelengths with those increases in test number 2210 being significant at 1216 and 584Å and borderline at 304Å while those in test number 2211 were significant at 304 and 584Å and borderline at 1216Å. These values differed from those obtained in the first test of Tedlar (No. 1838) in which in a borderline reflectance change was observed at 304Å, an insignificant change was observed at 584Å, and a significant change was observed at 1216Å.

Two possible explanations for the significant reflectance increases in the repeat tests are: (1) perhaps the mirrors were contaminated before the pretest reflectance measurements (causing abnormally low values) and subsequently cleaned up during the materials tests, or (2) perhaps the mirrors were contaminated in the tests and the deposits were fluorescing during measurement causing apparent reflectance increases.

There is no evidence to indicate that the mirrors in any of the three tests, the first or the two repeats, were contaminated at any time during testing or reflectance measurements. Mirror H-6 used in the first test, was initially measured with two other new mirrors. After the first test it was in the reflectometer for measurements with the mirror from test number 1837 of Cat-A-Lac black paint, which showed little if any evidence of contamination. The two mirrors used in the repeat tests were measured with other new mirrors before they were used in the tests, and they were together in the reflectometer with no other mirrors, for the after-test measurements. It therefore appears unlikely that inadvertently contaminated mirrors caused the observed reflectance increases.

The black pigment or dye in the present Tedlar samples masks the normal fluorescence of unpigmented Tedlar, which, under visual inspection, has a fluorescence emission peak that appears rather weak and orange in color (where the wavelength would be on the order of 5000 to 6000Å). Even if the two mirrors had fluoresced appreciably because of adsorbed outgas products of Tedlar, the orange emitted radiation would be in a wavelength region not detected by the reflectometer. It thus appears that the observed increases in reflectance could not have been caused by this phenomenon either.

Further study will be required before increases in reflectance such as those observed in the repeat tests of the black Tedlar can be explained.

5.3.3 Beta Cloth

Because of (1) the unsatisfactory and confusing results of the first four repeat tests and (2) the sizes and previous thermal vacuum exposure of the Beta Cloth samples, we chose to run the two repeat tests of Beta Cloth at a sample temperature of 75°C in the hope of definitely producing contaminant deposits sufficient to be meaningful. As in the previous repeat tests, one purpose was to check the hypothesis of cleanup during reflectance measurements.

These two final tests were numbers 2218 and 2219 using mirrors 25-28 and 25-29. In both tests the outgas products of the Beta Cloth produced visible deposits on the test mirrors. The reflectance measurements on mirror 25-28 after its use in test number 2218 were made in the normal order beginning with 1216Å. This mirror was in the reflectometer for measurements after the test with control mirrors 25-11 and 25-23 which may have already been contaminated to some degree (see Sections 5.2.3 and 5.2.4). However, the indications from the reflectance measurements on the control mirrors are that if cross-contamination occurred, it was of the control mirrors by mirror 25-28, and we assume that the reflectance of 25-28 was not appreciably changed as a result of the other two mirrors being in the reflectometer at the same time. The reflectance of the other test mirror, 25-29 which was used in test number 2219, was measured in reverse order beginning with 304Å, and there were no other mirrors in the reflectometer at the time.

The test results given in Table 5-5 show that the mirrors had significant reflectance changes for all measurements but one, with the reflectance changes being slightly greater at all wavelengths for mirror 25-28. Regardless of the order in which the measurements were made, greater reflectance changes were measured at 1216Å than at 584 or 304Å. Thus there was no evidence in this case to substantiate the hypothesis of cleanup during the measurements. Obviously, more such tests would be required to further test this hypothesis.

Section 6
DISCUSSION OF RESULTS

6.1 UNEXPECTED REFLECTANCE CHANGES

Throughout this program there were reflectance changes of the platinum mirrors which were difficult to understand and evaluate. These included (1) significant increases in reflectances, (2) those changes exemplifying the "1216Å anomaly", and (3) unexpected changes for no obvious reason. A list of some of the more plausible explanations includes the following:

- The cleanup-during-measurement effect
- Cross-contamination during measurement
- Wavelength-dependent absorption characteristics of contaminants
- Systematic and human errors
- Mirror contamination by unexpected sources and conditions
- Natural aging of platinum coatings
- Optical interference effects and scatter losses

6.1.1 Clean-Up Effect

The clean-up effect, as was discussed in Section 5.3, has been observed at other times on magnesium-fluoride-overcoated aluminum first surface mirrors used on other programs. However, during the repeat tests of this program this effect was not detected. Thus we conclude that it probably was not an appreciable factor in the "1216Å anomaly" we observed on the platinum mirrors in this program.

6.1.2 Cross-Contamination During Measurement

In the data there is substantial evidence of cross-contamination between the mirrors while they were together in the vacuum and room temperature environment of the reflectometer. Background test numbers 1849 and 1859 generally showed greater reflectance changes than did background test numbers 1835 and 1836. The mirrors from tests 1849 and 1859 had been in the reflectometer with other, possibly contaminated mirrors, whereas those from tests 18 and 1836 were measured together with no possibility of cross-contamination by other mirrors. (See Section 4.1.)

The most obvious example of cross-contamination was that of background-test and control mirror 25-4 when a visible deposit was produced on it apparently by outgas products from mirror 25-19 which had previously been contaminated in test number 1941 by the sample of silicone-impregnated glass cloth. (See Section 5.2.2.) Mirror H-4 from background test number 1836 was subsequently measured with mirror 25-4 and cross-contamination of H-4 apparently occurred at that time. (See Section 5.2.1.)

Another example of cross-contamination occurred when control mirror 25-11, which had previously exhibited only insignificant and borderline reflectance changes, became contaminated when it was measured along with two mirrors which had been contaminated by outgas products from Beta Cloth. (See Section 5.2.3.) It is also possible that cross-contamination occurred between mirrors 25-11 and 25-23 causing the erratic data for 25-23. (See Section 5.2.4.) Later, both control mirrors 25-11 and 25-23 were apparently again contaminated by outgas products from mirror 25-28 which had been contaminated in a repeat test of Beta Cloth.

It should be noted that in all of the examples of cross-contamination, apparently it took place between the time the mirrors were placed in the reflectometer and roughly one hour later when the measurements were begun. It is not valid, however, to say that cross-contamination will always occur between a significantly contaminated mirror and a reasonably clean one. For example, mirror 25-1 (from test number 1840 on aluminized mylar), apparently was not contaminated by mirror 25-2 when the two were together in the reflectometer and the conditions for cross-contamination presumably existed. Mirror 25-2 had been used in test number 1841 on the ATM Door Seal sample. This sample had the highest weight loss of all of the samples tested on this program and the visible deposit on the mirror, caused by the door seal, affected the ultraviolet reflectance more than the condensed outgas products in any other test.

6.1.3 Wavelength-Dependent Absorption Characteristics of Contaminants

The evidence strongly suggests that the expectation of similar or greater reflectance changes at the shorter ultraviolet wavelengths (i.e., 304 and 584Å) was wrong. It can be seen from the data that significant reflectance changes occurred more often at 1216Å than at the other two wavelengths, and a little more often at 584 than at 304Å. Some mirrors, such as those used in tests 1924 (see Table 4-2) and 2219 (see Table 5-5), and background-test and control mirror 25-4 (see Section 5.2.2), were unquestionably contaminated and had large reflectance changes at 1216 and 584Å. Yet they had no more than borderline changes at 304Å. In fact, even when mirror 25-4 was contaminated with a visible deposit, the reflectance change at 304Å was not significant. The other mirrors showed less pronounced spectral differences. Even so, to varying degrees almost all of them fit the pattern of being more sensitive to contamination at 1216 than at 304Å with the sensitivity at 584Å being somewhere between that at the other two wavelengths. We see no other explanation than the obvious; the condensed outgas products are more transparent at 304 than at 584 and 1216Å.

This suggests, at least for various polymers, that optical absorptance may not be high throughout the ultraviolet portion of the electromagnetic spectrum, but, as in the visible and infrared regions, absorption bands and "windows" may exist. Moreover this suggests that ultraviolet spectroscopy could be used to catalog and subsequently identify contaminant deposits even too thin to be visually detected.

6.1.4 Other Causes

Other possible causes of the unexpected results are human and systematic (equipment) errors, contamination of mirrors other than during test or storage, natural aging of the platinum coatings, optical scatter losses and other optical effects. However, none of these appear to be likely causes of the observed results. The unexpectedly large changes at 1216Å and the other changes that occurred in background tests or after the storage of mirrors were too regular to be attributable to random errors or the accidental contamination of mirrors. Non-random measurement errors could also have occurred, but such biased measurements would have had little effect on the relative reflectance change results which were calculated from the differences of these measurements.

It is also possible that the reflectances of platinum coatings changed naturally with aging. However, we have no strong evidence to support this since those control mirrors that showed significant reflectance changes following storage also had a prior history of probably having been contaminated. Furthermore, we would not expect aging to have produced a much more pronounced effect at 1216Å than at the other wavelengths.

It also seems unlikely that optical interference effects or scatter losses could have contributed appreciably to either the 1216Å results or to the other unexpected changes. For optical interference to have caused the similar patterns of reflectance changes observed on the various mirrors would have required that either (1) all the contaminant deposits were uniform and had similar thicknesses and optical properties, or (2) the combinations of different thicknesses and optical properties of each deposit were such that the optical effects were similar. Such circumstances appear highly improbable. Optical scatter by contaminants, rather than absorptance, is also an improbable explanation of the observed reflectance changes, because, in general, scatter losses at longer wavelengths would not be greater than those at shorter wavelengths[9].

The significant positive reflectance changes which were observed in this program are not readily explainable at the present time. Measurement errors and inadvertent contamination of mirrors are obvious suspect causes of such results, but, as we discussed in Section 5.3.2, there is no evidence at the present time to support these hypotheses. More work will be required before these positive reflectance changes can be explained.

6.2 TEST DATA

A major question pertaining to the test data is whether or not the results of the materials tests were affected by the factors contributing to the unexpected reflectance changes of the control and repeat test mirrors. It appears that, except for the unexplainable positive reflectance changes, the other unexpected, apparently significant reflectance changes were real and were due mostly to cross-contamination and to high sensitivity of the platinum mirrors to contamination at 1216Å.

The cross-contamination observed on the control mirrors was a direct result of the practice of measuring the reflectance of more than one mirror at a time. This practice has been used at BBRC for many years with magnesium-fluoride-overcoated aluminum first-surface mirrors. As mentioned previously, we have observed cleanup of such mirrors in vacuum at room temperature in time periods of a few hours or less. However, for those mirrors we had no evidence of appreciable cross-contamination under these conditions. We did not expect the platinum mirrors to be significantly different, so, in order to keep the cost of the current program at a reasonable level, we chose to measure the reflectances of two or three mirrors at the same time whenever this was possible.

It has since become obvious that cross-contamination did occur often for the platinum mirrors in the program. However, except for two of the background test mirrors (discussed previously) which may have been contaminated by other mirrors during reflectance measurements, it does not appear that any of the background or materials test data were compromised.

Examination of the test data in Table 4-2 and of the listing in Appendix B of the mirrors measured together shows that only mirrors 25-17 and 25 18 might possibly have contaminated another mirror (25-19) used in a later test (test number 1941). Study of the reflectance changes of 25-17 and 25-18, however, shows that none of the changes were as large as those generally observed on mirrors which later definitely cross-contaminated other mirrors.

Therefore, if cross-contamination occurred it probably did not affect the results of test number 1941 appreciably. Even if some contamination of mirror 25-19 did occur, it probably caused the before-test reflectance to be abnormally low, making the reported reflectance changes of test number 1941 (which already characterize the material as an unacceptable contamination threat) smaller than they would otherwise be.

In all other cases of mirrors from materials tests where a significantly contaminated mirror was in the reflectometer, it was either alone or with a similarly contaminated mirror from a test of the same type material, or the other mirrors with it in the reflectometer had reflectance changes of lower magnitude and thus probably did not cause the observed changes of the contaminated mirror.

It therefore appears that none of the reflectance changes noted for the mirrors used in the present materials tests were due to anything but condensation of outgas products from the tested materials.

Section 7
CONCLUSIONS AND RECOMMENDATIONS

The conclusions given below are based on limited testing, quite often on only one test of a material, or on limited observations of a condition or characteristic. Even so the conclusions are in general agreement with the results of extensive contamination testing of materials by BBRC on other programs and they are considered to be generally valid conclusions. The conclusions which were unexpected, yet are not inconsistent with later test results, are those pertaining to the rapidity of cross contamination of platinum mirrors and the relative insensitivity of the reflectance at 304Å of platinum mirrors to adsorbed outgas products.

The sixteen materials samples which were tested are grouped according to their contamination characteristics into four groups; those which are considered unacceptable, those which are undesirable, those which are borderline, and those which apparently represent no serious contamination threat to platinum coated ultraviolet-region optics.

The first group includes the ATM door seal and the silicone-impregnated glass cloth, when they will be used at or above 55°C, and S-13G white paint (with a 24-hour, 74°C bake at rough vacuum pressures) when it will be used at about 100°C. These materials produced appreciable quantities of ultraviolet-absorbing condensable outgas products and are considered unacceptable in proximity to ultraviolet optical surfaces in vacuum.

The second group includes Beta cloth when used at or above 55°C and S-13G white paint (cured in high vacuum at 93°C or higher for 24 hours or more) when used at about 100°C. These materials are not as bad as the first group, yet they still caused significant reflectance changes at extreme ultraviolet wavelengths and are considered undesirable in proximity to ultraviolet optical surfaces in vacuum.

The third group of materials includes Viton PLV 10008, Viton 1006A, Nomex lacing tape, O-ring compound V-747-75, Cat-A-Lac black paint, Black Tedlar, and S-13G paint when it is vacuum baked as for the second group. If they are to be used at or above 55°C, these materials are considered borderline threats and to have a reasonable chance to cause some contamination of ultraviolet optical surfaces under conditions conducive to contamination. Their use should be controlled to (1) prevent line-of-sight conditions between the materials and the optics, (2) prevent use of large quantities of the materials, and (3) prevent use of the materials where their temperatures are above those of the optics.

The fourth group of materials includes aluminized Mylar, the fiberglass standoff, the ATM flight cable, and the insulation button. When used at 55°C or less these four materials appear to have sufficiently low potentials for contamination of ultraviolet optics that they do not represent a serious contamination threat.

The three materials tests of samples of S-13G white paint, along with the repeat tests on this material, show that higher temperature bakes for long periods in high vacuum reduce the contamination potential of the paint, and make it comparable to some of the better of the sixteen materials tested.

Cross-contamination often occurs between platinum mirrors in vacuum at room temperature. The surprising aspect is that the cross-contamination occurs quite rapidly, perhaps in a period of an hour or less. Even though evaporation of some outgas products from the contaminated mirror must occur in order for it to cross-contaminate another mirror, appreciable cleanup of the contaminated mirror cannot be expected at room temperature. Apparently cross-contamination did not compromise the data of the materials tests reported above. However, this room-temperature cross-contamination of one mirror by another previously contaminated one has a significant implication for the contamination control of instruments. Obviously the non-line-of-sight placement of critical elements from contaminant sources does not offer enough protection if other intervening surfaces can be contaminated and then act as new sources of contamination.

The condition which was called the "1216Å anomaly" early in the program, i.e., greater reflectance changes at 1216Å than at 304 and often at 584Å, probably is not an anomaly except that it was unexpected. It is apparently the result of contaminants on platinum mirrors being more absorbant at 1216Å than they are at 584 and 304Å.

There is some evidence that the contamination characteristics of platinum coatings are different than those of magnesium-fluoride-overcoated aluminum coatings. Perhaps the platinum is more susceptible to adsorbed contaminants, making cleanup of the platinum by evaporation of the contaminant less likely to occur.

Based on the results obtained from the materials tests performed under this program, recommendations have already been made concerning the use of these materials. Even though they were limited by the amount of funds available, the investigations in this program of the "1216Å anomaly", the sensitivity of platinum mirrors to contamination and the cross-contamination of mirrors during measurement also produced results that have significant implications for other programs involving ultraviolet-region instruments, such as the large space telescope (LST).

We recommend that further studies be performed to determine whether, as the present study seems to indicate, the 1216Å region is in fact more sensitive to contaminant degradation than are shorter-wavelength regions. If so, perhaps future materials tests need only be performed at this more sensitive wavelength, thereby reducing the costs of such test programs. We also recommend that further studies be performed to compare the contaminant sensitivity of platinum mirrors to that of other mirror materials such as gold or magnesium-fluoride-overcoated aluminum, and to examine further the apparent threat of cross contamination of mirrors during reflectance measurements. Confirmation of the tentative results of this program will have significant cost impacts on future programs. Increased sensitivity of platinum mirrors to contamination will require tighter, more expensive contamination controls, while the danger of cross-contamination will require the more expensive measurement of only one mirror at a time.

Section 8
REFERENCES

1. BBRC, Final Report Apollo Telescope Mount Materials Contamination Test Program, F71-03, H. C. Poehlmann, et al, Boulder, Colorado, 30 April 1971.

2. D. N. Chorafas, Statistical Processes and Reliability Engineering, D. Van Nostrand Co., Inc., Princeton, New Jersey, 1960, pp 9-11.

3. Ibid, p. 12.

4. H. Margenau and G. M. Murphy, The Mathematics of Physics and Chemistry, second ed., D. Van Nostrand Co., Inc., Princeton, New Jersey, 1956, p. 511.

5. Ibid, p. 511.

6. Ibid, p. 513.

7. Ibid, p. 515.

8. James A. R. Samson, Techniques of Vacuum Ultraviolet Spectroscopy, John Wiley & Sons., Inc., New York, 1967, p. 187.

9. M. Born and E. Wolf, Principles of Optics, 4th ed., Pergamon Press, 1970, pp. 633-664.

Appendix A
TEST DATA SHEETS

This appendix consists of copies of the data sheets for all background tests, materials tests, and repeat tests.

BBRC MOS TEST II

DATE 12-23-71

MATERIAL Station 4 Background — TEST NO. 1335

CATEGORY 37; VEM Backgrounds

MANUFACTURER — PROGRAM M3??

PREPARATION —

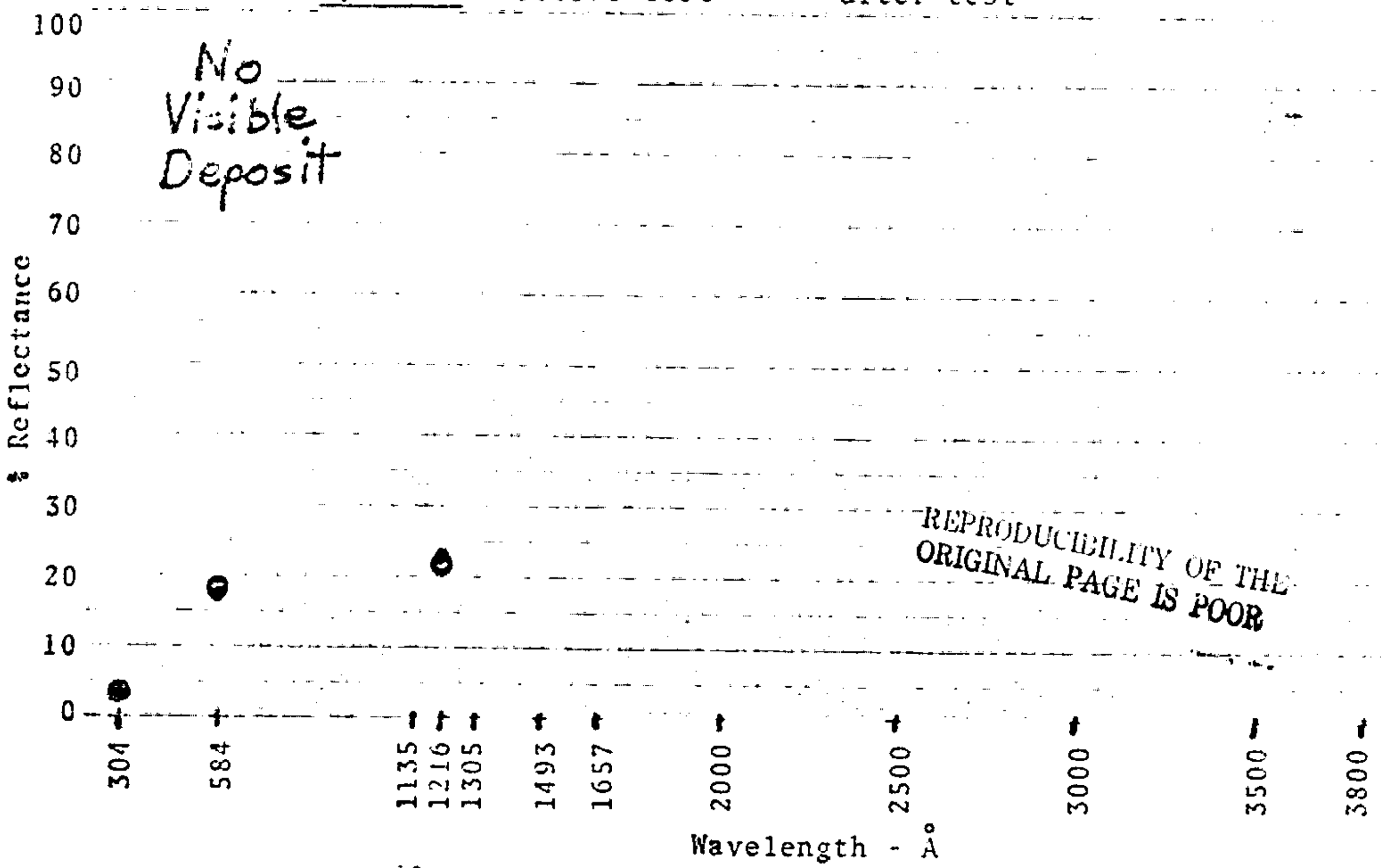
CURE —

TEST CONDITIONS: TIME 70.6 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA — SAMPLE WEIGHT LOSS — g

SAMPLE THICKNESS — MIRROR WEIGHT GAIN 0.00002 g

Mirror No. H-3 Reflectance before test -● Reflectance after test -○



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.3	17.5		22.9								
Reflectance, % After, R_2	3.4	17.9		22.0								
Change, % $R_1 - R_2$	+0.1	+0.4		-0.9								
% Change $100(R_1-R_2)/R_1$	+3.0	+2.3		-3.9								

ESTIMATED CHANGE PRECISION ~±0.4% @1216 Å; ~±0.2% @ other λ's

BBRC MOS TEST II

DATE 12-22-

MATERIAL Tation 5 Background

TEST NO. [illegible]

CATEGORY 1; VEN Backgrounds

MANUFACTURER —

PROGRAM MSFC

PREPARATION —

CURE —

TEST CONDITIONS: TIME 90.9 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA —

SAMPLE WEIGHT LOSS — g

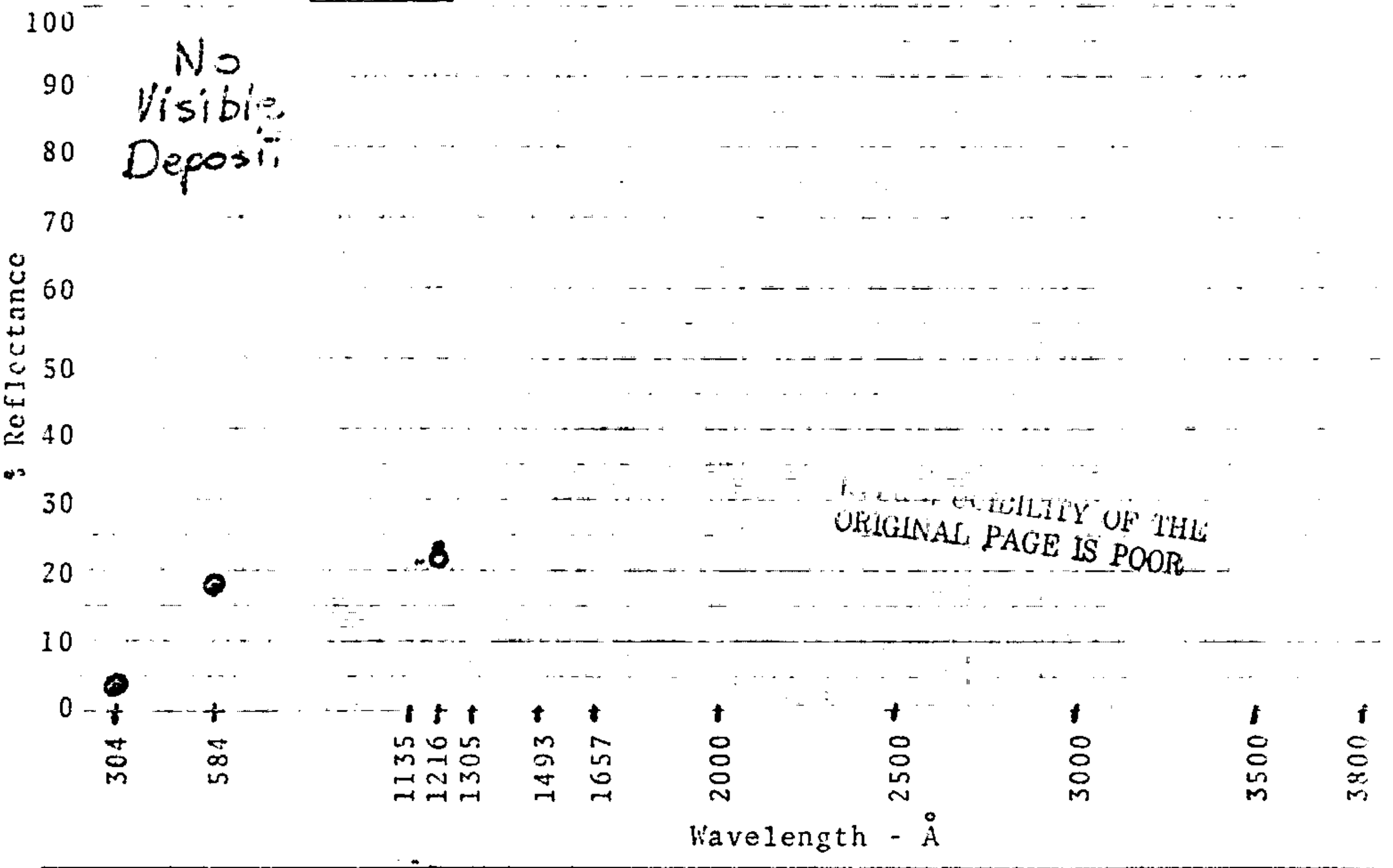
SAMPLE THICKNESS —

MIRROR WEIGHT GAIN -0.00005 g

Mirror No. H-4

Reflectance before test —•

Reflectance after test —○



LEGIBILITY OF THE ORIGINAL PAGE IS POOR

	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.2	17.5		23.3								
Reflectance, % After, R_2	3.3	18.0		21.8								
Change, % $R_1 - R_2$	+0.1	+0.5		-1.5								
% Change $100(R_1-R_2)/R_1$	+3.1	+2.9		-6.4								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

BBRC MOS TEST II

DATE 12-27-71

MATERIAL Cat-A-Lac Paint, Black TEST NO. 1-32

CATEGORY 06 & 77: Coating, Optical & Thermal Contr.

MANUFACTURER Finch Paint Co. PROGRAM MSFC

PREPARATION By MSFC (Finch No. 463-3-8)

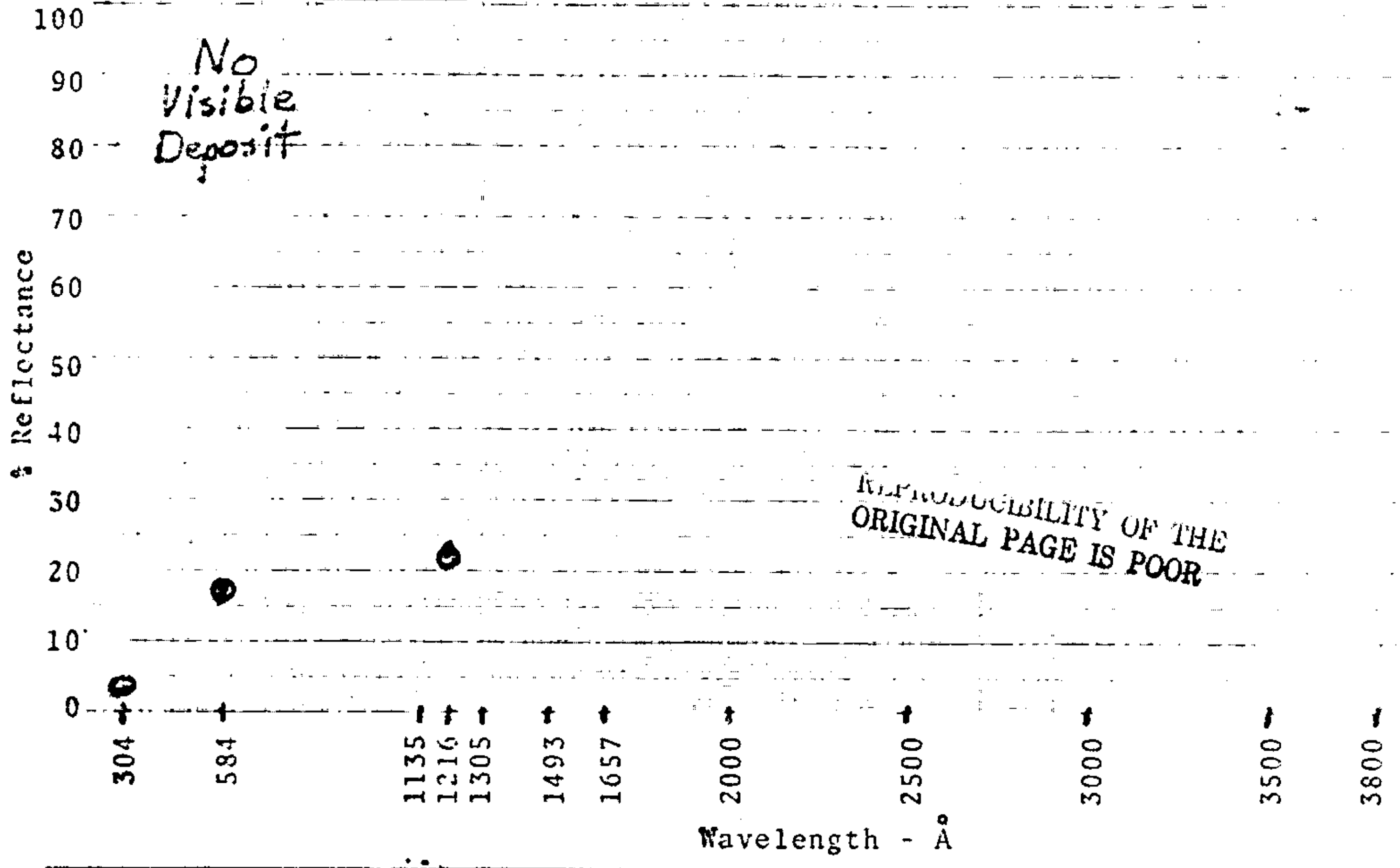
CURE By MSFC; baked 24 hrs @ 200°F (93.3°C)

TEST CONDITIONS: TIME 70.8 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA 25 cm² SAMPLE WEIGHT LOSS 0.00020 [illegible]

SAMPLE THICKNESS thin layer on Al foil MIRROR WEIGHT GAIN -0.00004 g

Mirror No. H-5 Reflectance before test —• Reflectance after test —o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.0	17.5		23.2								
Reflectance, % After, R_2	3.2	17.6		21.9								
Change, % $R_1 - R_2$	+0.2	+0.1		-1.3								
% Change $100(R_1 - R_2)/R_1$	+6.7	+0.6		-5.6								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216 Å, ~±0.2% @ other λs

BSFC MOS TEST II

DATE 12-[illegible]

MATERIAL Tedlar, Black

TEST NO. [illegible]

CATEGORY 12 & 18; Films & sheets, and Insulation, Thermal

MANUFACTURER ——

PROGRAM MSFC

PREPARATION tested as received from MSFC

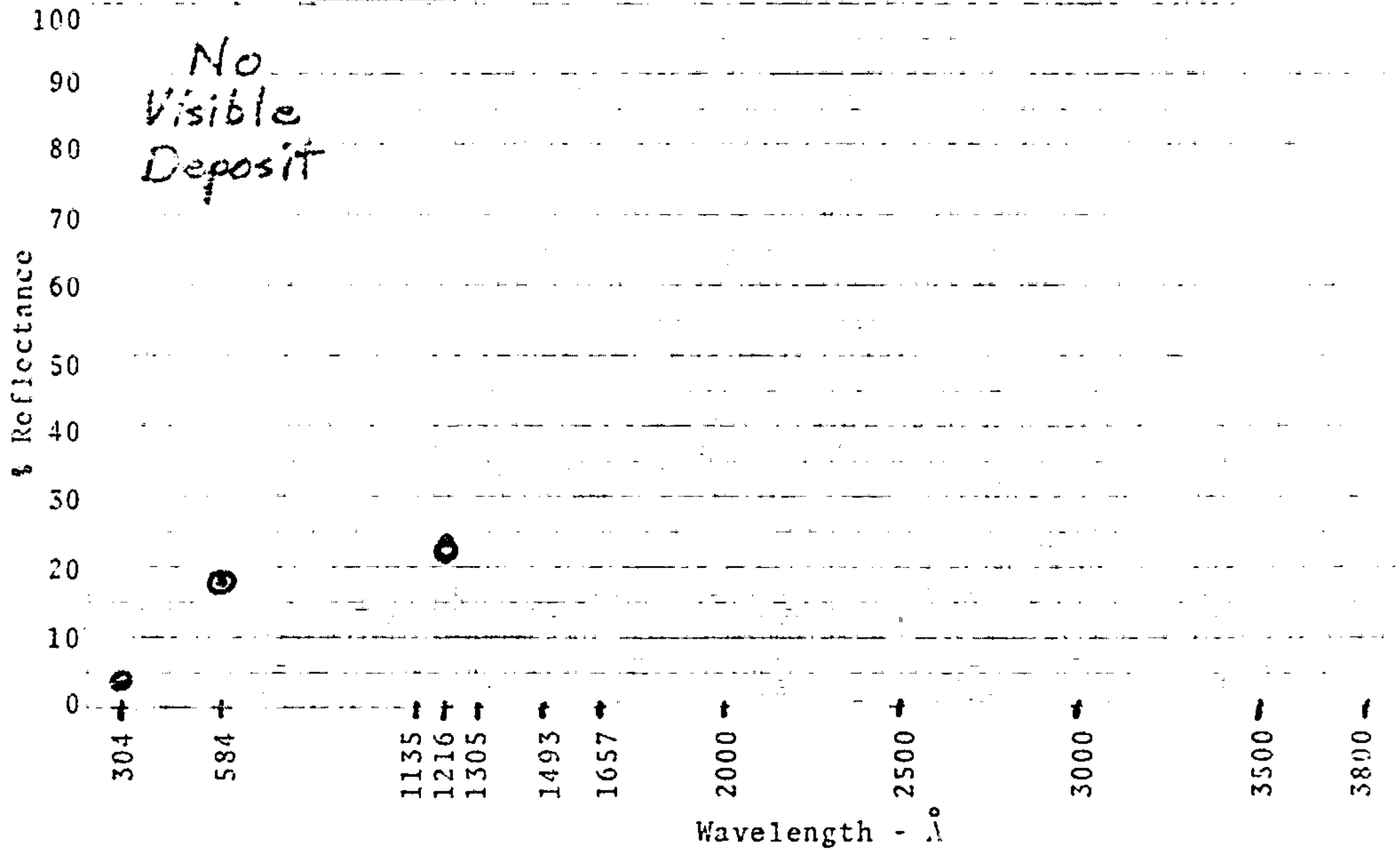
CURE ——

TEST CONDITIONS: TIME 70.3 hrs SAMPLE TEMP 55 °C MIRROR TEMP 25 °C

SAMPLE AREA 25 cm^2 SAMPLE WEIGHT LOSS 0.00031 g

SAMPLE THICKNESS thin sheet MIRROR WEIGHT GAIN 0.00001 g

Mirror No. H-6 Reflectance before test → Reflectance after test →



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.4	17.9		23.7								
Reflectance, % After, R_2	3.6	17.9		22.1								
Change, % $R_1 - R_2$	+0.2	0		-1.6								
% Change $100(R_1-R_2)/R_1$	[illegible]	0		-6.8								

ESTIMATED CHANGE PRECISION ~ ±0.4% @ 1216 Å, ~ ±0.2% @ other λs

BBRC MOS TEST II

DATE 1-4-72

MATERIAL Aluminized Mylar * TEST NO. [illegible]

CATEGORY 18; Insulation, Thermal

MANUFACTURER —— PROGRAM MSFC

PREPARATION tested as received from MSFC

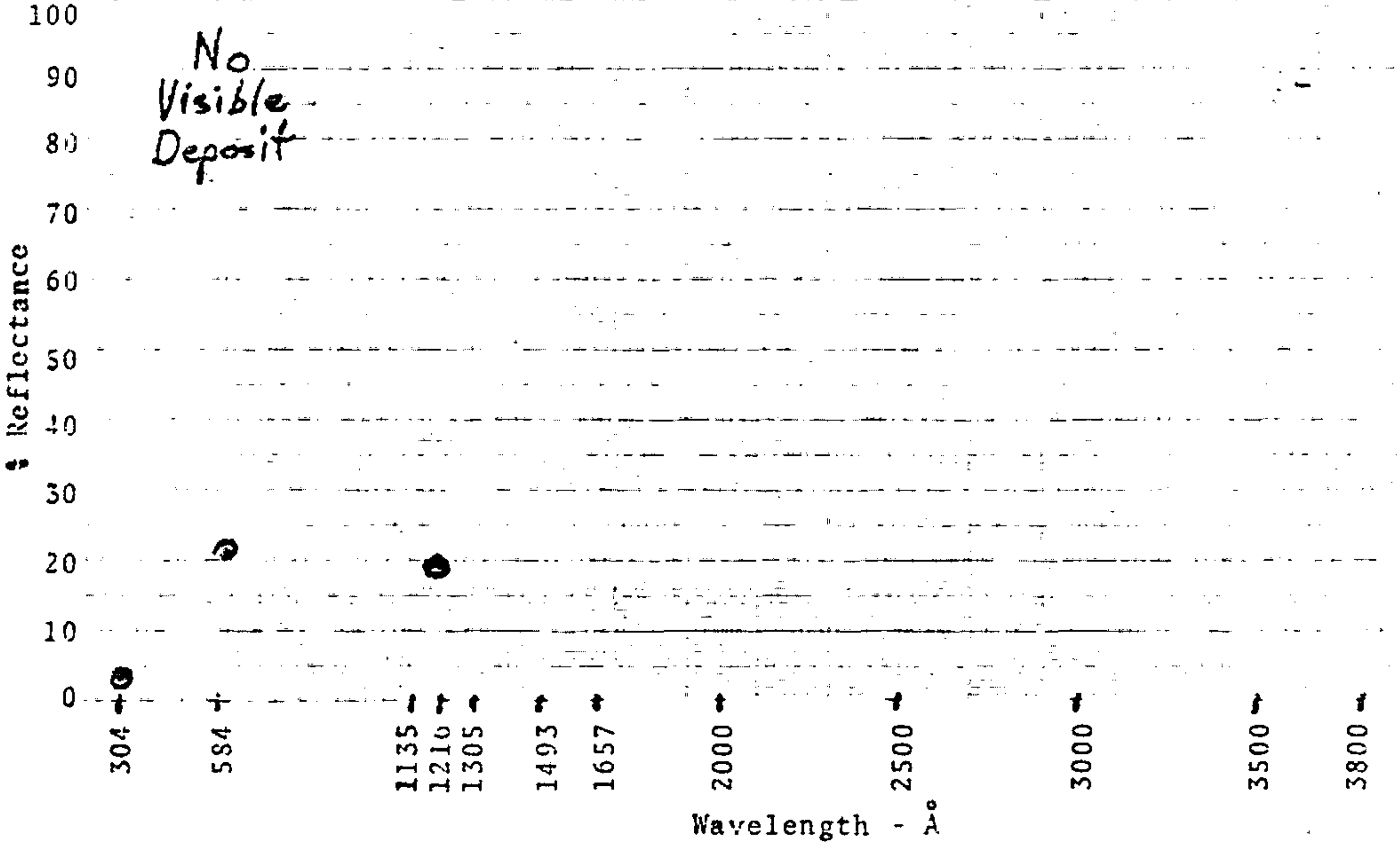
CURE —— * Aluminized on both sides

TEST CONDITIONS: TIME 72.0 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA 50 cm^2 SAMPLE WEIGHT LOSS 0.0[illegible]4 g

SAMPLE THICKNESS thin sheet MIRROR WEIGHT GAIN —— g

Mirror No. 25-1 Reflectance before test ● Reflectance after test ○



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.3	21.0		19.9								
Reflectance, % After, R_2	3.[illegible]	21.2		19.0								
Change, % $R_1 - R_2$	-0.[illegible]	+0.2		-0.9								
% Change $100(R_1 - R_2)/R_1$	-5.3	+1.0		-4.5								

ESTIMATED CHANGE PRECISION ~±3.7% @ 1216Å; ~±0.2% @ [illegible]

BBRC MOS TEST II

DATE 1-4-72

MATERIAL Door Seal, for ATM * TEST NO. 187

CATEGORY 30; Seals, Gaskets, O-Rings

MANUFACTURER —— PROGRAM MSFC

PREPARATION Tested as received from MSFC.

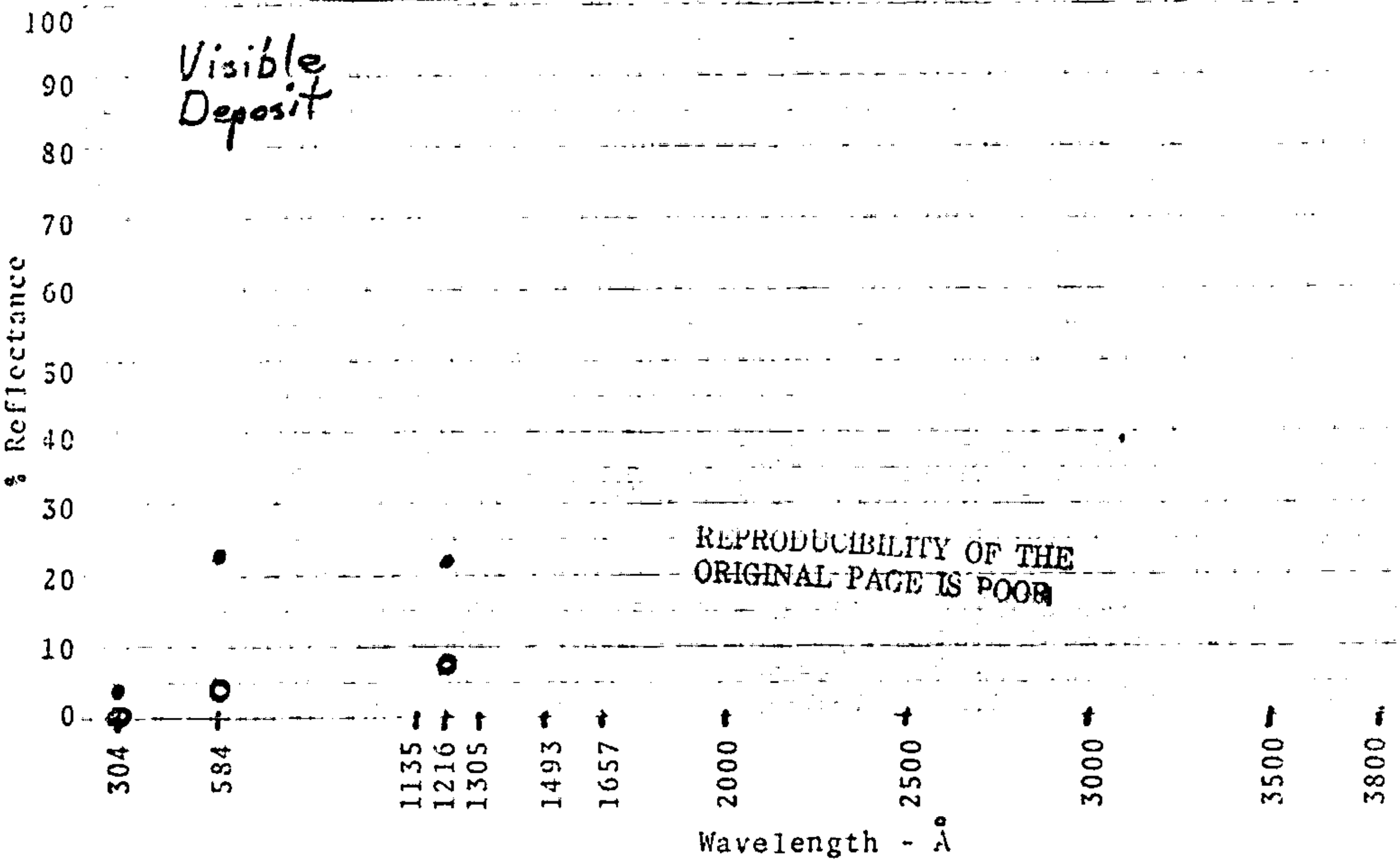
CURE ——, *red, tubular elastomer bonded to cloth

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~26 cm² SAMPLE WEIGHT LOSS 0.09552 g

SAMPLE THICKNESS —— MIRROR WEIGHT GAIN —— g

Mirror No. 25-2 Reflectance before test -• Reflectance after test -o



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	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.9	23.0		22.0								
Reflectance, % After, R_2	0.6	3.9		7.5								
Change, % $R_1 - R_2$	-3.3	-19.1		-14.5								
% Change $100(R_1-R_2)/R_1$	-84.6	-83.0		-65.9								

ESTIMATED CHANGE PRECISION ~±0.5% @1216Å; ~±0.2% @ others

BBRC MOS TEST II

DATE 1-17-72

MATERIAL Fiberglass Standoff TEST NO. [illegible]

CATEGORY 09 & 25; Components, Mechanical & Plastic, Structural

MANUFACTURER ——

PROGRAM MSFC

PREPARATION tested as received from MSFC

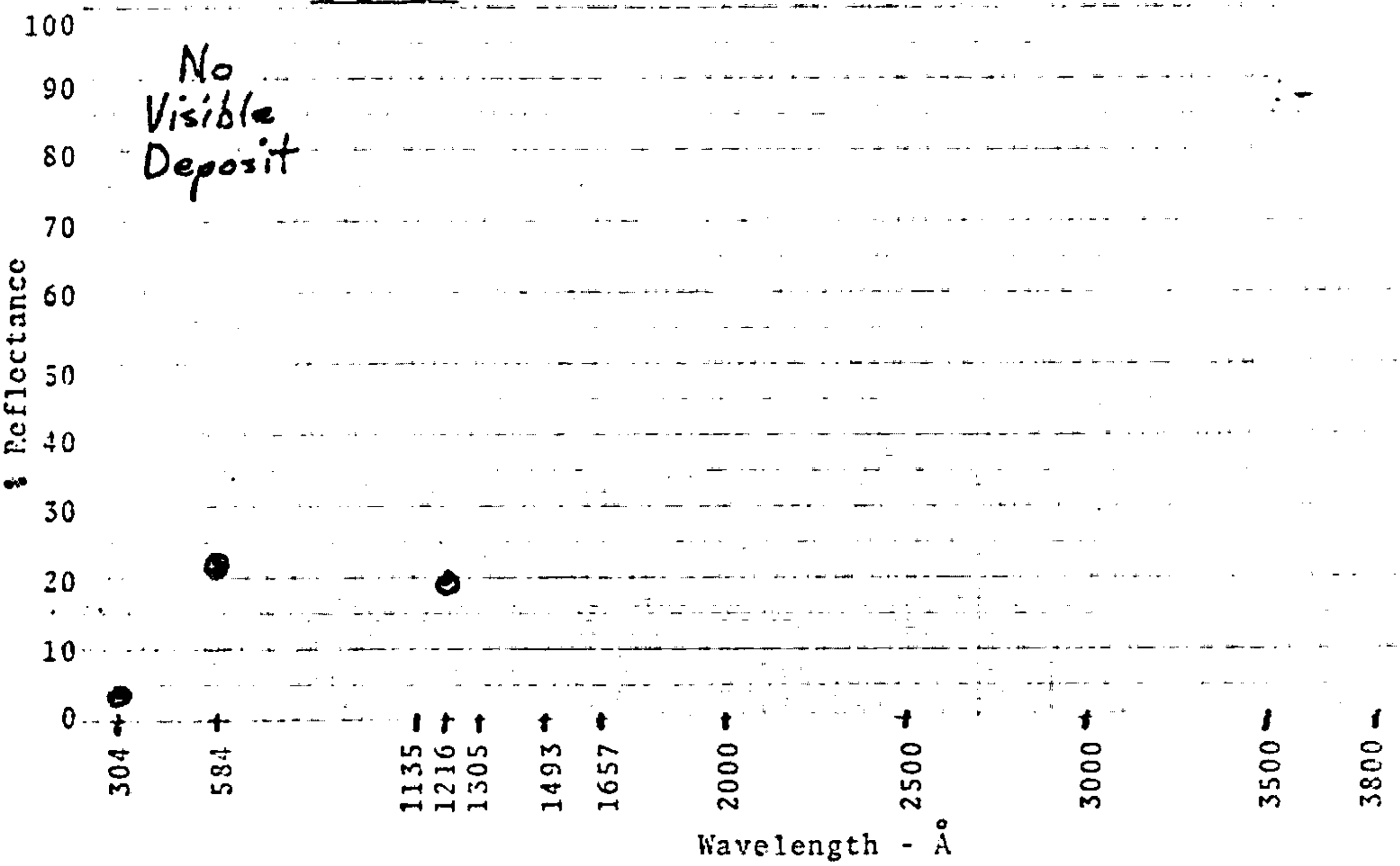
CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~28.9 cm² SAMPLE WEIGHT LOSS 0.00186 g

SAMPLE THICKNESS ~ 3 to 4 mm MIRROR WEIGHT GAIN ____ g

Mirror No. 25-3 Reflectance before test -• Reflectance after test -o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.8	22.0		19.9								
Reflectance, % After, R_2	3.6	21.9		19.0								
Change, % $R_1 - R_2$	-0.2	-0.1		-0.9								
% Change $100(R_1-R_2)/R_1$	-5.3	-0.5		-4.5								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

BBRC MOS TEST II

DATE 2-4-72

MATERIAL Station 10 Background PLATE NO. 1849

CATEGORY 37; VEN Backgrounds

MANUFACTURER —— PROGRAM MSFC

PREPARATION ——

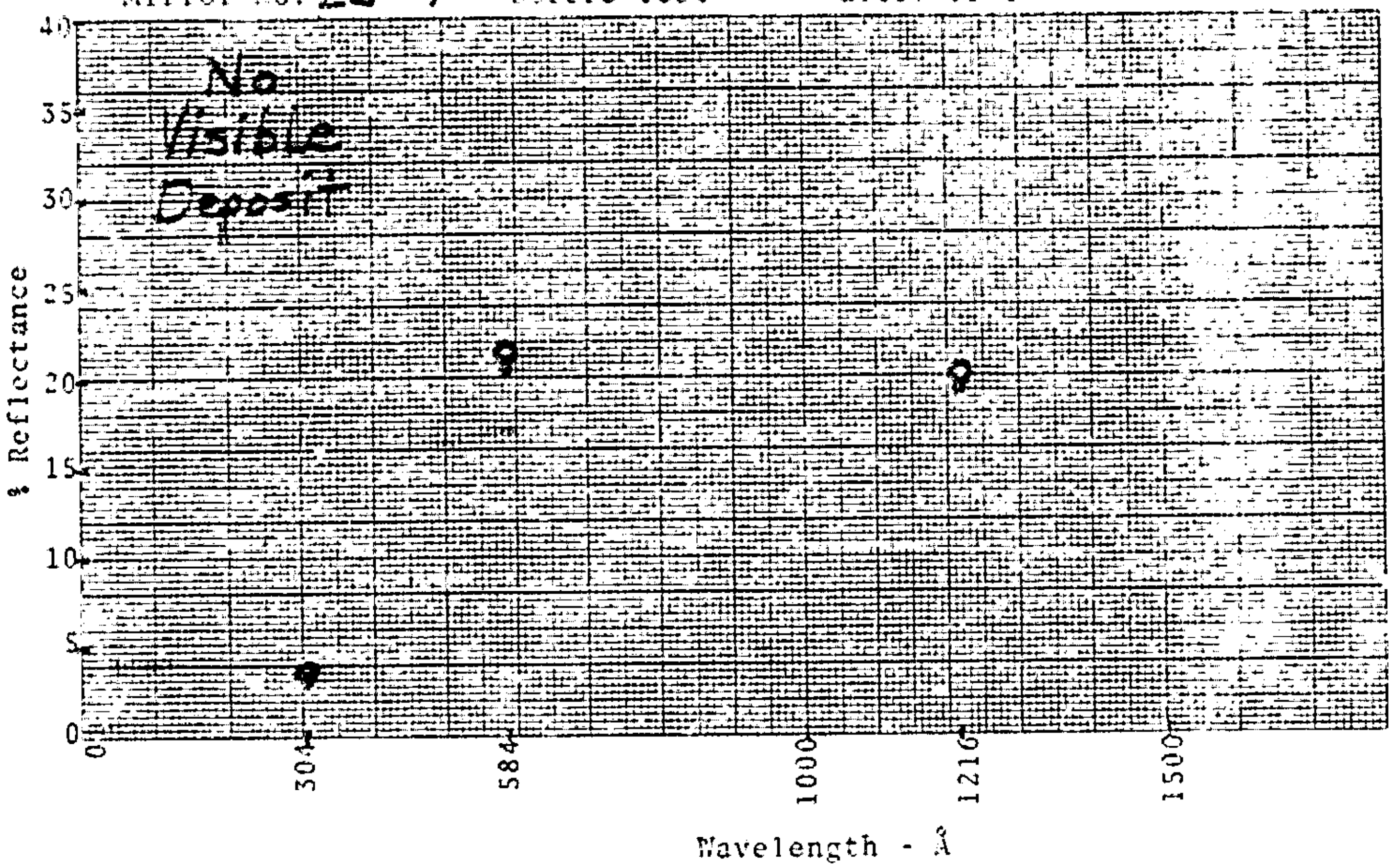
CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA —— SAMPLE WEIGHT LOSS —— g

SAMPLE THICKNESS —— MIRROR WEIGHT GAIN —— g

Mirror No. 25-4 Reflectance before test Reflectance after test



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.3	20.4		19.4								
Reflectance, % After, R_2	3.6	21.5		20.1								
Change, $R_1 - R_2$	+0.3	+1.1		+0.7								
% Change $100(R_1-R_2)/R_1$	+9.1	+5.4		+3.6								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λ:

BARC [illegible] TEST II

DATE 2-8-72

MATERIAL ATM Flight Cable Bundle * TEST NO. 1853

CATEGORY [illegible] Insulated Wire & Cable

MANUFACTURER ——— PROGRAM MSFC

PREPARATION tested as received from MSFC

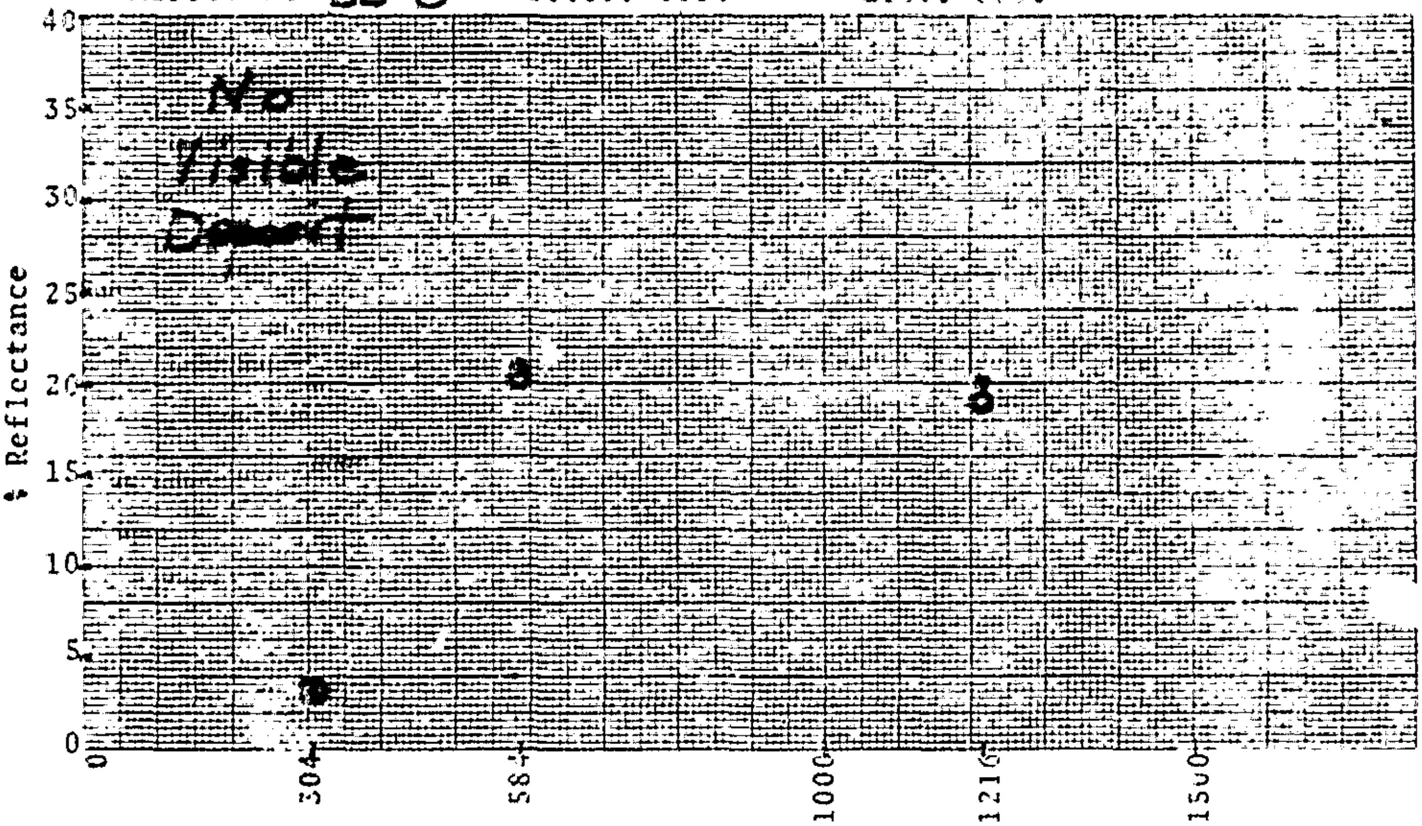
CURE ——— ; * with two lacing cord ties

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55 °C MIRROR TEMP 25 °C

SAMPLE AREA > 26.7 cm² SAMPLE WEIGHT LOSS 0.02072 g

SAMPLE THICKNESS ~ 1.2 cm dia MIRROR WEIGHT GAIN ——— g

Mirror No. 25-5 Reflectance before test -• Reflectance after test -○



Wavelength - Å

	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3300	3800
Reflectance, % Before, R_1	3.2	20.8		19.9								
Reflectance, % After, R_2	3.2	20.3		18.9								
Change, % $R_1 - R_2$	-0-	-0.5		-1.0								
% Change $100(R_1-R_2)/R_1$	-0-	-2.4		-5.0								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

[illegible] TEST II

DATE 2-15-72

MATERIAL Insulation Button for ATM TEST NO. 1357

CATEGORY C9; Components, Mechanical

MANUFACTURER —— PROGRAM MSFC

PREPARATION tested as received from MSFC

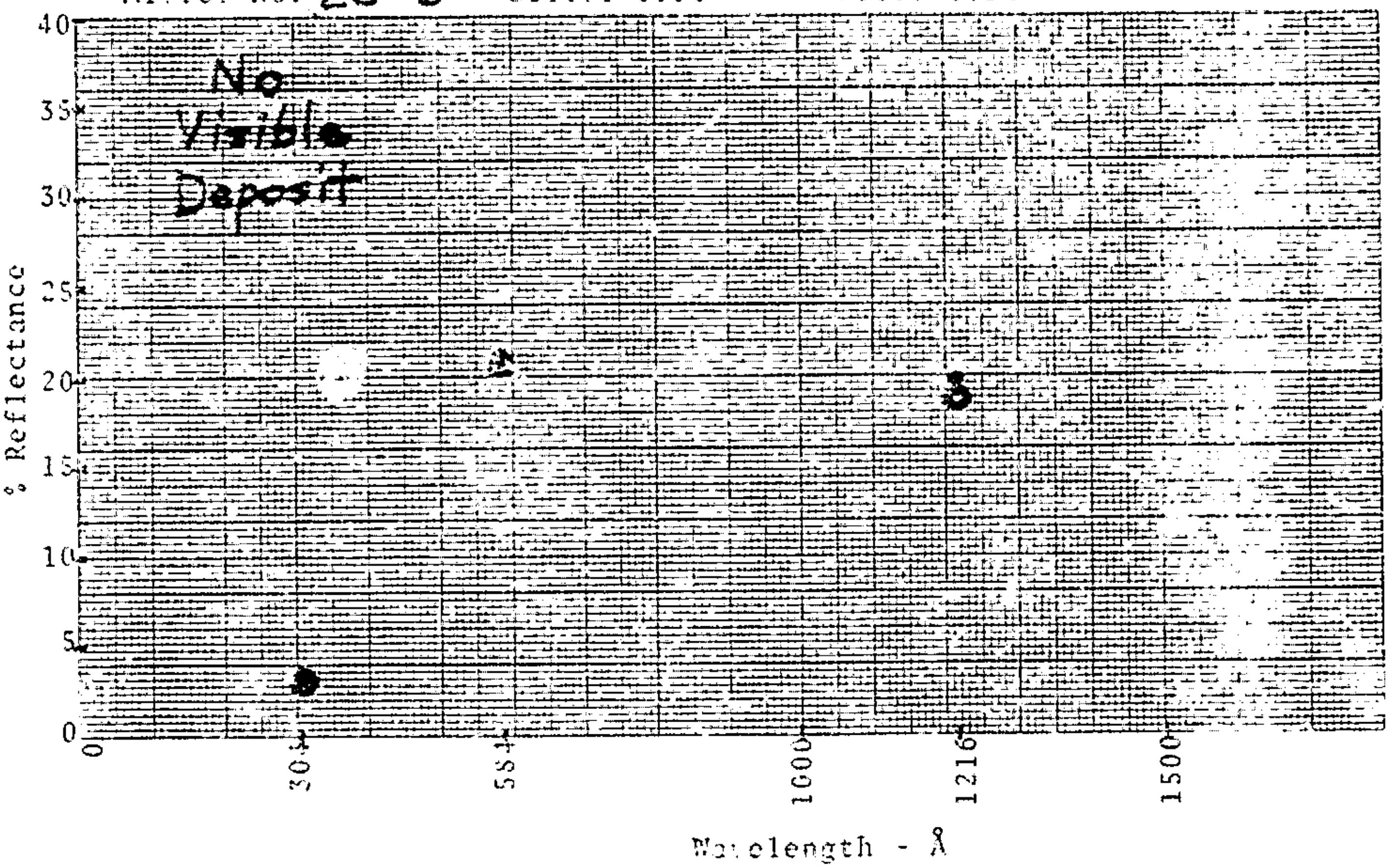
CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~23.7 cm^2 SAMPLE WEIGHT LOSS 0.0001+g

SAMPLE THICKNESS ~0.15 cm MIRROR WEIGHT GAIN —— g

Mirror No. 25-6 Reflectance before test —• Reflectance after test —o



	304	584	1135	1216	1303	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.3	21.0		19.8								
Reflectance, % After, R_2	3.2	20.6		18.7								
Change, % $R_1 - R_2$	-0.1	-0.4		-1.1								
% Change, $100(R_1-R_2)/R_1$	-3.0	-1.9		-5.6								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ others [illegible]

BBRC M05 TEST II

DATE 3-7-72

MATERIAL Station 5 Background

TEST NO. 1857

CATEGORY 37; VEN Backgrounds

MANUFACTURER —

PROGRAM MSFC

PREPARATION —

CURE —

TEST CONDITIONS: TIME 26.3 hrs SAMPLE TEMP 100°C MIRROR TEMP 25°C

SAMPLE AREA —

SAMPLE WEIGHT LOSS — g

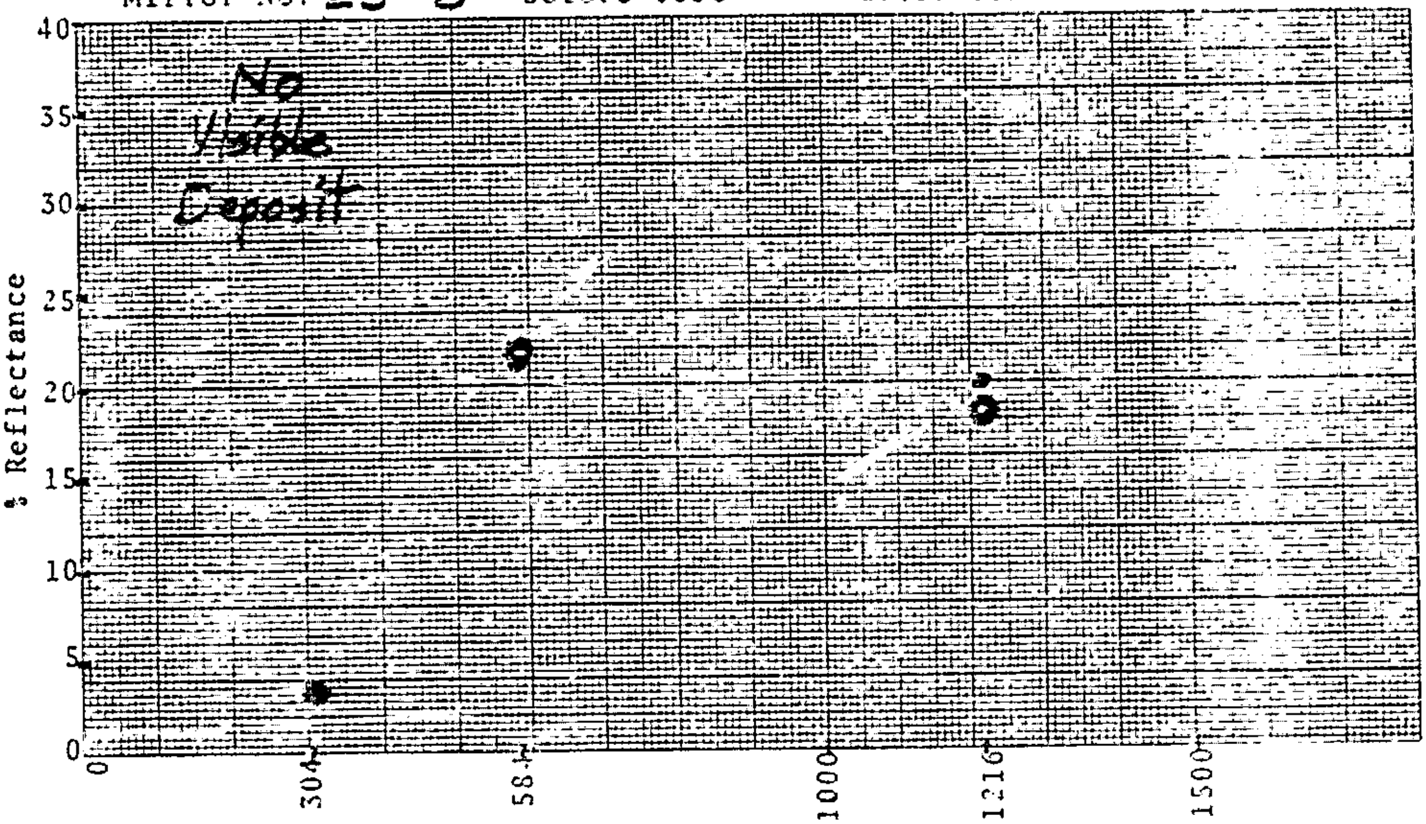
SAMPLE THICKNESS —

MIRROR WEIGHT GAIN — g

Mirror No. 25-8

Reflectance before test •

Reflectance after test ○



Wavelength - Å

	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.5	21.1		20.0								
Reflectance, % After, R_2	3.2	21.7		18.3								
Change, % $R_1 - R_2$	-0.3	+0.6		-1.7								
% Change $100(R_1-R_2)/R_1$	-3.6	+2.8		-8.5								

ESTIMATED CHANGE PRECISION ±0.7% @ 1216Å; ±0.2% @ other λ.

BMSC MOS TEST II

DATE 3-3-72

MATERIAL *Paint, White, S-13G* TEST NO. *1362*

CATEGORY *07j Coatings, Thermal Control*

MANUFACTURER *IITRI* PROGRAM *MSFC*

PREPARATION *by MSFC; lot 72-1-31-1 ~ 7+6 Sample #1*

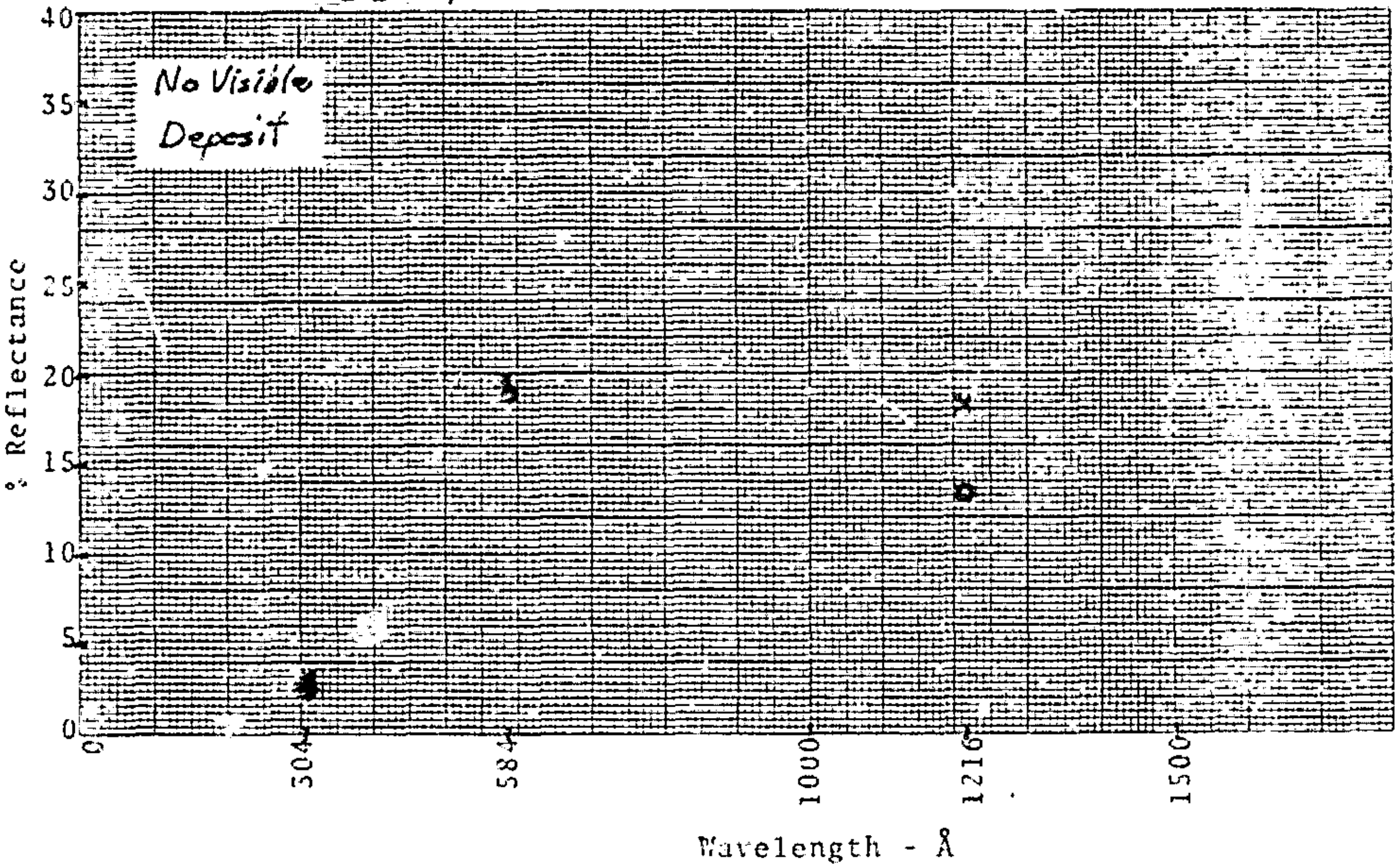
CURE *by MSFC; vacuum baked 48 hrs @ 300°F & 10^{-3} Torr*

TEST CONDITIONS: TIME *240* hrs SAMPLE TEMP *100*°C MIRROR TEMP *25*°C

SAMPLE AREA *~25 cm²* SAMPLE WEIGHT LOSS *0.0030?* g

SAMPLE THICKNESS *thin coating on foil* MIRROR WEIGHT GAIN *—* g

Mirror No. *25-9* Reflectance before test - × Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3300	3800
Reflectance, % Before, R_1	3.2	19.7		18.3								
Reflectance, % After, R_2	2.5	19.0		13.3								
Change, % $R_1 - R_2$	-0.7	-0.7		-5.0								
% Change $100(R_1-R_2)/R_1$	-21.9	-3.6		-27.3								

ESTIMATED CHANGE PRECISION *~ ±0.4% @ 1216Å; ~ ±0.2% @ other λs* *[illegible]*

BASIC MO3 TEST II

DATE 3-8-72

MATERIAL Paint, White, S-13G

TEST NO. 1863

CATEGORY 07; Coatings Thermal Control

MANUFACTURER IITRI

PROGRAM MSFC

PREPARATION by MSFC: Lot 72-1-31-1 C-046 Sample #2

CURE by MSFC: vacuum baked 24 hrs @ 200°F & 10^{-3} Torr

TEST CONDITIONS: TIME 24.0 hrs SAMPLE TEMP 100 °C MIRROR TEMP 25 °C

SAMPLE AREA ~25 cm²

SAMPLE WEIGHT LOSS 0.00072 g

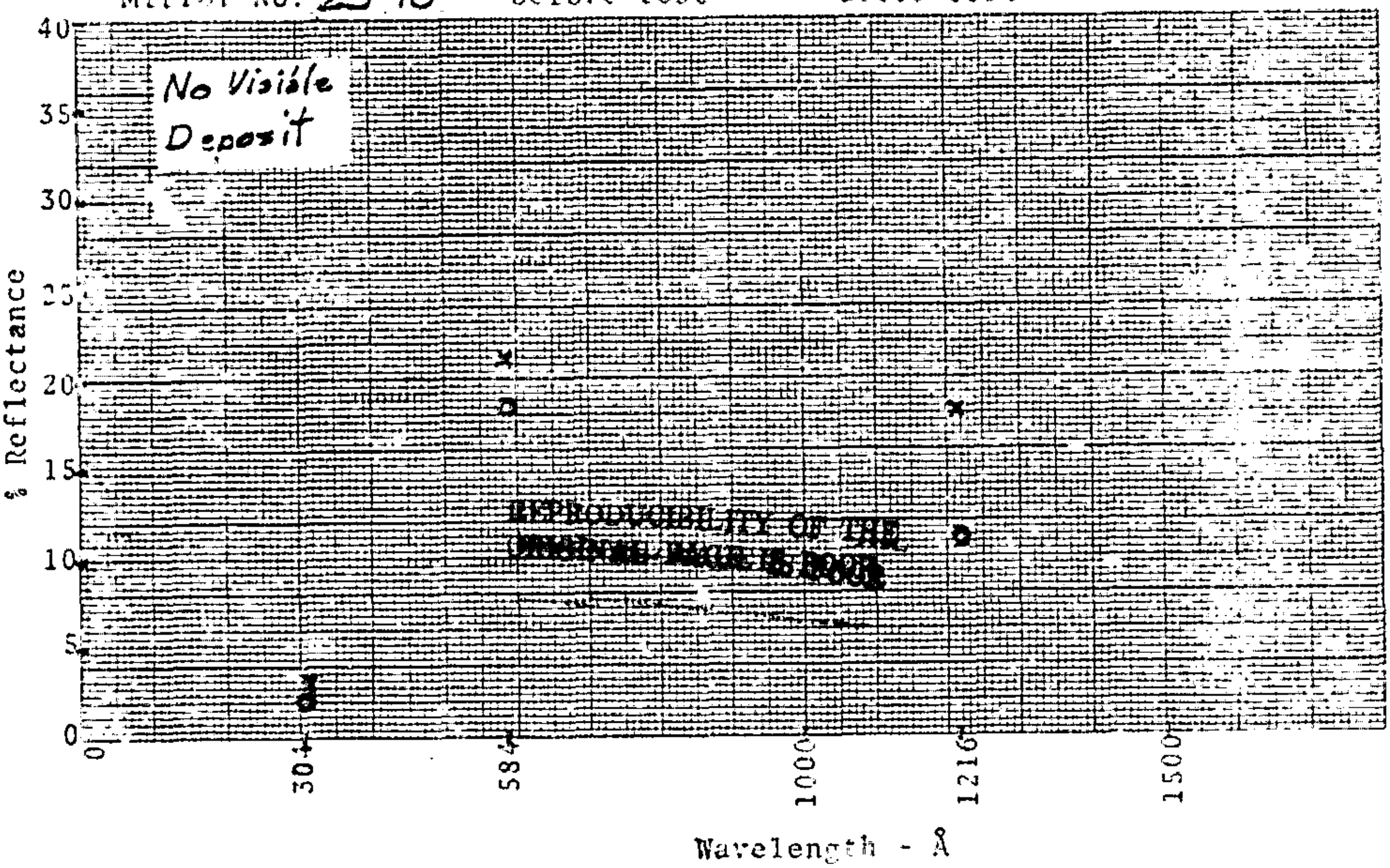
SAMPLE THICKNESS thin coating on foil

MIRROR WEIGHT GAIN —— g

Mirror No. 25-10

Reflectance before test - x

Reflectance after test - o



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

	304	584	1150	1216	1303	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.2	21.0		18.3								
Reflectance, % After, R_2	2.1	18.5		10.9								
Change, % $R_1 - R_2$	-1.1	-2.5		-7.4								
% Change $100(R_1-R_2)/R_1$	-34.4	-11.9		-40.4								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ others

BMSC VCM TEST II

DATE 7-14-72

MATERIAL Station 8 Background TEST NO. 1305

CATEGORY 37; VEN Backgrounds

MANUFACTURER — PROGRAM MSFC

PREPARATION —

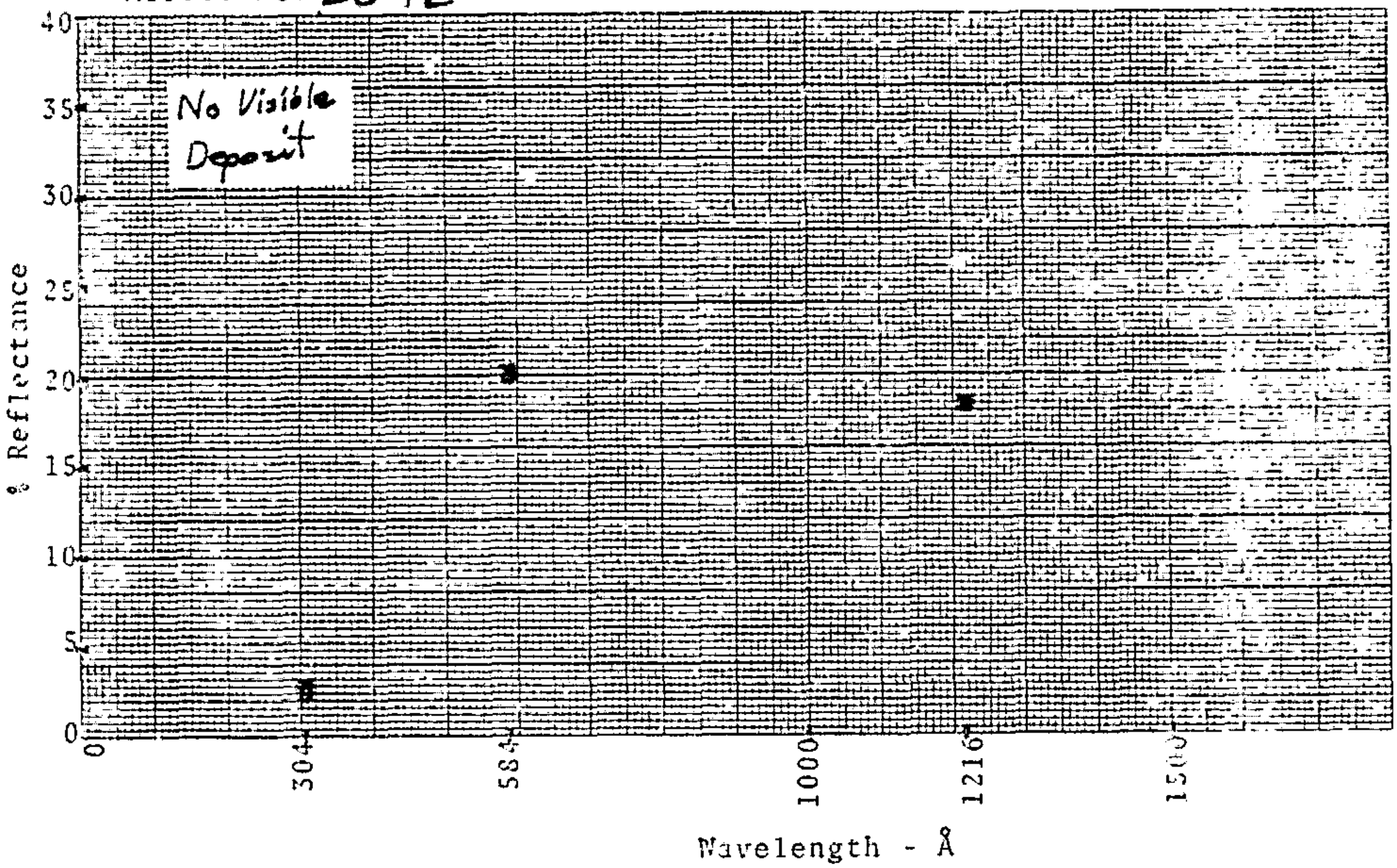
CURE —

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA — SAMPLE WEIGHT LOSS — g

SAMPLE THICKNESS — MIRROR WEIGHT GAIN — g

Mirror No. 25-12 Reflectance before test -■ ; Reflectance after test -○



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	3.3	20.2		17.9								
Reflectance, % After, R_2	2.9	20.0		17.9								
Change, % $R_1 - R_2$	-0.4	-0.2		0								
% Change $100(R_1-R_2)/R$	-12.1	-1.0		0								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ others

BERC MOS TEST II

DATE 7-21-72

MATERIAL Viton PLV 10008 TEST NO. 1909

CATEGORY 30; Seals, Gaskets, O-Rings

MANUFACTURER Pelmor Labs. PROGRAM MSFC

PREPARATION Tested as received from MSFC

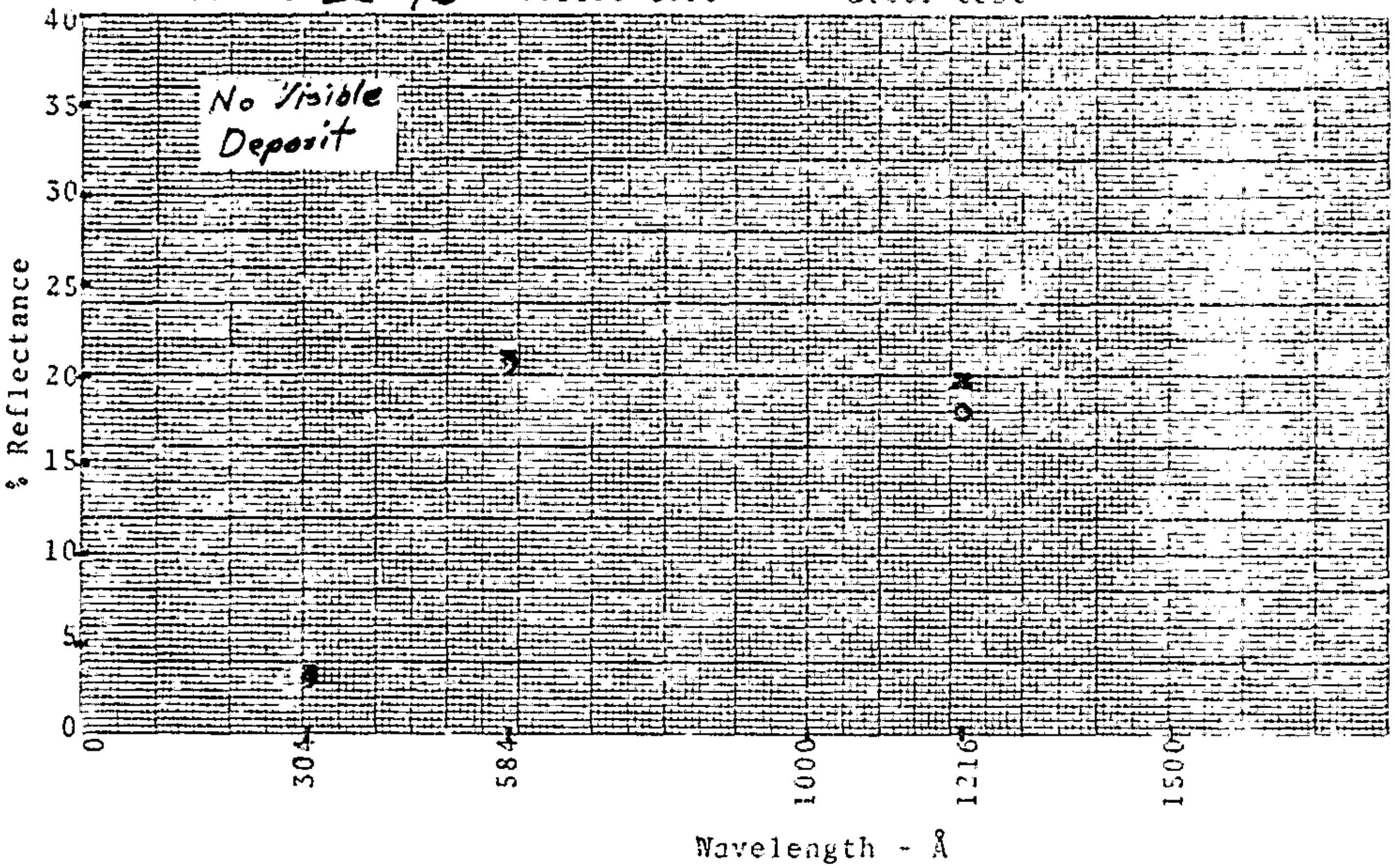
CURE (by MSFC) baked 24 hrs @ 450°F

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP ~25°C

SAMPLE AREA ~ 27.5 cm² SAMPLE WEIGHT LOSS 0.0080 g

SAMPLE THICKNESS ~ 0.19 cm MIRROR WEIGHT GAIN —— g

Mirror No. 25-13 Reflectance before test - ■ Reflectance after test - O



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3300	3800
Reflectance, % Before, R_1	3.5	21.1		19.8								
Reflectance, % After, R_2	3.0	20.6		18.0								
Change, % $R_1 - R_2$	-0.5	-0.5		-1.8								
% Change $100(R_1-R_2)/R_1$	-14.3	-2.4		-9.1								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

NHB 8060 TEST 11

DATE 8-1-77

MATERIAL Viton PLV 1006A TEST NO. 1316

CATEGORY 30; Seals, Gaskets, O-Rings

MANUFACTURER Pelmor Labs. PROGRAM MSFC

PREPARATION Tested as received from MSFC

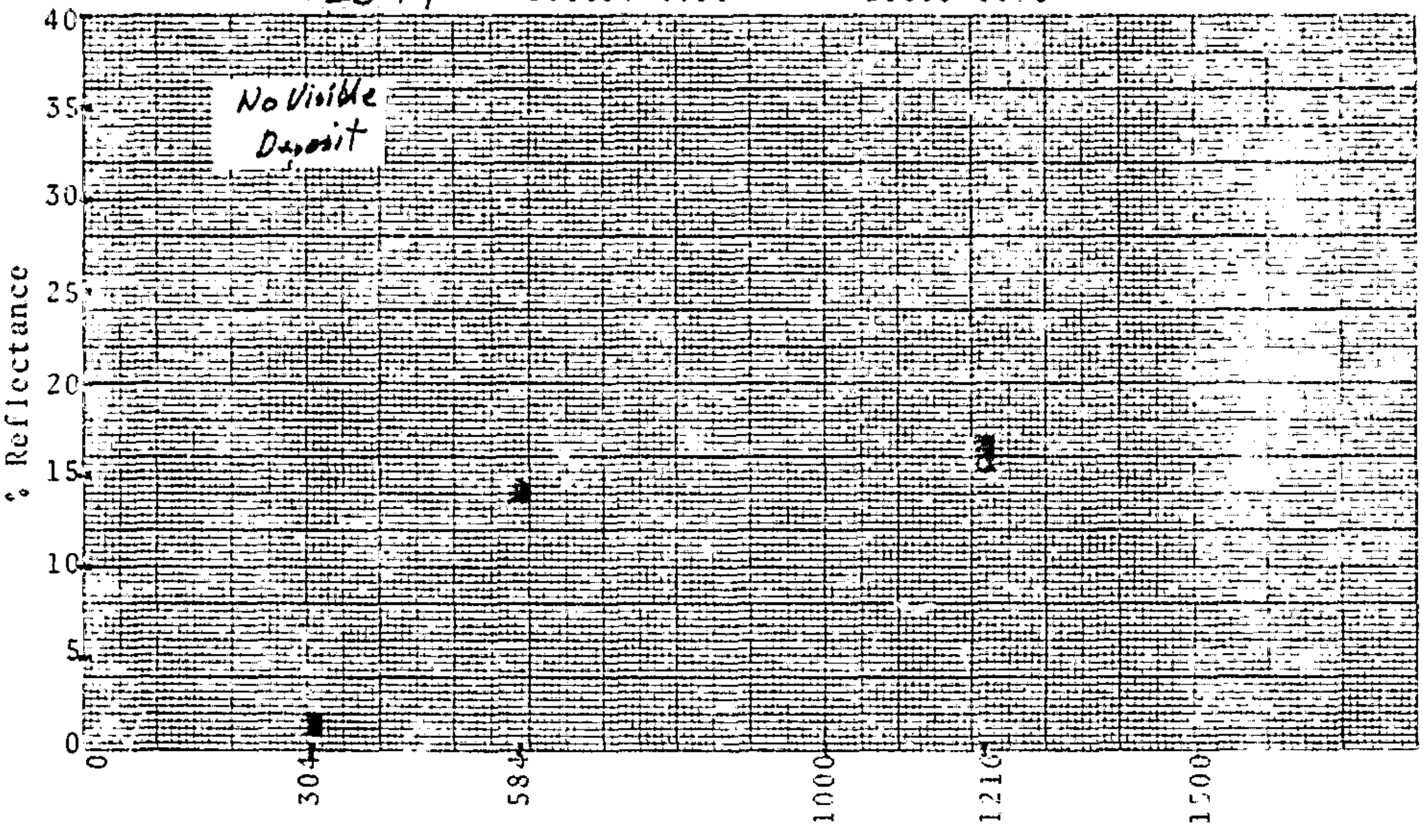
CURE (by MSFC) baked 2 hrs @ 200°F plus 16 hrs @ 450°F

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA 250 cm² SAMPLE WEIGHT LOSS 0.00399 g

SAMPLE THICKNESS 0.19 cm MIRROR WEIGHT GAIN — g

Mirror No. 25-14 Reflectance before test - ■ Reflectance after test - ●



Wavelength - Å

	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	1.3	14.0		16.6								
Reflectance, % After, R_2	1.6	14.3		15.6								
Change, % $(R_1 - R_2)(-1)$	+0.3	+0.3		-1.0								
% Change $-100(R_1 - R_2)/R_1$	+23.1	+2.1		-6.0								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216 Å; ~±0.2% @ other wavelengths

BBRC 3005 TEST 11

DATE 8-3-72

MATERIAL Beta Cloth, Fluorel Coated, RL-3487 TEST NO. ______

CATEGORY ______

MANUFACTURER Raybestos Manhattan PROGRAM MSFC

PREPARATION Tested as received from MSFC

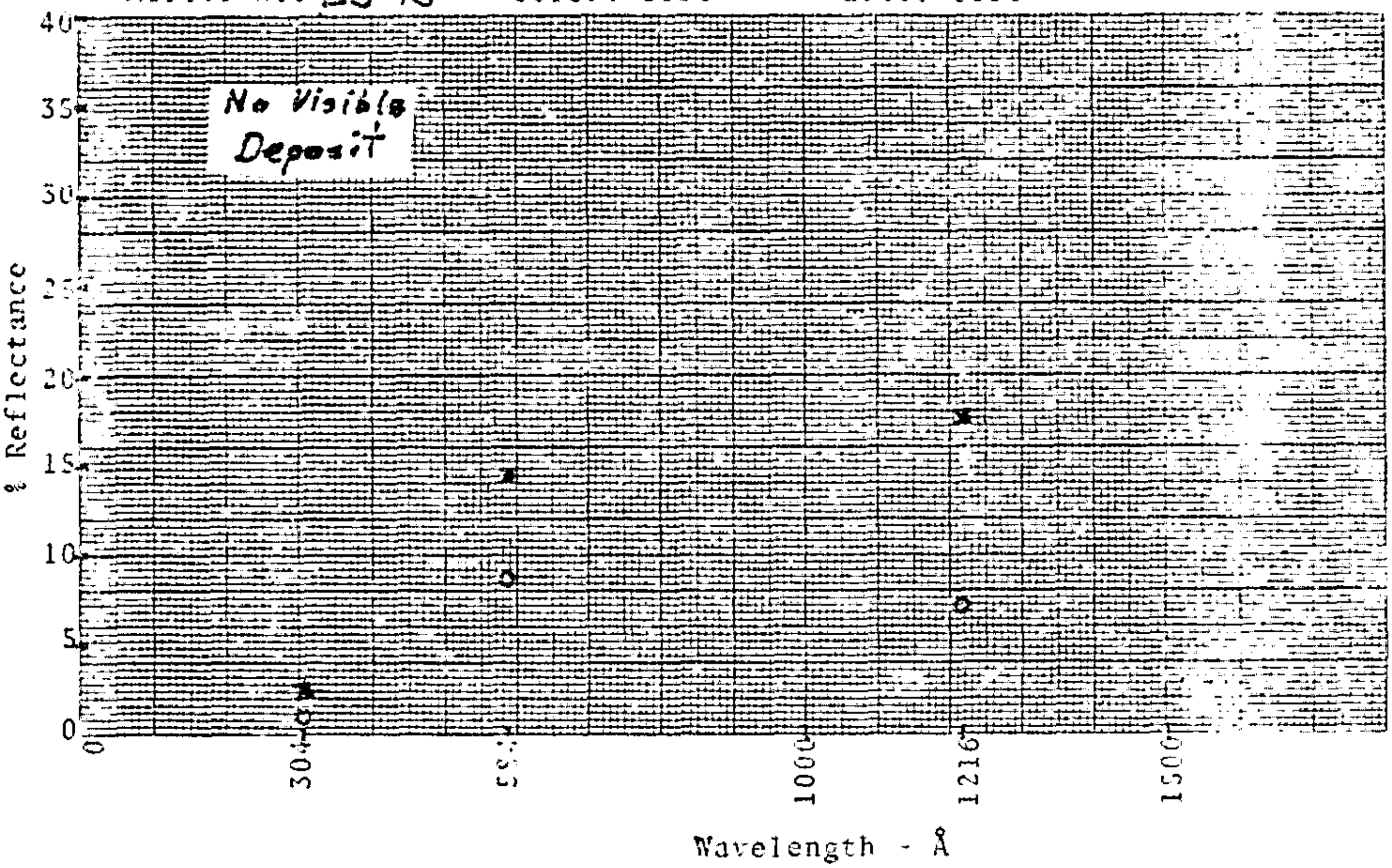
CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 25 cm² SAMPLE WEIGHT LOSS ______ g

SAMPLE THICKNESS thin sheet MIRROR WEIGHT GAIN ______ g.

Mirror No. 25-15 Reflectance before test - ☒ Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.5	14.5		17.7								
Reflectance, % After, R_2	1.0	8.7		7.2								
Change, % $R_1 - R_2$	-1.5	-5.8		-10.5								
% Change $100(R_1-R_2)/R_1$	-60.0	-40.0		-59.3								

ESTIMATED CHANGE PRECISION ~ ±0.4% @ 1216Å, ~ ±0.3% @ other λs

BSRC MA - TEST 11

DATE 5-31-72

MATERIAL Beta Cloth, Fluorel Coated, RL 3489-1 TEST NO. 1324

CATEGORY 11j Fabrics

MANUFACTURER Raybestos Manhattan PROGRAM MSFC

PREPARATION tested as received from MSFC

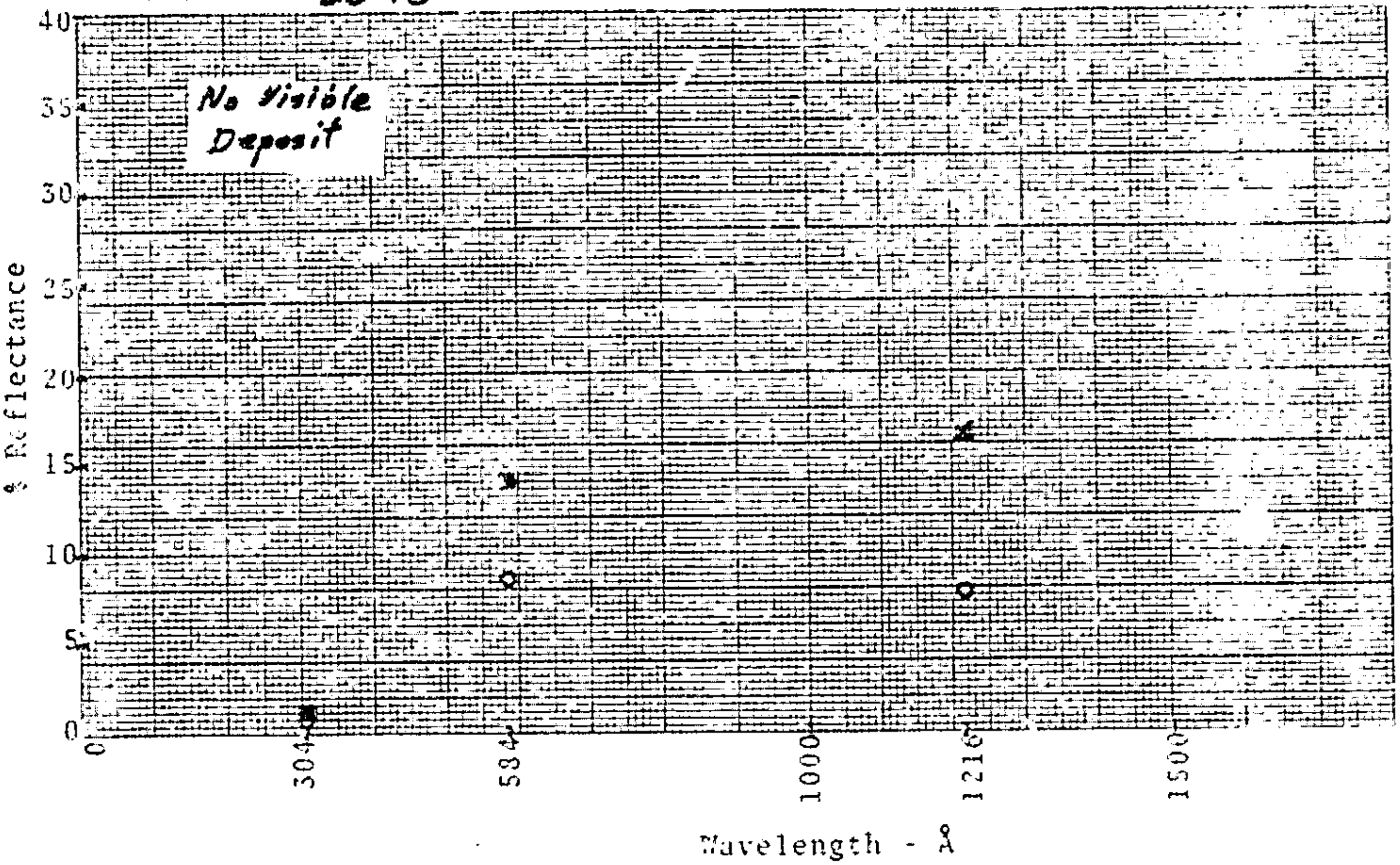
CURE unknown

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~24 cm² SAMPLE WEIGHT LOSS 0.0004 g

SAMPLE THICKNESS thin sheet MIRROR WEIGHT GAIN ——— g

Mirror No. 25-16 Reflectance before test - ■ Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	[illegible]	3300	3800
Reflectance, % Before, R_1	1.3	14.1		16.6								
Reflectance, % After, R_2	0.8	8.6		7.8								
Change, % $R_1 - R_2$	-0.5	-5.5		-8.8								
% Change $100(R_1-R_2)/R_1$	-38.5	-39.0		-53.0								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

BBRC MOD TEST II

DATE 8-23-72

MATERIAL Lacing Tape, Nomex* TEST NO. 1925

CATEGORY 11, Fabrics

MANUFACTURER Gudebrod Bros. PROGRAM MSFC

PREPARATION tested as received from MSFC

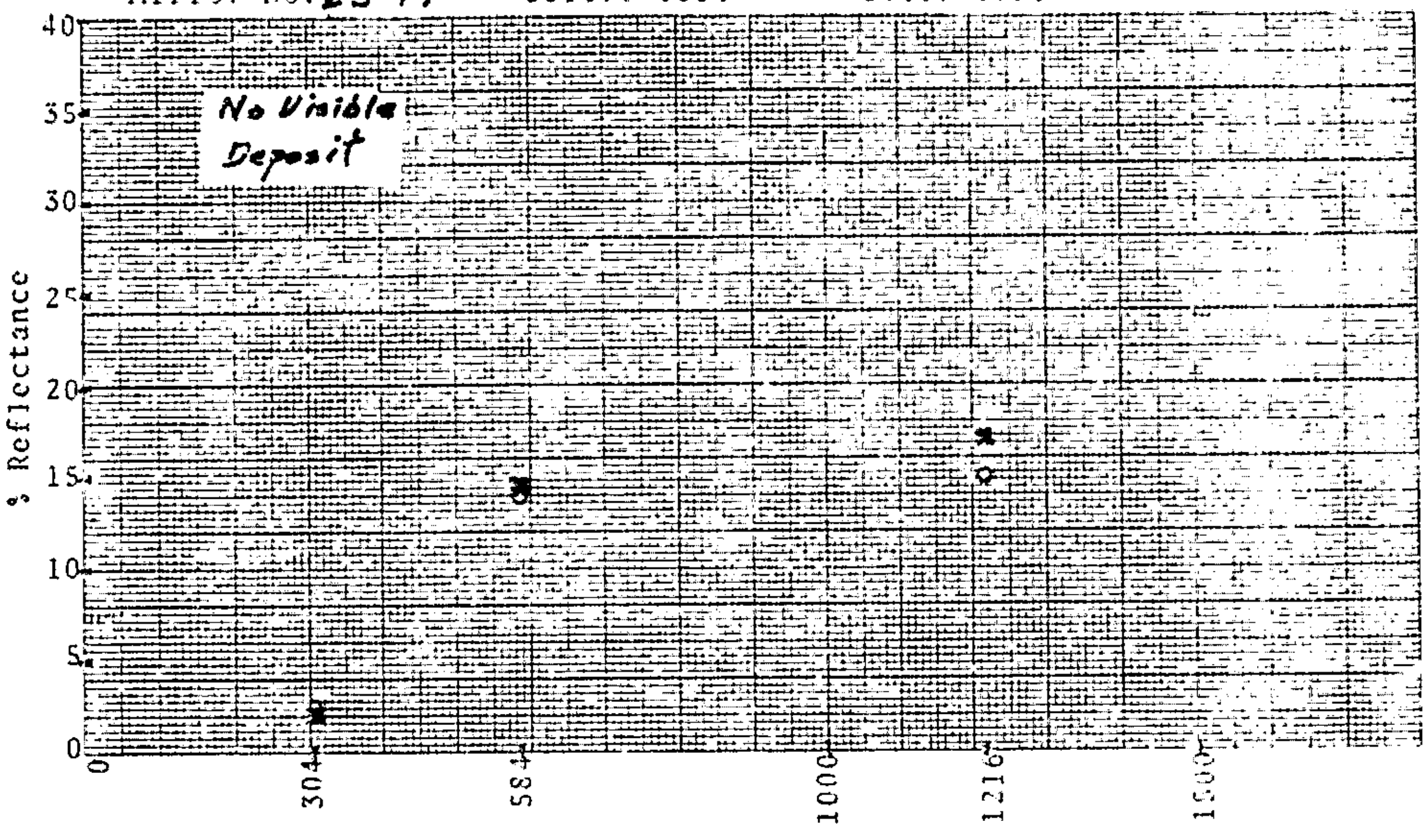
CURE unknown *with polycarbonate finish (#723P)

TEST CONDITIONS: TIME ___ hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 25 cm² SAMPLE WEIGHT LOSS ___ g

SAMPLE THICKNESS ~ 0.1 cm MIRROR WEIGHT GAIN ——— g

Mirror No. 25-17 Reflectance before test - ■ ; Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.1	14.6		17.1								
Reflectance, % After, R_2	2.5	14.0		15.0								
Change, % $R_1 - R_2$	+0.4	-0.6		-2.1								
% Change $100(R_1-R_2)/R_1$	+19.0	-4.1		-12.3								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216Å; ~±0.2% @ other λs

DSRC [illegible] TEST II

DATE 9-3-72

MATERIAL O-Ring Compound V-747-75 TEST NO. 1932

CATEGORY 30; Seals, Gaskets, O-Rings

MANUFACTURER Packer PROGRAM MSFC

PREPARATION tested as Received from MSFC

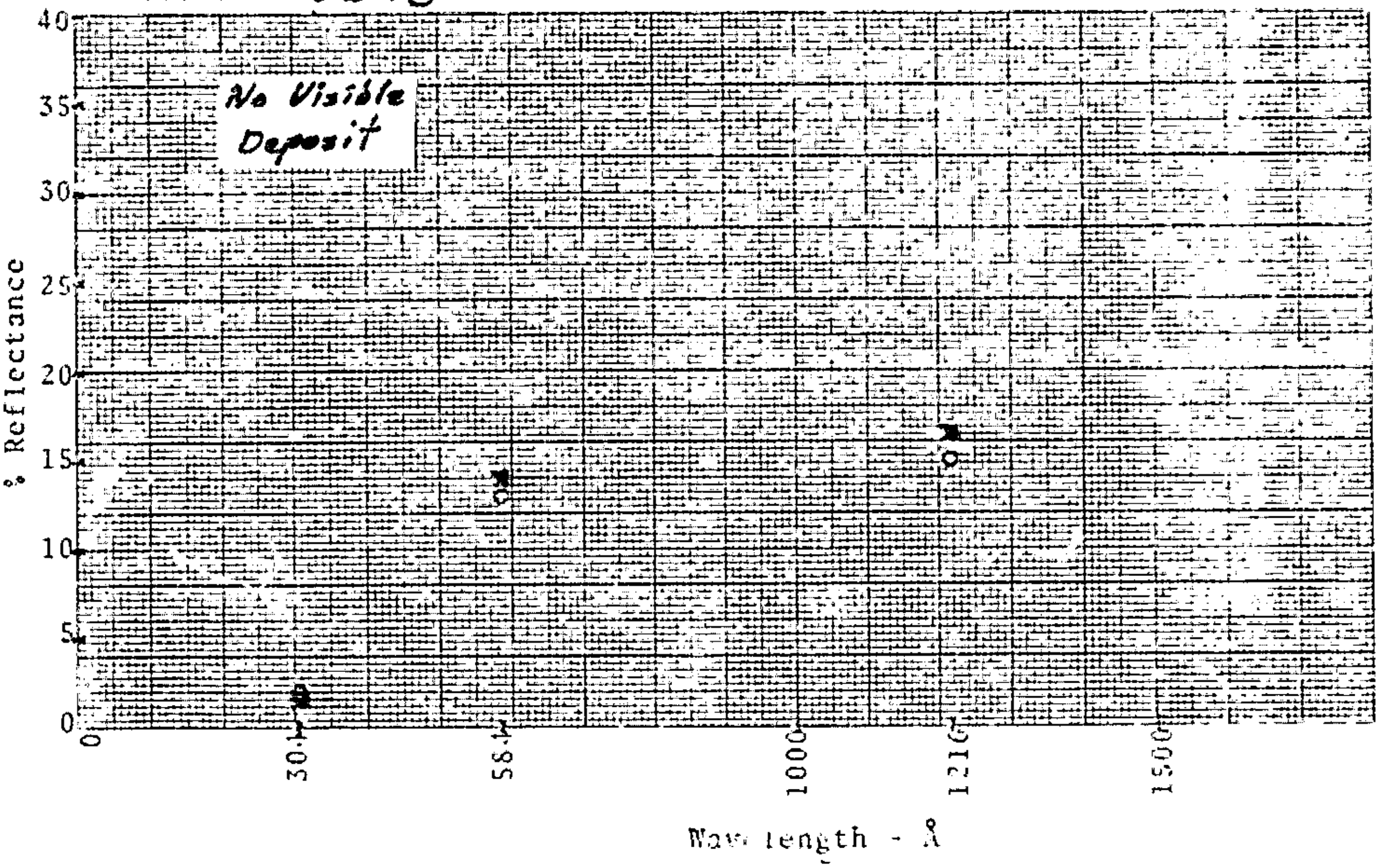
CURE unknown

TEST CONDITIONS: TIME ~74 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~9.6 cm² SAMPLE WEIGHT LOSS ____ g

SAMPLE THICKNESS ~0.18 cm MIRROR WEIGHT GAIN ——— g

Mirror No. 25-18 Reflectance before test -✖ Reflectance after test -o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	1.6	14.0		16.5								
Reflectance, % After, R_2	2.0	13.5		15.0								
Change, % $R_1 - R_2$	+0.4	-0.5		-1.5								
% Change $100(R_1-R_2)/R_1$	+25.0	-3.6		-9.1								

ESTIMATED CHANGE DETECTION ~±0.4% @ 1216Å; ~±0.2% @ other λs

[illegible]

DATE 9-26-72

MATERIAL Glass Cloth, Silicone Impregnated TEST NO. 1941

CATEGORY 11; Fabrics

MANUFACTURER 3M Co. - No. SRG-0607 PROGRAM MSFC

PREPARATION Tested as received from MSFC

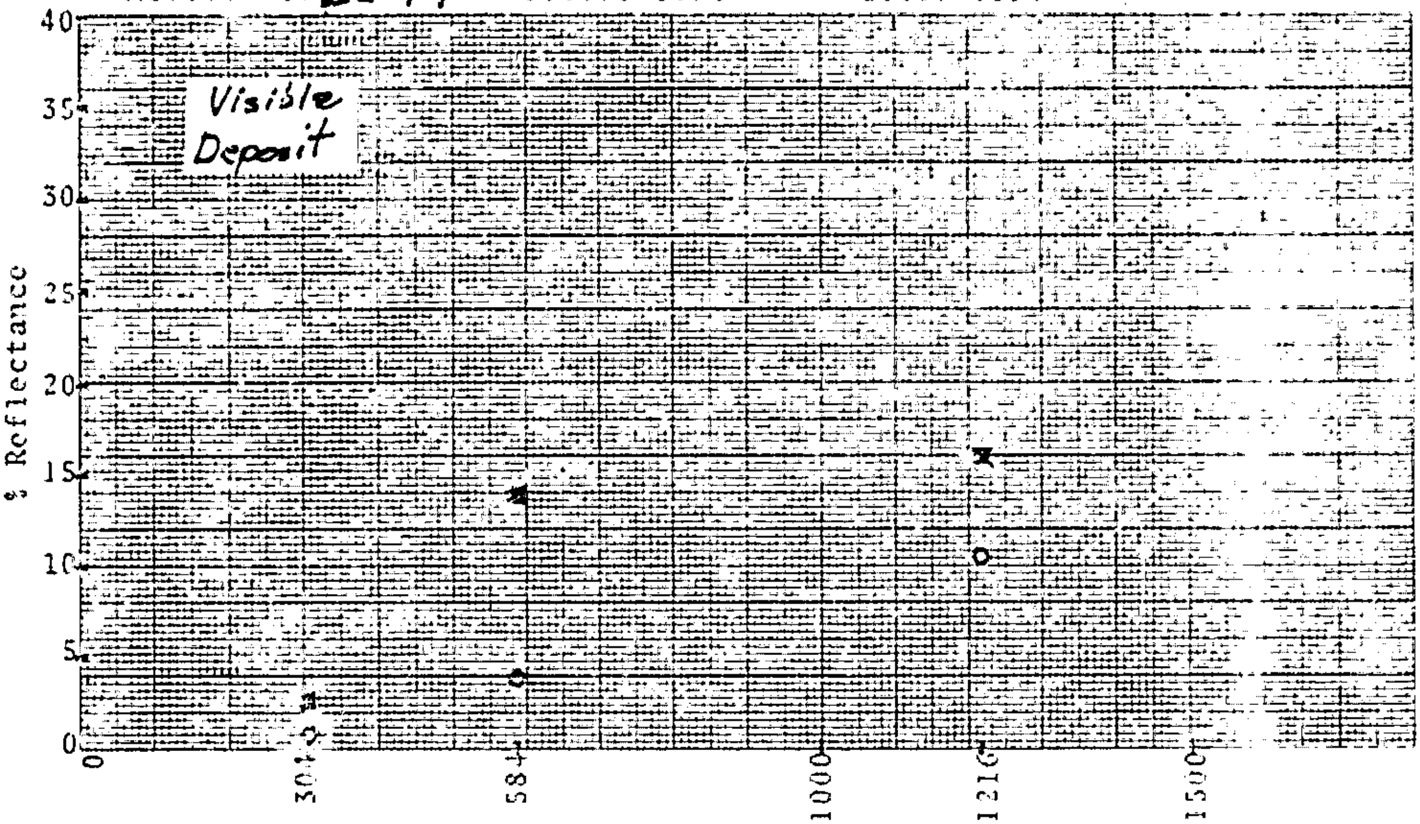
CURE unknown

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 25 cm² SAMPLE WEIGHT LOSS 0.0005 g

SAMPLE THICKNESS ~ 0.2 cm MIRROR WEIGHT GAIN —— g

Mirror No. 25-19 Reflectance before test - ■ Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.7	13.9		16.0								
Reflectance, % After, R_2	0.8	3.9		10.5								
Change, % $R_1 - R_2$	-1.9	-10.0		-5.5								
% Change $100(R_1-R_2)/R_1$	-70.4	-71.9		-34.4								

ESTIMATED CHANGE PRECISION ~±0.4% @ 1216 Å; ~±0.2% at other λs

DATE 10-26-73

MATERIAL PAINT, WHITE, S-13G TEST NO. 2192

CATEGORY 07; COATINGS, THERMAL CONTROL

MANUFACTURER IITRI PROGRAM MSFC

PREPARATION BY MSFC: LOT 72-131-1 C-046 SAMPLE #2

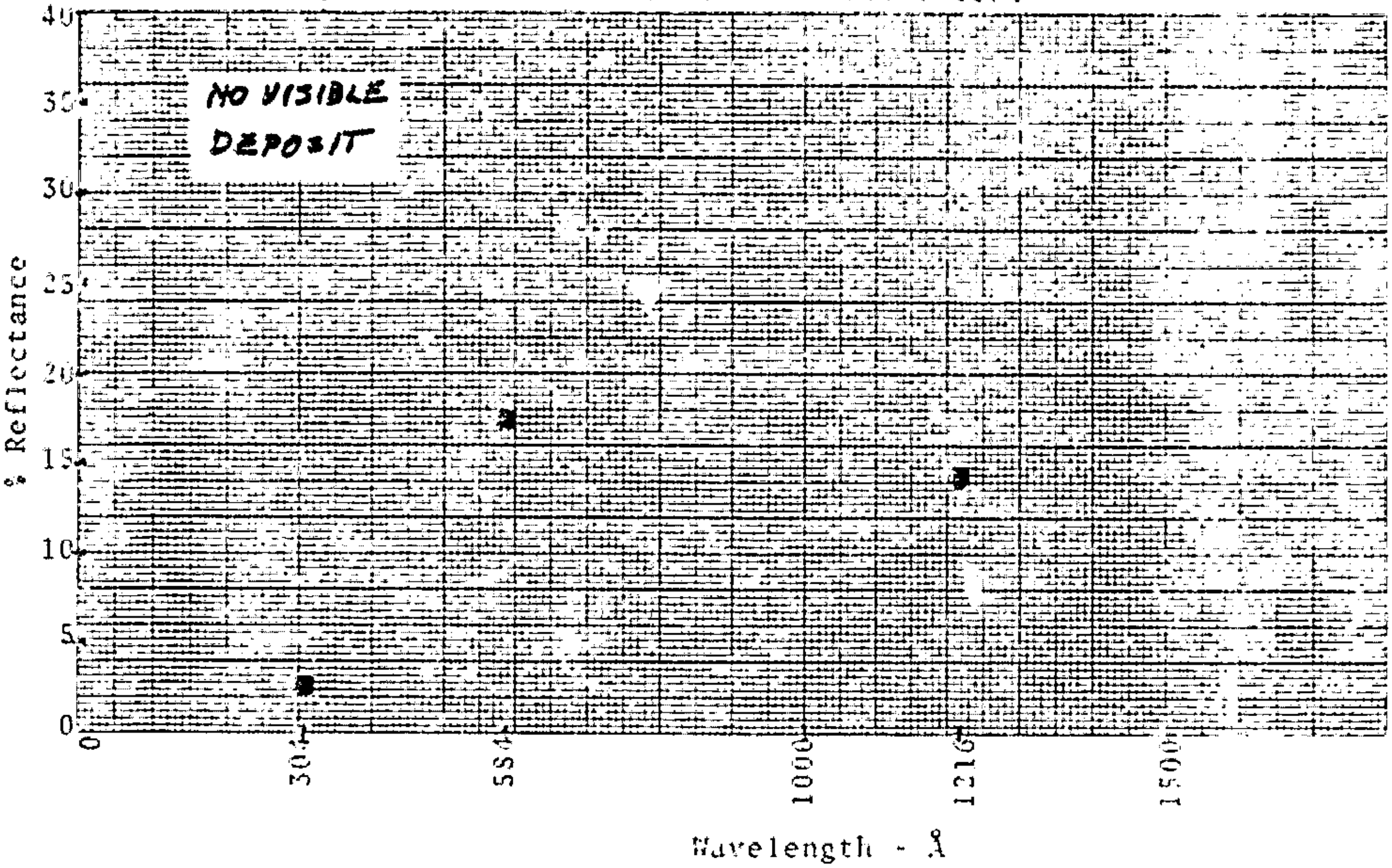
CURE BY MSFC: VACUUM BAKED 24 HRS @ 200°F & 10^{-3} TORR

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 12.85 cm^2 SAMPLE WEIGHT LOSS 0.000 4 g

SAMPLE THICKNESS THIN COATING ON FOIL MIRROR WEIGHT GAIN ——— g

PT- COATED
Mirror No. 25-24 Reflectance before test - ■ Reflectance after test - ○



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.7	17.4		14.4								
Reflectance, % After, R_2	2.6	17.5		14.2								
Change, $(R_1 - R_2)(-1)$	-0.1	+0.1		-0.2								
% Change $-100(R_1-R_2)/R_1$	-3.7	+0.6		-1.4								

ESTIMATED CHANGE PRECISION ~±0.3@1216Å; ~±0.1@ OTHER λ's

BORC TOS TEST II

DATE 10-23-73

MATERIAL PAINT, WHITE, S-13G

TEST NO. 2123

CATEGORY 07; COATINGS, THERMAL CONTROL

MANUFACTURER IITRI

PROGRAM MSFC

PREPARATION BY MSFC: LOT 72-1-31-1 C-046 SAMPLE #1

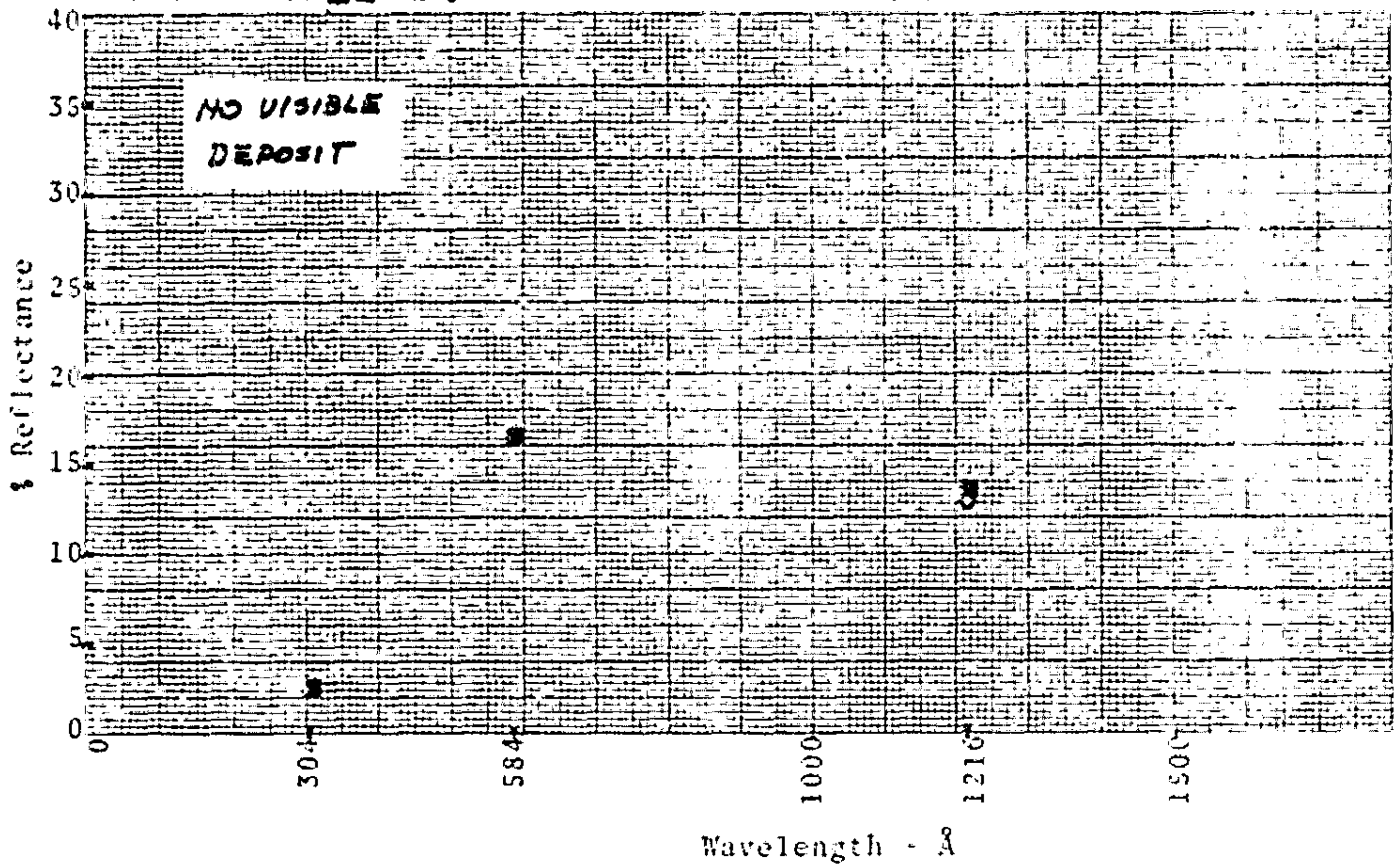
CURE BY MSFC: VACUUM BAKED 40 HRS @ 300°F & 10^{-8} TORR

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~14 cm² SAMPLE WEIGHT LOSS 0.00062 g

SAMPLE THICKNESS THIN COATING ON FOIL MIRROR WEIGHT GAIN ——— g

PX-COATED Mirror No. 25-25 Reflectance before test - ■ Reflectance after test - o



	304	584	1135	1216	1305	1495	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.5	16.5		13.6								
Reflectance, % After, R_2	2.5	16.6		12.9								
Change, % $(R_1 - R_2)(-1)$	-0-	+0.1		-0.7								
% Change $-100(R_1-R_2)/R_1$	-0-	+0.6		-5.1								

ESTIMATED CHANGE PRECISION ~±0.3 @ 1216Å; ~±0.1 @ OTHER

BOBC MOS TEST II

DATE 11-2-73

MATERIAL TEDLAR, BLACK TEST NO. 2212

CATEGORY 12 & 3; FILMS & SHEETS; AND INSULATION, THERMAL

MANUFACTURER DU PONT PROGRAM MSFC

PREPARATION TESTED AS RECEIVED

CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 25 cm²

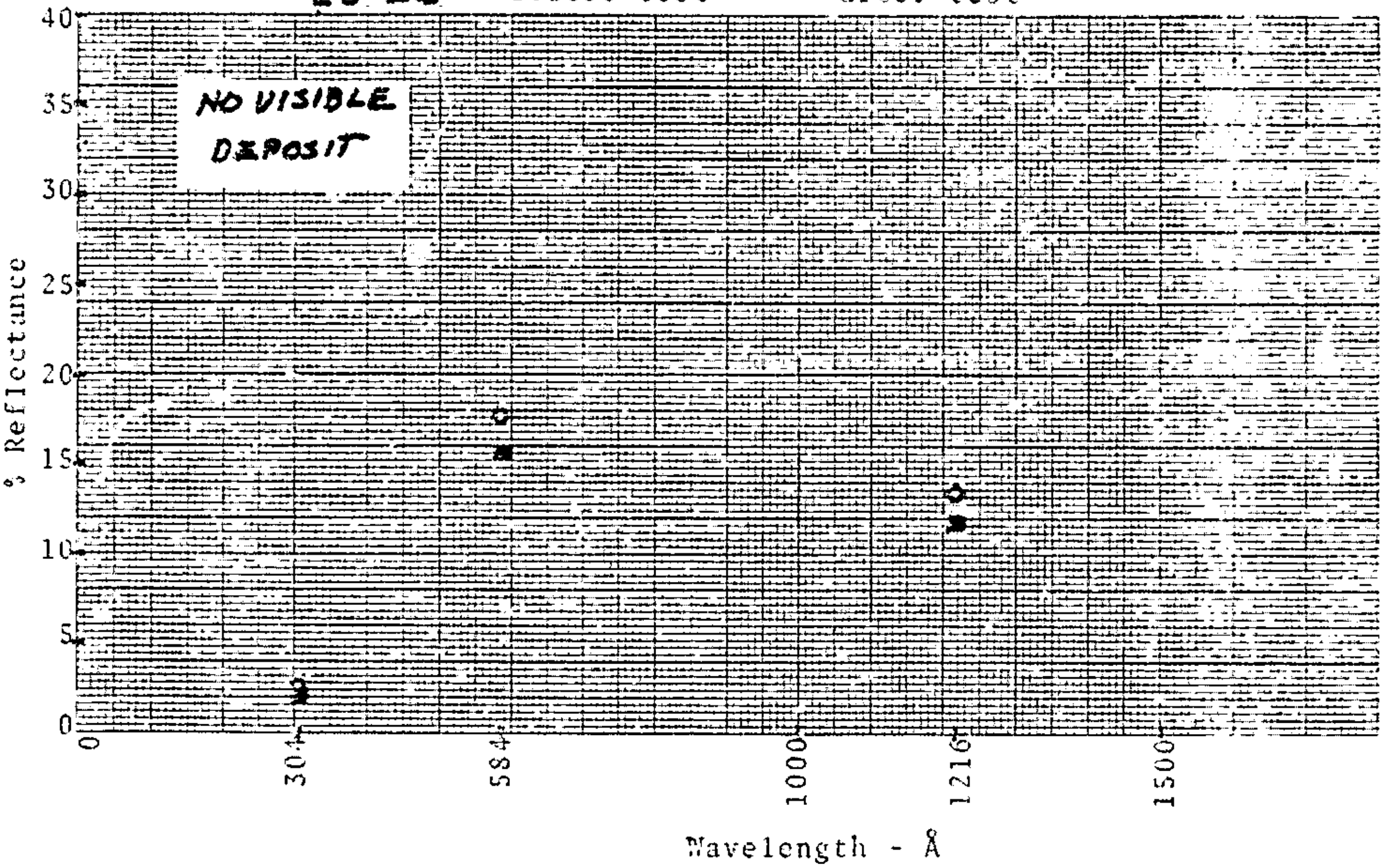
SAMPLE WEIGHT LOSS 0.0007 g

SAMPLE THICKNESS ~ 0.1 mm (~4 mil) MIRROR WEIGHT GAIN —— g

Pt-COATED Mirror No. 25-26

Reflectance before test - ■

Reflectance after test - O



	304	584	1135	1216	1305	1433	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.0	15.6		11.8								
Reflectance, % After, R_2	2.6	17.7		13.5								
Change, $(R_1 - R_2)(-1)$	+0.6	+2.1		+1.7								
% Change $-100(R_1-R_2)/R_1$	+30	+13.5		+14.4								

ESTIMATED CHANGE PRECISION ~ ±0.3 @ 1216 Å; ~ ±0.1 @ OTHER λ's

BB&C MOS TEST II

DATE 11-2-73

MATERIAL TEDLAR, BLACK TEST NO. 2211

CATEGORY 12 & 13; FILMS & SHEETS; AND INSULATION, THERMAL

MANUFACTURER DU PONT PROGRAM MSFC

PREPARATION TESTED AS RECEIVED

CURE ——

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 55°C MIRROR TEMP 25°C

SAMPLE AREA ~ 25 cm²

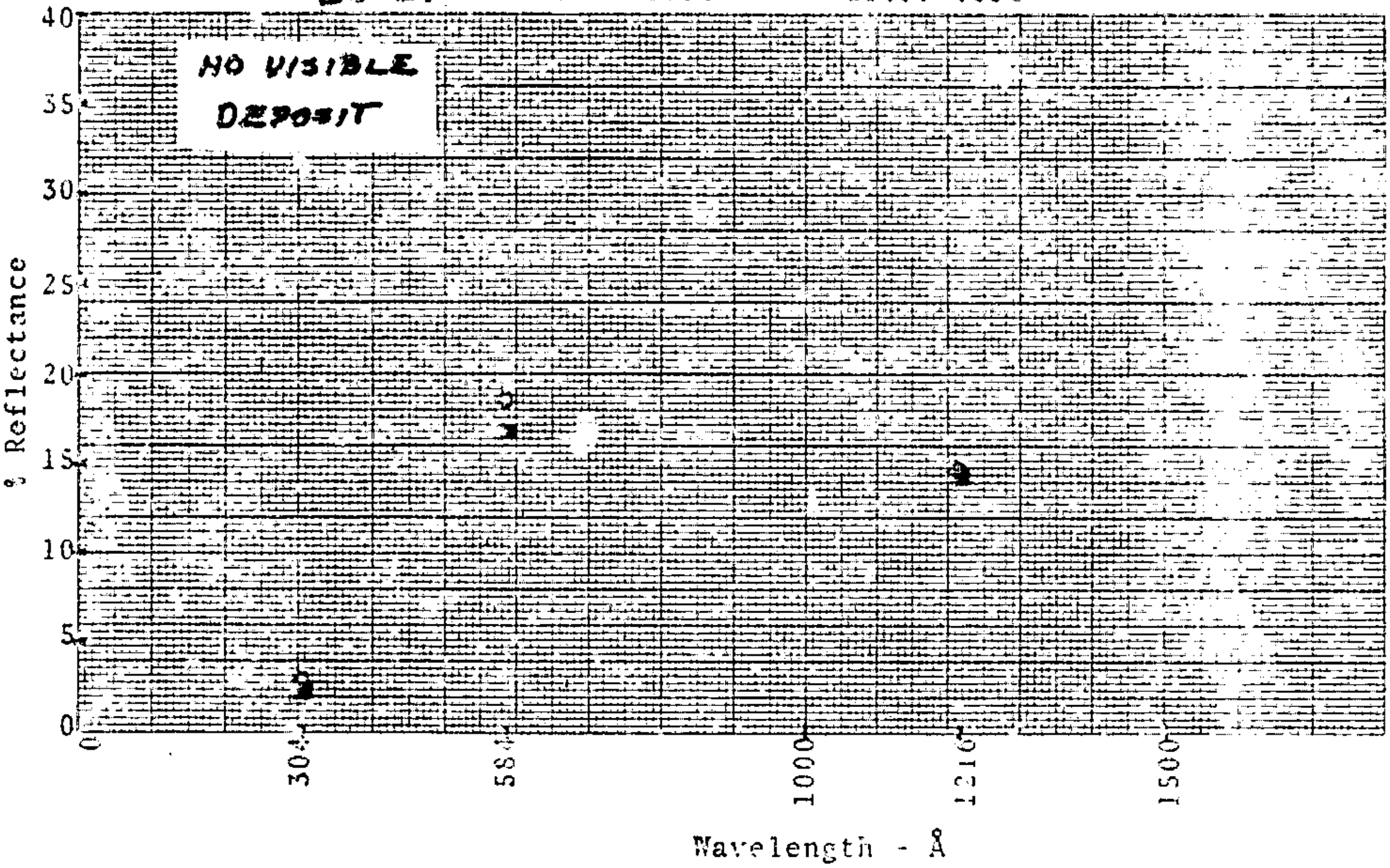
SAMPLE WEIGHT LOSS 0.00011 g

SAMPLE THICKNESS ~0.1 mm (~4 mil)

MIRROR WEIGHT GAIN —— g

Pt-COATED Mirror No. 25-27

Reflectance before test - ■ Reflectance after test - ○



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.3	16.8		14.3								
Reflectance, % After, R_2	3.0	18.6		14.7								
Change, % $(R_1 - R_2)(-1)$	+0.7	+1.3		+0.4								
% Change $-100(R_1 - R_2)/R_1$	+30.4	+10.9		+2.8								

ESTIMATED CHANGE PRECISION ~±0.3 @ 1216 Å; ~±0.1 @ OTHER Å's

[illegible] TEST II   RL 3489-1   DATE 11-16-73

MATERIAL BETA CLOTH, FLUOREL COATED   TEST NO. 2218

CATEGORY 11j FABRICS

MANUFACTURER RAYBESTOS MANHATTAN   PROGRAM MSFC

PREPARATION AS RECEIVED PLUS 72 HRS @ 55°C & < 10^{-5} TORR

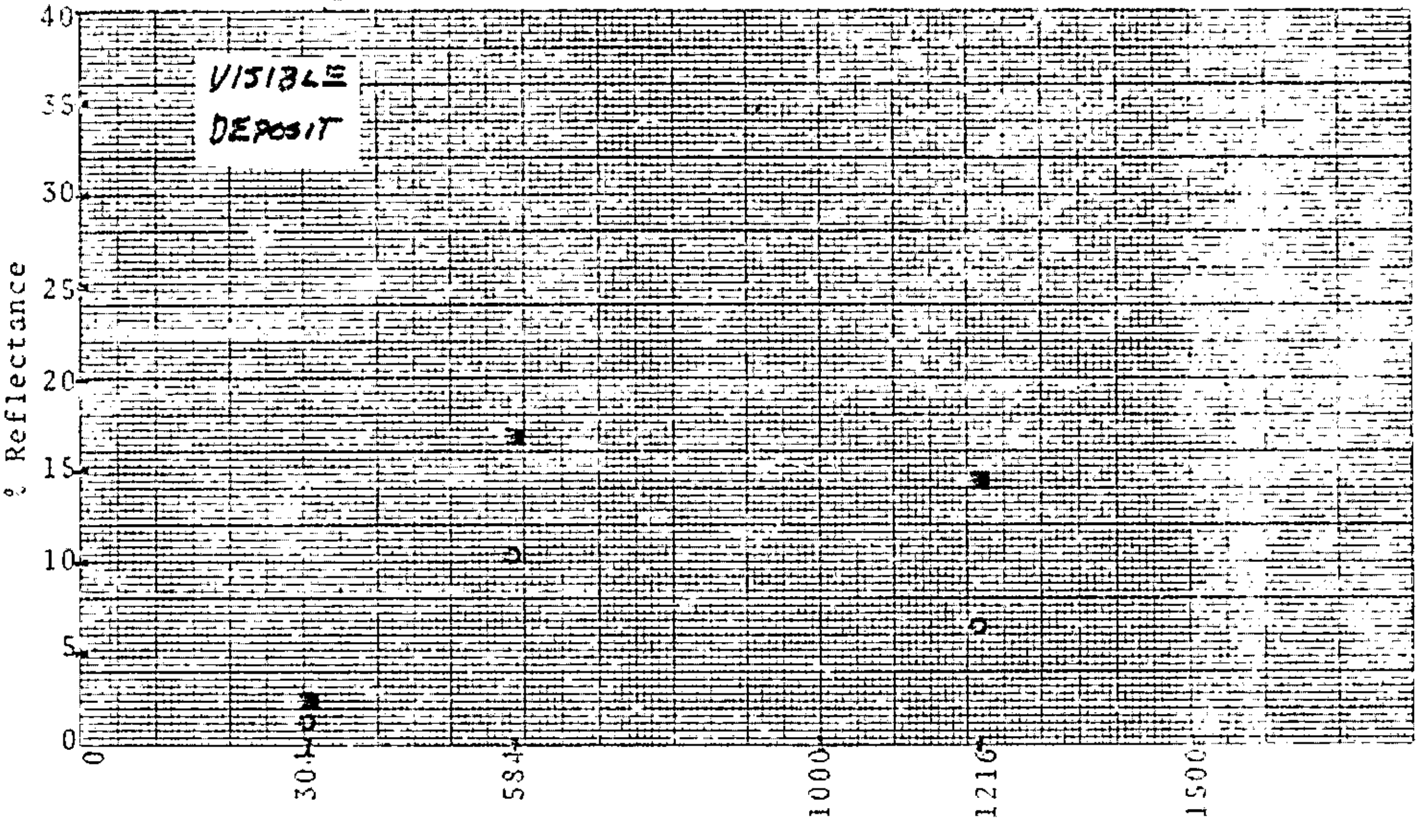
CURE UNKNOWN

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 75°C MIRROR TEMP 25°C

SAMPLE AREA ~ 12 cm^2 SAMPLE WEIGHT LOSS 0.00021 g

SAMPLE THICKNESS THIN SHEET   MIRROR WEIGHT GAIN —— g

PA - COATED
Mirror No. 25-28   Reflectance before test - ■   Reflectance after test - o



	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.4	16.8		14.4								
Reflectance, % After, R_2	1.3	10.4		6.5								
Change, % $(R_1 - R_2)(-1)$	-1.1	-6.4		-7.9								
% Change $-100(R_1-R_2)/R_1$	-45.8	-38.1		-54.7								

ESTIMATED CHANGE PRECISION ~ ±0.3 @ 1216 Å; ~ ±0.1 @ OTHER λs

BRRC MOG TEST II

DATE 11-16-73

RL 3489-1

MATERIAL BETA CLOTH, FLUOREL COATED

TEST NO. 2219

CATEGORY II; FABRICS

MANUFACTURER RAYBESTOS MANHATTAN

PROGRAM MSFC

PREPARATION AS RECEIVED PLUS 72 HRS @ 55°C & $< 10^{-5}$ TORR

CURE UNKNOWN

TEST CONDITIONS: TIME 72 hrs SAMPLE TEMP 75°C MIRROR TEMP 25 °C

SAMPLE AREA ~ 12 cm^2

SAMPLE WEIGHT LOSS 0.00024 g

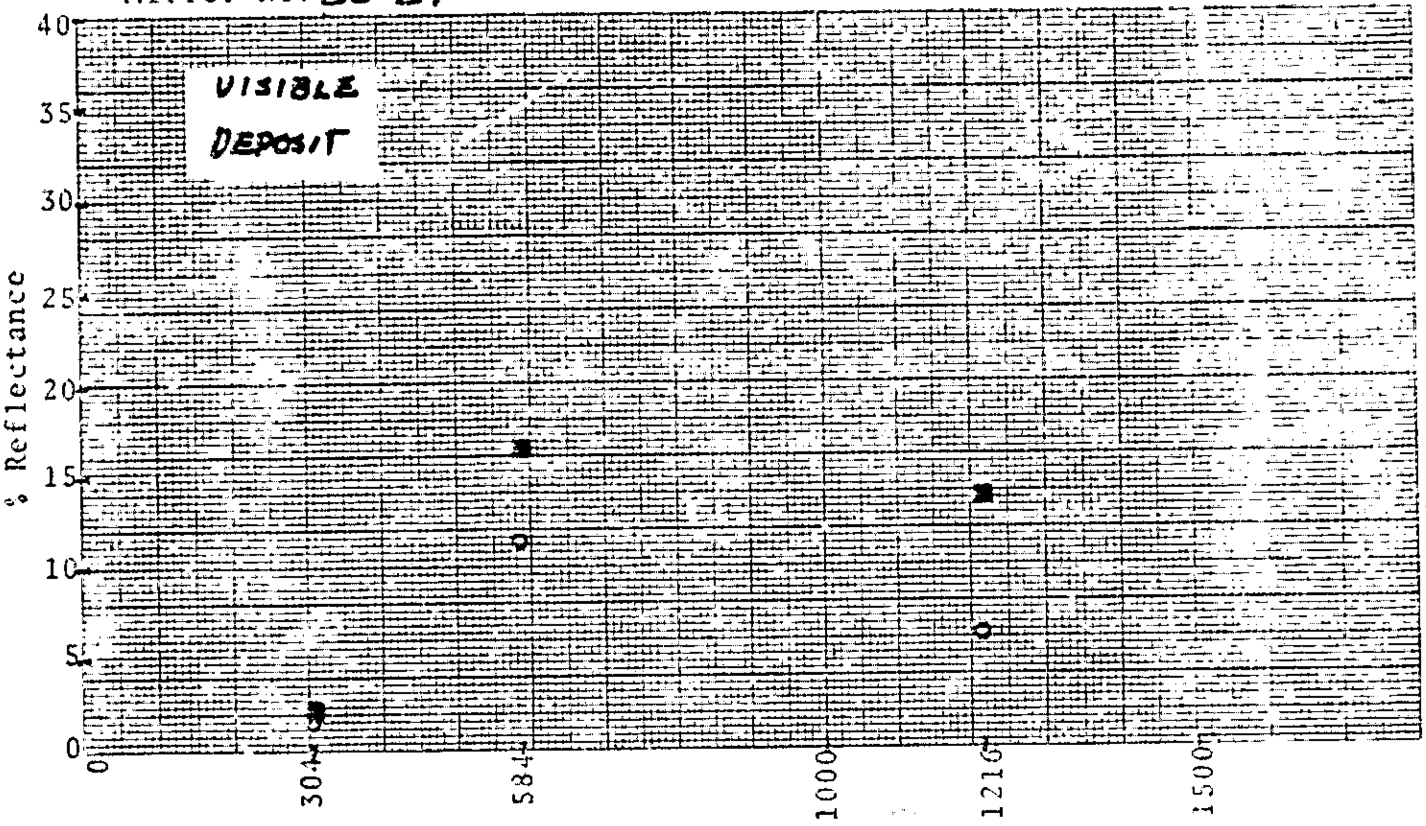
SAMPLE THICKNESS THIN SHEET

MIRROR WEIGHT GAIN —— g

Pt - COATED
Mirror No. 25-29

Reflectance before test - ■

Reflectance after test - o



Wavelength - Å

	304	584	1135	1216	1305	1493	1657	2000	2500	3000	3500	3800
Reflectance, % Before, R_1	2.2	16.4		13.7								
Reflectance, % After, R_2	1.6	11.4		6.3								
Change, $(R_1 - R_2)(-1)$	-0.6	-5.0		-7.4								
% Change $-100(R_1-R_2)/R_1$	-27.3	-30.5		-54.0								

ESTIMATED CHANGE PRECISION ~±0.3 @ 1216Å; ~±0.1 @ OTHER λs

HH

Appendix B
MIRRORS IN REFLECTOMETER

Table B-1

LISTING OF MIRRORS IN THE REFLECTOMETER TOGETHER

Date	Mirrors and Prior Uses
12-6-71	H-1, H-2, H-3 (all new)
12-6-71	H-4, H-5, H-6 (all new)
12-30-71	H-3 (background 1835), H-4 (background 1836)
12-30-71	H-5 (test 1837), H-6 (test 1838)
1-3-72	25-1, 25-2, 25-3 (all new)
1-4-72	25-4, 25-5, 25-6 (all new)
1-4-72	25-7, 25-8, 25-9 (all new)
1-14-72	25-1 (test 1840), 25-2 (test 1841)
1-17-72	25-3 (test 1845), 25-10 (new), 25-11 (new)
2-21-72	25-4 (background 1849), 25-5 (test 1853), 25-6 (test 1857)
2-22-72	H-4 (storage)
3-23-72	25-4 (storage), 25-11 (storage), 25-12 (new)
3-23-72	25-8 (background 1859), 25-9 (test 1860), 25-10 (test 1863)
3-24-72	25-13, 25-14, 25-15 (all new)
3-24-72	25-16, 25-17, 25-18 (all new)
8-11-72	25-4 (storage), 25-14 (test 1916)
8-11-72	25-11 (storage), 25-12 (background 1905), 25-13 (test 1909)
9-20-72	25-11 (storage), 25-15 (unnumbered Beta cloth test), 25-16 (test 1924)
9-20-72	25-17 (test 1925), 25-18 (test 1932), 25-19 (new)
10-11-72	25-20, 25-21, 25-22 (all new)
10-12-72	25-4 (storage), 25-11 (storage), 25-19 (test 1941)
10-12-73	25-11 (storage), 25-23 (new)
10-15-73	25-24, 25-25, 25-26 (all new)
10-16-73	25-27, 25-28, 25-29 (all new)
10-30-73	25-11 (storage), 25-23 (storage), 25-24 (test 2192)

(continued)

Table B 1 (continued)

Date	Mirrors and Prior Uses
10-30-73	25-25 (test 2193)
11-8-73	25-11 (storage), 25-23 (storage)
11-8-73	25-26 (test 2210), 25-27 (test 2211)
11-21-73	25-11 (storage), 25-23 (storage), 25-28 (test 2218)
11-21-73	25-29 (test 2219)
12-12-73	H-4(storage), 25-4 (storage)