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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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*This work was performed on Contract NAS5-9244 under Task Assignment (TA) 713-2132 with Electro-Mechanical Research, Inc. and was supervised by George Lewis.

**This work was performed on Contract NAS5-3743 with Electro-Mechanical Research, Inc., College Park, Maryland.

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SECTION I

DIGEST

Charles H. Duncan

DIGEST

I. SOLAR SIMULATION STUDIES (713-124-09-05-06)

1. A-1200 Solar Simulator

All of the electronic modifications which could be made, pending delivery of some transformers and capacitors essential for 150 amp operations, have been completed. The system was used to test the ATS SASSE F 3 flight package. Uniformity of ±2.5% was obtained over the test package with an intensity of 48 MW cm^{-2}. No malfunctions occurred during the test.

Calculations and test data have been obtained which will be used for the design of the plumbing system required for water cooling of the primary collectors. A flow rate of one (1) gallon per minute (gpm) was used to obtain test data of the temperature increment of the collector with the lamp operating at 2600 watts, 2880 watts, and 3300 watts. These data were extrapolated to 5000 watts which indicated that the temperature increment would be approximately 57° F. This indicates that a flow rate of 1 gpm will be sufficient to provide adequate cooling for the collectors.

Prior to the ATS SASSE F 3 flight package test, lamp number 13 developed a short circuit across two segments of the lamp cage which resulted in destruction of the cage. The molten metal of the cage dropped onto the water cooled turning flat in the lamp housing forming several small lacunas, which penetrated the Kanigen coating. The original turning flat will be utilized until repairs are completed. (EMR)

2. Arc Research (Vortex-Stabilized Radiation Source—VSRS)

Analyses completed recently indicate that:

a. high vortex velocities reduce thermal excitation of the plasma creating a negative resistance characteristic;

b. plasma potential is a direct function of electrode spacing; and,

c. plasma potential is a direct function of atomic mass for inert gases. (Neuder)

3. Spectral Irradiance Measurements

Spectral irradiance measurements were obtained for:

1-2 - Hanovia 550 watt medium pressure mercury lamp—0, 400 hours;

3 - Zirconium 25 watt lamp—0 hours;

4 - VSRS, Helium - 80 psig - 4000 watts - open loop;

5-9 - X-25L Solar Simulator at 0, 40, 90, 310, and 319 hours;

10-16 - Osram 2500 watt Xenon at 0, 72, 132, 228, 300, 402, and 570 hours;

17-21 - Osram 2500 watt Xenon lamp with aconic collector at 0, 54, 106, 202, and 274 hours; and,

22-27 - PEK 7500 watt Xenon lamp at 0, 24, 48, 72, 144, and 240 hours.

The X-25L data show spectral degradation in the ultraviolet and visible portions of the spectrum, approximately a 50% loss of u.v. and a 15% loss of visible irradiance in a period of 300 hours. Contamination of the front surfaced aluminum optical components is the cause of most of this spectral degradation. The Osram Xenon lamp data showed only small variations throughout the 570 hour test whereas the Osram Xenon lamp in the aconic collector showed approximately a 50% reduction of ultraviolet irradiance and a 15% reduction of visible irradiance. The PEK 7500 watt Xenon lamp showed a decrease of about 40% in the ultraviolet and about 5% in the visible irradiance over the 240 hour period. (EMR)

4. Convair 990 Flight Experiment

Structural, mechanical, and electronic modifications necessary for reliable operation aboard the Convair 990 have been designed and submitted to Fabrication Division. The equipment to be flown and spectral regions covered will be:

(a) ITT electronic scanning spectrometer (250 nm-600 nm);

(b) Leiss Instrumentation (250 nm-2600 nm);

(c) Filter radiometer (250 nm-2600 nm); and,

(d) Eppley normal incidence pyrheliometer (total).

The flights are scheduled for July 10—July 28 which will require shipment of all components no later than June 16. (Webb - EMR)

II. COATINGS QUALIFICATION STUDIES

1. Thermal Shock

Several paint specimens were subjected to an atmospheric thermal shock test between the temperatures of -195° C and +83° C. Dow Corning (D. C.) Q92-007 applied over Minnesota Mining and Manufacturing (3M) white with D.C. Sylgard primer exhibited the most satisfactory adhesion properties. The test indicated that thickness of substrate, primer used, and intermediate coating were essential parameters to be considered in thermal shock tests. (Seidenberg - Hobbs)

2. Materials Development

A TiO_2 flame sprayed coating and a Ti and Al vacuum flame sprayed coating have been tested for possible use as a thermal shroud coating. The former has a normal emittance of 0.62 to 0.64 and the latter, 0.81 to 0.82. The absorptances were 0.89 and 0.91, respectively. Ultraviolet irradiance has no effect upon the spectral absorption characteristics of these materials. In addition, the coatings are tough and durable and would eliminate the present requirement of recoating thermal shrouds at periodic intervals. (Seidenberg - Hobbs)

3. Thermal Vacuum Research

One sample of each of the specimens sent to the Boeing Corporation were subjected to a thermal vacuum test. The pressure was 10^{-4} torr and the temperature, 110° C. The purpose of the test was to eliminate all remaining volatile material from the samples and to determine what effect this has upon the optical properties. The samples were weighed before and after 194 hours in the above environment. The greatest change noted was the TiO_2 (Rutile) methyl silicone over a General Electric primer (Joe Colony Paint); the smallest change was with S-13, ZnO methyl silicone. Photomicrographs of each sample were obtained before and after the tests to determine surface changes. The methyl silicone materials did not show much surface change while the potassium silicates and vacuum deposited aluminum over Logo laquer showed the most change. (Nicoletta)

4. Electron Damage Studies

The paint specimens which were sent to Boeing have been irradiated with electrons of energies of 400 kev, 700 kev, and 1 Mev. The total flux at each energy level was 10^{14} electrons cm^{-2}. The samples were exposed in 10^{-6} Torr environment with spectral reflectance measurements obtained in air. The changes in absorptance at 700 nm and 425 nm varied from 36% to 1.8%. This was most probably due to temperature which exceeded 30° C for this test. The tests at 400 kev and 1 Mev showed changes of 0% to 2.0%. (Nicoletta)

5. Spectrum Dependent Degradation Studies

Data concerning the effect of the spectrum of Xe, Hg-Xe, Hg, and C upon thermal control materials have been obtained. Spectrum had no noticeable effect upon D.C. Q92-090, methyl silicone - TiO_2 (Anatase). Total irradiance and total flux also had very little effect upon the spectral absorptance. The methyl silicone ZnO (SP-500) developed by Joe Colony of the Coatings Section was not affected by spectrum for short term degradation but spectrum was important for long term degradation. Short term degradation is defined at that which induces a change in 24 hours or less. This paint showed the most degradation from irradiation by a Xenon source and the least from the Hg-Xe source. The sample was exposed to Hg-Xe with three times the total flux of the Xe but the degradation obtained was about 10% less.

The Cat-a-lac white epoxy paint was also independent of spectrum for the short term degradation. Indications are that short term degradation reaches a maximum very quickly, in ten to sixty minutes, and experiences very little degradation thereafter.

The D.C. A007 methyl silicone TiO_2 (Rutile) exhibited a strong correlation between degradation and spectrum. This is especially noticeable in the Hg and Hg-Xe data. The same total flux resulted in approximately 40% more degradation when the Hg lamp was used. The sample exposed to Xenon for approximately 1/3 of the total flux received from Hg and Hg-Xe resulted in a change only 5% less than Hg-Xe but 43% less than Hg. The level of irradiance of the Hg was 70 MW cm^{-2} whereas the Xe and Hg-Xe level was 140 MW cm^{-2}. This indicates that a reciprocal relationship between total flux and irradiance level may not be valid.

The methyl silicone TiO_2 (R960), also developed by Joe Colony of the Coatings Section, shows about 25% more degradation from Hg than Hg-Xe although the sample was exposed for 17 more equivalent ultraviolet (e.u.v.) hours to Hg-Xe than to Hg. The degradation, for 1/3 the flux, was greater with Xenon than Hg-Xe illumination.

The major conclusions to be drawn from this work are:

(1) data obtained by assumption of reciprocal relationships between total flux and irradiance level are not generally valid;

(2) the spectrum of the source used for degradation has a definite effect upon the results obtained, especially for long term degradation which occurs in intervals greater than 24 hours; and,

(3) two mechanisms are involved, one whose effect is noticeable in less than 24 hours and another whose effect is noticeable over intervals of hundreds of hours. The latter is characterized by increased spectral absorptance by the material in the wavelength region below 400 nm. (Duncan - EMR, Colony of Coatings Section)

6. Boeing Corporation Degradation Studies (NAS5-9650)

Three each of all of the samples sent to Boeing have been measured in the following sequence:

1 - atmospheric pressure;

2 - 10^{-4} torr;

3 - 5×10^{-7} torr;

4 - after 10^{13} electrons cm^{-2};

5 - after 10^{14} electrons cm^{-2};

6 - after 10^{15} electrons cm^{-2}; and

7 - atmospheric pressure after irradiation.

The temperature of the samples for all of the measurements was 23°C. 50 kev electrons were used. The exposure times were 10 minutes for 10^{13} electrons cm^{-2} and 40 minutes for each of the others. Some of the data is summarized in the following table:

Absorptance Values as Measured "In Situ"

Code	Material	Initial	10^{13} e cm^{-2}	10^{14} e cm^{-2}	10^{15} e cm^{-2}
A	D.C. Q92-0090 TiO_2 - methyl silicone (Anatase)	28.3	22.2	29.4	31.4
B	ZnO methyl silicone ITTRI S-13	21.0	16.7	18.7	20.9
C	ZnO - methyl silicone	15.1	15.1	15.8	17.6
D	Al_2O_3-K_2SiO_3	10.1	9.5	10.7	12.0
E	TiO_2-K_2SiO_3	26.5	25.9	29.1	35.9
F	ZnO-K_2SiO_3	26.2	25.9	26.6	31.4

All of the samples have been exposed to atmospheric conditions since the completion of the test. This has resulted in complete recovery of all samples to the initial values. This recovery occurs very rapidly, in less than 24 hours. Some of the materials above show an absorptance which is less than the initial value; this is most likely due to the cleansing away of surface contamination. The Al_2O_3-K_2SiO_3 shows the least damage due to 50 kev electrons while the TiO_2-K_2SiO_3 experiences the most damage. The S-13 ZnO methyl silicone shows a final value of absorptance which is the same as the initial indicating immunity to damage from 50 kev electrons.

III. SOLAR CELL CALIBRATION TECHNIQUES (713-120-33-01-01)

The report describing the McPherson Spectral Measuring System has been completed and is being reproduced at present. Measurements of the voltage-current characteristics of various cells were obtained. (EMR)

IV. PUBLICATIONS

1. X-713-67-81 - "Recent Progress with the Vortex Stabilized Arc," Neuder, Urschel, McIntosh.

2. X-713-67-86 - "Germanium and its Role in Future Aerospace Coatings," Seidenberg.

3. X-713-67-73 - "Radiometry Research" - Radiometry Section.

4. X-713-67-108 - "Electronic Scanning Spectrometer for U.V. Measurements" - Webb.

N67-32595

SECTION II

THERMAL LABORATORY

Quarterly Progress Report
1 December through 28 February, 1967

Prepared by

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Electron Mechanical Research, Inc.

Work covered in this report was performed by the following under contract NAS-5-9244:

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D. Lester
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L. Hallman
M. Goldenberg
T. Lomax
I. Sandiford

THERMAL LABORATORY

AREA OF CONCERN

The efforts discussed in this report cover the following task responsibilities:

(1) Operating and upgrading the A1200 solar simulator

(2) Conducting a portion of a coatings qualification program

(3) Maintaining an electronics support and calibrations laboratory.

SUMMARY OF WORK ACCOMPLISHED

The electrical and thermal modifications to the A1200 solar simulator to enable a 5 kw operation per module were one-third completed during this quarter. These modifications include improved system efficiencies and a significant reduction in man hours required for system calibration. A detector calibration program has been completed incorporating five different types of total irradiance detectors. The design of the Mono-SSCEDS (Mono-Sample Solar Concomitant Environment Degradation System) was initiated. Also, periodic checks have been made with Cook Vacuum Company concerning the fabrication of the Multi-SSEDS (Multi-Sample Solar Environment Degradation System).

The A1200 solar simulator was used to test and calibrate an ATS SASSE F-3 back-up flight package. All of the electronic modifications that had been installed in the simulator system worked excellently during this test. The new console has made it possible to greatly reduce manpower requirements for setup and alignment of the system. Under the old system it took 3 men approximately 16 hours each for electrical alignment, now one man can perform the same task in less than 1 hour. Optical components were cleaned and aligned prior to this test, resulting in a ±2.5% uniformity with a 48 MW/cm^2 mean total irradiance at the package.

A malfunction occurred in the A1200 solar simulator during the pre-test electrical alignment with module No. 13. An arc occurred in a faulty lamp housing melting some of the housing material. The molten metal dropped onto the plano turning mirror causing damage to the Kanigen undercoating. A modification to the lamp housing has been designed to prevent this damage from recurring. The cost of repairing the mirror is estimated by Spectrolab to be $2700 and the estimated time for delivery is 60 days. A smaller mirror previously used in the system will be used as a replacement.

Two types of water cooled collectors were tested at various power levels in preparation for thermal modifications to the A1200 solar simulator. The results of these tests are given in Table 1. Case 1 shows the operating temperature of an air cooled collector. The epoxy seal collector (Case 2) was fabricated by the thermal laboratories and is structurally stable but not very efficient. The Spectrolab collector is more efficient (Case 3). The cost of in-house modifications of the present epoxy type collector is about $100 each; the cost of having Spectrolab modify the collector is approximately $300 each. Unfortunately, the choice here is not strictly one of economics, because the collector lifetime is greatly affected by temperature. It appears, then, that the greater initial expenditure for the more efficient collector is necessary.

The uniformity filters have undergone further investigation. The platinum films used on the uniformity filters have been tested for 1101 hours, showing only initial changes in transmission during the first 24 hour period (Figure 1). Recently measurements have been made of these filters to verify these neutral density characteristics as a function of thickness of the film. Figure 2 shows the transmission of a 1-Y compensating type filter in the areas of greatest and least transmission. It can be seen from this curve that the filter is essentially neutral.

Some degradation of spectral filters used in the A1200 solar simulator was observed. Two of these filters were in locations that received 5 to 10 times higher irradiance than the other filters experiencing 2 to 4 times more energy than they would be exposed to under normal operation. Other users of these filters (Spectrolab, Boeing Co.), have observed similar effects. It is the opinion of these experimenters that there is an upper limit, comprising total irradiance and temperature, beyond which the filter degrades. A test plan was derived which will attempt to evaluate the filter degradation in terms of the above parameters. Figure 3 shows the spectral transmission of a degraded and non-degraded filter. Apparently the coating has been burnt or otherwise removed in a localized spot of the filter; therefore, the transmission curve of the substrate is seen.

The "in-situ" uniformity scanner to be used in the Thermal Vacuum Solar Simulator (TVSS - A1200 solar simulator) has been fabricated by Airtronics Corp. The scanner did not pass "factory check-out" (required before delivery) because a unidirectional vacuum motor was used instead of a bidirectional motor. A new motor must be ordered and this involves a three month delay in delivery (projected for May 30).

The first phase in a total irradiance detector study has been completed. During this phase five types of detectors were calibrated using a secondary

Table 1
Temperature Distribution of Water Cooled Collectors

	Position of Temperature Measurement on Collector	Electrical Power Input - Lamp						
		°C At Watts-2400	°C At Watts-2500	°C At Watts-3500	°C At Watts-4200	°C At Watts-4700	°C At Watts-5500	°C At Watts-5700
	Case #1							
No H_2O Cooling	Top	159						
	Top	162.5						
	Position A - Middle	127						
	Position B - Middle	134						
	Position C - Middle	108						
	Bottom	95						
	Case #2							
Epoxy Seal - H_2O Cooled Collector	Top	95				109		119.5
	Top	86				95		102
	Casing	152				168		178.5
	Top Middle	23				34.5		41
	Top Middle	26.7				44.2		48
	Top Middle	15.5				22.5		24
	Top Middle	19				29		31.5
	Middle	8.2				11		11.5
	Middle	10				15		15.8
	Bottom	18				27		29.5
	Bottom	15				23		24.5
	Water Outlet	10				14		14.5
	Case #3							
Spectrolab H_2O Cooled Collector	Top		26.4	31	37.5		43	
	Top		15.5	17.5	20		23	
	Top		42	47	51.5		63	
	Bottom		9.5	10	11.5		12	
	Bottom		8.5	9	11		11	
	Bottom		10	10.8	12.5		13.5	
	Water Jacket		7	7.2	7.9		8.1	

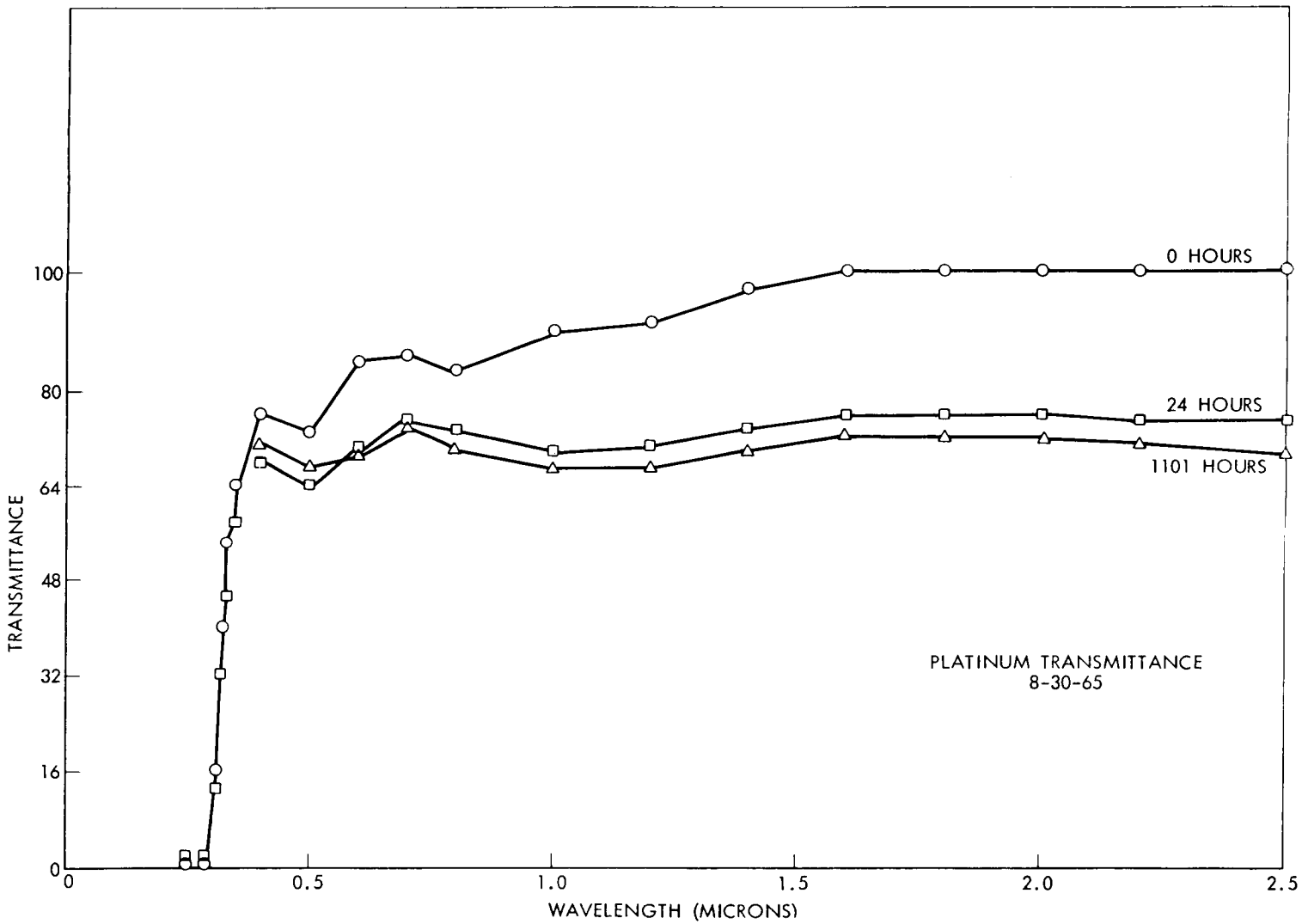


Figure 1. Spectral Transmission of Platinum-SiO_2 Uniformity Filter

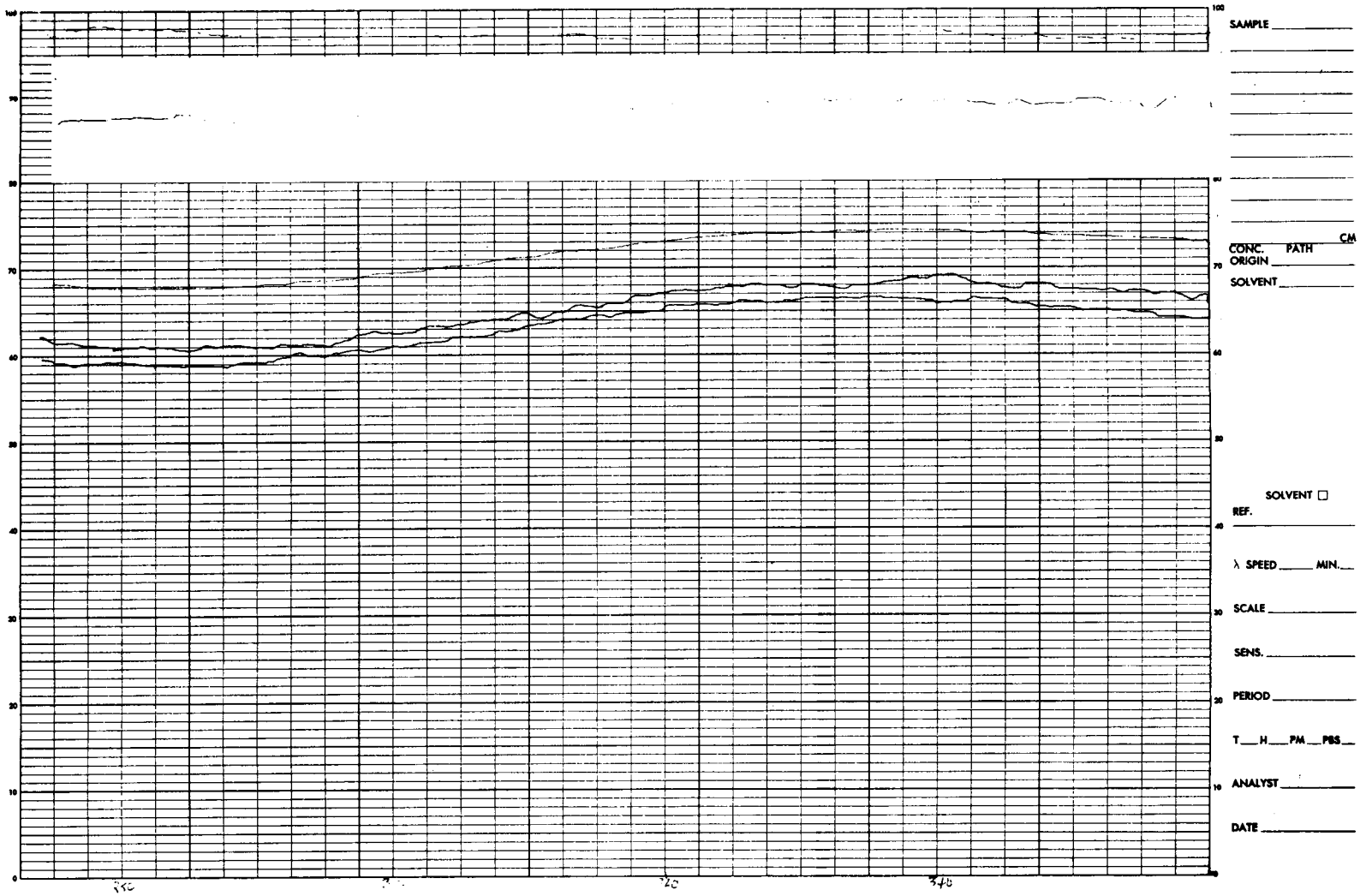


Figure 2a. Transmission of Pt Filter

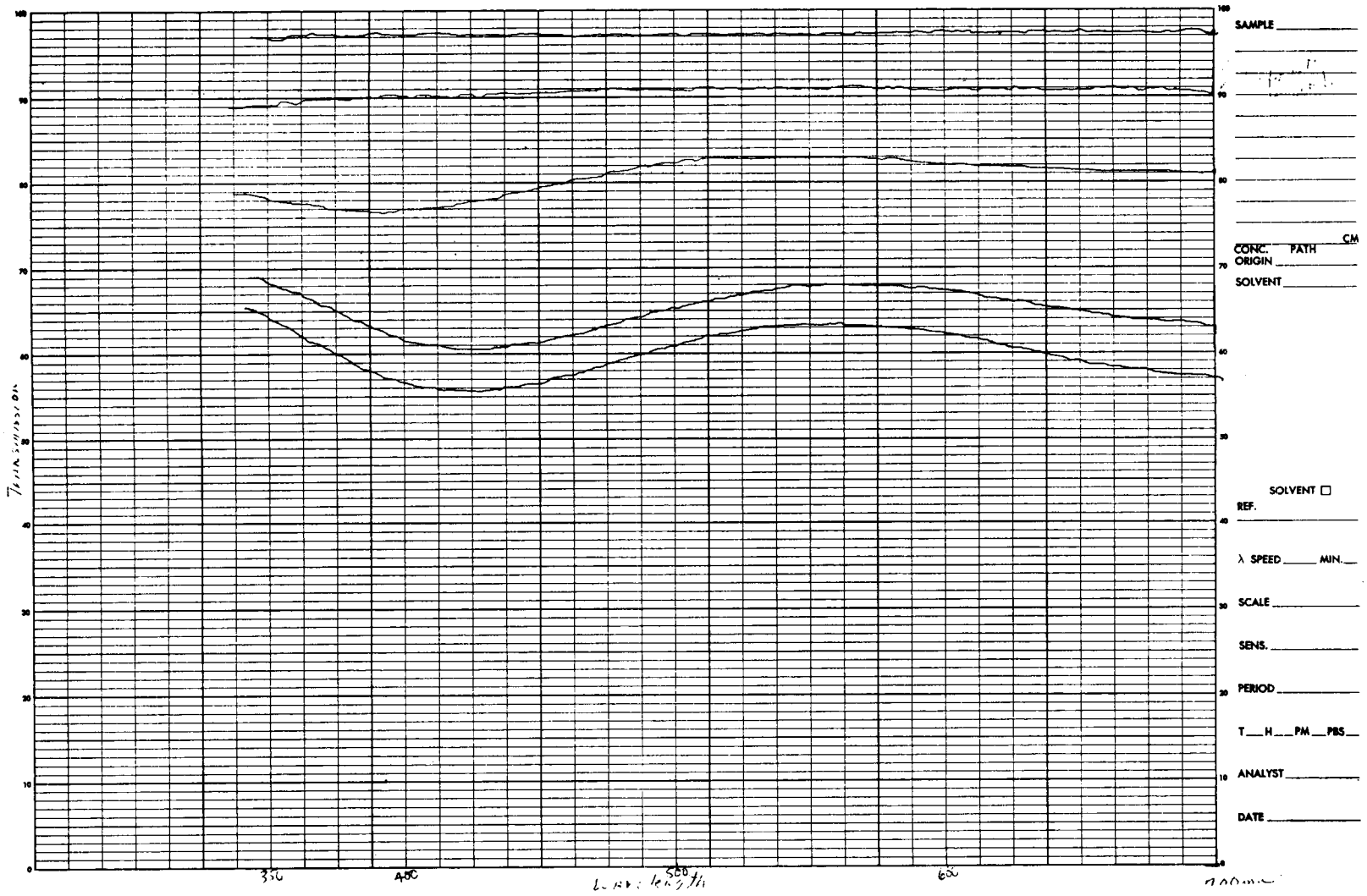


Figure 2b. Transmission of Pt Filter (Continued)

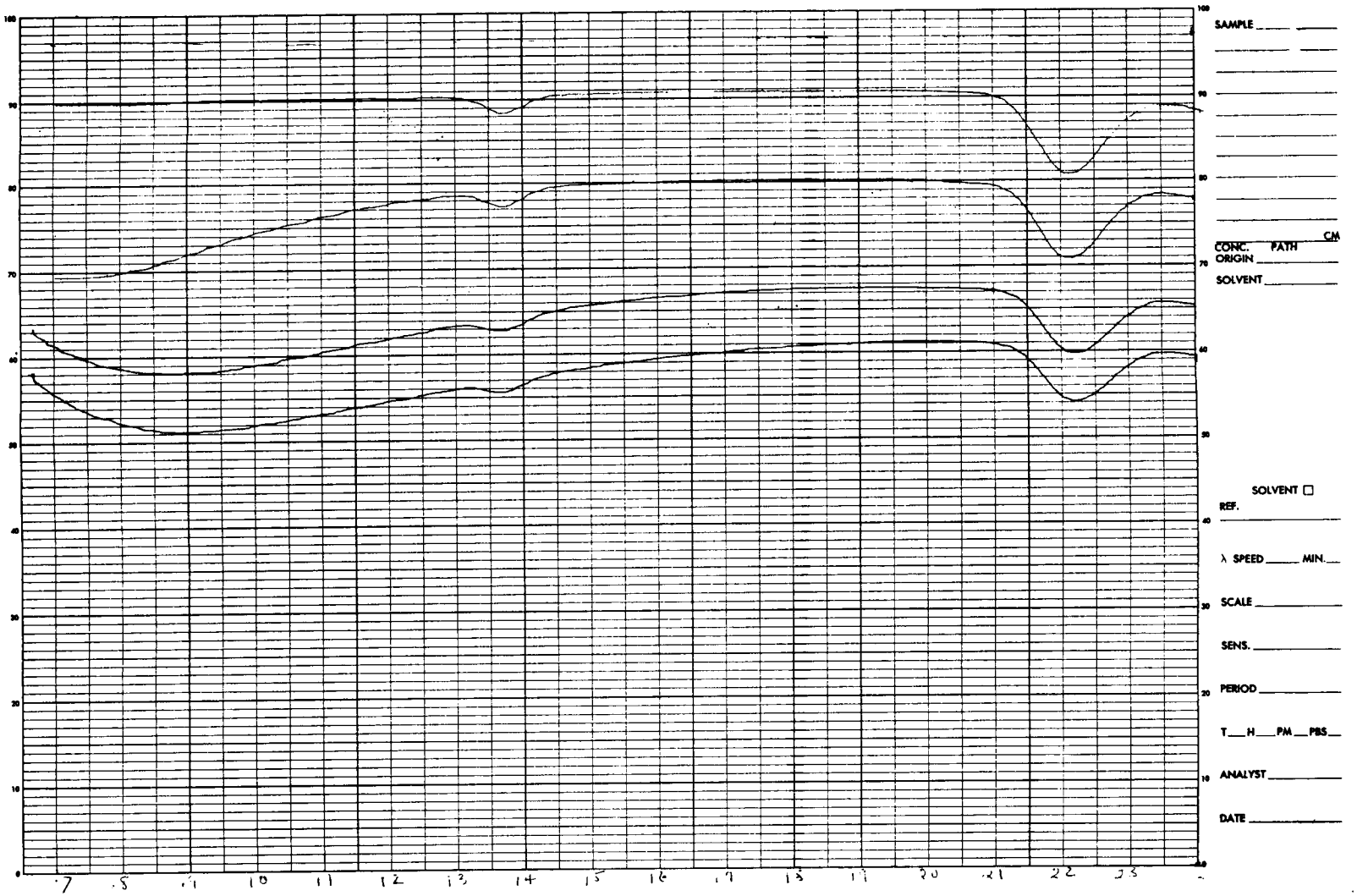


Figure 2c. Transmission of Pt Filter (Continued)

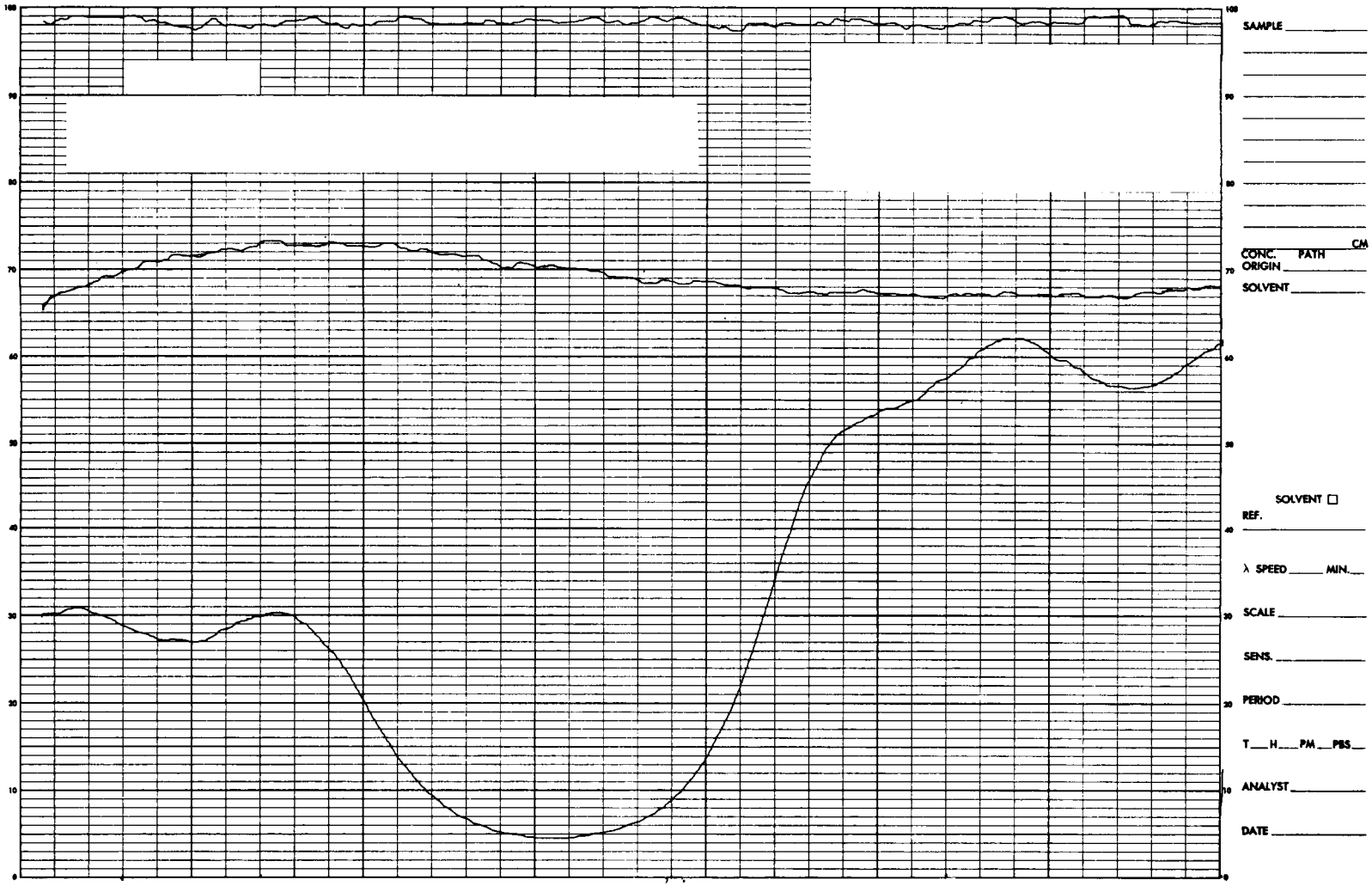


Figure 3a. Spectral Transmission of A-1200 Spectral Filter

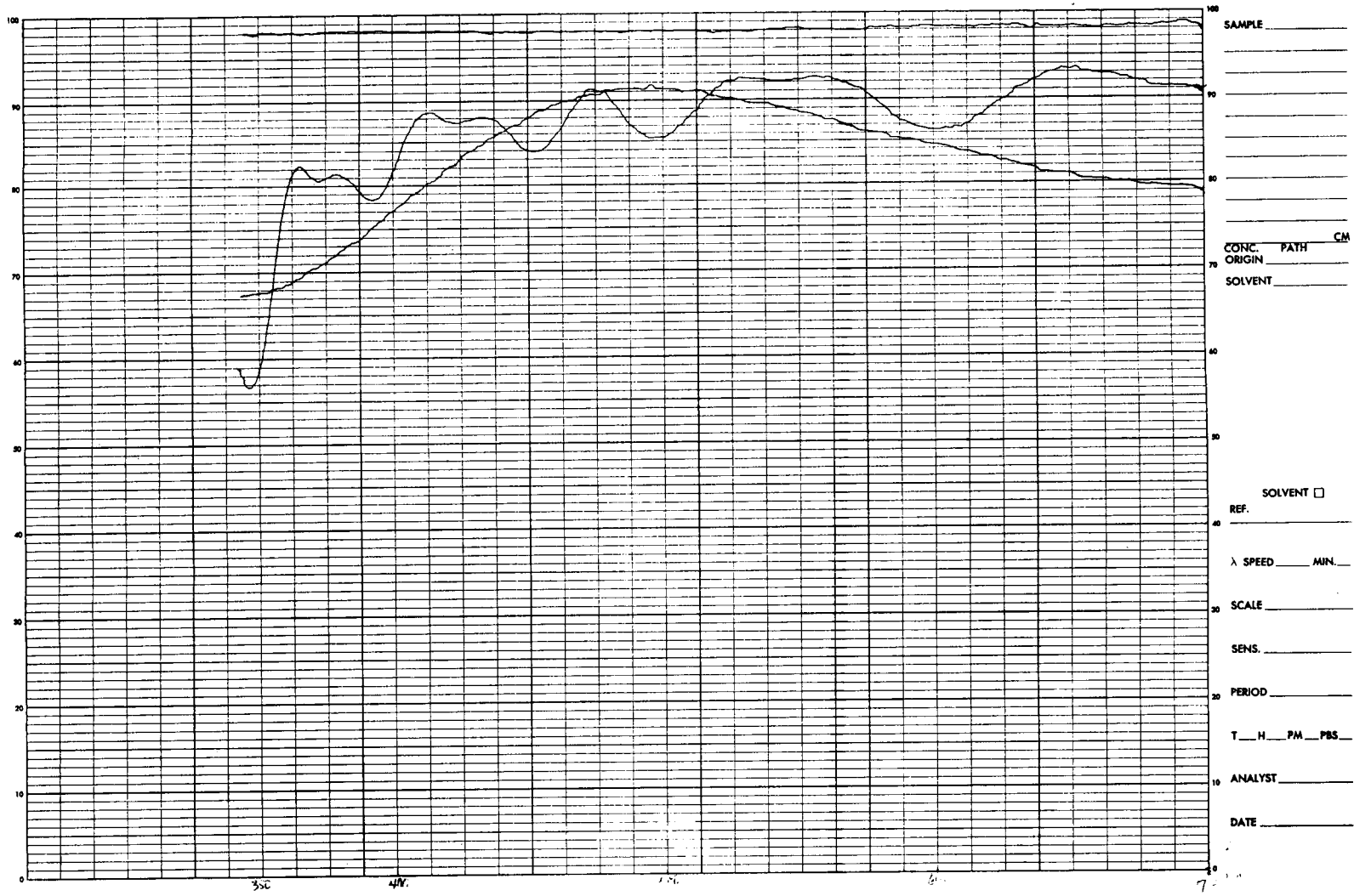


Figure 3b. Spectral Transmission of A-1200 Spectral Filter (Continued)

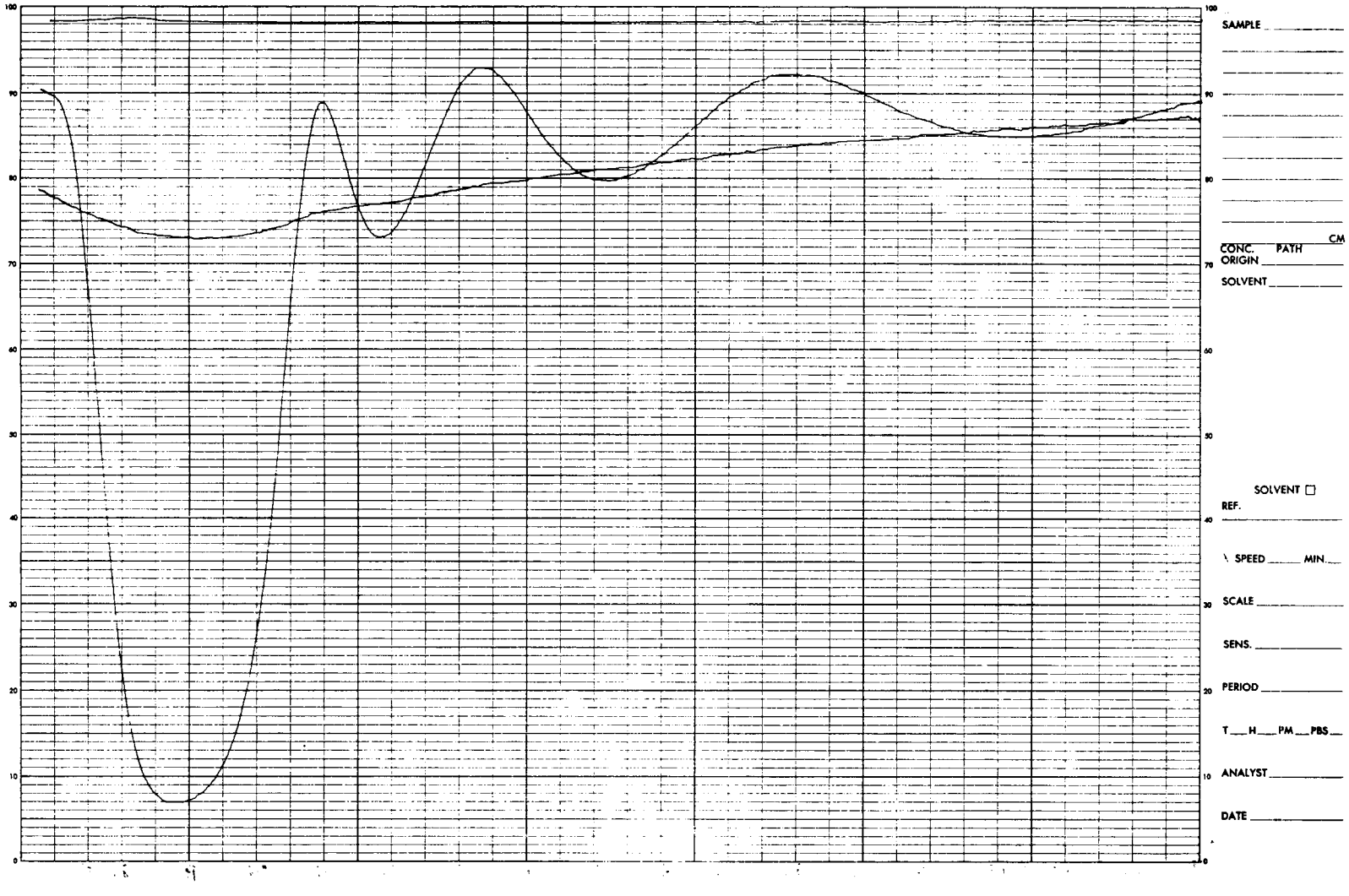


Figure 3c. Spectral Transmission of A-1200 Spectral Filter (Continued)

standard (Ångstrom Compensation Pyrheliometer). A summary of the results of this calibration effort is shown in Table 2. The table shows (1) total irradiance level of calibration, (2) old calibration factors given by manufacturer, (3) new calibration factors obtained by comparison with Ångstrom Compensation Pryheliometer, (4) new total irradiance value corrected for decollimation factor for a specific detector and for a source with a collimation angle of less than 7°. The decollimation factor is used to correct the Ångstrom Compensation Pryheliometer reading for uncollimated sources used in the laboratory. The next phase of the detector study will study the linearity of the detector output as a function of irradiance.

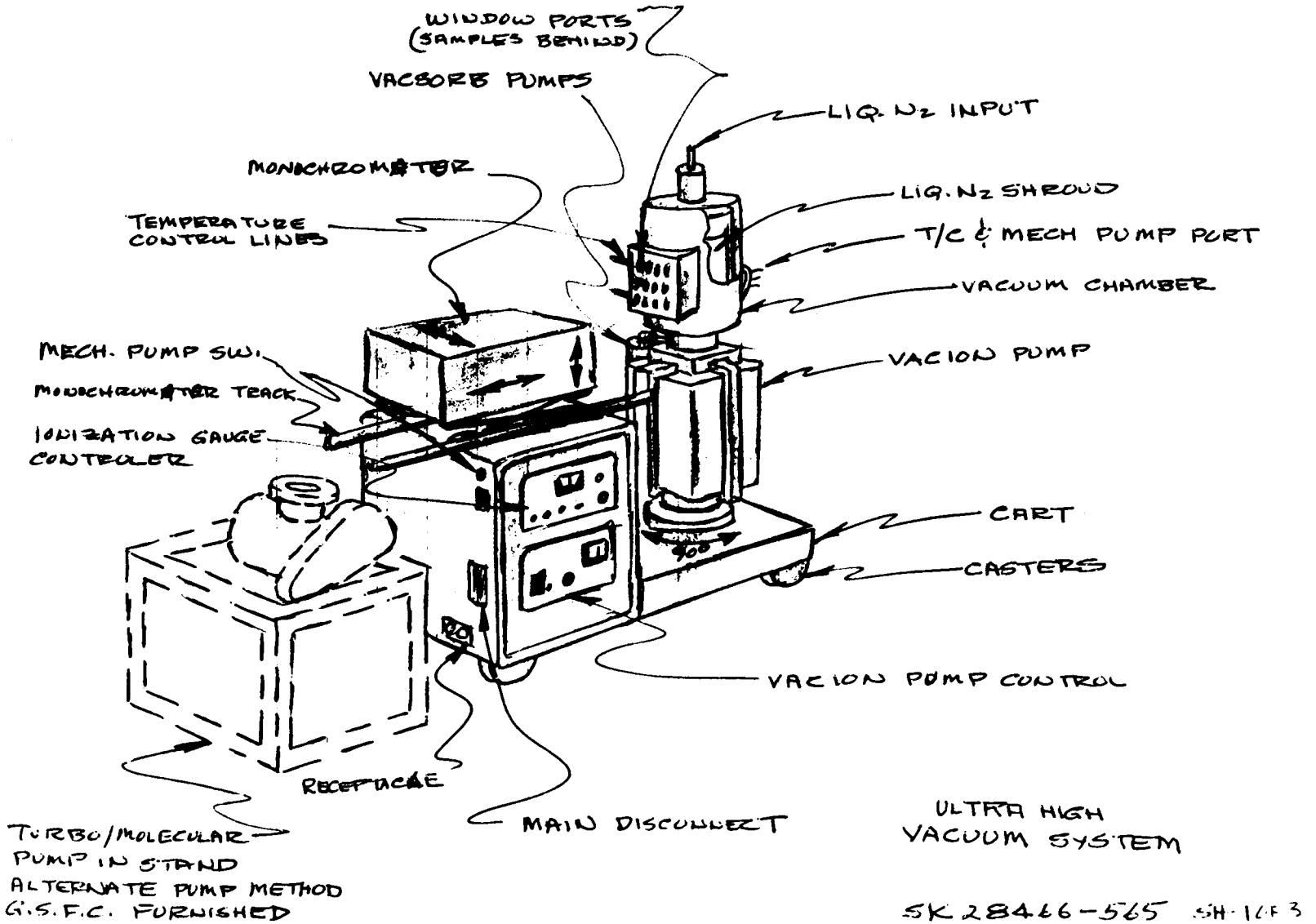
The "Multi Sample Solar Environment Degradation System" (Multi-SSEDS) is scheduled for delivery from Cook Vacuum Company on March 30. This system is capable of testing sixteen 1" samples and making optical "in-situ" reflectance measurements of each sample. Two visits have been made to Cook Vacuum Company and system progress indicates that March 30th is a realistic delivery date. The final "factory check-out" of the system will be the last week in March. Pictorial schematics of this system are shown in Figures 4 through 6.

A "Mono-Sample Solar Concomitant Environment Degradation System" (Mono-SSCEDS) is nearing completion. This system is capable of low energy particle radiation (<30 kev) and optical "in-situ" reflectance measurements using the same regime as the "Multi-SSEDS." Present plans are to operate the Multi-SSEDS and Mono-SSCEDS together. A floor plan showing the proposed utilization of space for these systems and their supporting equipment in Room 140B is shown in Figure 7.

Table 2

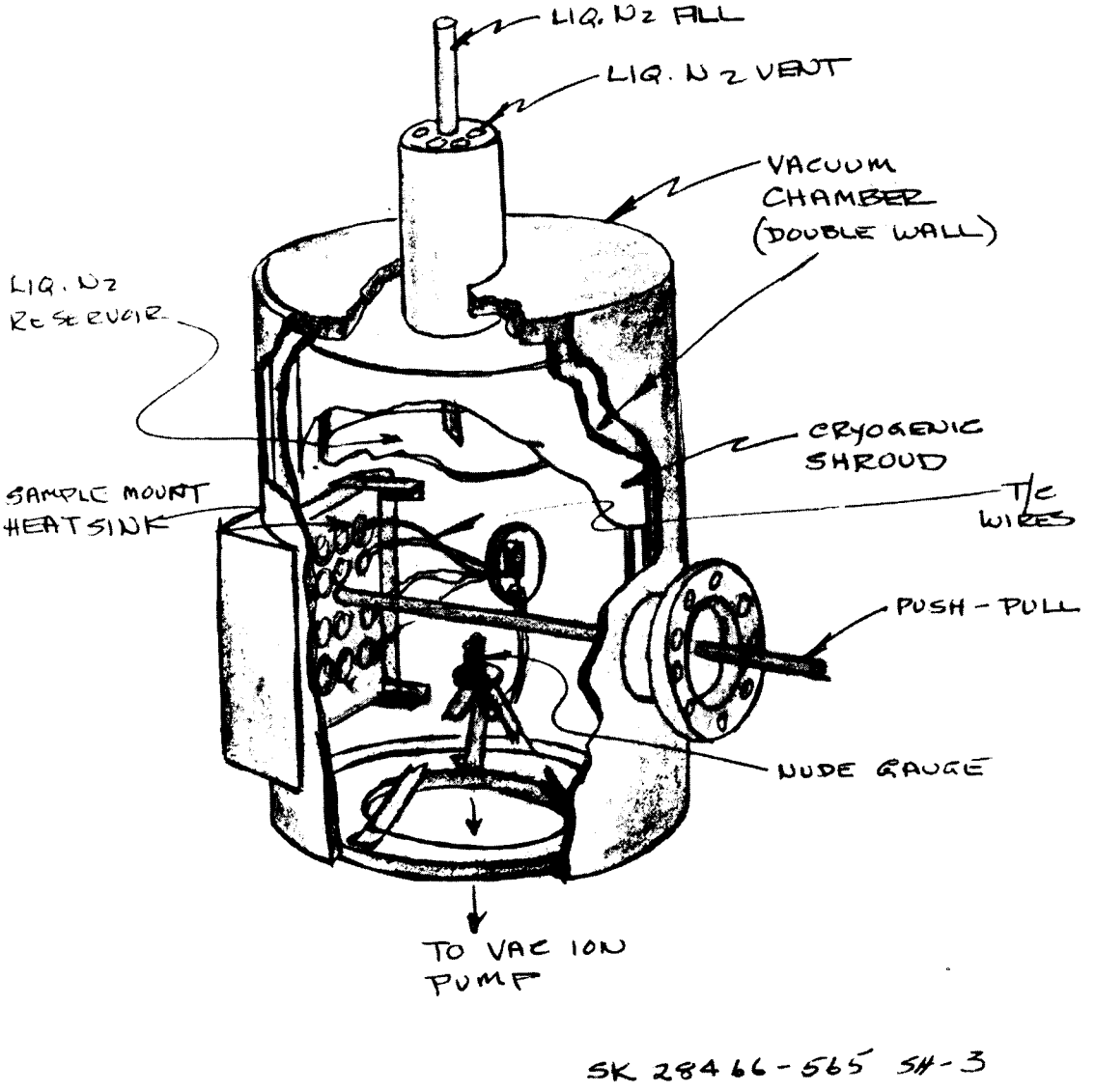
Detector Calibration Data (Decollimation Factor 1.088)

Detector	Total Irradiance in MW cm^{-2} By Existing Calibration Factor			Total Irradiance in MW cm^{-2} using the New Detector Calibration Factor			Old Detector Calibration Factor in MW MV^{-1}	Preliminary Detector Calibration Factors in MW MV^{-1}		New Calibration Factor in MW MV^{-1} = X-25L Calibration X Decollimation Factor
	X-25L	Sun at Table Mountain	Sun	X-25L	Sun at Table Mountain	Sun		X-25L	Sun	
Å Pyrheliometer #5175 Normal Incidence	129.0	99.1	63.8							
Pyrheliometer	145.7	103.6	65.9	140.3	99.8	63.5	19.34	17.12	18.72	18.63
Å Pyrheliometer #5744 Normal Incidence	129.4		61.4							
Pyrheliometer	137.1		64.6	140.8		61.1	21.85	19.01	20.76	20.68
Å Pyrheliometer #30198 Hy-Cal	130.3		—							
Pyrheliometer	140.8		—	141.8		—	30.11	27.86	—	30.31
Å Pyrheliometer #30200 Hy-Cal	130.6		—							
Pyrheliometer	136.7		—	142.1		—	26.67	25.50	—	27.74
Å Pyrheliometer #30196 Hy-Cal	130.2		—							
Pyrheliometer	140.3		—	141.6		—	25.23	23.40	—	25.46
Å Pyrheliometer GE Detector #2	114.3									
(T&E Division)	156.0		—	124.7		—	18.86	13.86	—	15.08
Å Pyrheliometer GE Detector #1	114.0									
(T&E Division)	161.5		—	124.1			18.04	12.75		13.87



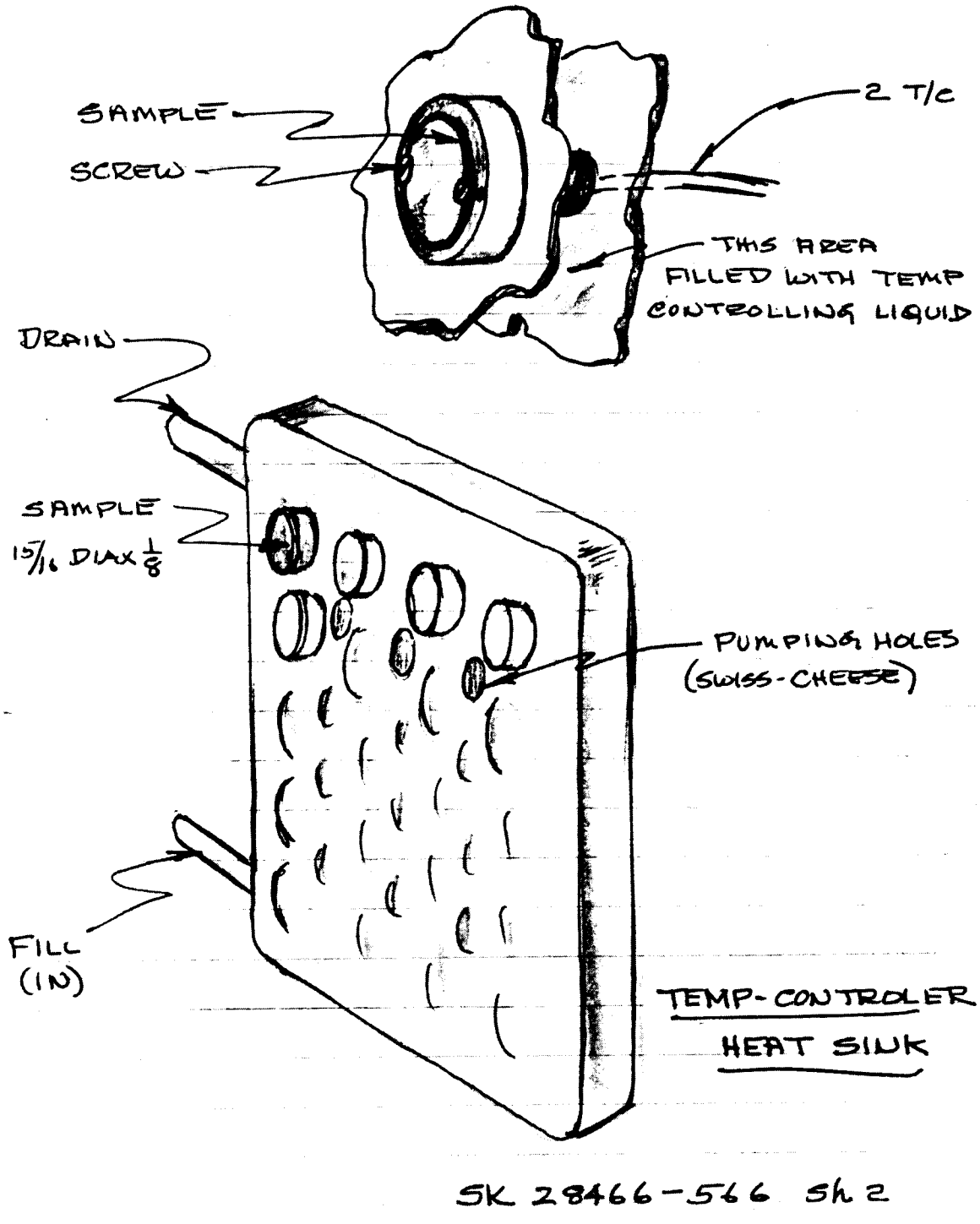
Multi-Sample Solar Environment Degradation System
(Multi-SSEDS)

Figure 4. Degradation System



Vacuum Chamber of Multi-SSEDS

Figure 5. Vacuum Chamber



Front Plate of Multi-SSEDS

Figure 6. Sample Holder

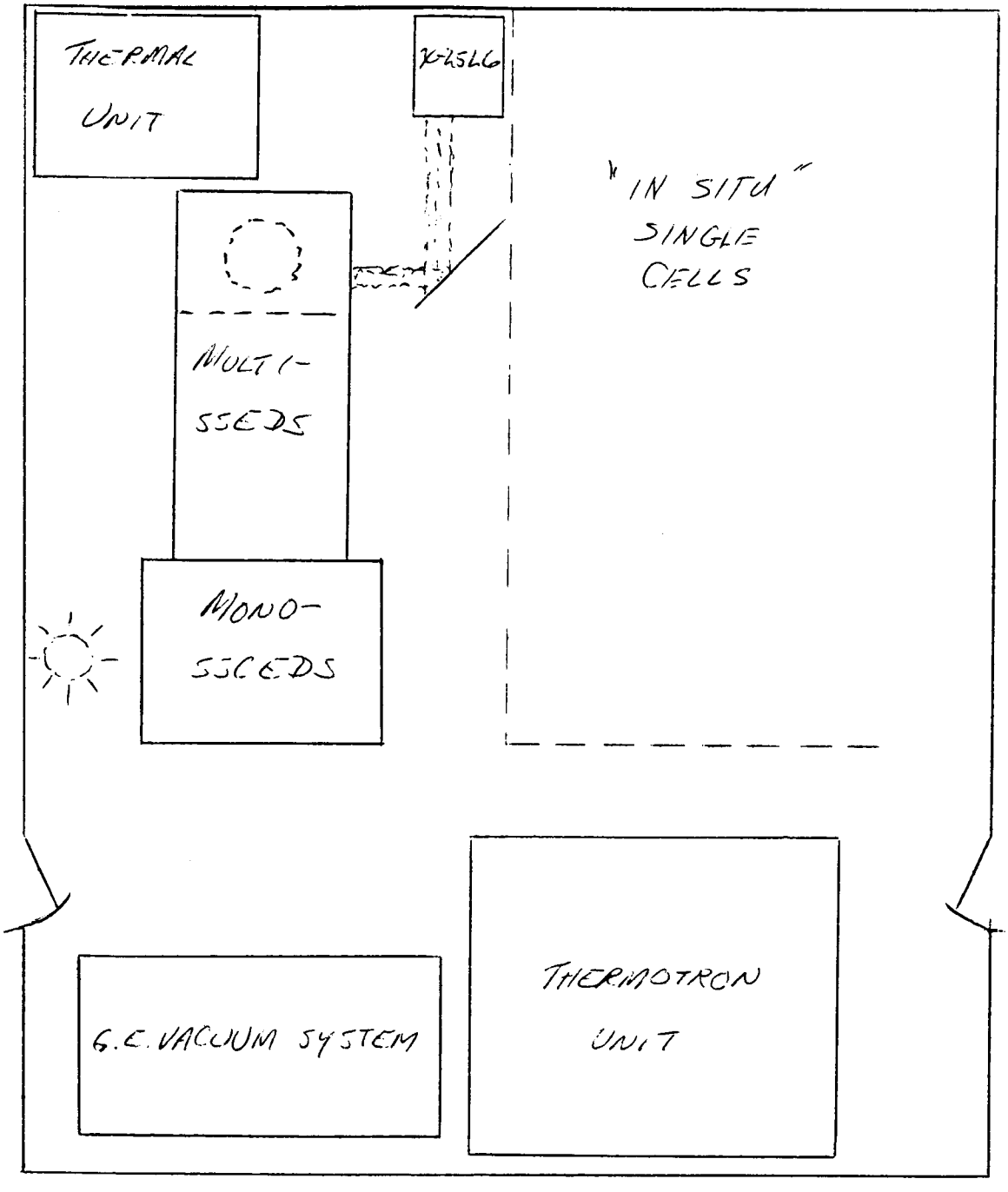


Figure 7. Equipment Layout

N67-32596

SECTION III

ARC RESEARCH

Stanley M. Neuder

ARC RESEARCH

FACILITIES

1. The 80 kw vortex stabilized arc has been received from Spectrolab. A considerable amount of time has been devoted to planning the necessary facilities and ordering needed equipment. Room modifications and additions should be completed during the next quarter.

EXPERIMENTATION

1. A report has been written on the recent progress of the vortex stabilized arc research and is due out as an X-note.

2. The spectral distribution of a zirconium lamp has been measured in the range 0.3 to 2.4 microns. The data has been reduced and plotted. Most of the spectral emission lies in the near IR. This is discussed in Section IV.

3. Progress with the 25 kw vortex system has been stalled because of faulty procedures in the fabrication of the W-CU electrodes. These were precision machined prior to, rather than following, the high temperature braze. The subsequent electrode deformation resulted in excessive water leakage.

4. Analysis of recent data verified that:

   (a) High vortex velocities reduce thermal excitation of the plasma causing a drop in plasma current and an increase in voltage. Short arc characteristics (spreading plasma, high current to voltage ratio) have been simulated in the vortex system by sufficiently reducing gas vortex velocity.

   (b) Plasma potential is a function of inter-electrode spacing, increasing with increased gap width.

   (c) Inert gases of higher atomic masses sustain higher electrical potentials for a specific current.

Theoretical Considerations

Several spectroscopic methods of measuring ion and electron temperatures of an optically thin plasma in local thermal equilibrium have been considered.

One of the more promising methods would apply directly to relatively low power arcs (e.g., 1-2 kw short arc) enabling a determination of plasma temperature distributions to be made. This method is limited only by the requirement that a knowledge of transition probabilities and statistical weights must exist for the gas under investigation.

Spectroscopic methods applicable to high current densities and extreme pressure ambients are presently being investigated.

Calculations of ion and electron densities in a plasma may be made once the temperature is determined. Again this calculation assumes relatively high pressures so that local thermal equilibrium exists. (At low pressures, the electron temperature runs extremely high while the gas temperature remains near room ambient. In fact, the concept of electron temperature loses significance under the latter conditions.)

Experimental methods of finding charge densities are being investigated.

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SECTION IV

ELECTROMAGNETIC MEASUREMENTS

Progress Report for Period
1 December, 1966 to 28 February, 1967

R. McIntosh
Supervising Engineer

The work reported herein was performed by the following under contract NAS-5-9244:

Roberta Urschel
Daryl Mosier
Ralph Stair
Sam Hall

VORTEX STABILIZED ARC

SPECTRAL MEASUREMENTS

During this period one spectral irradiance measurement was made on the vortex stabilized arc shown in Figure 8. This was

V-22 Helium 80 p.s.i.g. @ 4kw (open loop)

In addition the data was plotted from three previously made spectral measurements (Figures 9, 10, and 11). These were

V-19	Argon	70 p.s.i.g.	@ 3kw, 1200 cc/min. flow
V-20	Argon	70 p.s.i.g.	@ 2kw, 364 cc/min. flow
V-21	Argon	70 p.s.i.g.	@ 3.6kw, very high flow

The computer printout for the latter measurement is shown in Table 3.

EQUIPMENT

Several new electrodes were fabricated for use in the vortex arc. However, when they were used the arc length was changed and as a result the voltage, current characteristics were changed. To investigate these changes under controlled conditions a set of three new cathode adapters were fabricated. These adapters will provide three different arc lengths.

Three new inner quartz tubes for the vortex arc were received from the Giannini Scientific Company. When examined they were found to have too small an inside diameter. The ends of the tubes which were too small were ground down to the correct size in the NASA-GSFC Optical Shop.

The inner quartz tubes mentioned above cost $61.00 each when purchased from the Giannini Scientific Company. Because of this and the fact that the last three units purchased were not the correct size, attempts have been made to purchase this tubing from a quartz manufacturer. If possible, a significant dollar savings could be made. To date, the efforts in this area have not been successful. Thusfar, the General Electric Company and the Corning Glass Works have been contacted. The Corning quartz was transluscent and quite unacceptable. The General Electric quartz (type 204 or 208) had a satisfactory transmission but G.E. has been unable to provide tubes with satisfactory tolerances.

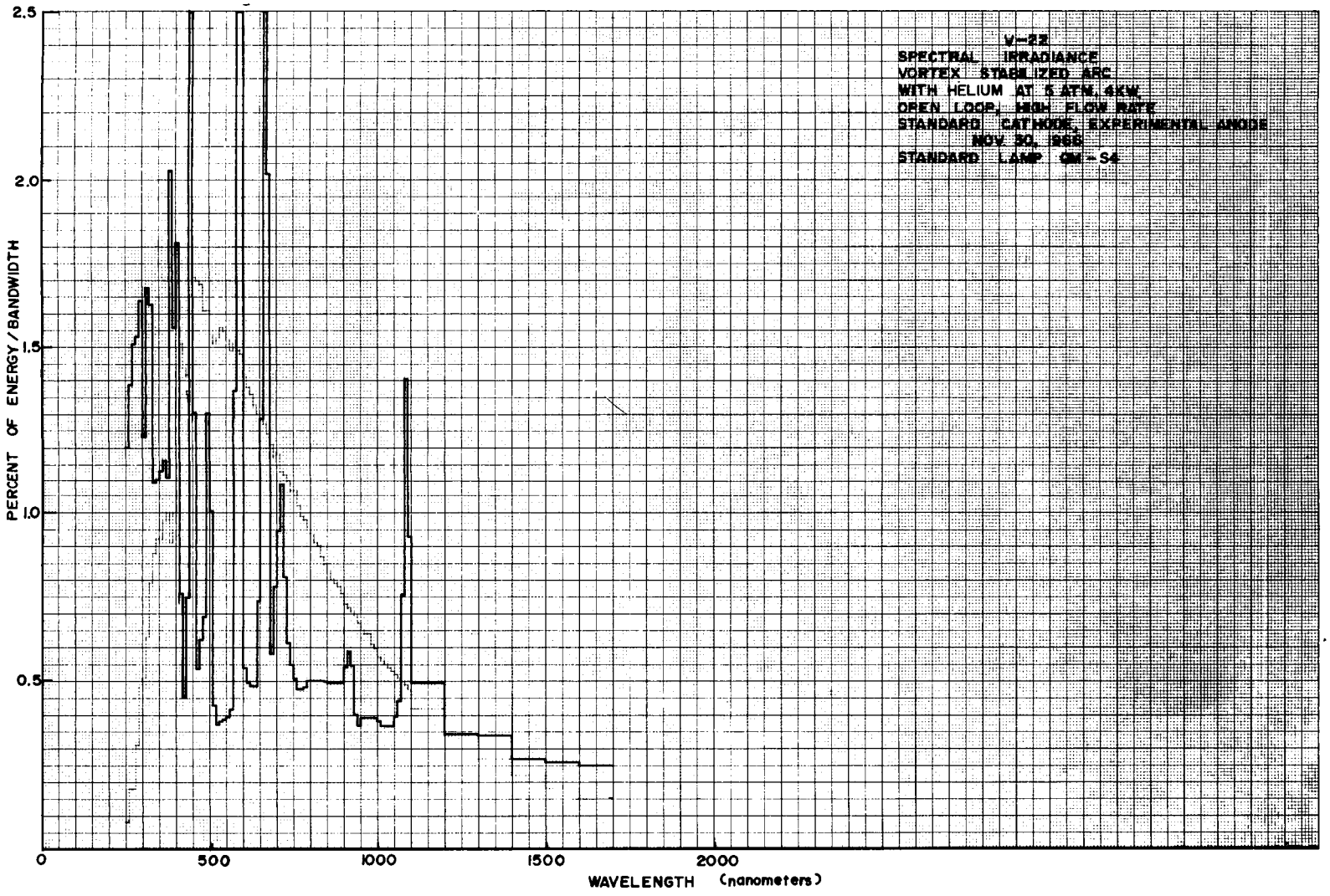

Figure 8. VSRS Helium 80 psig @ 4 kw, Open Loop

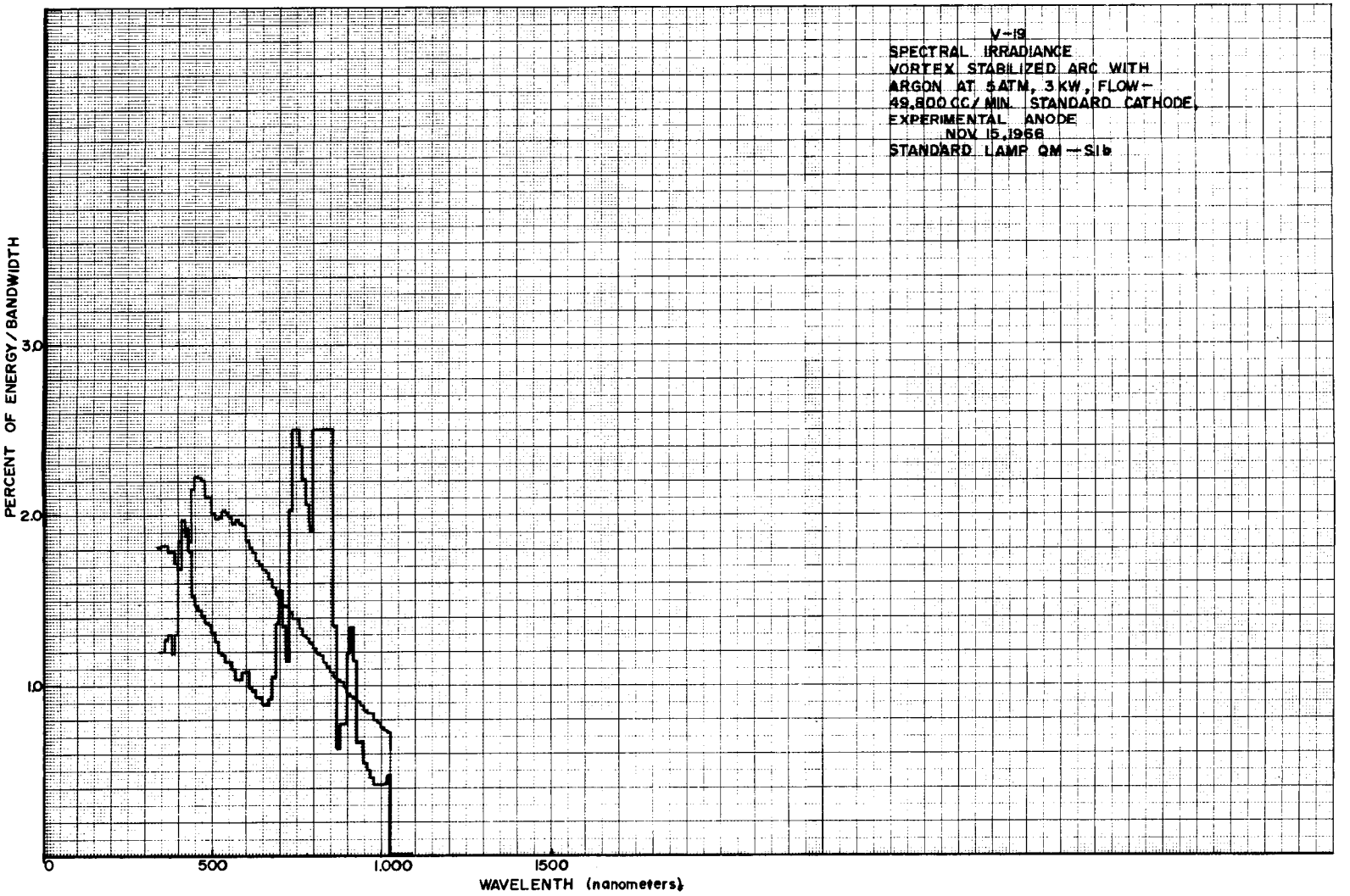

Figure 9. VSRS Argon 70 psig @ 3 kw, 1200 cc/min Flow

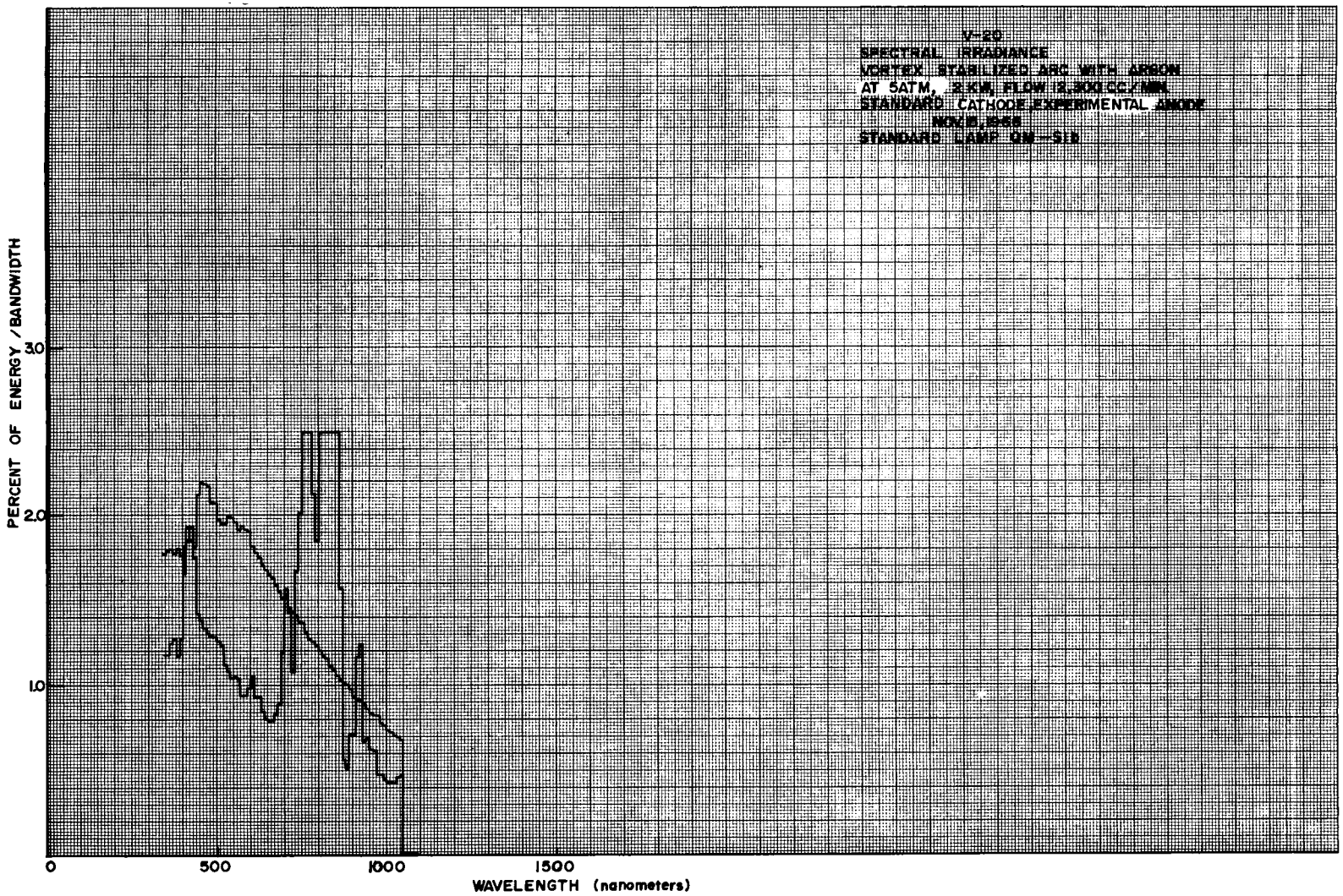

Figure 10. VSRS Argon 70 psig @ 2 kw, 364 cc/min Flow

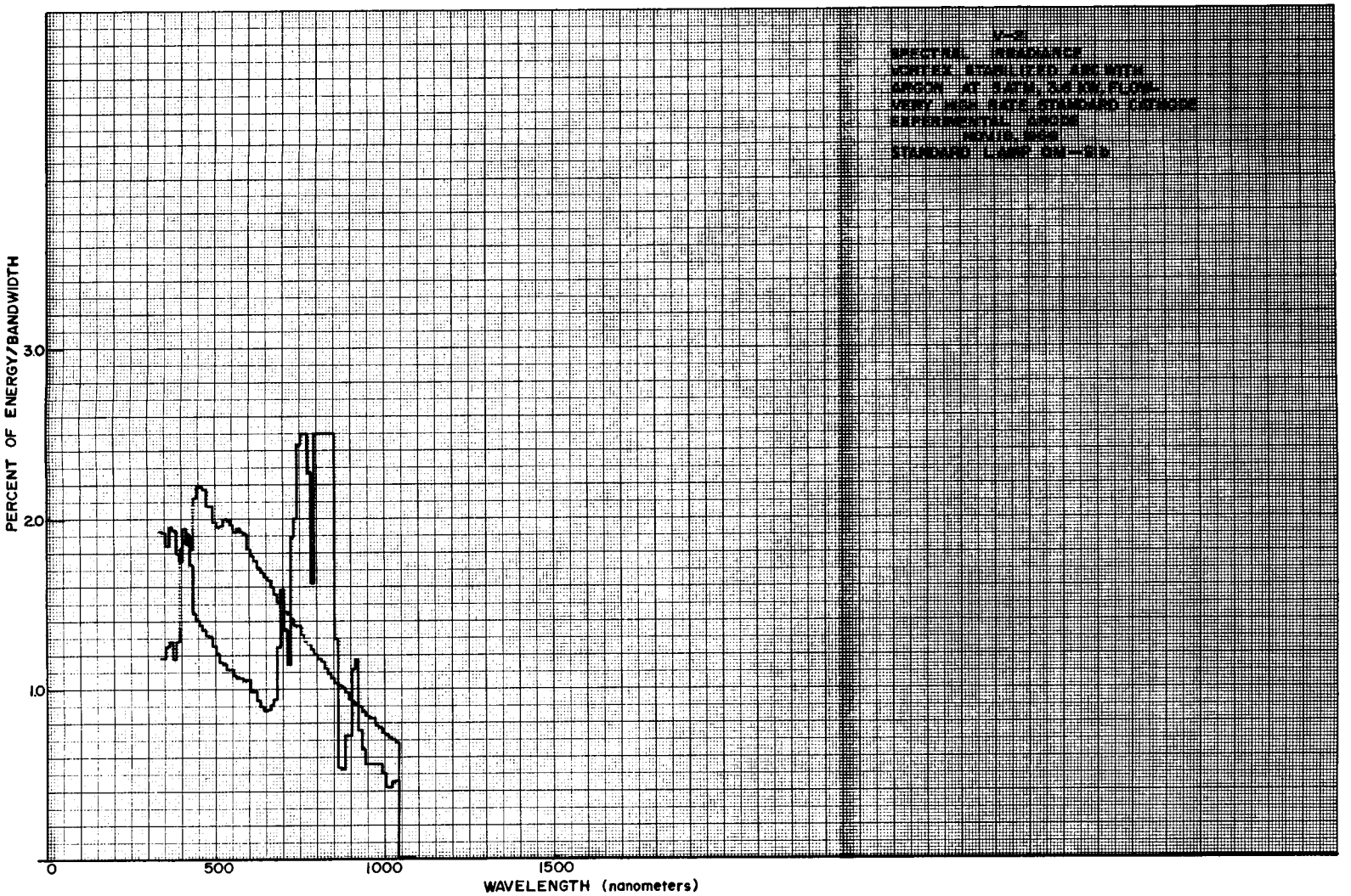

Figure 11. VSRS Argon 70 psig @ 3.6 kw, Very High Flow

Table 3
Computer Printout VSRS, 70 psig @ 3.6 kw

V-22 HELIUM 5ATM 4Kb LNO. 2 S: HIGH FLOW RATE

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIO	TESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL			
255.	1.199	0.077	15.62	
265.	1.386	0.175	7.90	
275.	1.509	0.175	8.60	
285.	1.53[illegible]	0.307	4.99	
295.	1.638	0.482	3.40	
305.	1.239	0.504	2.44	
315.	1.677	0.635	2.63	
325.	1.527	0.789	2.06	
335.	1.090	0.877	1.24	
345.	1.10[illegible]	0.92[illegible]	1.20	
355.	1.130	0.921	1.23	
365.	1.162	0.976	1.19	
375.	1.109	0.999	1.11	
385.	2.029	0.910	2.23	
395.	1.552	0.998	1.56	
405.	1.812	1.425	1.27	
415.	0.755	1.513	0.50	
425.	0.449	1.436	0.31	
435.	0.745	1.414	0.53	
445.	3.206	1.655	1.94	
455.	1.305	1.710	0.76	
465.	0.532	1.699	0.31	
475.	0.619	1.698	0.37	
485.	0.689	1.611	0.43	
495.	1.304	1.621	0.81	
505.	1.002	1.535	0.65	
515.	0.424	1.513	0.28	
525.	0.366	1.524	0.24	
535.	0.378	1.557	0.24	
545.	0.352	1.546	0.23	
555.	0.39[illegible]	1.524	0.26	
565.	0.424	1.491	0.28	
575.	1.370	1.513	0.91	
585.	5.263	1.491	3.53	
595.	6.727	1.480	4.54	
605.	0.535	1.414	0.38	
615.	0.491	1.38[illegible]	0.36	
625.	0.481	1.359	0.35	
635.	0.46[illegible]	1.326	0.36	
645.	0.735	1.305	0.56	
655.	1.282	1.283	1.00	
665.	2.759	1.272	2.15	
675.	2.019	1.239	1.63	
685.	0.572	1.206	0.45	
695.	0.777	1.173	0.66	
705.	0.945	1.184	0.80	
715.	1.037	1.129	0.92	
725.	0.805	1.118	0.72	
735.	0.509	1.096	0.46	
745.	0.545	1.063	0.51	
755.	0.502	1.063	0.47	
765.	0.47[illegible]	1.020	0.46	
775.	0.47[illegible]	0.987	0.48	
785.	0.479	0.976	0.49	
795.	0.498	0.954	0.52	
805.	0.498	0.932	0.53	
815.	0.496	0.910	0.55	
825.	0.498	0.899	0.55	
835.	0.498	0.866	0.58	
845.	0.495	0.844	0.59	
855.	0.491	0.822	0.60	
865.	0.49[illegible]	0.800	0.61	
875.	0.49[illegible]	0.789	0.62	
885.	0.49[illegible]	0.778	0.63	
895.	0.492	0.756	0.65	
905.	0.540	0.724	0.75	
915.	0.586	0.713	0.82	
925.	0.543	0.702	0.77	
935.	0.395	0.691	0.58	
945.	0.364	0.669	0.55	
955.	0.388	0.647	0.60	
965.	0.388	0.636	0.61	
975.	0.385	0.636	0.61	
985.	0.388	0.603	0.64	
995.	0.388	0.592	0.66	
1005.	0.377	0.570	0.66	
1015.	0.363	0.559	0.65	
1025.	0.362	0.548	0.66	
1035.	0.363	0.537	0.68	
1045.	0.352	0.526	0.69	
1055.	0.292	0.515	0.75	
1065.	0.439	0.504	0.87	
1075.	0.753	0.493	1.53	
1085.	1.405	0.482	2.91	
1095.	0.926	0.471	1.96	
1150.	0.491	0.415	1.18	
1250.	0.338	0.332	1.02	
1350.	0.335	0.267	1.25	
1450.	0.2[illegible]5	0.217	1.22	
1550.	0.256	0.178	1.44	
1650.	0.245	0.147	1.67	

Within recent weeks it has come to the attention of the author that NASA-GSFC has established a Glass Technology Laboratory within the Fabrication Division. Mr. George Bergin of this Technology Laboratory has been contacted concerning this problem. He seems quite confident that he will be able to secure tubing with the necessary dimensions and tolerances.

STANDARD LAMPS

During this reporting period a new power supply has been fabricated to operate with the standards of spectral irradiance. The power supply used previously did not provide adequate resolution and control. This new supply will provide much better control and the quality of the overall spectral measurements will be improved.

Considerable difficulty has been encountered recently in the routine calibrations of working standards of spectral irradiance. This difficulty has been particularly prevalent in the infrared region of the spectrum where an Ektron lead sulphide cell is used as the photodetector. The output of this PbS cell has been drifting badly. At least part of this drift stems from changes in cell temperature due to changes in room temperature. At the suggestion of the vendor, the Kodak Company, a second dark cell used as a load resistor for the detection cell, has been used. This second cell is supposed to compensate for changes in cell temperature. This technique has not proven helpful in this application. If the spectral measurements are to be improved, it appears that an LN_2 cooled cell should be purchased. This has been made an objective for the next quarter. In the meantime a different technique to calibrate the working standards will be used to minimize the errors inherent in the old technique. In the future, the output from the working standard will be measured at each point immediately after measuring the output of the NBS calibrated standard. This will take considerably more time and effort but it is felt necessary for maintenance of reasonable precision and accuracy.

80KW ARC LAMP

The components for the 80kw vortex stabilized arc lamp have been received from Spectrolab. In preparation for the assembly and installation of this new lamp, Room 145 in Building 4 has been rearranged to maximize use of available space. The new lamp will be assembled and tested as soon as the power supply used to operate the lamp is received from Westinghouse and the required utilities in Room 145 are installed.

PLUMBING MODIFICATIONS

Because of the anticipated work with rarer and more expensive gases (xenon, krypton, etc.) the plumbing for the vortex arc has been examined thoroughly. Several minor modifications have been made and all of the leaks in the gas recirculating system corrected.

An adapter has been designed and fabricated which will permit the lamp assembly to be tested for water and gas leaks before final assembly. This adapter will mate the lamp assembly to the Veeco vacuum leak detector. This will save a good deal of time and ensure that no water leaks are present. If water were to leak into the arc chamber during operation a catastrophic failure would result.

A gas manifold has been ordered which will attach to several gas cylinders at a time. In the past it has been necessary to change the cylinders many times during a spectral measurement when the arc was operated in the open loop configuration. This new manifold will save time and ensure that no air will get into the arc system during a measurement.

A1200 SOLAR SIMULATOR

SPECTRAL MEASUREMENTS

The A1200 solar simulator was used for the solar simulation test of the ATS-B SASSE F-3 thermal Coatings Experiment. A spectral distribution measurement was made during this test (Figures 12 and 13, A-15). The data for this measurement together with the calculated effective absorptances for all of the coatings involved is shown in Table 4.

IN VACUUM UNIFORMITY SCANNER

The fabrication of the in vacuum uniformity scanner for the A1200 solar simulator was completed during this quarter. The unit was prepared for the required preliminary acceptance tests which were to be performed at the Melpar, Inc. test facility in Virginia. The vacuum system, in which the unit was to be tested, was evacuated and the power to the motor turning the scanner arm was applied to observe the motor's rotation. The scanner was removed from the vacuum system and it was later determined that the wrong motor had been specified by the mechanical designers. The scanner requires a reversible motor, but the motor purchased was non-reversible. The Fabrication Division

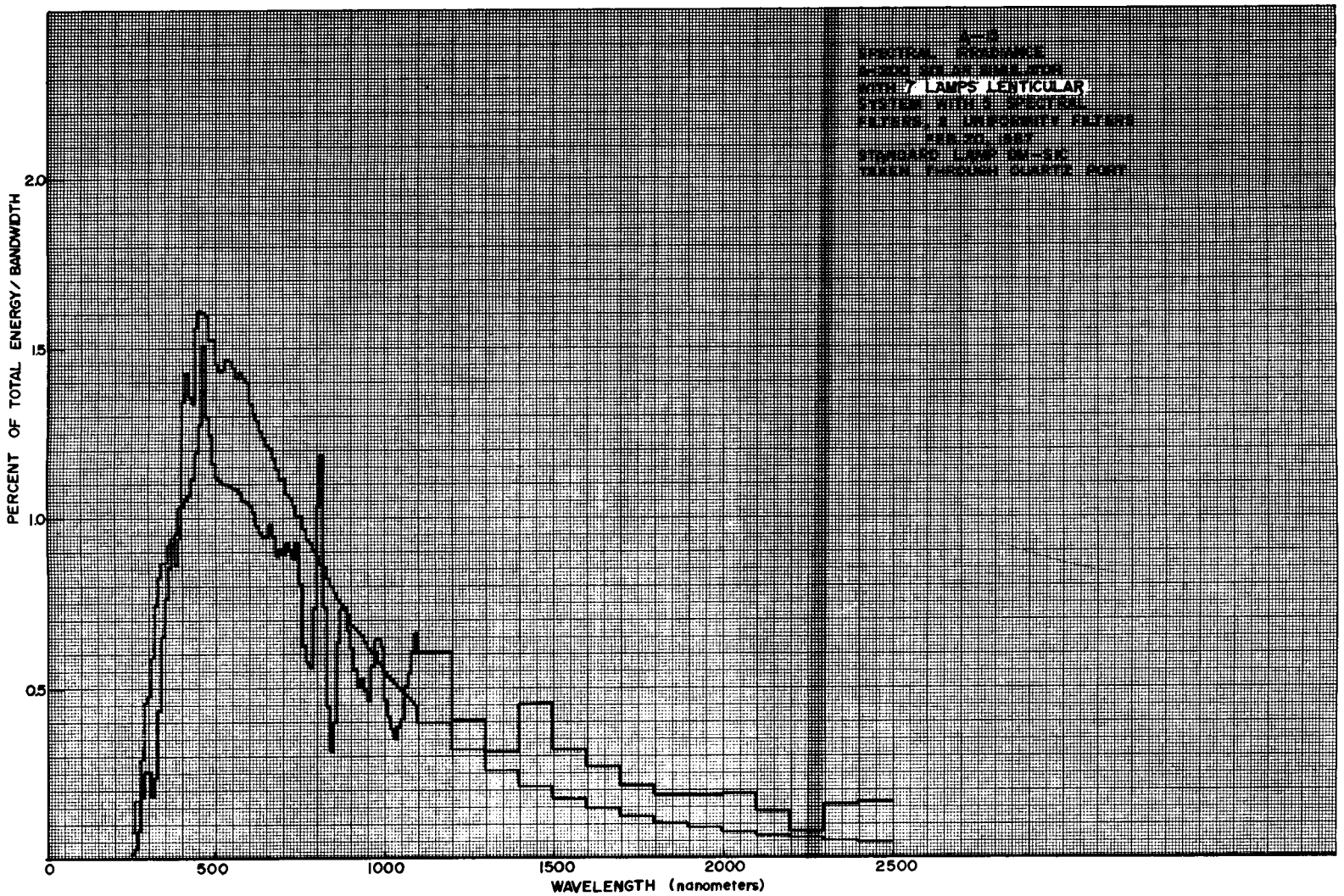

Figure 12. Spectral Distribution—A-1200 Solar Simulator

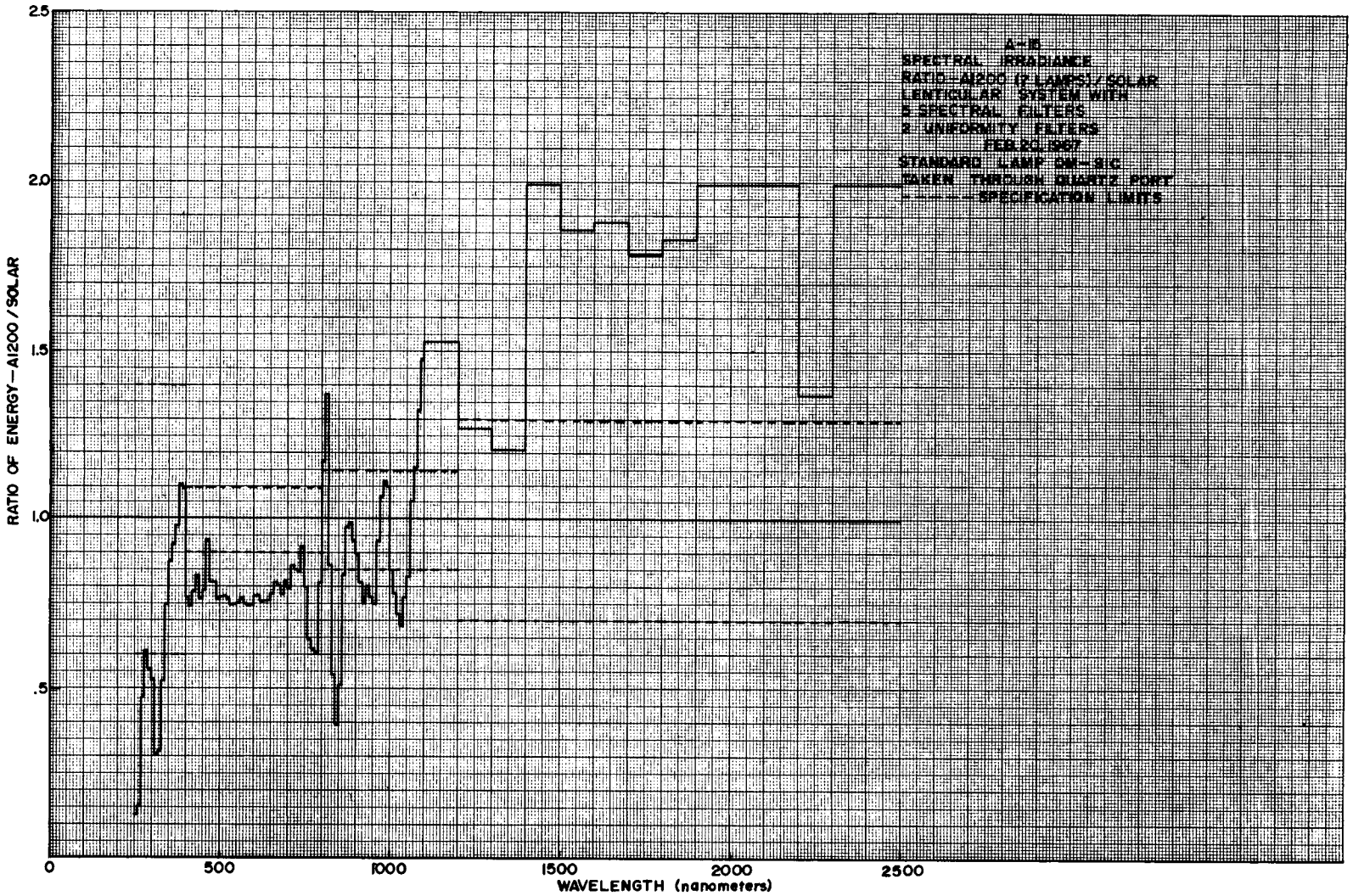

Figure 13. Ratio A-1200 to Solar Irradiance

Table 4
Computer Printout A-1200

A-15 7XE 5SPEC 2UNIF LND, 3 S-1C SASSE F-3

WAVELENGTH	TEST LAMP ENERGY PER 10NM WAVELENGTH INTERVAL	SOLAR ENERGY PER 10NM WAVELENGTH INTERVAL	RATIOTESTLAMP/SOLAR
255.	0.009	0.072	0.13
265.	0.026	0.166	0.15
275.	0.079	0.166	0.48
285.	0.178	0.290	0.61
295.	0.252	0.456	0.55
305.	0.248	0.476	0.52
315.	0.176	0.590	0.30
325.	0.235	0.746	0.31
335.	0.433	0.828	0.52
345.	0.652	0.870	0.75
355.	0.763	0.870	0.88
365.	0.857	0.922	0.93
375.	0.925	0.942	0.98
385.	0.954	0.859	1.11
395.	1.032	0.942	1.09
405.	1.033	1.346	0.77
415.	1.055	1.429	0.74
425.	1.069	1.357	0.79
435.	1.127	1.336	0.84
445.	1.194	1.564	0.76
455.	1.278	1.615	0.79
465.	1.509	1.605	0.94
475.	1.294	1.595	0.81
485.	1.239	1.522	0.81
495.	1.155	1.522	0.76
505.	1.117	1.450	0.77
515.	1.106	1.429	0.77
525.	1.097	1.439	0.76
535.	1.095	1.470	0.74
545.	1.093	1.460	0.75
555.	1.081	1.439	0.75
565.	1.083	1.408	0.77
575.	1.070	1.429	0.75
585.	1.047	1.408	0.74
595.	1.045	1.398	0.75
605.	1.035	1.336	0.77
615.	1.013	1.305	0.78
625.	0.97	1.284	0.76
635.	0.953	1.253	0.76
645.	0.938	1.231	0.76
655.	0.946	1.212	0.78
665.	0.980	1.201	0.82
675.	0.941	1.170	0.80
685.	0.935	1.139	0.77
695.	0.909	1.108	0.82
705.	0.887	1.118	0.79
715.	0.925	1.067	0.87
725.	0.900	1.056	0.85
735.	0.875	1.036	0.84
745.	0.927	1.004	0.92
755.	0.80	1.004	0.80
765.	0.616	0.963	0.64
775.	0.57	0.932	0.61
785.	0.554	0.922	0.60
795.	0.735	0.901	0.82
805.	1.039	0.880	1.18
815.	1.184	0.859	1.39
825.	0.731	0.849	0.86
835.	0.440	0.818	0.54
845.	0.31	0.797	0.39
855.	0.397	0.777	0.51
865.	0.635	0.756	0.84
875.	0.73	0.746	0.98
885.	0.727	0.735	0.99
895.	0.667	0.715	0.93
905.	0.622	0.683	0.90
915.	0.546	0.673	0.81
925.	0.497	0.663	0.75
935.	0.525	0.652	0.81
945.	0.486	0.632	0.77
955.	0.457	0.611	0.75
965.	0.564	0.60	0.94
975.	0.642	0.602	1.07
985.	0.639	0.570	1.12
995.	0.613	0.559	1.10
1005.	0.457	0.538	0.85
1015.	0.41	0.528	0.78
1025.	0.372	0.518	0.72
1035.	0.346	0.507	0.68
1045.	0.384	0.497	0.77
1055.	0.406	0.487	0.83
1065.	0.505	0.476	1.06
1075.	0.542	0.466	1.16
1085.	0.607	0.456	1.33
1095.	0.660	0.445	1.48
1150.	0.505	0.392	1.53
1250.	0.399	0.314	1.27
1350.	0.303	0.253	1.21
1450.	0.45	0.205	2.20
1550.	0.312	0.168	1.86
1650.	0.262	0.139	1.89
1750.	0.206	0.115	1.79
1850.	0.177	0.096	1.83
1950.	0.176	0.082	2.16
2050.	0.184	0.069	2.66
2150.	0.130	0.059	2.19
2250.	0.070	0.051	1.37
2350.	0.154	0.043	3.55
2450.	0.162	0.038	4.23

Table 4 (Continued)
Computer Printout A-1200

```
A-25 7XE 5SPEC 2UNIF LNO. 3 S-1C SASSE F-3
SASSE F-3 CUP NO. 600
      18,709
SASSE F-3 CUP NO. 605
      20,652
SASSE F-3 CUP NO. 606
      11,809
SASSE F-3 CUP NO. 610
      15,904
SASSE F-3 CUP NO. 613
      10,439
SASSE F-3 CUP NO. 616
      12,436
SASSE F-3 CUP NO.617
      13,250
SASSE F-3 CUP NO. 620
      99,720
SASSE F-3 CUP NO. 622
      14,602
ALUMIMUN OXIDE AT 10 DEGREES
      11,342
ALUMIMUN OXIDE AT 75 DEGREES
      10,635
TOTAL ABSORPTIVITY OF CAT-A-LAC WHITE PAINT 12 COATS
      19,472
CAT A LAC WHITE OVER EVAPORATED ALUMINUM ONE COAT
      17,430
 3M WHITE, 8 COATS OVER GE PRIMER
      31,400
 CAT A LAC WHITE, 8 COATS
      23,120
CAT A LAC WHITE OVER CAT A LAC BLACK TWELVE COATS
      13,145
TWO COATS CAT A LAC WHITE AND FIVE COATS TITANIUM OXIDE SILICONE
      12,236
 Q007 OVER CAT A LAC WHITE  OCT,66 PS TEST
      16,382
 Q007, TIO2,  8 COATS OVER DOW CORNING PRIMER
      17,116
 Q090 OVER CAT A LAC WHITE  OCT, 66 PS TEST
      16,605
 Q090, TIO2, 8 COATS OVER DOW CORNING PRIMER
      18,498
 Q090, TIO2 DOW CORNING, 8 COATS OVER CAT A LAC WHITE, 2 COATS
      16,406
SILICONE OXIDE OVER EVAPORATED ALUMIMUN OVER BUFFED ALUMIMUN
      10,215
 S/13 OVER GE PRIMER OCT, 66 PS TEST
      19,959
 S-13 ZNO, 8 COATS OVER DOW CORNING PRIMER
      13,648
 S-13 , 8COATS OVER GE PRIMER
      11,100
TOTAL ABSORPTIVITY OF GOLD
      13,617
TOTAL ABSORPTIVITY OF ZINC OXIDE WITH SILICONE
      11,479
TOTAL ABSORPTIVITY OF ZINC OXIDE WITH SILICATE
      16,898
 COLONY ZNO OVER GE PRIMER  88-2  OCT, 66 PS TEST
      18,804
 K2SIO3 WITH TIO2 AND AL2O3  OCT, 66 PS TEST
      24,167
TOTAL ABSORPTIVITY OF ACLAR  COATED WITH IR61-E
      19,272
 TIO2, ZNO, K2SIO3, AL2O3  OCT, 66 PS TEST
      18,113
   EPOXY FIBERGLASS   ISIS-A  NO.21
      33,887
TOTAL ABSORPTIVITY OF CAT-A-LAC BLACK PAINT
      94,765
TOTAL ABSORPTIVITY OF 3M VELVET BLACK PAINT
      97,240
COLONY 88S
      17,365
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Table 4 (Continued)
Computer Printout A-1200

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A-15 7XE 5SPEC 2UNIF LNO. 3 S-1C SASSE F-3
TCTAL ABSORPTIVITY OF SILVER
        3.178
TCTAL ABSORPTIVITY OF ALUMINUM
        6.697
  EVAPCRATED ALUMINUM
        7.222
   SANDBLASTED ALUMINUM PANEL
       29.062
TCTAL ABSORPTIVITY OF TITANIUM OXIDE WITH SILICATE
       21.851
TCTAL ABSORPTIVITY OF TITANIUM OXIDE WITH SILICONE
       19.269
TITANIUM OXIDE SILICONE OVER EVAPORATED ALUMINUM TWELVE COATS
       11.855
TITANIUM OXIDE SILICONE OVER CAT A LAC BLACK TWELVE COATS
       12.408

OLONY WHITE TIO2 78-2, 8 COATS OVER GE PRIMER, 1 COAT
       16.840
ALUMIMUN OXICE AT 20 DEGREES
       11.342
ALUMIMUN OXIDE AT 75 DEGREES
       12.635
TCTAL ABSORPTIVITY OF CAT-A-LAC WHITE PAINT  12 COATS
       19.472
CAT A LAC WHITE OVER EVAPORATED ALUMINUM ONE COAT
       17.480
 3M WHITE, 8 COATS OVER GE PRIMER
       21.400
 CAT A LAC WHITE, 8 COATS
       23.120
CAT A LAC WHITE OVER CAT A LAC BLACK TWELVE COATS
       13.145
TWC COATS CAT A LAC WHITE AND FIVE COATS TITANIUM OXIDE SILICONE
       16.236
 C007 OVER CAT A LAC WHITE  OCT,66 PS TEST
       16.382
 C007, TIO2,  8 COATS OVER DOW CORNING PRIMER
       17.216
 C09C OVER CAT A LAC WHITE  OCT, 66 PS TEST
       16.605
 C09C, TIO2, 8 COATS OVER DOW CORNING PRIMER
       18.498
 C09C, TIC2 DOW CORNING, 8 COATS OVER CAT A LAC WHITE, 2 COATS
       15.406
SILICONE OXIDE OVER EVAPORATED ALUMIMUN OVER BUFFED ALUMIMUN
       1 .215
 S/13 OVER GE PRIMER OCT, 66 PS TEST
       19.989
 S-13 ZNO, 8 COATS OVER DOW CORNING PRIMER
       18.648
 S-13 , 8COATS OVER GE PRIMER
       21.200
TCTAL ABSORPTIVITY OF GOLD
       15.627
TCTAL ABSORPTIVITY OF ZINC OXIDE WITH SILICONE
       21.479
TCTAL ABSORPTIVITY OF ZINC OXICE WITH SILICATE
       26.898
 CCLCNY ZNO OVER GE PRIMER  E8-2  OCT, 66 PS TEST
       18.804
 K2SIC3 WITH TIO2 AND AL2O3  OCT, 66 PS TEST
       24.167
TCTAL ABSORPTIVITY OF ACLAR  COATED WITH IR81-E
       15.272
 TIC2, ZNO, K2SIC3, AL2O3  OCT, 66 PS TEST
       16.223
   EPCXY FIBERGLASS   ISIS-A  NO.1
       31.887
TCTAL ABSORPTIVITY OF CAT-A-LAC BLACK PAINT
       94.765
TCTAL ABSORPTIVITY OF 3M VELVET BLACK PAINT
       97.240
CCLCNY 88S
       17.365
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of NASA-GSFC is currently supervising the procurement of another motor. Because of the motor malfunction it was impossible to determine whether the other components of the scanner were operational.

As a result of this malfunction the scanner will probably not be operational for several more months since the vacuum motor required is custom built and a completely new one must be fabricated.

X-25L SPECTRAL DEGRADATION

An interesting series of spectral irradiance measurements has been in progress on the X-25L solar simulator. This simulator is used for coatings degradation testing, solar cell calibrations, thermal α/ϵ measurements, etc. All of these uses require, to a greater or lesser extent, good solar spectral match and more importantly, a stable spectrum. That is, the spectral output should remain constant in both quantity and quality with time. The total irradiance of the X-25L is quite constant (±2%) but only limited information was available as to the spectral degradation of the light output. Therefore, a study was undertaken to investigate this degradation. A series of five spectral measurements were made as follows:

M-21	0 hours after installation of new lamp
M-22	40 hours after installation of new lamp
M-23	90 hours after installation of new lamp
M-25	310 hours after installation of new lamp
M-27	319 hours with cleaned and re-evaporated optics.

The data from these measurements are contained in Tables 5-9. The curves have been published in GSFC X713-67-73. Table 10 represents the percentages of the total output (250 nm - 2500 nm) of the X-25L in the UV (250 - 400 nm), visible (400 - 700 nm) and infrared (700 - 2500 nm) regions of the spectrum. From this data, it can be seen that the UV is down by ≈50% in 300 hours. This degradation is especially important in the area of coatings degradation and the thermal α/ϵ measurements, since in both cases the output of the X-25L does not approximate the output of the sun in space.

The results of this study indicate that extreme care should be exercised when using the X-25L in an application requiring a close spectral match (to the sun) or a stable spectrum (with time).

Table 5
Computer Printout X-25L—0 hours

M-21 X-25L AT 6FT, COLLIMATING LENS, GE PORT, LNO.3,0HR,10/28/66

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL		
265.	0.127	0.166	0.77
275.	0.230	0.166	1.39
285.	0.354	0.290	1.22
295.	0.379	0.456	0.83
305.	0.258	0.477	0.54
315.	0.232	0.591	0.39
325.	0.471	0.746	0.63
335.	0.787	0.829	0.95
345.	0.961	0.870	1.10
355.	1.013	0.870	1.17
365.	1.092	0.922	1.18
375.	1.135	0.943	1.20
385.	1.179	0.860	1.37
395.	1.256	0.943	1.33
405.	1.282	1.347	0.95
415.	1.323	1.430	0.93
425.	1.319	1.358	0.97
435.	1.365	1.337	1.02
445.	1.416	1.565	0.91
455.	1.516	1.617	0.94
465.	1.791	1.606	1.11
475.	1.616	1.596	1.01
485.	1.636	1.523	1.07
495.	1.561	1.523	1.02
505.	1.487	1.451	1.03
515.	1.467	1.430	1.03
525.	1.466	1.440	1.02
535.	1.473	1.472	1.00
545.	1.474	1.461	1.01
555.	1.475	1.446	1.02
565.	1.475	1.409	1.05
575.	1.459	1.430	1.02
585.	1.432	1.409	1.02
595.	1.397	1.399	1.00
605.	1.397	1.337	1.04
615.	1.381	1.306	1.06
625.	1.371	1.285	1.07
635.	1.315	1.254	1.05
645.	1.303	1.233	1.06
655.	1.319	1.212	1.09
665.	1.352	1.202	1.12
675.	1.295	1.171	1.11
685.	1.186	1.140	1.04
695.	1.216	1.109	1.10
705.	1.130	1.119	1.05
715.	1.235	1.067	1.16
725.	1.192	1.057	1.13
735.	1.118	1.036	1.08
745.	1.150	1.005	1.14
755.	0.922	1.005	0.92
765.	0.777	0.964	0.73
775.	0.580	0.933	0.62
785.	0.538	0.922	0.58
795.	0.567	0.902	0.62
805.	0.867	0.881	0.98
815.	1.088	0.860	1.26
825.	0.734	0.85	0.86
835.	0.456	0.819	0.56
845.	0.236	0.798	0.30
855.	0.392	0.777	0.50
865.	0.533	0.756	0.71
875.	0.654	0.746	0.89
885.	1.040	0.736	1.41
895.	0.925	0.715	1.29
905.	0.673	0.684	0.98
915.	0.581	0.674	0.86
925.	0.538	0.663	0.81
935.	0.573	0.653	0.88
945.	0.549	0.632	0.87
955.	0.516	0.611	0.84
965.	0.567	0.601	0.94
975.	0.602	0.601	1.00
985.	0.662	0.570	1.16
995.	0.589	0.560	1.05
1005.	0.519	0.539	0.96
1015.	0.519	0.528	0.98
1025.	0.344	0.518	0.66
1035.	0.335	0.508	0.66
1045.	0.357	0.497	0.72
1055.	0.392	0.487	0.80
1065.	0.421	0.477	0.88
1075.	0.494	0.466	1.06
1085.	0.549	0.456	1.20
1095.	0.540	0.446	1.21
1150.	0.457	0.393	1.16
1250.	0.323	0.314	0.71
1350.	0.211	0.253	0.83
1450.	0.315	0.205	1.53
1550.	0.201	0.168	1.20
1650.	0.152	0.139	1.09
1750.	0.109	0.115	0.94
1850.	0.086	0.096	0.89
1950.	0.085	0.082	1.04
2050.	0.094	0.069	1.22
2150.	0.070	0.059	1.18
2250.	0.059	0.051	1.16
2350.	0.057	0.044	1.31
2450.	0.044	0.038	1.15

Table 6
Computer Printout X-25L—40 hc

M-22 X-25L AT 6FT. COLLIMATING LENS,GE PORT,LNO.3,40HRS.11/7/66

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL		
265.	0.101	0.166	0.61
275.	0.191	0.166	1.15
285.	0.292	0.290	1.01
295.	0.322	0.456	0.71
305.	0.231	0.477	0.48
315.	0.213	0.591	0.36
325.	0.385	0.746	0.52
335.	0.688	0.829	0.83
345.	0.797	0.870	0.92
355.	0.807	0.870	0.93
365.	0.849	0.922	0.92
375.	0.881	0.943	0.93
385.	0.881	0.860	1.02
395.	0.923	0.943	0.98
405.	0.949	1.347	0.70
415.	0.962	1.430	0.67
425.	0.995	1.358	0.73
435.	1.050	1.337	0.79
445.	1.115	1.565	0.71
455.	1.197	1.617	0.74
465.	1.345	1.606	0.84
475.	1.299	1.596	0.81
485.	1.244	1.523	0.82
495.	1.220	1.523	0.80
505.	1.213	1.451	0.84
515.	1.130	1.430	0.79
525.	1.128	1.440	0.78
535.	1.133	1.472	0.77
545.	1.133	1.461	0.78
555.	1.149	1.440	0.80
565.	1.153	1.409	0.82
575.	1.187	1.430	0.83
585.	1.246	1.409	0.88
595.	1.246	1.399	0.89
605.	1.317	1.337	0.99
615.	1.324	1.306	1.01
625.	1.250	1.285	0.97
635.	1.225	1.254	0.98
645.	1.199	1.233	0.97
655.	1.215	1.212	1.00
665.	1.230	1.202	1.02
675.	1.205	1.171	1.03
685.	1.110	1.140	0.97
695.	1.114	1.109	1.00
705.	1.109	1.119	0.99
715.	1.126	1.067	1.05
725.	1.104	1.057	1.04
735.	1.067	1.036	1.03
745.	1.070	1.005	1.06
755.	0.915	1.005	0.91
765.	0.717	0.964	0.74
775.	0.591	0.933	0.63
785.	0.529	0.922	0.57
795.	0.645	0.902	0.72
805.	0.776	0.881	0.88
815.	0.953	0.860	1.11
825.	0.647	0.850	0.76
835.	0.647	0.819	0.79
845.	0.421	0.798	0.53
855.	0.477	0.777	0.61
865.	0.506	0.756	0.67
875.	0.564	0.746	0.76
885.	0.762	0.736	1.04
895.	0.726	0.715	1.02
905.	0.677	0.684	0.99
915.	0.620	0.674	0.92
925.	0.559	0.663	0.84
935.	0.579	0.653	0.89
945.	0.567	0.632	0.90
955.	0.525	0.611	0.86
965.	0.585	0.601	0.97
975.	0.636	0.601	1.06
985.	0.750	0.570	1.32
995.	0.656	0.560	1.17
1005.	0.497	0.539	0.92
1015.	0.497	0.528	0.94
1025.	0.422	0.518	0.81
1035.	0.319	0.508	0.63
1045.	0.344	0.497	0.69
1055.	0.349	0.487	0.72
1065.	0.373	0.477	0.78
1075.	0.436	0.466	0.94
1085.	0.485	0.456	1.06
1095.	0.516	0.446	1.16
1150.	0.597	0.393	1.52
1250.	0.356	0.314	1.13
1350.	0.277	0.253	1.10
1450.	0.405	0.205	1.97
1550.	0.281	0.168	1.68
1650.	0.209	0.139	1.50
1750.	0.154	0.115	1.34
1850.	0.117	0.096	1.21
1950.	0.108	0.082	1.31
2050.	0.123	0.069	1.77
2150.	0.096	0.059	1.62
2250.	0.097	0.051	1.90
2350.	0.129	0.044	2.95
2450.	0.194	0.038	5.07

Table 7
Computer Printout X-25L—90 hours

M-23 X-25L AT 6FT.COLLIMATING LENS.GE PORT.LND.3,100HRS.11/14/66

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL		
265.	0.073	0.166	0.44
275.	0.147	0.166	0.89
285.	0.243	0.290	0.84
295.	0.264	0.456	0.58
305.	0.184	0.477	0.38
315.	0.171	0.591	0.29
325.	0.338	0.746	0.45
335.	0.631	0.829	0.76
345.	0.758	0.870	0.87
355.	0.821	0.870	0.94
365.	0.900	0.922	0.98
375.	0.965	0.943	1.02
385.	1.004	0.860	1.17
395.	1.088	0.943	1.15
405.	1.129	1.347	0.84
415.	1.156	1.430	0.81
425.	1.184	1.358	0.87
435.	1.233	1.337	0.92
445.	1.327	1.565	0.85
455.	1.378	1.617	0.85
465.	1.581	1.606	0.98
475.	1.508	1.596	0.94
485.	1.516	1.523	1.00
495.	1.458	1.523	0.96
505.	1.439	1.451	0.99
515.	1.353	1.430	0.95
525.	1.351	1.440	0.94
535.	1.351	1.472	0.92
545.	1.353	1.461	0.93
555.	1.354	1.440	0.94
565.	1.354	1.409	0.96
575.	1.342	1.430	0.94
585.	1.321	1.409	0.94
595.	1.306	1.399	0.93
605.	1.303	1.337	0.97
615.	1.297	1.306	0.99
625.	1.285	1.285	1.00
635.	1.295	1.254	1.03
645.	1.296	1.233	1.05
655.	1.296	1.212	1.07
665.	1.315	1.202	1.09
675.	1.144	1.171	0.98
685.	1.142	1.140	1.00
695.	1.183	1.109	1.07
705.	1.158	1.119	1.03
715.	1.191	1.067	1.12
725.	1.146	1.057	1.08
735.	1.090	1.036	1.05
745.	1.113	1.005	1.11
755.	0.909	1.005	0.90
765.	0.685	0.964	0.71
775.	0.588	0.933	0.63
785.	0.573	0.922	0.62
795.	0.628	0.902	0.70
805.	0.828	0.881	0.94
815.	0.956	0.860	1.11
825.	0.699	0.850	0.82
835.	0.671	0.819	0.82
845.	0.228	0.798	0.29
855.	0.499	0.777	0.64
865.	0.499	0.756	0.66
875.	0.636	0.746	0.85
885.	0.741	0.736	1.01
895.	0.696	0.715	0.97
905.	0.642	0.684	0.94
915.	0.575	0.674	0.85
925.	0.540	0.663	0.81
935.	0.580	0.653	0.89
945.	0.559	0.632	0.88
955.	0.500	0.611	0.82
965.	0.609	0.601	1.01
975.	0.726	0.601	1.21
985.	0.709	0.570	1.24
995.	0.651	0.560	1.16
1005.	0.651	0.539	1.21
1015.	0.410	0.528	0.77
1025.	0.374	0.518	0.72
1035.	0.335	0.508	0.66
1045.	0.363	0.497	0.73
1055.	0.401	0.487	0.82
1065.	0.443	0.477	0.93
1075.	0.497	0.466	1.07
1085.	0.598	0.456	1.31
1095.	0.624	0.446	1.40
1150.	0.515	0.393	1.31
1250.	0.302	0.314	0.96
1350.	0.252	0.253	1.00
1450.	0.384	0.205	1.87
1550.	0.237	0.168	1.41
1650.	0.183	0.139	1.32
1750.	0.135	0.115	1.18
1850.	0.106	0.096	1.10
1950.	0.105	0.082	1.28
2050.	0.106	0.069	1.53
2150.	0.086	0.059	1.46
2250.	0.080	0.051	1.58
2350.	0.080	0.044	1.84
2450.	0.081	0.038	2.13

Table 8
Computer Printout X-25L—310 hours

M-25 X-25L AT 6FT,COLLIMATING LENS,GE PORT,LNO.3,310HRS,12/5/66

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL		
265.	0.044	0.166	0.26
275.	0.081	0.166	0.49
285.	0.123	0.290	0.42
295.	0.135	0.456	0.30
305.	0.095	0.477	0.20
315.	0.088	0.591	0.15
325.	0.169	0.746	0.23
335.	0.319	0.829	0.39
345.	0.400	0.870	0.46
355.	0.436	0.870	0.50
365.	0.485	0.922	0.53
375.	0.530	0.943	0.56
385.	0.556	0.860	0.65
395.	0.605	0.943	0.64
405.	0.638	1.347	0.47
415.	0.659	1.430	0.46
425.	0.696	1.358	0.51
435.	0.732	1.337	0.55
445.	0.786	1.565	0.50
455.	0.871	1.617	0.54
465.	1.064	1.606	0.66
475.	0.989	1.596	0.62
485.	1.022	1.523	0.67
495.	1.020	1.523	0.67
505.	1.006	1.451	0.69
515.	0.975	1.430	0.68
525.	0.974	1.440	0.68
535.	0.996	1.472	0.68
545.	1.015	1.461	0.69
555.	1.032	1.440	0.72
565.	1.036	1.409	0.74
575.	1.041	1.430	0.73
585.	1.049	1.409	0.74
595.	1.069	1.399	0.76
605.	1.110	1.337	0.83
615.	1.130	1.306	0.87
625.	1.107	1.285	0.86
635.	1.132	1.254	0.90
645.	1.133	1.233	0.92
655.	1.133	1.212	0.93
665.	1.156	1.202	0.96
675.	1.115	1.171	0.95
685.	1.026	1.140	0.90
695.	1.059	1.109	0.96
705.	1.040	1.119	0.93
715.	1.082	1.067	1.01
725.	1.049	1.057	0.99
735.	1.001	1.036	0.97
745.	1.008	1.005	1.00
755.	0.845	1.005	0.84
765.	0.667	0.964	0.69
775.	0.612	0.933	0.66
785.	0.629	0.922	0.68
795.	0.629	0.902	0.70
805.	0.789	0.881	0.90
815.	0.976	0.860	1.13
825.	0.716	0.850	0.84
835.	0.597	0.819	0.73
845.	0.448	0.798	0.56
855.	0.448	0.777	0.58
865.	0.566	0.756	0.75
875.	0.745	0.746	1.00
885.	0.738	0.736	1.00
895.	0.710	0.715	0.99
905.	0.649	0.684	0.95
915.	0.587	0.674	0.87
925.	0.546	0.663	0.82
935.	0.588	0.653	0.90
945.	0.553	0.632	0.87
955.	0.474	0.611	0.78
965.	0.474	0.601	0.79
975.	0.474	0.601	0.79
985.	0.474	0.570	0.83
995.	0.474	0.560	0.85
1005.	0.474	0.539	0.88
1015.	0.474	0.528	0.90
1025.	0.474	0.518	0.91
1035.	1.030	0.508	2.03
1045.	0.349	0.497	0.70
1055.	0.365	0.487	0.75
1065.	0.410	0.477	0.86
1075.	0.498	0.466	1.07
1085.	0.518	0.456	1.14
1095.	0.553	0.446	1.24
1150.	0.521	0.393	1.33
1250.	0.312	0.314	0.99
1350.	0.253	0.253	1.00
1450.	0.367	0.205	1.79
1550.	0.289	0.168	1.72
1650.	0.198	0.139	1.43
1750.	0.267	0.115	2.32
1850.	0.263	0.096	2.73
1950.	0.266	0.082	3.25
2050.	0.298	0.069	4.30
2150.	0.237	0.059	4.01
2250.	0.228	0.051	4.49
2350.	0.275	0.044	6.31
2450.	0.269	0.038	7.03

Table 9

Computer Printout X-25L—319 hours

M-27 X-25L AT 6FT,COLLIMATING LENS,GE PORT,LNO.3,CLEANED ORTHGS

WAVELENGTH	TEST LAMP ENERGY PER 10NM WAVELENGTH INTERVAL	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
265.	0.134	0.166	0.81
275.	0.218	0.166	1.31
285.	0.313	0.290	1.08
295.	0.322	0.456	0.71
305.	0.220	0.477	0.46
315.	0.220	0.591	0.37
325.	0.425	0.746	0.57
335.	0.720	0.829	0.87
345.	0.854	0.870	0.98
355.	0.916	0.870	1.05
365.	1.020	0.922	1.11
375.	1.095	0.943	1.16
385.	1.122	0.860	1.30
395.	1.204	0.943	1.28
405.	1.201	1.347	0.89
415.	1.202	1.430	0.84
425.	1.204	1.358	0.89
435.	1.217	1.337	0.91
445.	1.195	1.565	0.76
455.	1.334	1.617	0.83
465.	1.616	1.606	1.01
475.	1.454	1.596	0.91
485.	1.429	1.523	0.94
495.	1.353	1.523	0.89
505.	1.283	1.451	0.88
515.	1.260	1.430	0.88
525.	1.251	1.440	0.87
535.	1.252	1.472	0.85
545.	1.233	1.461	0.84
555.	1.254	1.440	0.87
565.	1.279	1.409	0.91
575.	1.273	1.430	0.89
585.	1.214	1.409	0.86
595.	1.215	1.399	0.87
605.	1.255	1.337	0.94
615.	1.275	1.306	0.98
625.	1.261	1.285	0.98
635.	1.215	1.254	0.97
645.	1.220	1.233	0.99
655.	1.236	1.212	1.02
665.	1.264	1.202	1.05
675.	1.169	1.171	1.00
685.	1.141	1.140	1.00
695.	1.182	1.109	1.07
705.	1.155	1.119	1.03
715.	1.190	1.067	1.11
725.	1.168	1.057	1.11
735.	1.126	1.036	1.09
745.	1.158	1.005	1.15
755.	0.991	1.005	0.99
765.	0.751	0.964	0.78
775.	0.655	0.933	0.70
785.	0.655	0.922	0.71
795.	0.635	0.902	0.70
805.	0.928	0.881	1.05
815.	1.080	0.860	1.26
825.	0.845	0.850	0.99
835.	0.591	0.819	0.84
845.	0.401	0.798	0.50
855.	0.543	0.777	0.70
865.	0.577	0.756	0.76
875.	0.601	0.746	0.81
885.	0.865	0.736	1.18
895.	0.797	0.715	1.11
905.	0.758	0.684	1.11
915.	0.688	0.674	1.02
925.	0.620	0.663	0.93
935.	0.652	0.653	1.00
945.	0.647	0.632	1.02
955.	0.595	0.611	0.97
965.	0.625	0.601	1.04
975.	0.766	0.601	1.28
985.	0.844	0.570	1.48
995.	0.682	0.560	1.22
1005.	0.682	0.539	1.27
1015.	0.592	0.528	1.12
1025.	0.393	0.518	0.76
1035.	0.364	0.508	0.72
1045.	0.396	0.497	0.80
1055.	0.422	0.487	0.87
1065.	0.442	0.477	0.93
1075.	0.531	0.466	1.14
1085.	0.573	0.456	1.26
1095.	0.591	0.446	1.33
1150.	0.507	0.393	1.29
1250.	0.298	0.314	0.95
1350.	0.234	0.253	0.92
1450.	0.335	0.205	1.63
1550.	0.233	0.168	1.39
1650.	0.167	0.139	1.21
1750.	0.120	0.115	1.04
1850.	0.092	0.096	0.96
1950.	0.086	0.082	1.05
2050.	0.094	0.069	1.35
2150.	0.076	0.059	1.29
2250.	0.072	0.051	1.42
2350.	0.070	0.044	1.62
2450.	0.076	0.038	1.98

Table 10
Energy Distribution - X-25L Spectral Degradation
(Percent)

Time	UV	Visible	IR	Total
0 Hours	9.5%	42.8%	47.7%	100.0%
50 Hours	8.1	37.9	54.0	100.0
90 Hours	7.6	39.2	53.2	100.0
310 Hours	4.7	34.1	61.2	100.0
310 Hours	8.8	38.0	53.2	100.0 (new Lamp)

MISCELLANEOUS SPECTRAL MEASUREMENTS

Three miscellaneous spectral measurements were made during the past quarter as follows: (Figures 14, 15, 16 and 17, and Tables 11, 12, and 13)

M-24 Medium pressure Hg lamp, 350 hours
M-26 Medium pressure Hg lamp, new
M-28 Zirconium compact arc lamp, 25 watts

The mercury lamps (Hanovia 673A10) which were measured are used by Mr. J. Colony of the Coatings Section for the evaluation of various types of paints and coatings.

COMPUTATION OF EFFECTIVE ABSORPTANCES

As a routine portion of the data reduction from the spectral irradiance measurements on various light sources the effective absorptances of a large number of paints and coatings are computed. These computed effective absorptances provide an indication of the closeness of spectral match to the sun. A complete description of the technique used in these computations can be found in Appendix I. Table 14 shows the computed effective absorptances of a great many paints and coatings.

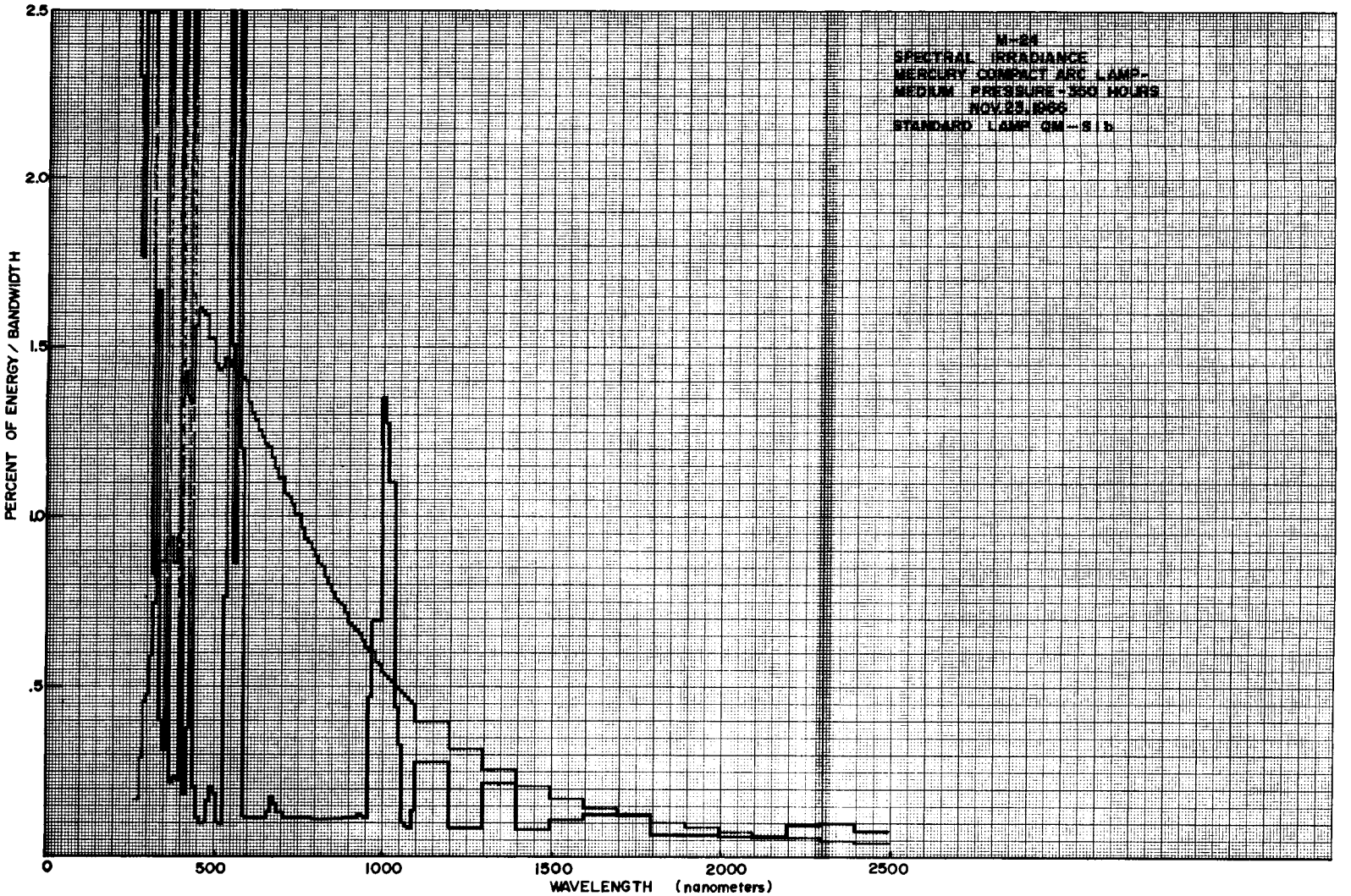

Figure 14. Spectral Distribution Hanovia 673A10 Hg Lamp 350 Hours

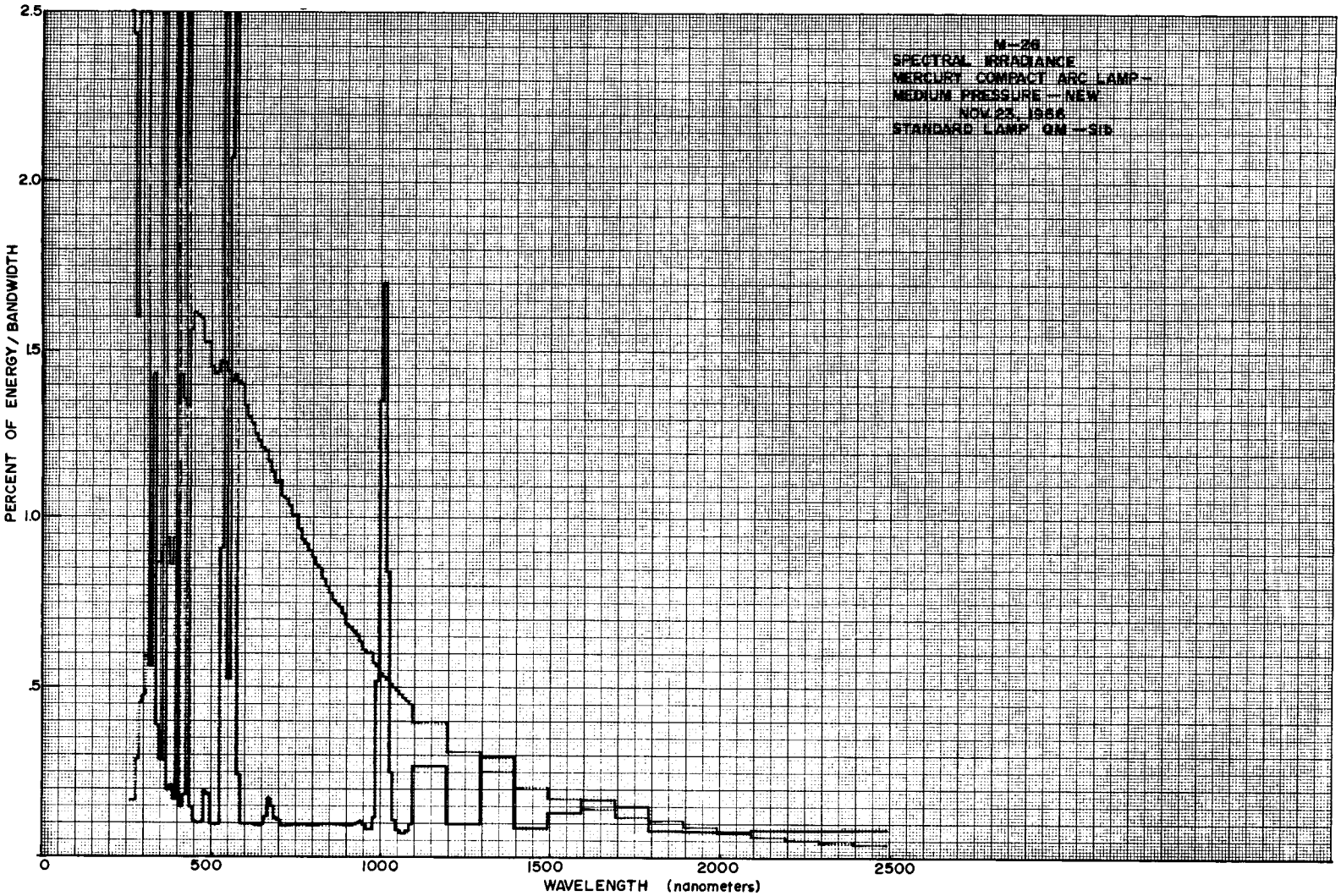

Figure 15. Spectral Distribution Hanovia 673A10 Hg Lamp 0 Hours

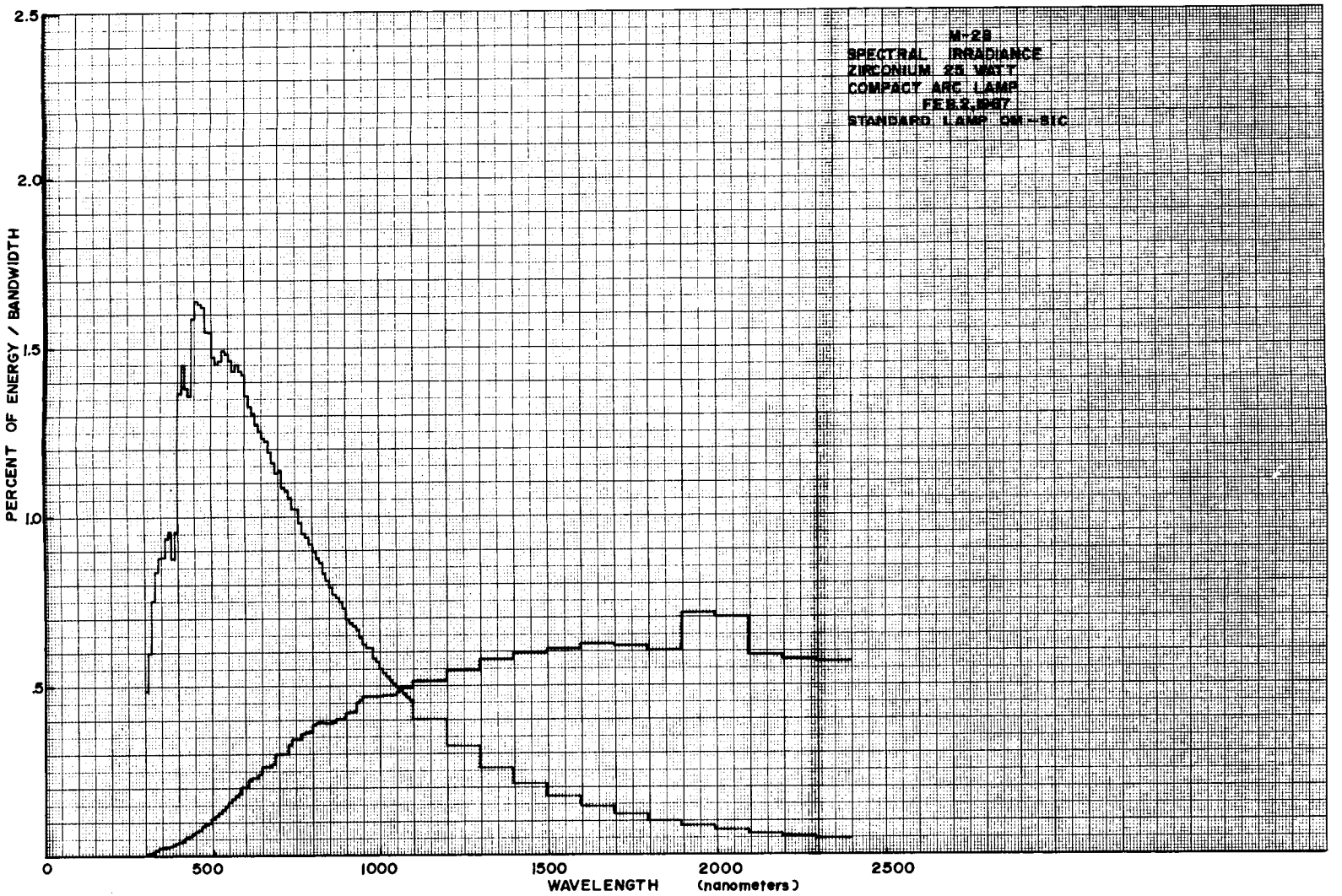

Figure 16. Spectral Distribution Zirconium 25 Watt Lamp

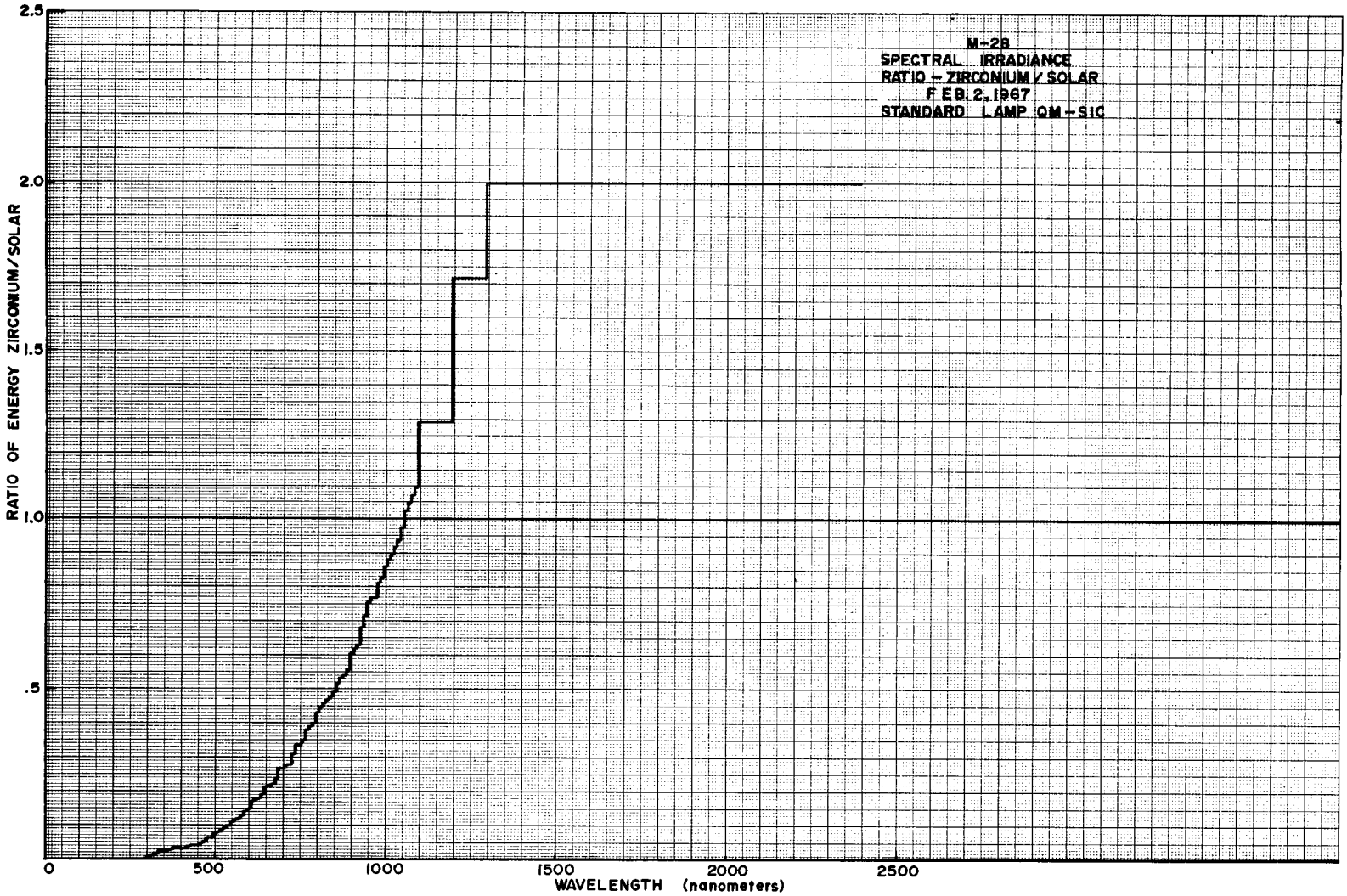

Figure 17. Ratio Zirconium Arc to Solar Irradiance

Table 11
Computer Printout - Hanovia Hg Lamp—350 hours

M-24 HG LAMP HANOVIA NO. 673A10 350 HRS LN03 S1

WAVELENGTH	TEST LAMP ENERGY	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
	PER 10NM WAVELENGTH INTERVAL		
265.	5.744	0.166	34.64
275.	2.262	0.166	13.64
285.	1.734	0.290	5.97
295.	3.093	0.456	6.79
305.	5.219	0.477	10.95
315.	11.208	0.591	18.97
325.	0.811	0.746	1.09
335.	1.641	0.829	1.98
345.	0.387	0.870	0.44
355.	0.304	0.870	0.35
365.	10.343	0.922	11.21
375.	0.208	0.943	0.22
385.	0.225	0.869	0.26
395.	0.218	0.943	0.23
405.	4.373	1.347	3.25
415.	0.173	1.430	0.12
425.	0.370	1.358	0.27
435.	6.613	1.337	4.95
445.	0.197	1.565	0.13
455.	0.106	1.617	0.07
465.	0.093	1.606	0.06
475.	0.096	1.596	0.06
485.	0.165	1.523	0.10
495.	0.201	1.523	0.13
505.	0.177	1.451	0.12
515.	0.092	1.430	0.06
525.	0.093	1.440	0.06
535.	0.754	1.472	0.51
545.	6.538	1.461	4.47
555.	1.478	1.440	1.03
565.	0.943	1.439	0.66
575.	7.552	1.430	5.28
585.	1.177	1.439	0.83
595.	0.109	1.399	0.08
605.	0.105	1.337	0.08
615.	0.106	1.306	0.08
625.	0.105	1.285	0.08
635.	0.106	1.254	0.08
645.	0.106	1.233	0.09
655.	0.106	1.212	0.09
665.	0.127	1.202	0.11
675.	0.171	1.171	0.15
685.	0.149	1.140	0.13
695.	0.122	1.109	0.11
705.	0.122	1.119	0.11
715.	0.105	1.057	0.10
725.	0.105	1.057	0.10
735.	0.105	1.036	0.10
745.	0.107	1.005	0.11
755.	0.111	1.005	0.11
765.	0.112	0.964	0.12
775.	0.109	0.933	0.12
785.	0.109	0.922	0.12
795.	0.103	0.902	0.11
805.	0.102	0.881	0.12
815.	0.102	0.860	0.12
825.	0.103	0.850	0.12
835.	0.104	0.819	0.13
845.	0.104	0.798	0.13
855.	0.105	0.777	0.14
865.	0.105	0.756	0.14
875.	0.106	0.746	0.14
885.	0.106	0.736	0.14
895.	0.103	0.715	0.15
905.	0.108	0.684	0.16
915.	0.108	0.674	0.16
925.	0.112	0.663	0.17
935.	0.113	0.653	0.18
945.	0.111	0.632	0.18
955.	0.106	0.611	0.17
965.	0.469	0.601	0.77
975.	0.680	0.601	1.13
985.	0.680	0.570	1.19
995.	0.680	0.560	1.22
1005.	1.329	0.539	2.47
1015.	1.099	0.528	2.08
1025.	0.858	0.518	1.66
1035.	0.858	0.508	1.69
1045.	0.203	0.497	0.41
1055.	0.097	0.487	0.20
1065.	0.080	0.477	0.17
1075.	0.079	0.466	0.17
1085.	0.077	0.456	0.17
1095.	0.131	0.446	0.29
1150.	0.266	0.393	0.68
1250.	0.075	0.314	0.24
1350.	0.204	0.253	0.81
1450.	0.071	0.205	0.35
1550.	0.101	0.168	0.60
1650.	0.116	0.139	0.84
1750.	0.115	0.115	1.00
1850.	0.058	0.096	0.60
1950.	0.058	0.082	0.70
2050.	0.051	0.069	0.74
2150.	0.049	0.059	0.82
2250.	0.087	0.051	1.72
2350.	0.092	0.044	2.11
2450.	0.067	0.038	1.76

Table 12
Computer Printout - Hanovia Hg Lamp—0 hours

M-26 HG HANOVIA NO. 673A1J 0HRS LN03 S1

WAVELENGTH	TEST LAMP ENERGY PER 10NM WAVELENGTH INTERVAL	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
265.	5.846	0.166	35.26
275.	2.191	0.166	13.21
285.	1.923	0.290	6.63
295.	3.015	0.456	6.61
305.	4.324	0.477	9.07
315.	7.540	0.591	12.76
325.	5.535	0.746	9.72
335.	1.386	0.829	1.67
345.	0.369	0.870	0.42
355.	0.273	0.879	0.31
365.	11.809	0.922	12.80
375.	0.186	0.943	0.20
385.	0.203	0.869	0.24
395.	0.153	0.943	0.17
405.	3.971	1.347	2.95
415.	0.137	1.437	0.10
425.	0.175	1.358	0.13
435.	6.842	1.337	5.12
445.	0.135	1.565	0.09
455.	0.096	1.617	0.06
465.	0.092	1.606	0.06
475.	0.098	1.596	0.06
485.	0.187	1.523	0.12
495.	0.174	1.523	0.11
505.	0.090	1.451	0.06
515.	0.085	1.436	0.06
525.	0.091	1.440	0.06
535.	0.697	1.472	0.47
545.	6.527	1.461	4.47
555.	0.193	1.449	0.13
565.	1.392	1.409	0.99
575.	8.683	1.439	6.08
585.	0.272	1.409	0.19
595.	0.106	1.399	0.08
605.	0.106	1.337	0.08
615.	0.108	1.306	0.08
625.	0.108	1.285	0.08
635.	0.107	1.254	0.08
645.	0.102	1.233	0.08
655.	0.126	1.212	0.09
665.	0.134	1.202	0.11
675.	0.195	1.171	0.17
685.	0.166	1.141	0.15
695.	0.124	1.109	0.11
705.	0.117	1.119	0.10
715.	0.099	1.067	0.09
725.	0.099	1.057	0.09
735.	0.102	1.036	0.10
745.	0.106	1.025	0.11
755.	0.106	1.015	0.11
765.	0.107	0.964	0.11
775.	0.108	0.933	0.12
785.	0.108	0.922	0.12
795.	0.104	0.922	0.12
805.	0.103	0.881	0.12
815.	0.103	0.862	0.12
825.	0.109	0.850	0.13
835.	0.112	0.819	0.14
845.	0.112	0.798	0.14
855.	0.111	0.777	0.14
865.	0.109	0.756	0.14
875.	0.109	0.746	0.15
885.	0.109	0.736	0.15
895.	0.104	0.715	0.15
905.	0.104	0.684	0.15
915.	0.104	0.674	0.15
925.	0.108	0.663	0.16
935.	0.115	0.653	0.18
945.	0.119	0.632	0.19
955.	0.104	0.611	0.17
965.	0.091	0.601	0.15
975.	0.092	0.601	0.15
985.	0.132	0.570	0.23
995.	0.595	0.560	1.05
1005.	1.537	0.539	2.85
1015.	1.932	0.528	3.66
1025.	0.951	0.518	1.83
1035.	0.283	0.508	0.55
1045.	0.119	0.497	0.24
1055.	0.087	0.487	0.18
1065.	0.073	0.477	0.16
1075.	0.078	0.466	0.17
1085.	0.088	0.456	0.19
1095.	0.111	0.446	0.25
1150.	0.305	0.393	0.78
1250.	0.109	0.314	0.35
1350.	0.338	0.253	1.34
1450.	0.095	0.225	0.46
1550.	0.153	0.168	0.89
1650.	0.193	0.139	1.39
1750.	0.169	0.115	1.47
1850.	0.088	0.096	0.91
1950.	0.085	0.082	1.04
2050.	0.088	0.069	1.26
2150.	0.096	0.059	1.62
2250.	0.093	0.051	1.83
2350.	0.095	0.044	2.17
2450.	0.096	0.038	2.50

Table 13
Computer Printout - Zirconium Arc

M-28 25WATT ZIRCONIUM LAMP 2/2/67 LNO. 2, SIC

WAVELENGTH	TEST LAMP ENERGY PER 10NM WAVELENGTH INTERVAL	SOLAR ENERGY	RATIOTESTLAMP/SOLAR
305.	0.002	0.484	0.00
315.	0.006	0.599	0.01
325.	0.011	0.757	0.01
335.	0.016	0.841	0.02
345.	0.022	0.883	0.02
355.	0.023	0.883	0.03
365.	0.025	0.936	0.03
375.	0.028	0.957	0.03
385.	0.031	0.873	0.04
395.	0.036	0.957	.04
405.	0.040	1.367	0.03
415.	0.046	1.451	0.03
425.	0.055	1.378	0.04
435.	0.057	1.357	0.04
445.	0.065	1.588	0.04
455.	.071	1.641	0.04
465.	.078	1.650	0.05
475.	.087	1.620	0.05
485.	.097	1.546	0.06
495.	0.109	1.546	0.06
505.	0.111	1.472	0.08
515.	.118	1.451	0.08
525.	0.127	1.462	0.09
535.	0.137	1.493	0.09
545.	0.146	1.483	0.10
555.	.160	1.462	0.11
565.	0.166	1.430	0.12
575.	0.176	1.451	0.12
585.	0.184	1.430	0.13
595.	0.202	1.420	0.14
605.	0.202	1.357	0.15
615.	0.225	1.325	0.17
625.	0.230	1.304	0.18
635.	0.230	1.272	0.18
645.	0.241	1.251	0.19
655.	0.263	1.230	0.21
665.	0.263	1.220	.22
675.	0.263	1.188	0.22
685.	0.272	1.157	0.23
695.	0.301	1.125	0.27
705.	0.301	1.136	0.26
715.	0.307	1.083	0.28
725.	0.301	1.073	0.28
735.	0.327	1.052	0.31
745.	.343	1.020	.34
755.	0.343	1.020	0.34
765.	.343	.978	0.35
775.	0.367	0.946	0.38
785.	0.366	.936	.39
795.	0.366	0.915	0.40
805.	0.386	0.894	0.43
815.	0.392	0.873	0.45
825.	.396	0.862	0.46
835.	0.399	0.831	0.47
845.	0.388	.810	0.48
855.	0.388	0.789	0.49
865.	0.398	0.768	0.52
875.	0.404	0.757	0.53
885.	0.404	0.747	0.54
895.	.404	0.726	0.56
905.	0.421	0.694	0.61
915.	0.424	.684	0.62
925.	0.424	0.673	0.63
935.	0.452	0.663	0.68
945.	0.459	0.641	0.72
955.	0.470	0.620	0.76
965.	0.470	0.610	0.77
975.	0.470	0.610	0.77
985.	0.470	0.578	0.81
995.	0.470	0.568	0.83
1005.	0.471	0.547	0.86
1015.	0.473	0.536	0.88
1025.	0.473	0.526	0.90
1035.	0.473	0.515	0.92
1045.	0.473	0.505	0.94
1055.	.482	0.494	0.98
1065.	0.496	0.484	1.03
1075.	0.496	0.473	1.05
1085.	0.496	0.463	1.07
1095.	0.496	0.452	1.10
1105.	0.516	0.399	1.29
1250.	0.547	0.219	1.72
1350.	0.579	0.257	2.26
1450.	0.597	0.208	2.87
1550.	0.611	0.177	3.59
1650.	0.625	0.141	4.44
1750.	0.617	0.117	5.29
1850.	0.603	0.096	6.17
1950.	0.715	0.083	8.62
2050.	0.701	0.070	9.95
2150.	0.588	0.060	9.81
2250.	0.574	.052	11.14
2350.	0.568	0.044	12.85

Table 14
Absorptance Values of Thermal Control Materials

Name of Coating	Irradiance Sources									
	Xe	M-13 Filtered X-25L	M-20 HgXe	V-3 Ar 5KW	M-24 Hg	M-5 Kr	M-11 Ar	M-9 H-Xe	M-14 Carbon Arc	Solar Energy
Silver	4.0	4.0	13.4	10.1	28.5	6.0	3.2	5.2	3.2	5.0
Aluminum	8.0	7.4	6.5	8.5	7.1	7.3	5.5	7.2	7.1	7.6
J. Colony white 78 - 2 coats over G.E. primer-Methyl silicon-TiO_2 (R960)	14.5	17.6	33.2	24.4	49.4	20.9	22.2	19.8	15.6	18.2
3M white - 8 coats over G.E. primer (Polyester)	17.4	20.5	35.2	27.1	51.1	23.3	24.0	22.3	19.9	
Cat-a-lac white - 8 coats (Epoxy)	18.4	21.3	36.5	28.0	50.9	25.2	27.8	24.1	21.0	
Dow Corning Q007 over Cat-a-lac white-Methyl silicon - TiO_2 (Rutile)	13.2	16.0	31.1	23.3	48.4	18.4	17.9	17.4	15.2	16.2
Dow Corning Q090 over Cat-a-lac white-Methyl silicon - TiO_2 (Anatase)	14.0	16.0	30.3	23.1	46.5	19.3	19.5	18.2	14.9	16.3
S-13 over G.E. Primer-Methyl silicon - ZnO (SP500)	16.5	18.8	34.5	25.8	50.2	22.6	23.7	21.3	18.1	18.9
Gold	14.6	18.6	23.5	22.0	38.5	12.8	7.1	14.0	16.6	19.8
Cat-a-lac black-epoxy	94.9	94.8	94.6	94.7	94.3	94.7	94.7	94.8	94.8	94.8
3M Velvet black	97.2	97.2	97.2	97.2	97.1	97.3	97.3	97.2	97.2	97.2
J. Colony white 88-S over G.E. Primer - Methyl silicon - TiO_2	14.0	16.2	32.1	23.4	46.1	20.1	21.0	18.8	15.4	

ULTEK TRIP

During this quarter a trip was made to the Ultek Corporation in Sunnyvale, California to assist in the preliminary acceptance tests of a series of eight (8) ion pumped vacuum systems. These systems have been purchased to support the Coatings Qualification effort of the Radiometry Section, Thermophysics Branch of NASA-GSFC. A complete and detailed account of the important facets of this trip is contained in Appendix II.

GENERAL ELECTRIC ULTRA HIGH VACUUM SYSTEM

Preparations are now being made for the cleaning and repainting of the shroud of the G.E. system. In addition, the entire vacuum system will be thoroughly cleaned and rehabilitated as required. The electronics, heating, and refrigeration systems will also be checked and repaired as necessary. The system should be back in operation by the end of April, 1967.

CONVAIR 990 SOLAR IRRADIANCE EXPERIMENT

The design modifications for the Leiss monochromator and the Eppley Mark VA radiometer have been completed. The designs for the Leiss monochromator housing and elevation mechanism have also been completed. The completed drawings for these designs have been turned over to the Fabrication Division of NASA-GSFC so that the hardware may be constructed.

A review of the narrow bandpass interference filters for use with the Eppley Mark VA radiometer has been made and those filters needed to complete the set have been ordered. The spectrum from 300 nm to 1100 nm should be covered very well with these filters.

Most of the equipment needed for this experiment has been ordered and should arrive during the next quarter.

GOALS FOR NEXT QUARTER

VORTEX STABILIZED ARC

The effect of arc gap length on current - voltage characteristics and spectral distribution will be investigated through measurements with three different arc gaps.

Spectral measurements will be attempted with krypton and xenon as the arc gases to determine the potential of these gases for use alone or in mixtures as a source for solar simulation.

When the Westinghouse power supplies for the 80kw arc source are received and the utilities installed for operation of the arc this new source will be installed and checked out.

GENERAL ELECTRIC VACUUM SYSTEM

The G.E. ultra high vacuum system will be operational again by the end of the next quarter.

CONVAIR 990 SOLAR IRRADIANCE EXPERIMENT

During the next quarter the complete experiment will be assembled and checked out together with all of the associated electronics. The final designs and design modification will be completed for electronics racks and the instrument support frames.

N67-32598

SECTION V

SPECTRAL IRRADIANCE MEASUREMENTS

Spectral Properties of Solar Simulation Lamps During Extended Operation

Prepared for

Thermal Systems Branch - GSFC
Contract No. NAS5-3743

Submitted by

Electro-Mechanical Research, Inc.
Aerospace Sciences Division
5012 College Avenue
College Park, Maryland 20740

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EMR

C. Duncan
Tech. Monitor, NASA-GSFC

ABSTRACT

The optical characteristics and spectral irradiance of three solar simulation lamps during extended operating times to approximately 600 hours have been measured. The degree of degradation in intensity of the lamps was significant although tolerable for most applications. The spectral distribution from one lamp to another was quite uniform and predictable.

These studies were conducted under sponsorship of NASA-Goddard Space Flight Center, Greenbelt, Maryland, with Mr. C. Duncan, Technical Monitor. The entire program was performed at the Aerospace Sciences Division of Electro-Mechanical Research, College Park, Maryland.

SPECTRAL IRRADIANCE MEASUREMENTS

INTRODUCTION

Solar simulation sources utilizing high pressure arc lamps are generally arranged to evaluate the thermo-optical properties of spacecraft materials and components. Although there is a wide choice of gases one can use in these lamps, the xenon gas spectrum comes closest in its spectral distribution to the solar spectrum in space. Xenon exhibits a spectrum which matches closely the solar visible region but deviates in the infrared and ultra violet regions. Therefore, it is customary to incorporate band pass filters and filter extraneous radiations to better match the solar spectrum.

The subject evaluation was concerned with stability of the xenon high pressure arc lamp during continuous operation at rated power. Three lamps with 2.5 and 7.5 kw ratings were arranged for measurement of their spectral irradiance at periodic intervals. Data and results are prepared to show degradation in overall intensity and degree of stability in the spectral distributions.

PROCEDURE

Three xenon high pressure arc lamps are arranged for continuous operation and measured to determine the stability of their spectral irradiance. A description of the test lamps and the procedures used to evaluate their characteristics are as follows:

Test Lamps

Three high pressure arc lamps filled with xenon gas were supplied by NASA-GSFC for test and evaluation. Of the three lamps, two were rated at 2500 watts and one at 7500 watts. The two 2500 watt lamps are manufactured by the Hanovia Lamp Division of Engelhord, Hanovia, Inc. and supplied as standard items. The 7500 watt lamp is an experimental lamp manufactured by PEK Labs., Inc. of California. Each of the lamps consist of a quartz envelope and tungsten electrodes, and are operated at applied rated D.C. potential.

Test Arrangement

Each of the test lamps are arranged individually in an air cooled housing as illustrated in Figure 18. One 2.5 kw lamp is mounted in a standard 6 feet high electronic relay rack with an aconic reflector and turning flat mirror. This arrangement of lamp, reflector, and mirror greatly simulate the optical path

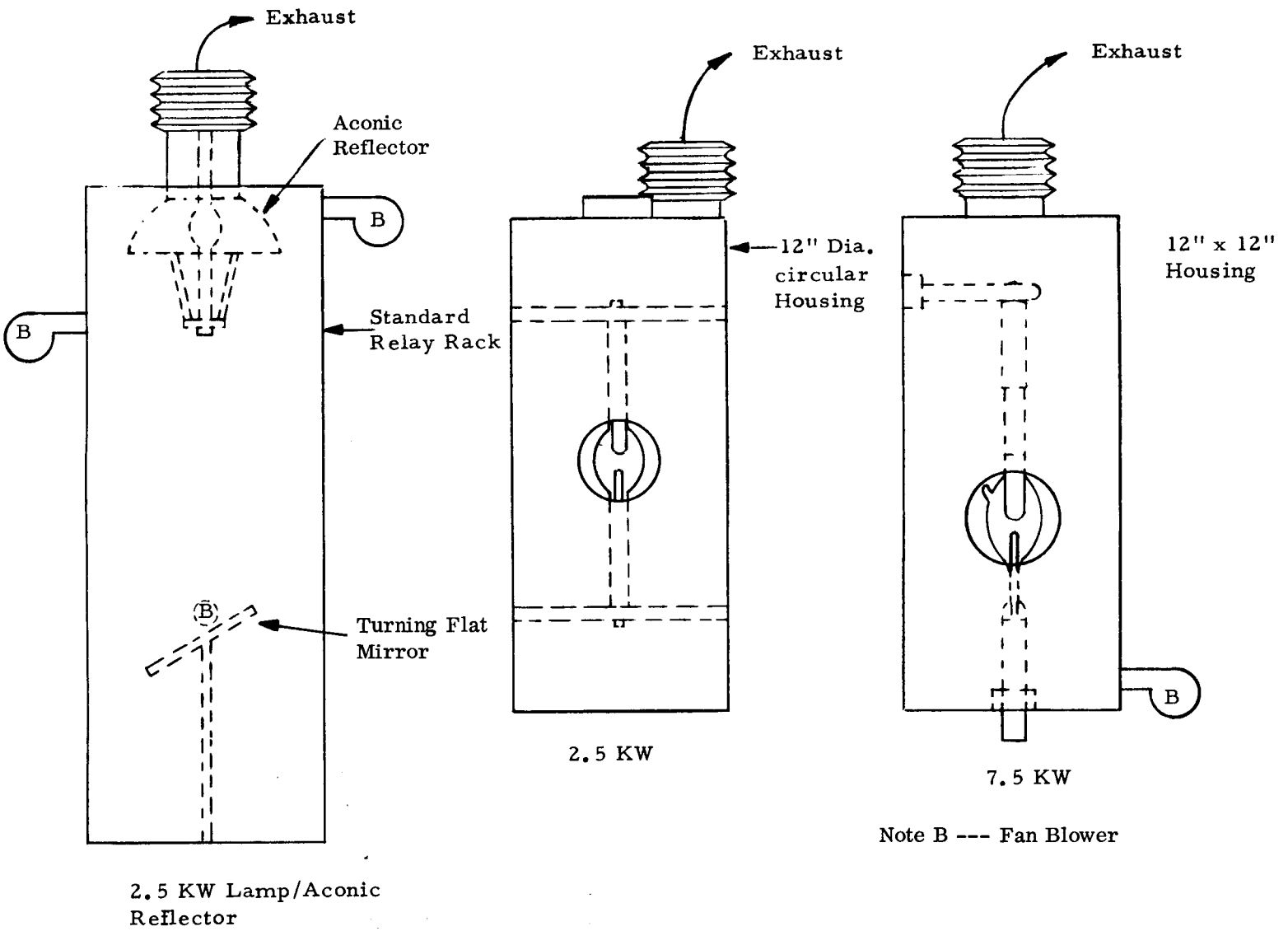


Figure 18. Lamp Housings

of a solar simulator. The other 2.5 kw lamp is housed in a 12 inch diameter enclosure equipped with electrodes and lamp mountings. The 7.5 kw lamp is installed in a 12 x 12 inch square enclosure designed especially for this specialized lamp. Each of the lamp housings is forced cooled internally, with fan blowers and positive exhaust venting. The external surfaces of the housings are painted black to increase the radiation of thermal energy and to assist in keeping the lamps at a nominal operating temperature. Thermocouples installed on the lamp electrodes and the aconic reflector are monitored to indicate temperature excursions beyond the design operating temperature limitations. Thermocouples as shown in Figure 19 are fabricated from gage chromel-alumel wire and mounted with silver epoxy cement. To facilitate measurements of spectral irradiance of each lamp, the housings are arranged about a Leiss monochrometer, as shown in Figure 20. The 7.5 kw and the 2.5 kw with aconic reflector are fixed in place whereas the second 2.5 kw housing is moved on its rail support to a position in optical alignment with the monochrometer. During

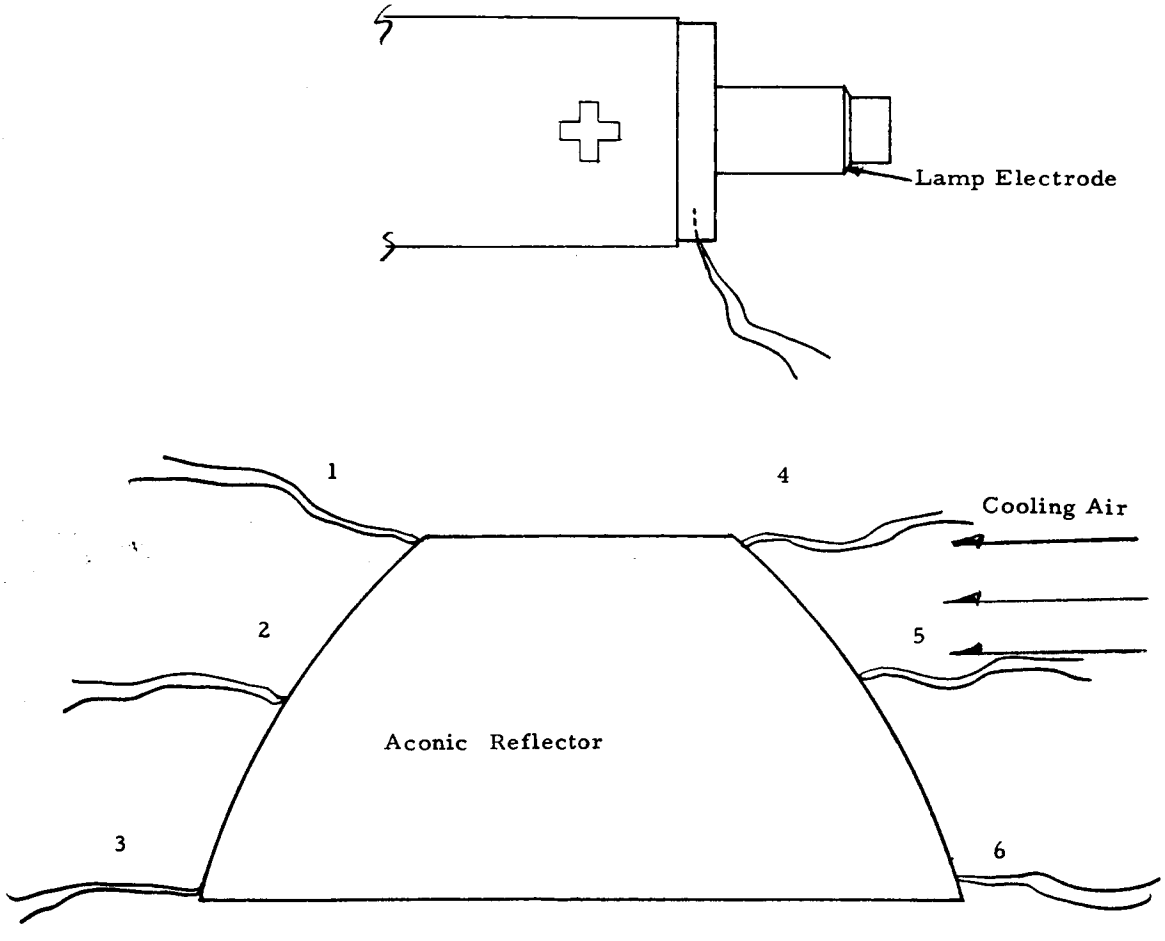


Figure 19. Thermocouple Placement

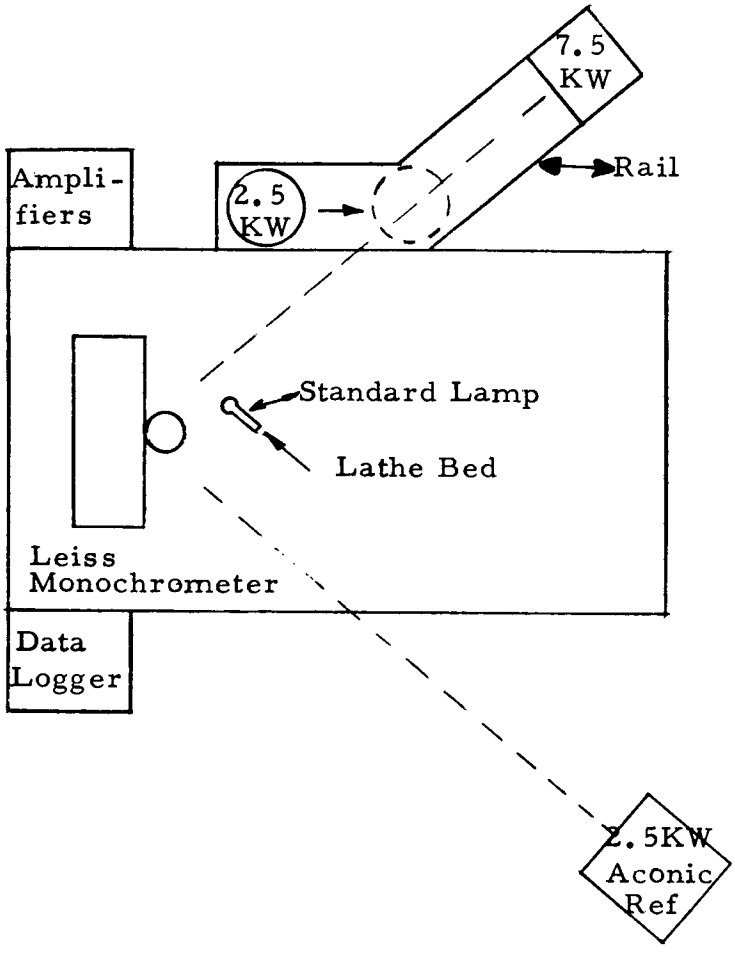
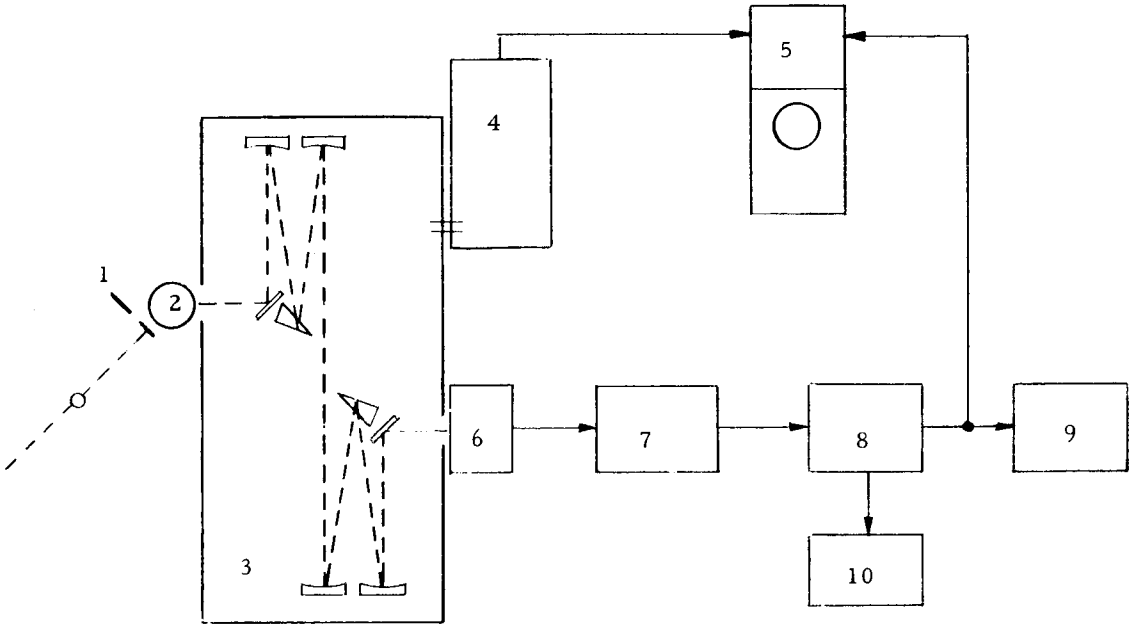


Figure 20. General Layout

measurements, a shutter in the housing is opened to irradiate an integrating sphere used with the monochrometer. The integrating sphere insures elimination of any specular components of radiation which are focused on the Leiss detector. A schematic of the optical path length and associated electronics used to make the measurements is presented in Figure 21. A standard lamp mounted on an optical lathe bed is arranged to insure precise optical alignment during each measurement of the reference irradiance. The reference standard consisting of a 1000 watt NBS calibrated QMS-4, quartz iodine tungsten filament lamp is powered by a power stat regulated D.C. power supply. Electric current for each xenon lamp is provided through regulated D.C. power supplies. The 2.5 kw lamp with aconic reflector is arranged with a Westinghouse supply whereas the 7.5 kw and second 2.5 kw lamps are powered by individual Christie supply units. The 2.5 kw lamps are supplied at 84 amps and 30 volts and the 7.5 kw lamp is supplied at 221 amps and 34 volts. Since the functional characteristics of amperage versus voltage are non-linear, the amperage is controlled at pre-set levels to maintain a constant power input to the lamps.



1. Mechanical Chopper
2. Intergrating MgO Sphere
3. Leiss Double Prism Monochrometer
4. Wavelength Shaft-Driver/Optical Encoder (CEC Model 1066)
5. Spectrometer Data Logger (CEC Model 1066)
6. 7102 and IP28PH Photomultiplier, and PbS Thermopile Detector
7. Preamplifier (Brower Lab Model 129)
8. Main Amplifier (Brower Lab Model 129)
9. Strip Chart X-Y Recorder (Photovolt Corporation)
10. Oscilloscope (HP-130 C)

Figure 21. Data Recording Schematic

Data Recording

Spectral irradiance measurements of each lamp are obtained at periodic intervals during the period of testing. The intervals between measurements are initially at shorter periods of time than later in the running time of the lamps. These shorter intervals are selected to permit a study of changes which occur usually during early periods of lamp operation.

As shown in the schematic in Figure 21, the radiating beam of energy from the test lamp is aligned optically with the integrating sphere of a Leiss Double

Prism Monochrometer. The wavelength shaft driver is synchronized electronically with a tape data logger and a strip chart X-Y plotter. Data from the tape deck can be extracted for arrangement on punched IBM cards and programmed on a computer for comparison with solar-spectral-energy distributions. Curves from the X-Y plotter can be reduced manually for presentation in simplified linear X-Y graphs. Data for the test lamps and the standard reference lamp are obtained in a similar manner. The test procedure requires that a standard reference distribution be obtained immediately following each measurement of a test lamp. Reduction of the test data converted monochrometer drum numbers to wavelength and detector millivolt outputs to intensity.

Temperature measurements of lamp electrodes and reflector housing are made continuously by recording all thermocouples on a strip-chart, multichannel millivolt recorder.

RESULTS

Test measurements of spectral irradiance of three xenon high pressure arc lamps and other experimental parameters are presented in the following discussion.

Spectral Irradiance

Spectral irradiance distributions of each test lamp are illustrated in the graphical plots, Figures 22 through 42. Composite plotting of initial measurements and later measurements are presented in Figures 29, 35, and 42 to illustrate the nature of changes obtained in the irradiance measurements.

The data as recorded on the X-Y plotter is illustrated in Figure 43 and which represents approximately 10% of a total measurement. To expedite reduction of the X-Y plots, a point-by-point manual analysis was performed and which results in the spectral-intensity plots shown in Figures 22 through 42. To convert the irradiance data to absolute values of intensity it is necessary to reference each wavelength of interest to a standard lamp output at the same wavelength. The spectral irradiance distribution of the standard lamp is shown in Figure 44.

Measurements of each lamp are conducted in accordance with the schedule shown in Table 15. The run numbers, identified as cm-, represent the sequence of measurement periods. The first two measurement periods on the 2.5 kw lamp without reflector were made with a painted MgO sphere on the monochrometer. This proved to be unsatisfactory and the sphere was recoated with

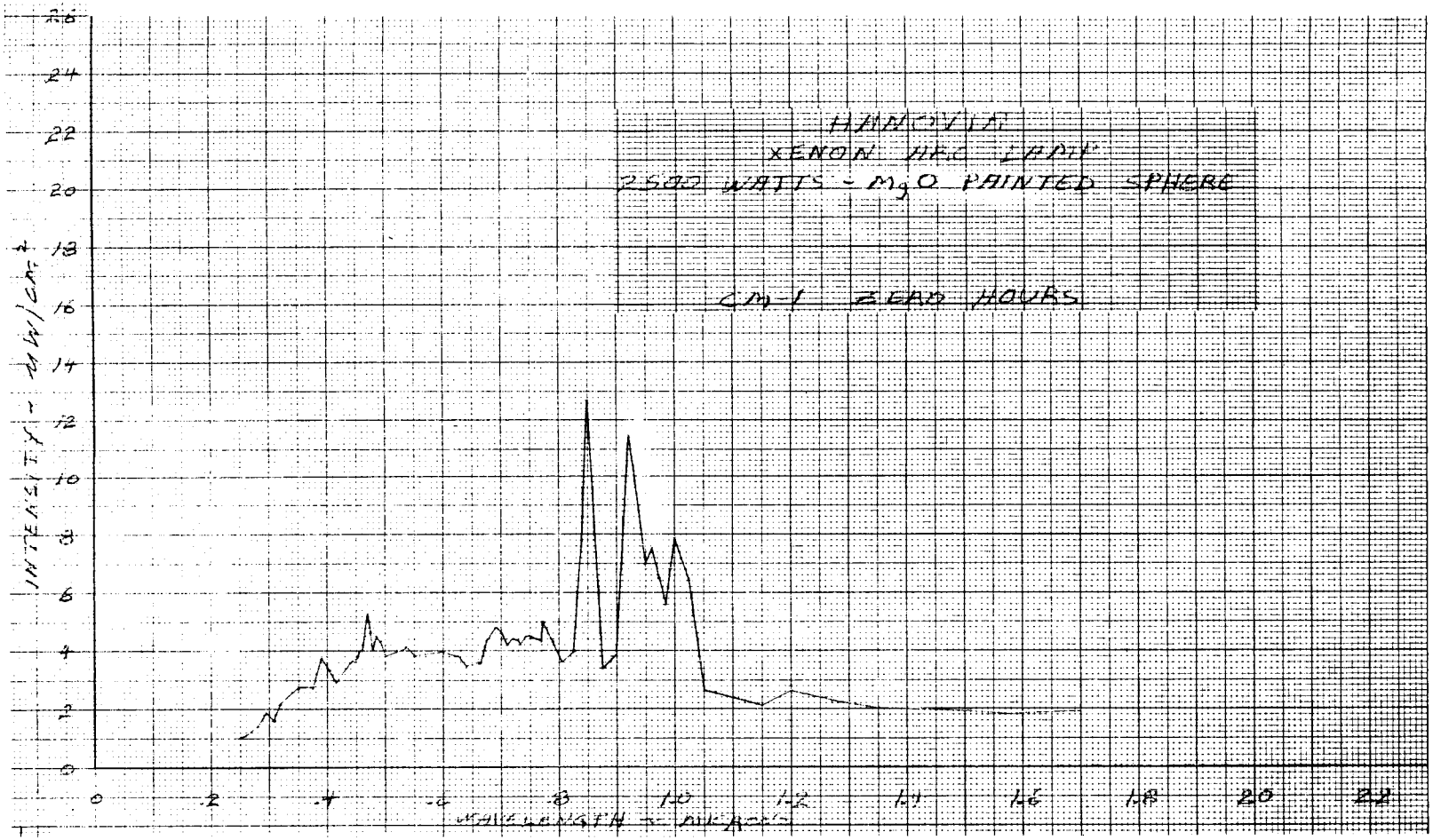


Figure 22. Hanovia Xenon Lamp—0 Hours

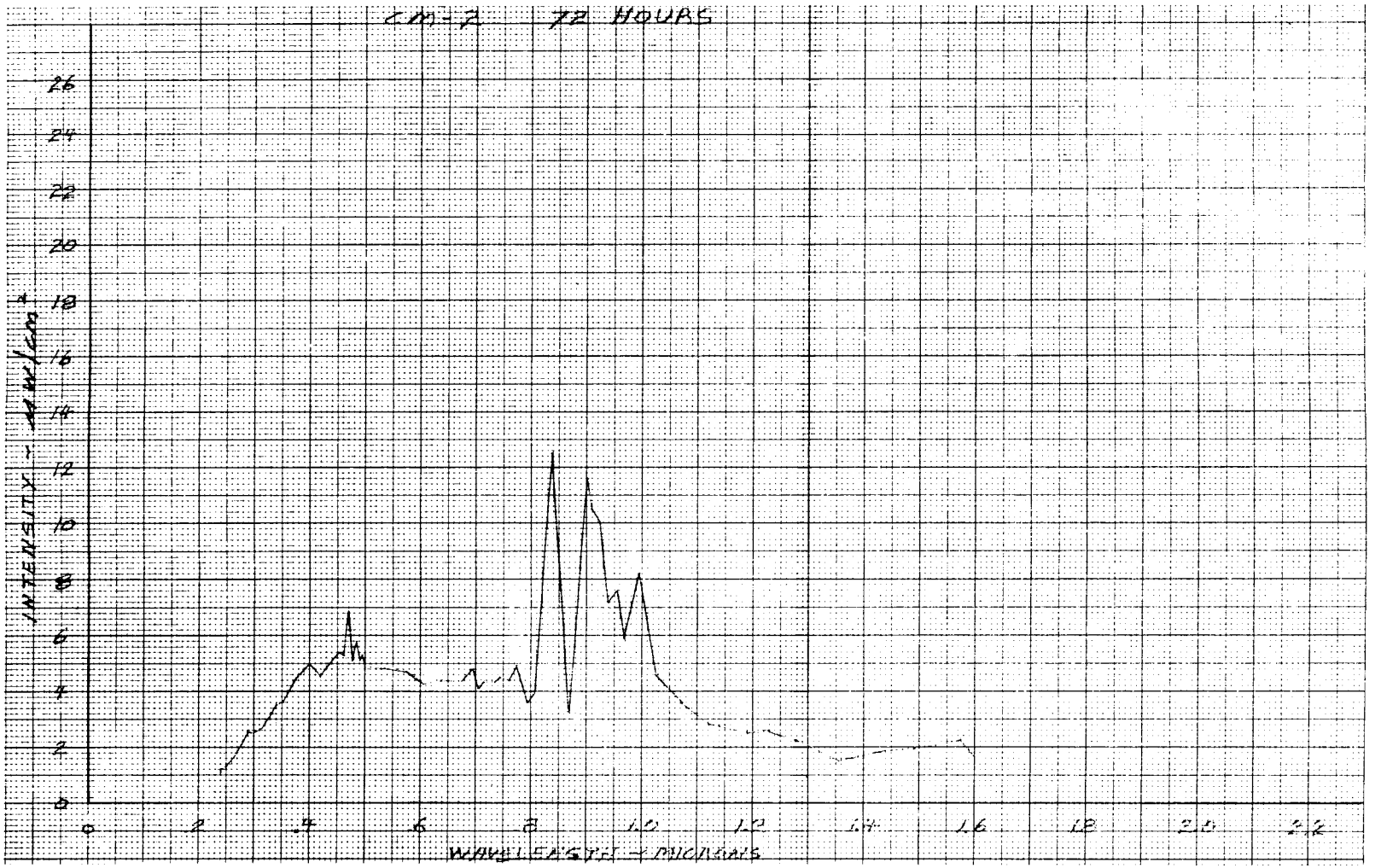


Figure 23. Hanovia Xenon Lamp—72 Hours

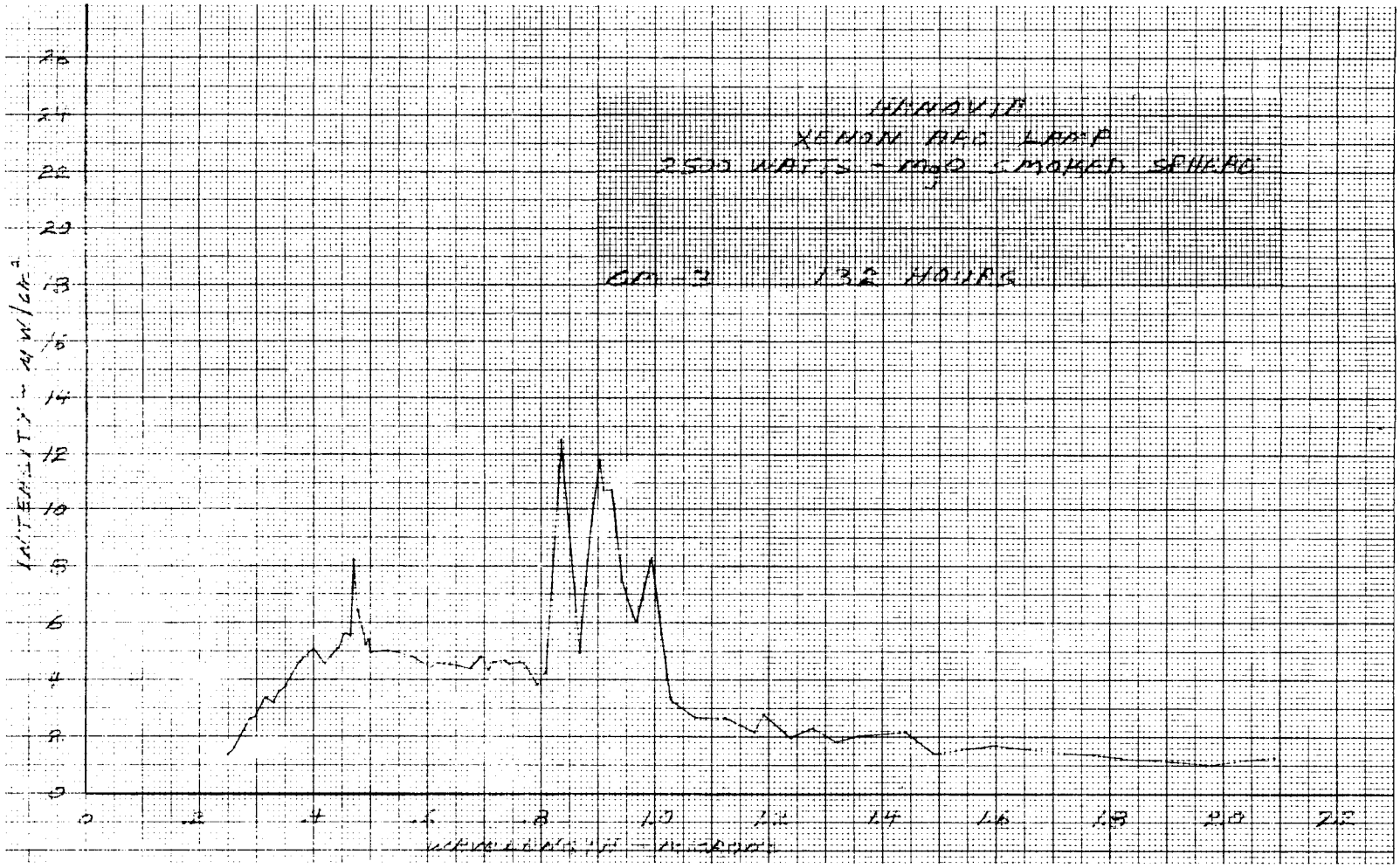


Figure 24. Hanovia Xenon Lamp—132 Hours

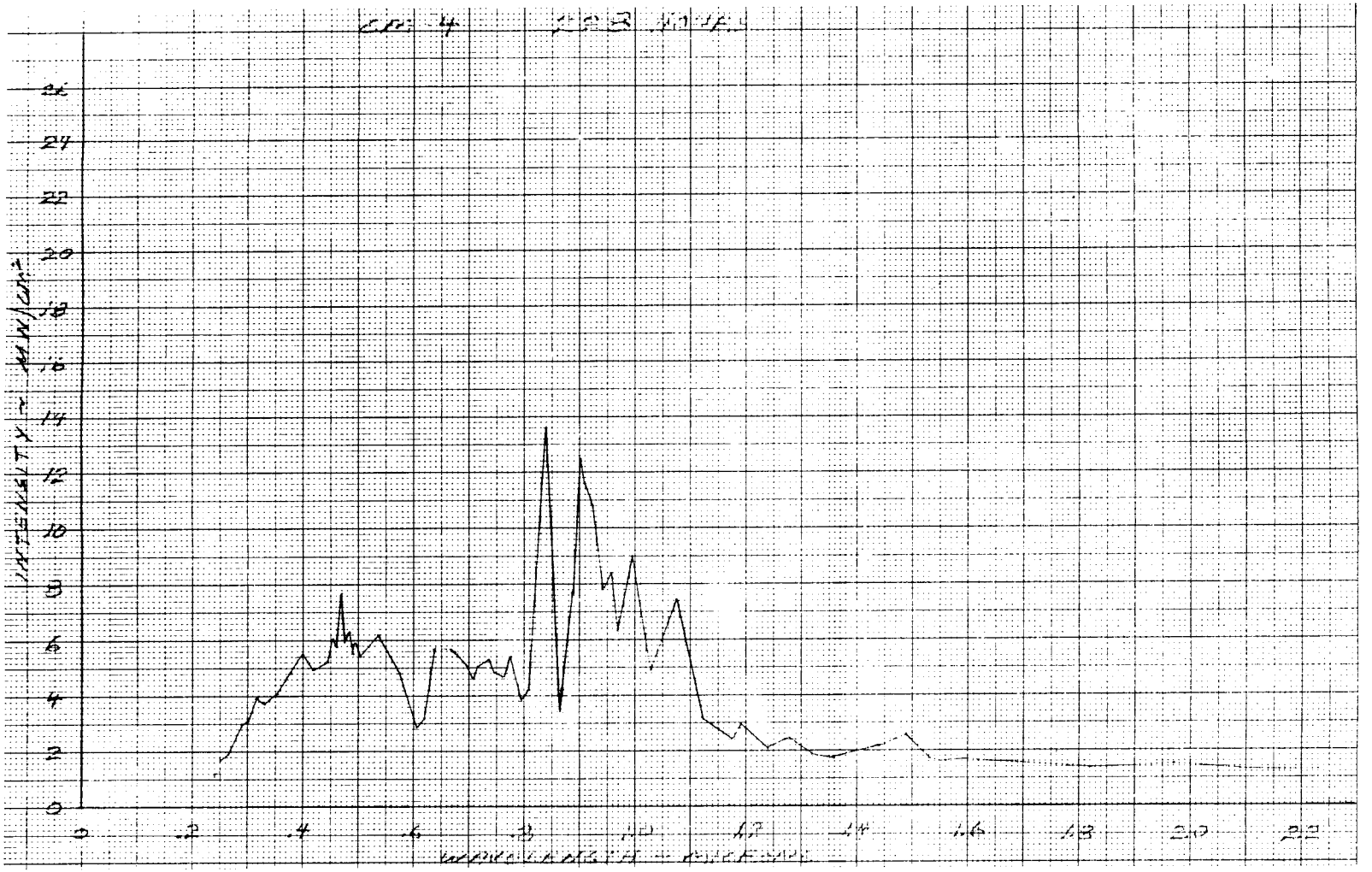


Figure 25. Hanovia Xenon Lamp—228 Hours

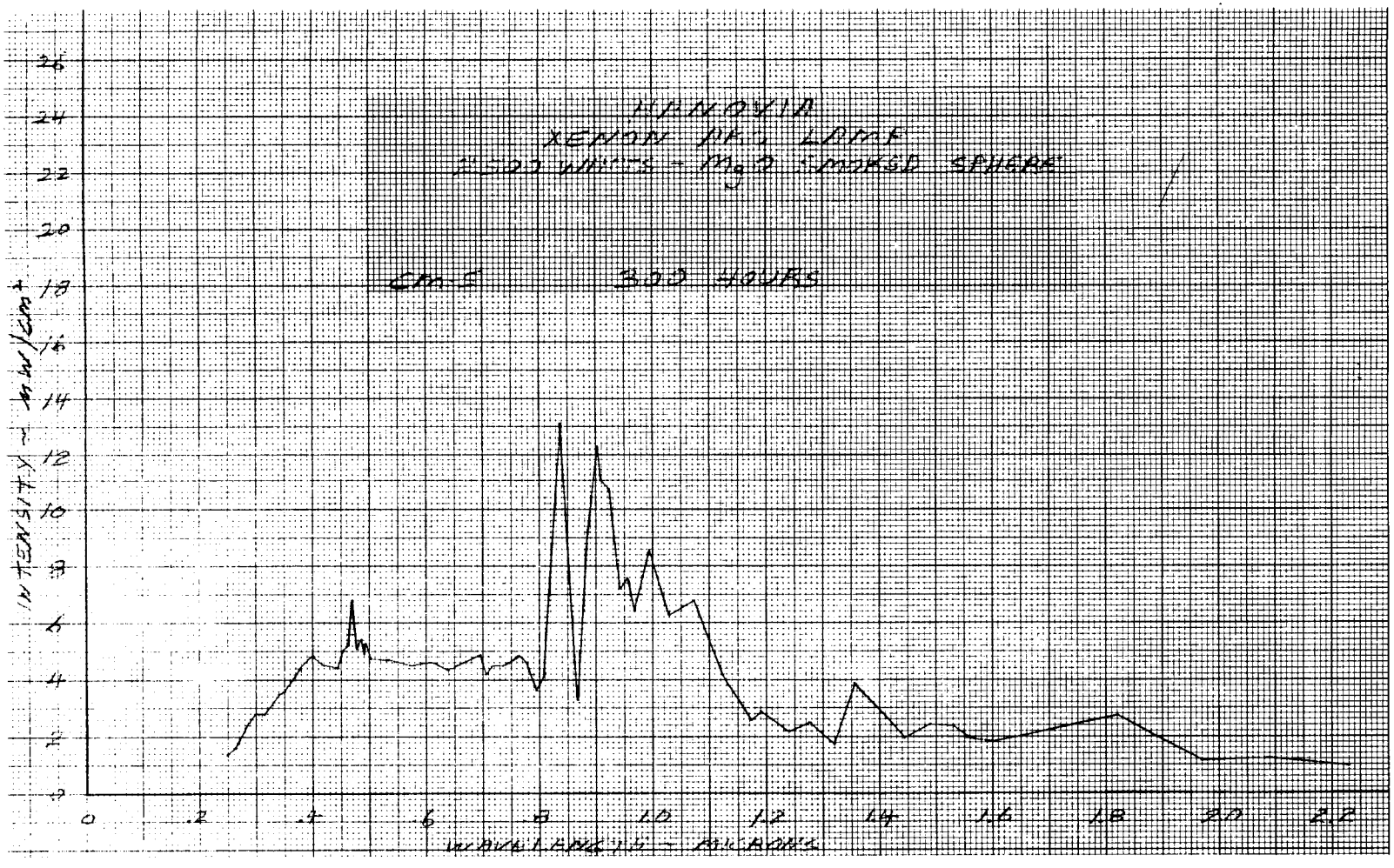


Figure 26. Hanovia Xenon Lamp—300 Hours

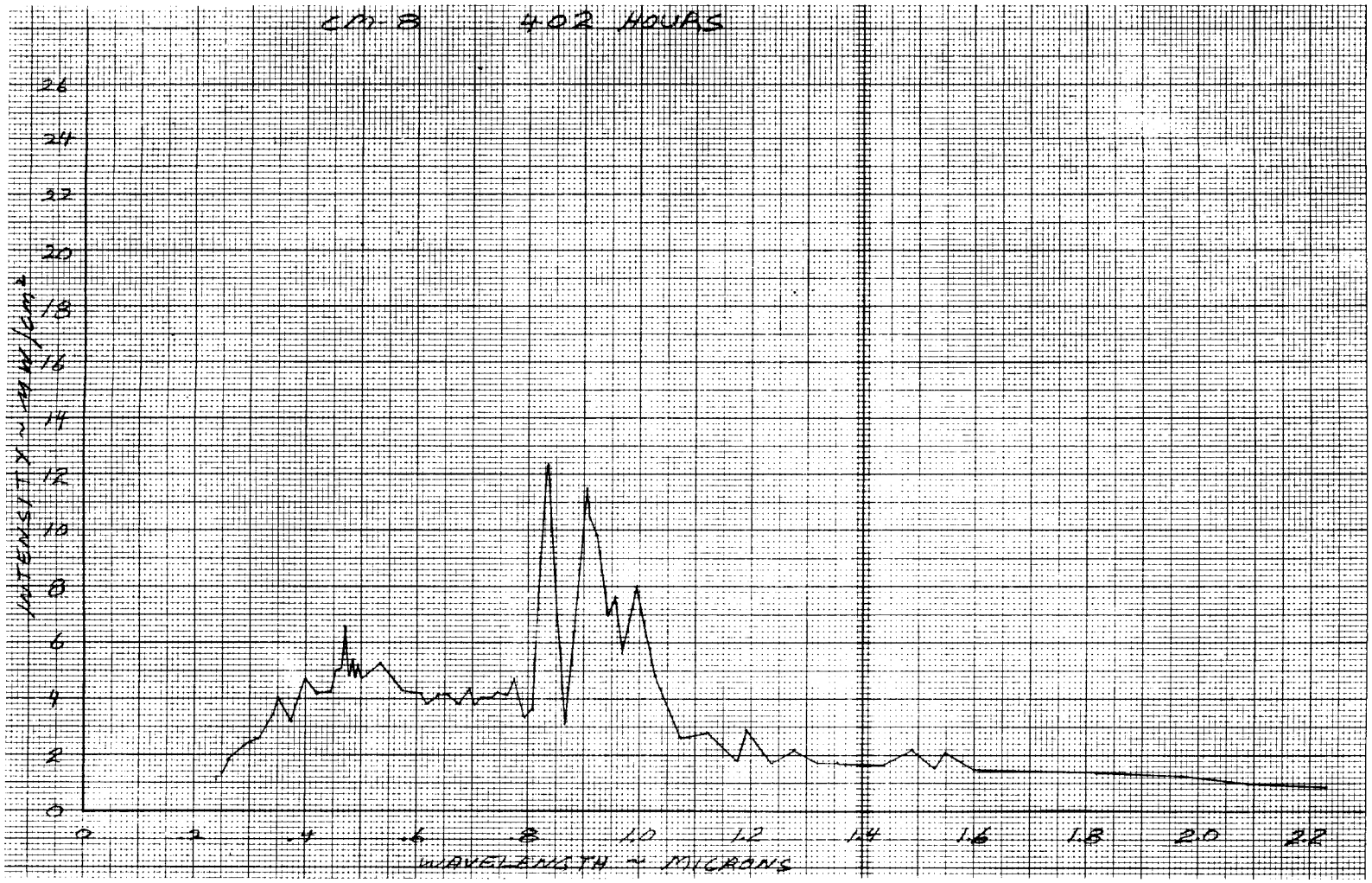


Figure 27. Hanovia Xenon Lamp—402 Hours

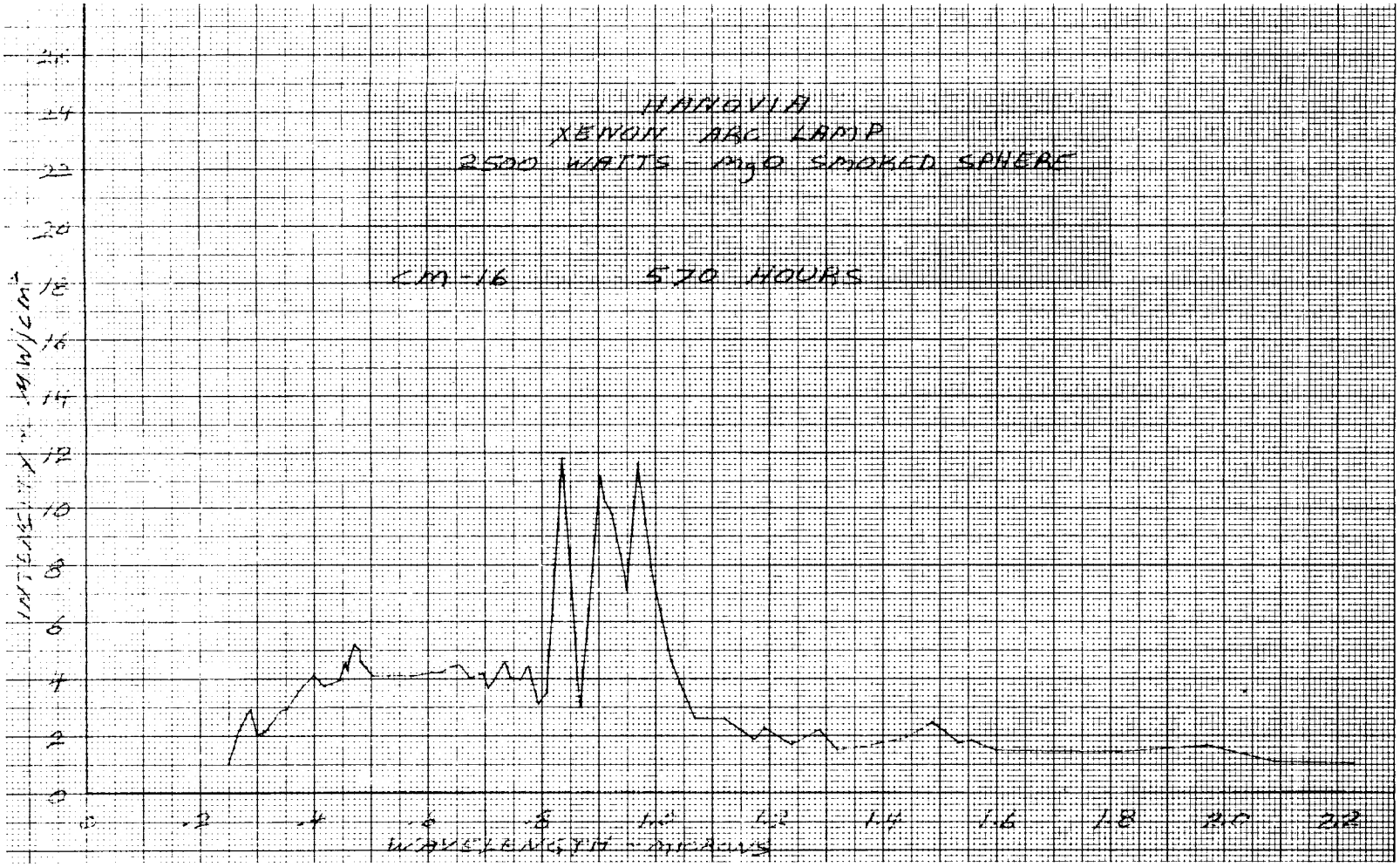


Figure 28. Hanovia Xenon Lamp—570 Hours

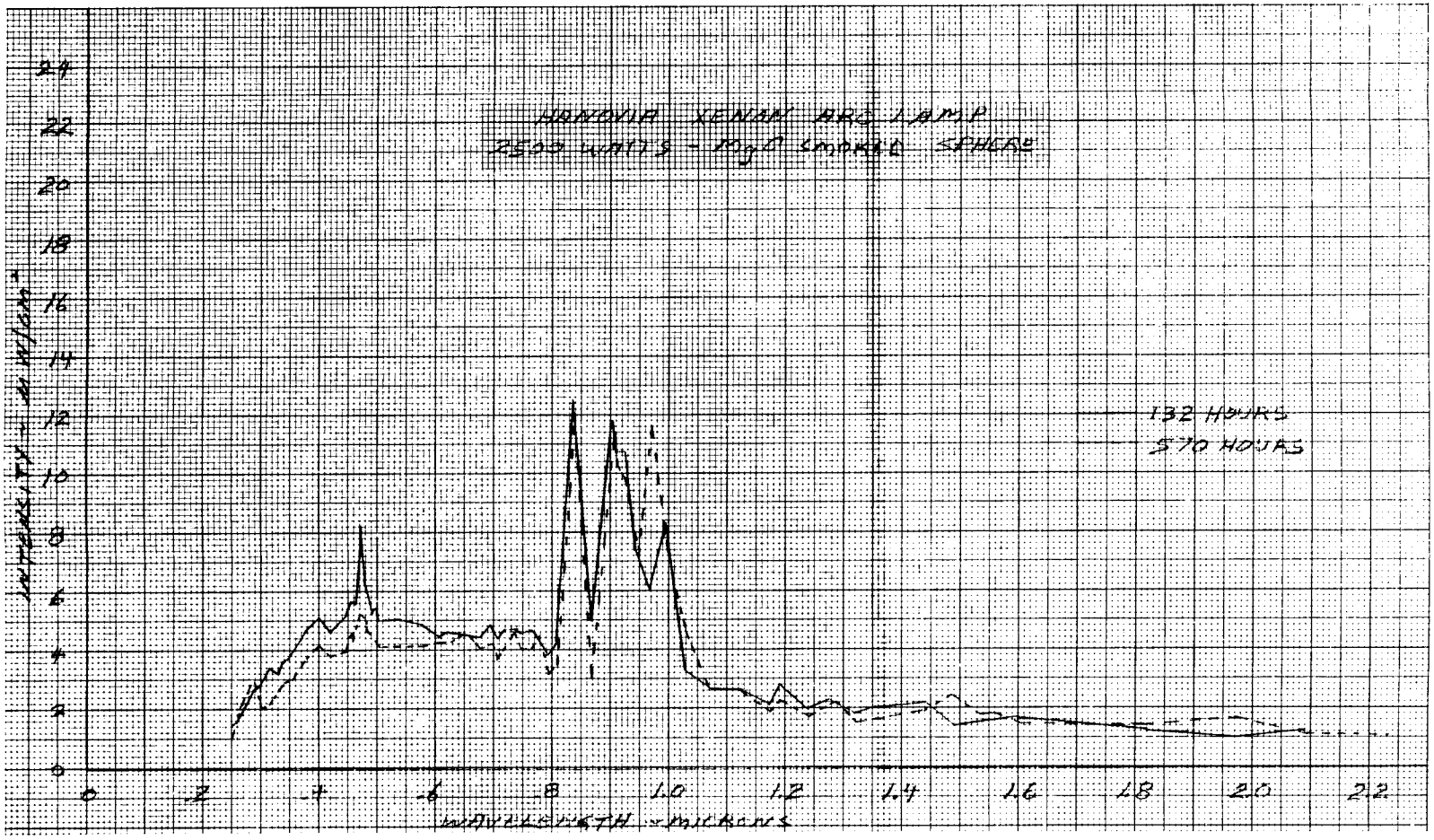


Figure 29. Hanovia Lamp—132 & 570 Hours

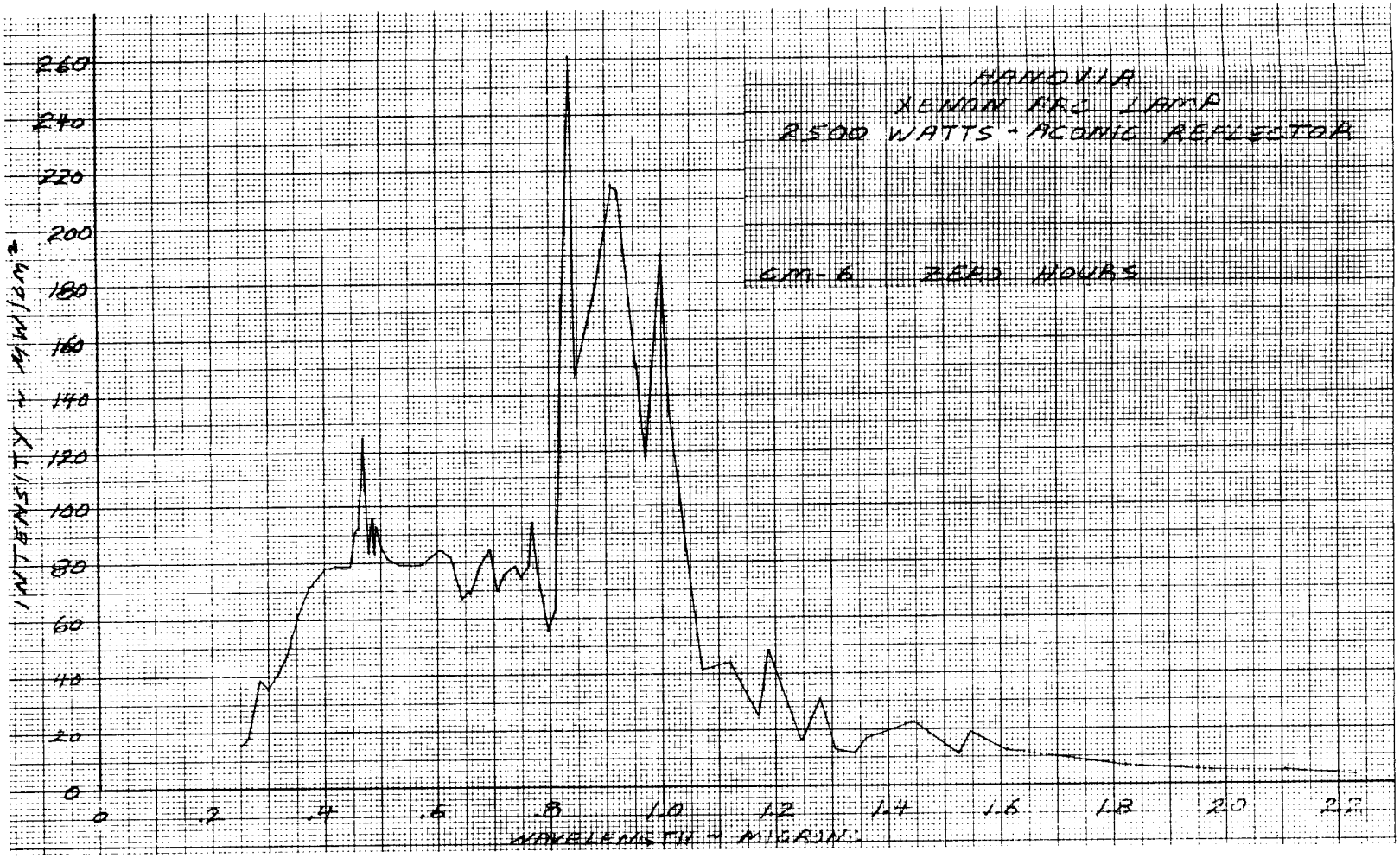


Figure 30. Hanovia Xenon Lamp with Collector—0 Hours

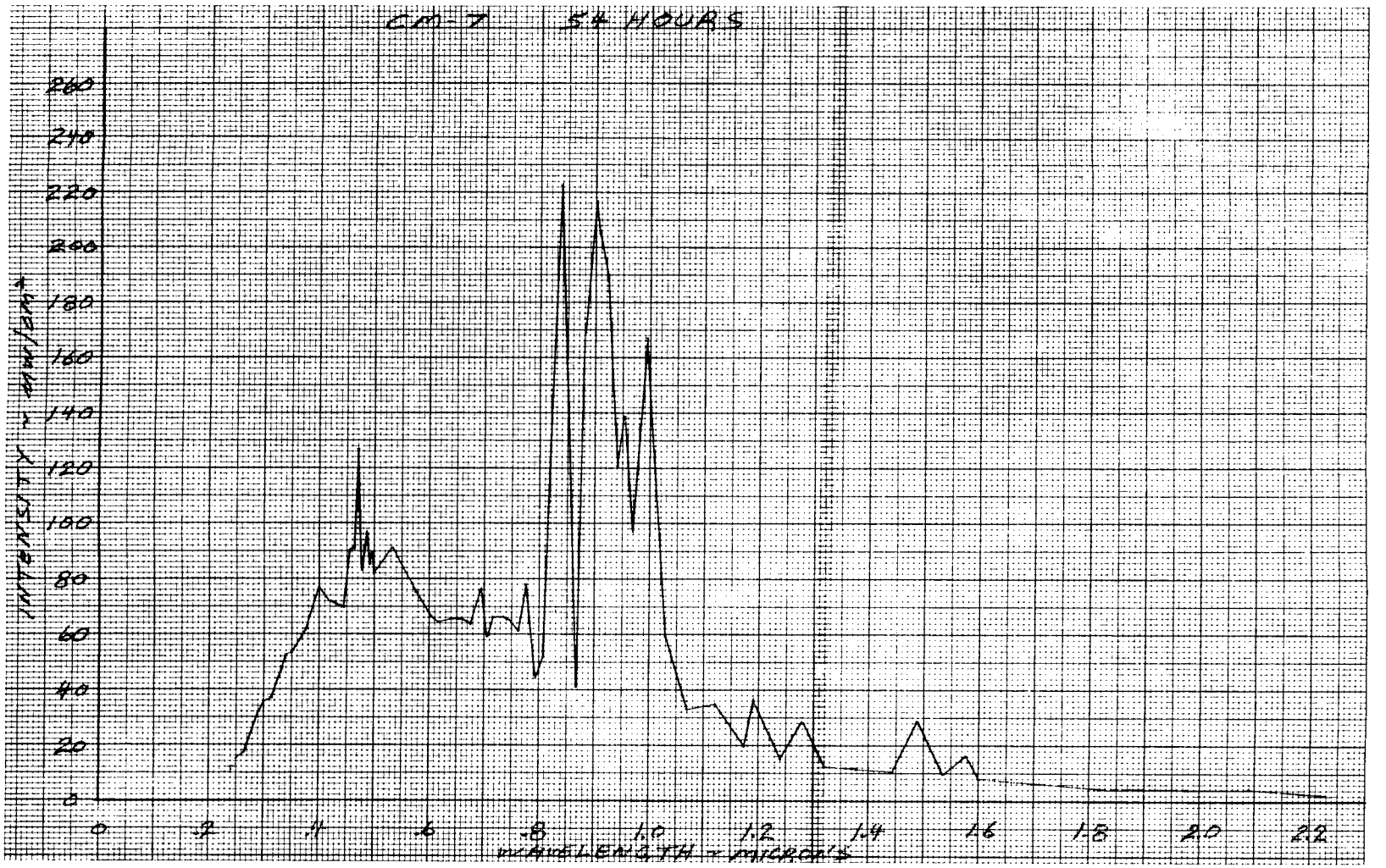


Figure 31. Hanovia Xenon Lamp with Collector—54 Hours

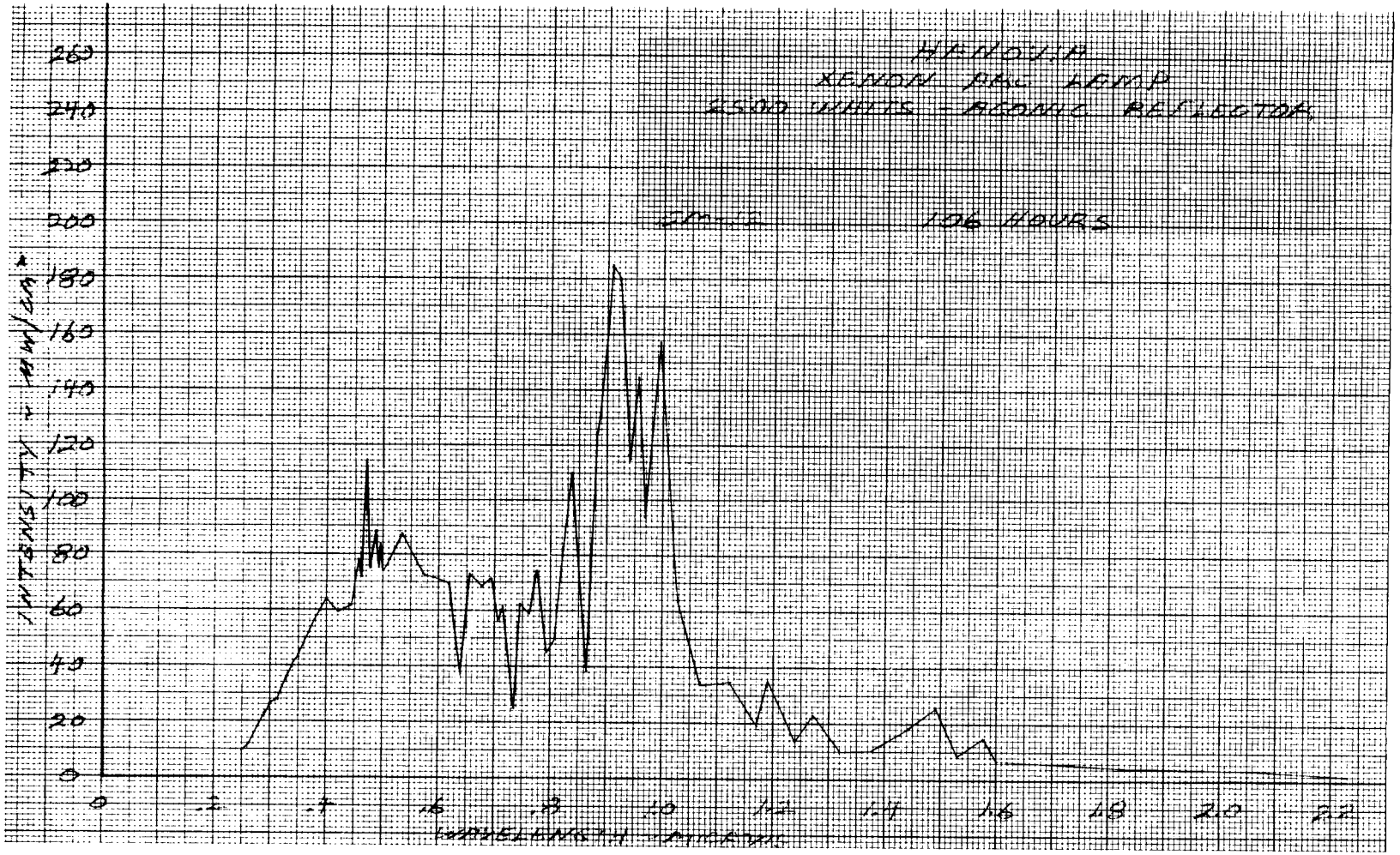


Figure 32. Hanovia Xenon Lamp with Collector—106 Hours

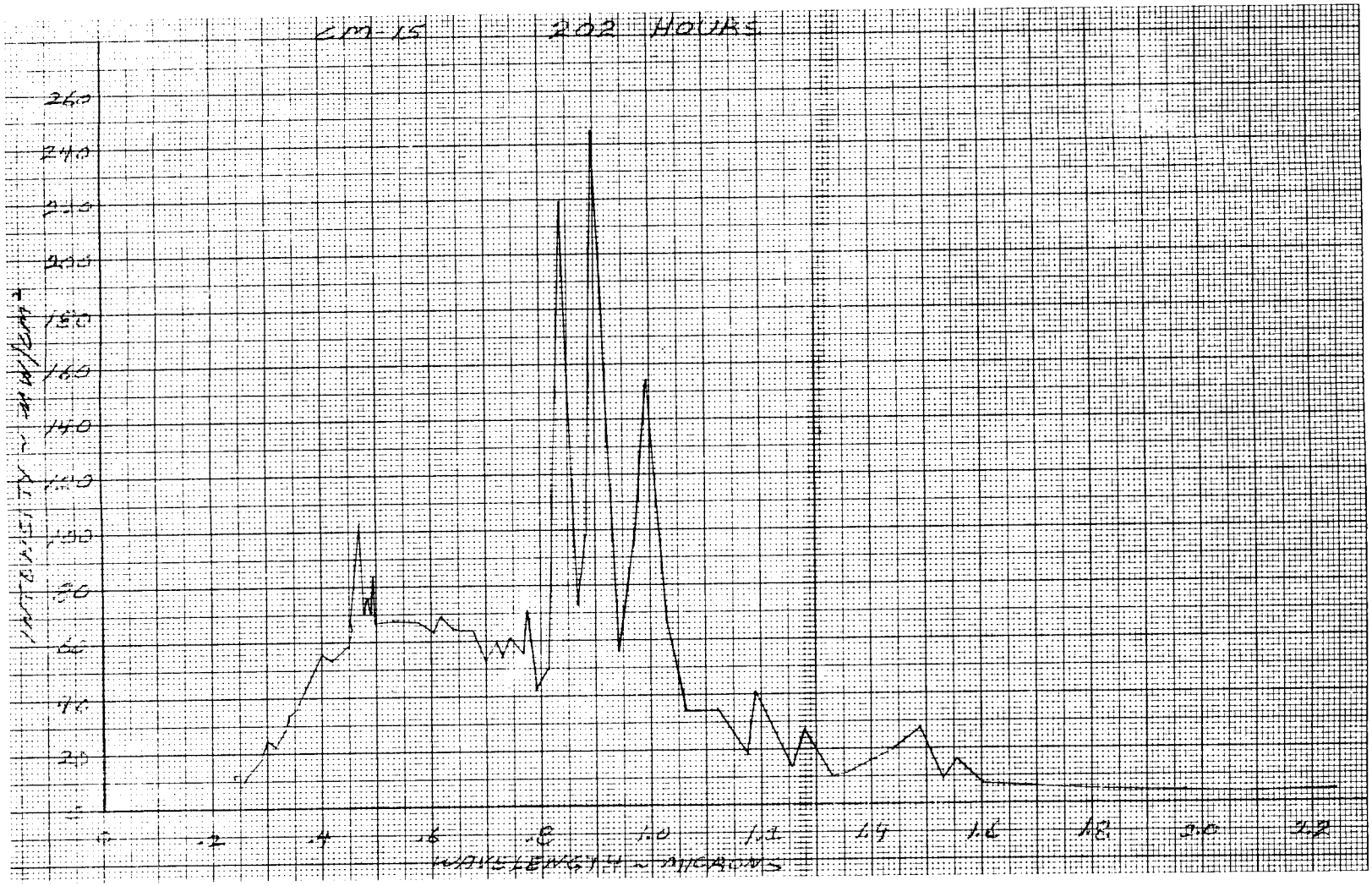


Figure 33. Hanovia Xenon Lamp with Collector—202 Hours

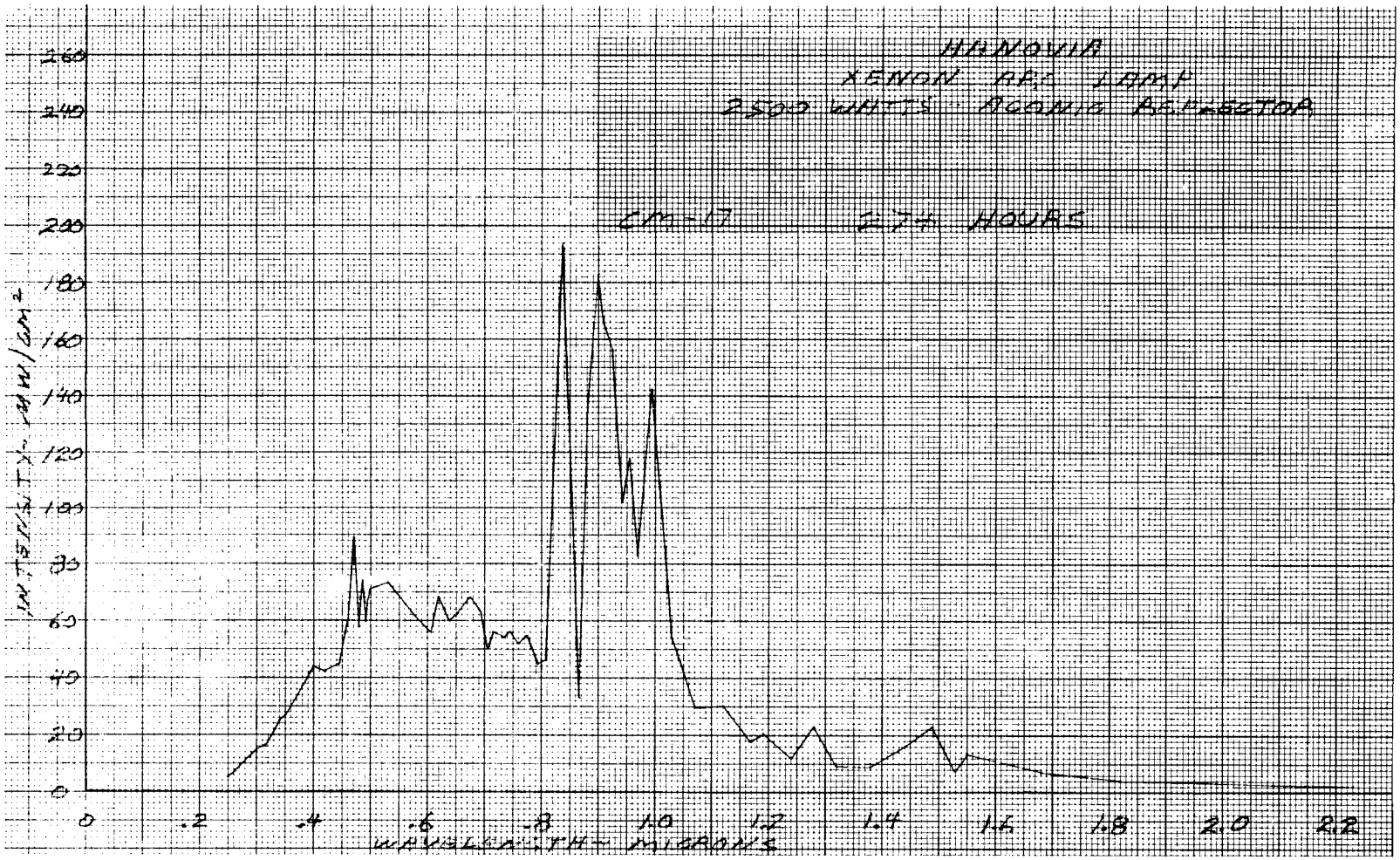


Figure 34. Hanovia Xenon Lamp with Collector—274 Hours

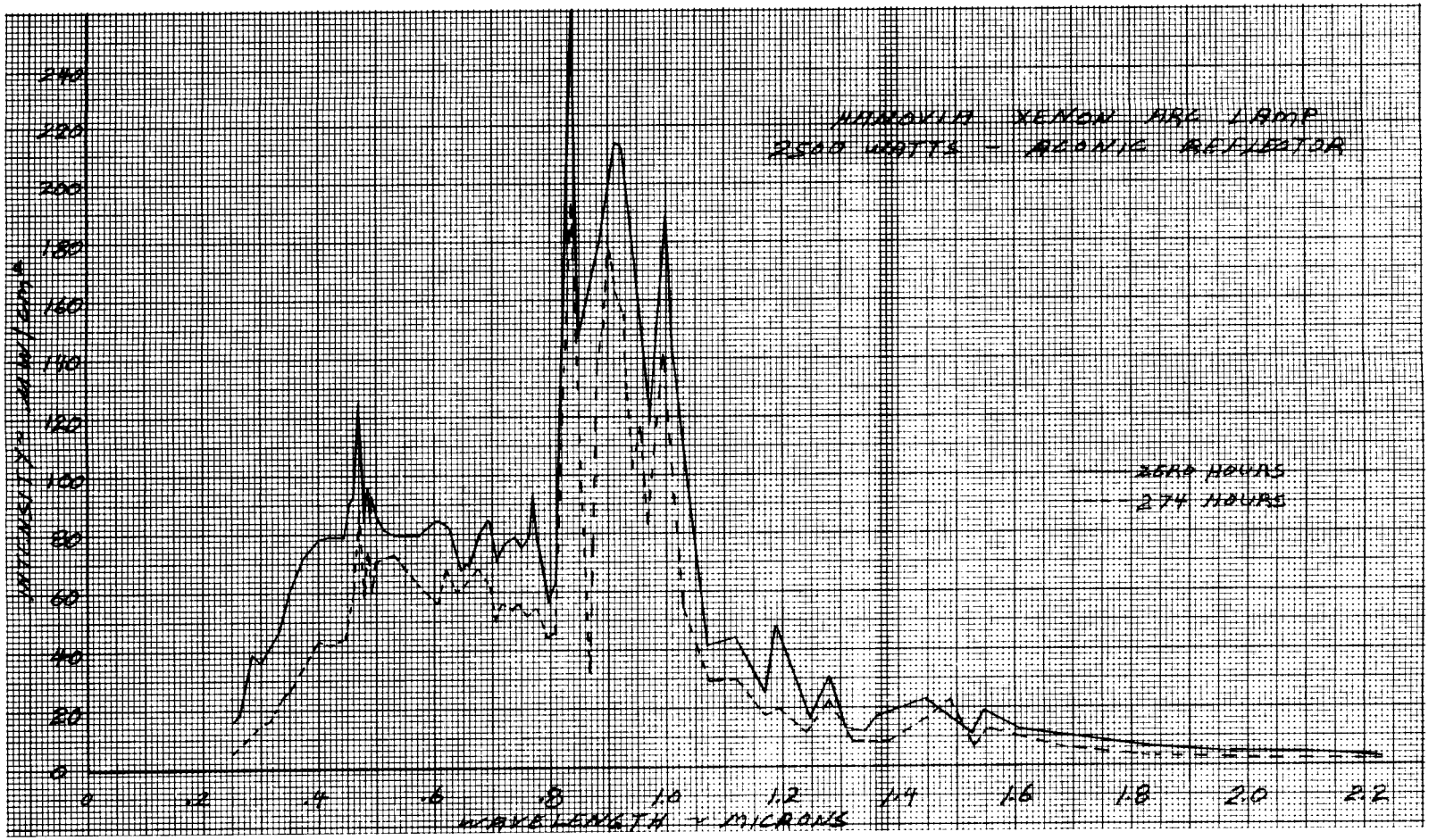


Figure 35. Hanovia Xenon Lamp with Collector—0 & 274 Hours

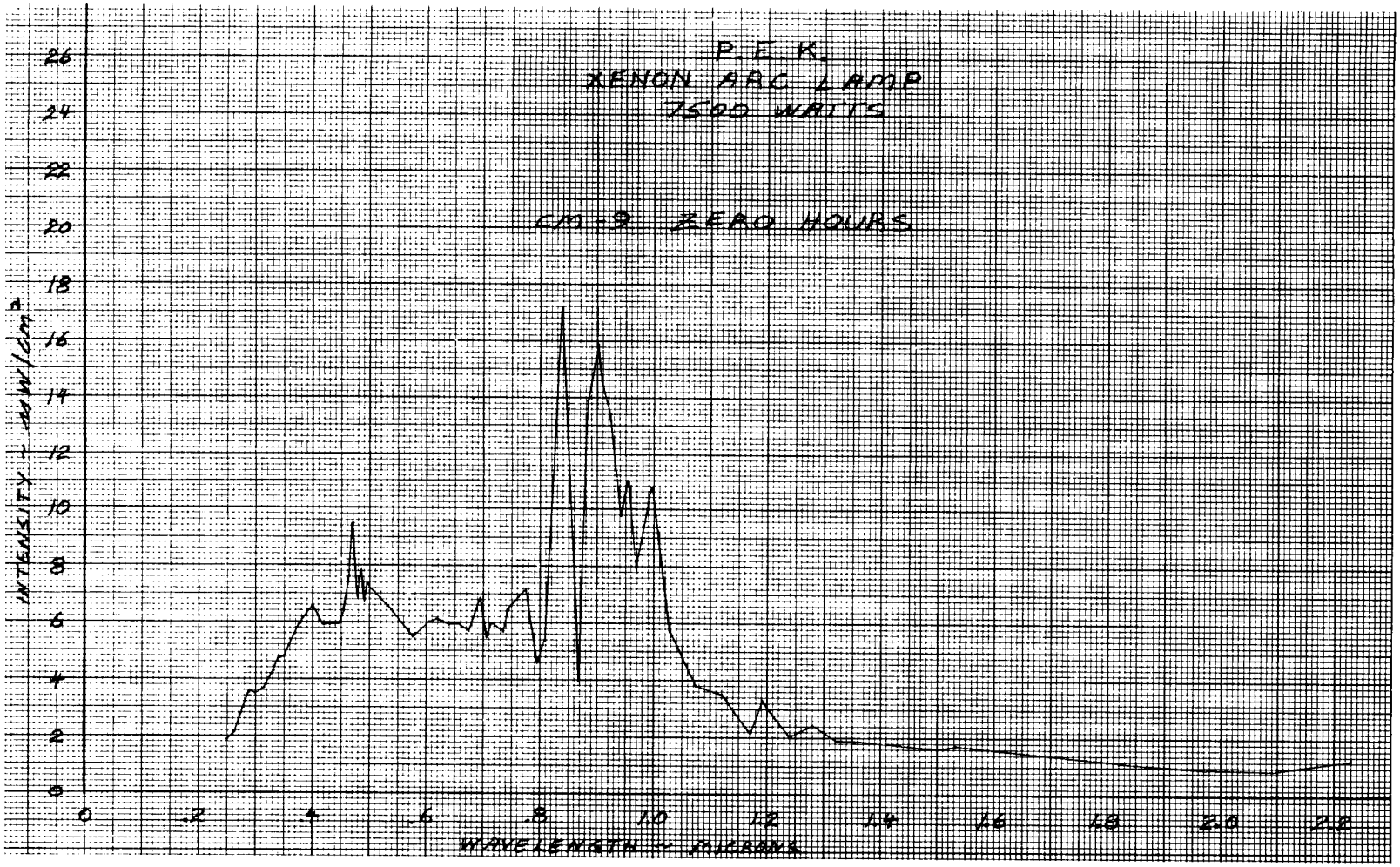


Figure 36. P.E.K. Xenon 7500 Watt Lamp—0 Hours

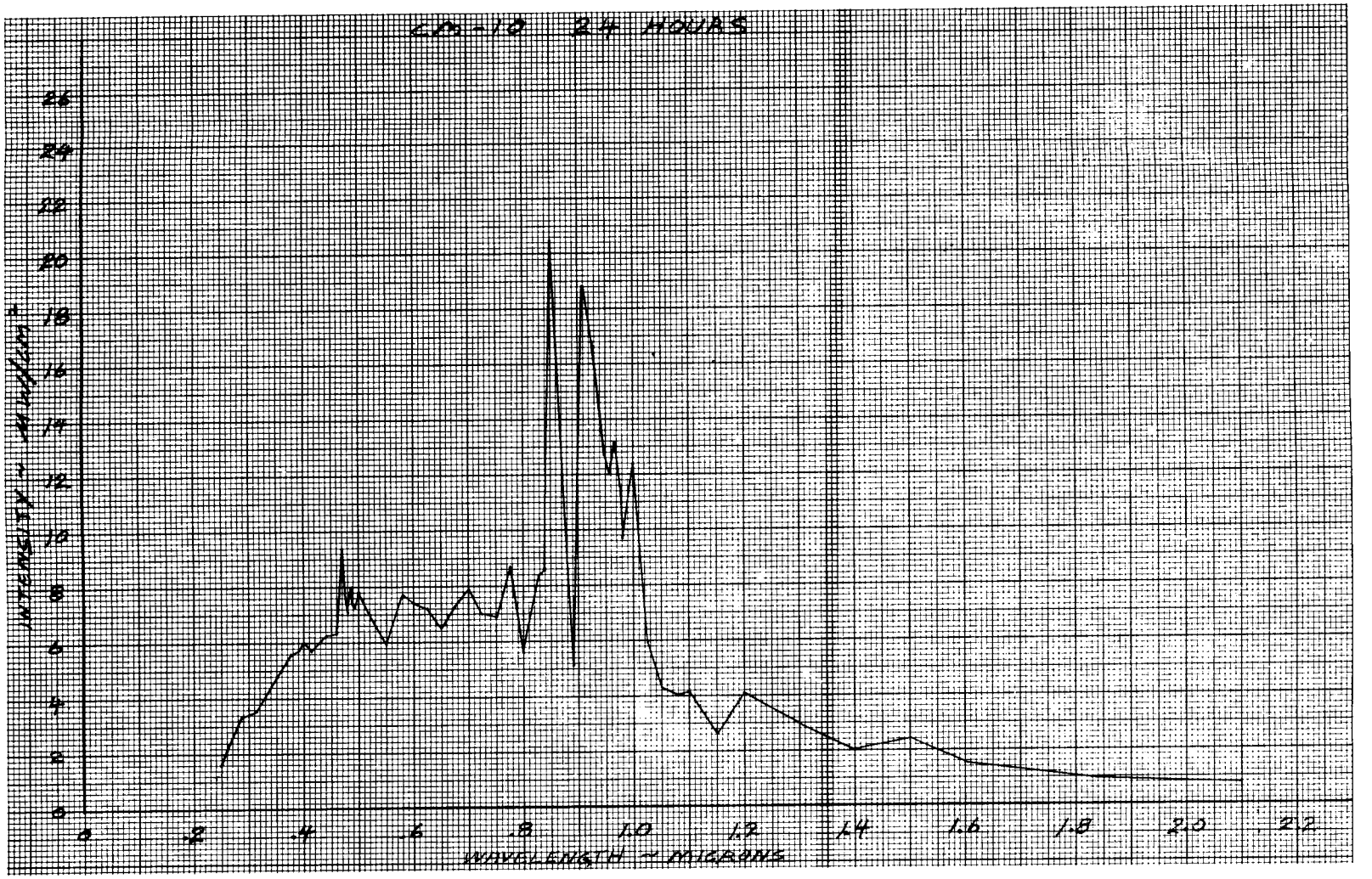


Figure 37. P.E.K. Xenon 7500 Watt Lamp—24 Hours

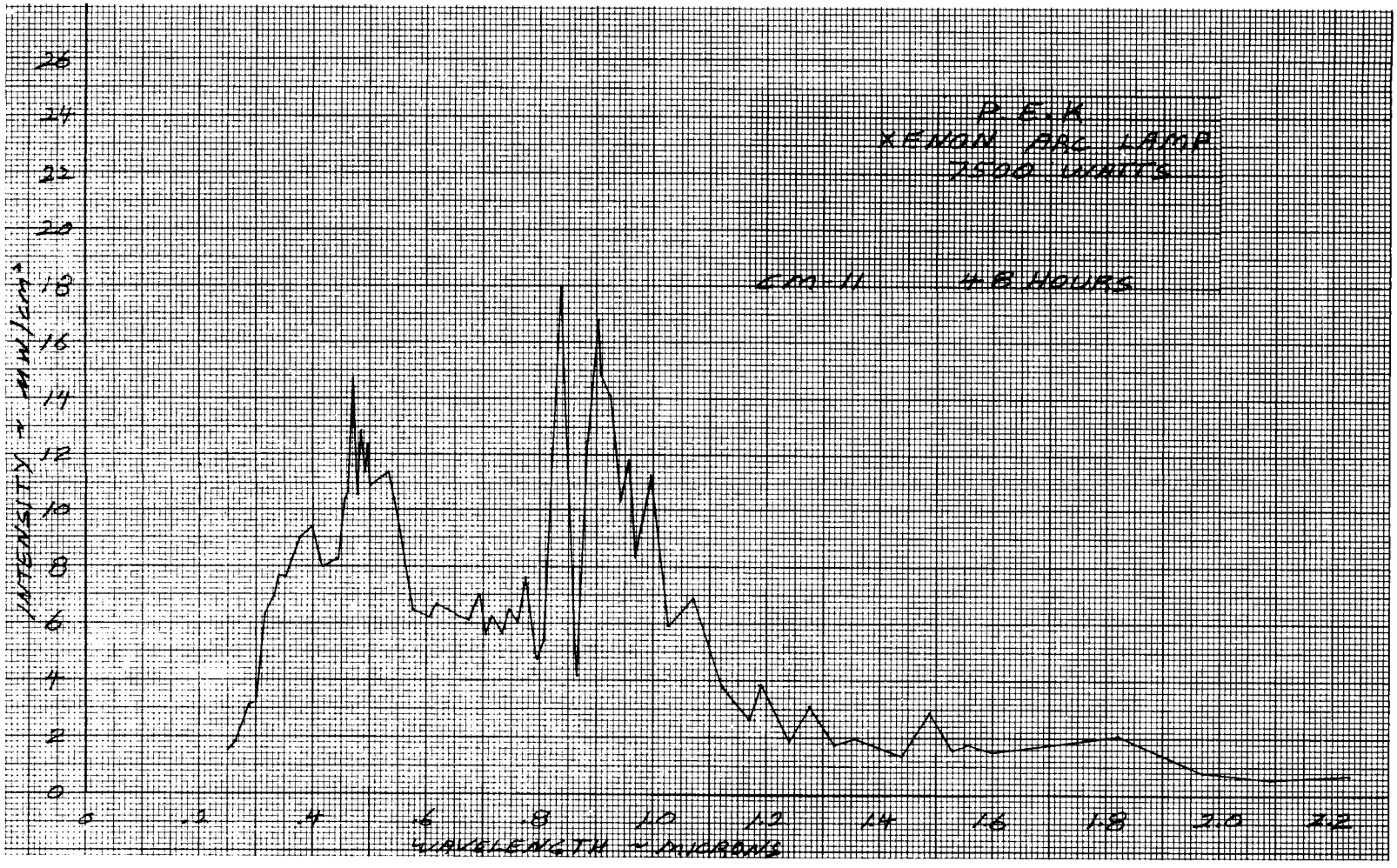


Figure 38. P.E.K. Xenon 7500 Watt Lamp—48 Hours

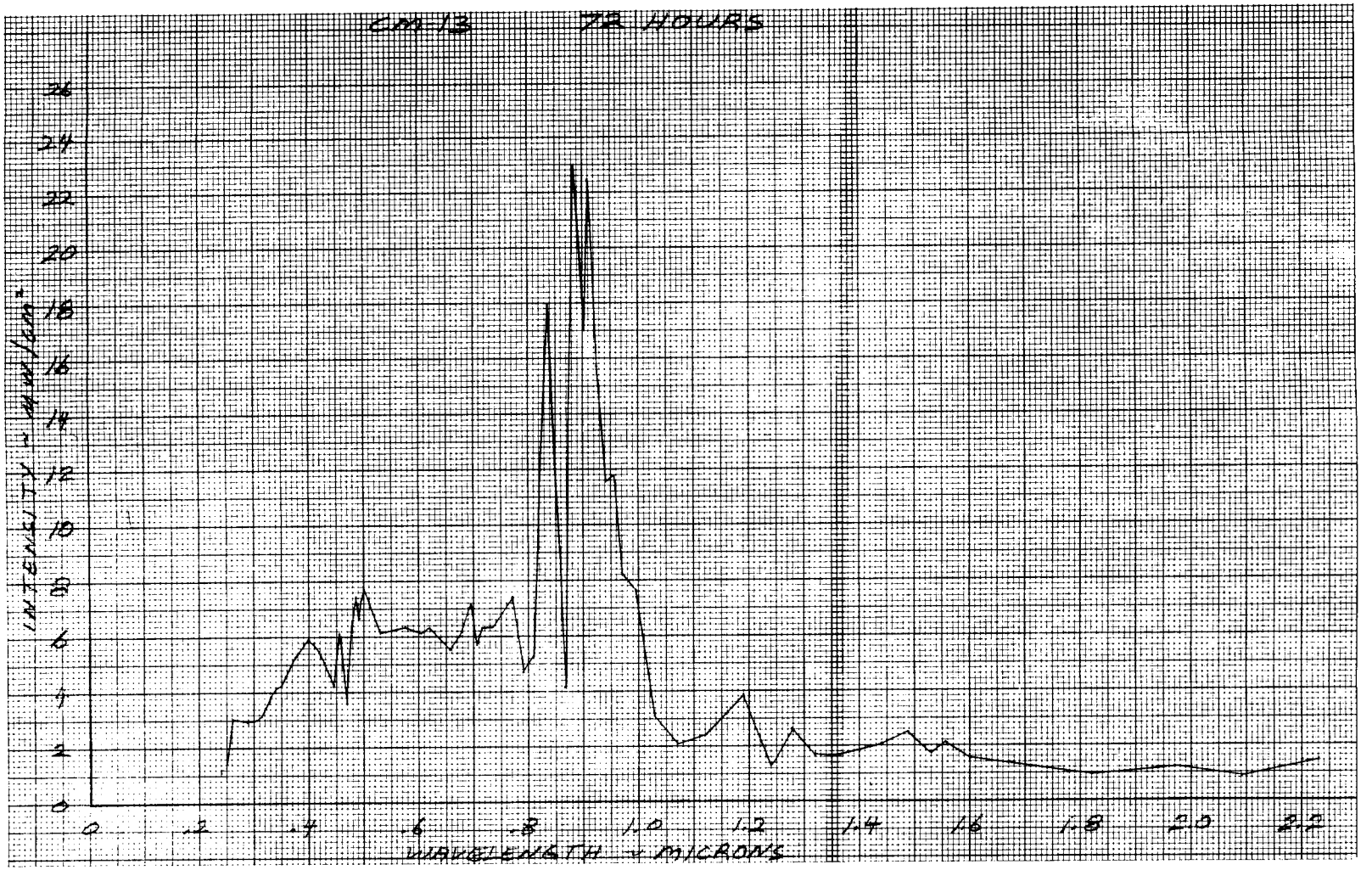


Figure 39. P.E.K. Xenon 7500 Watt Lamp—72 Hours

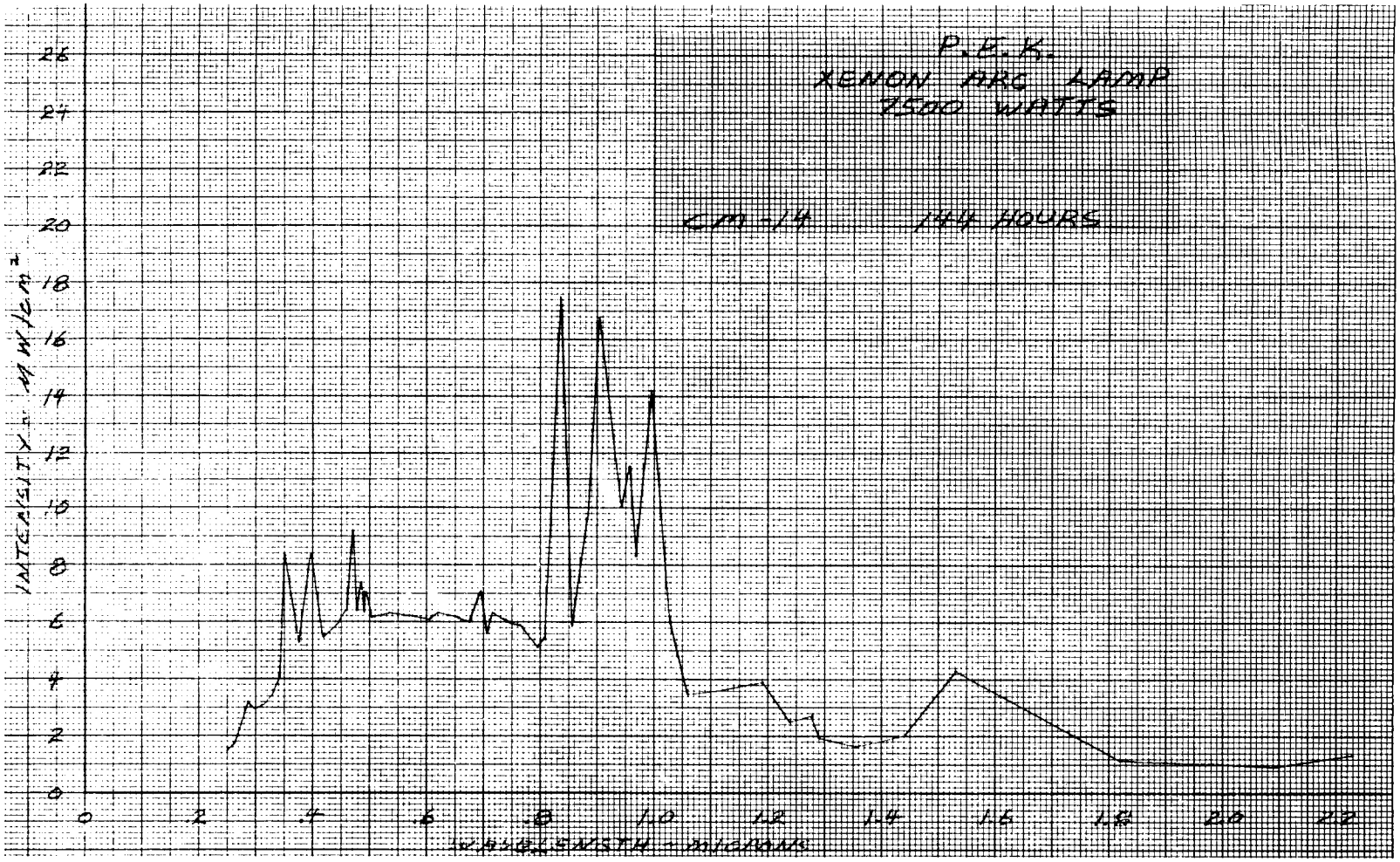


Figure 40. P.E.K. Xenon 7500 Watt Lamp—144 Hours

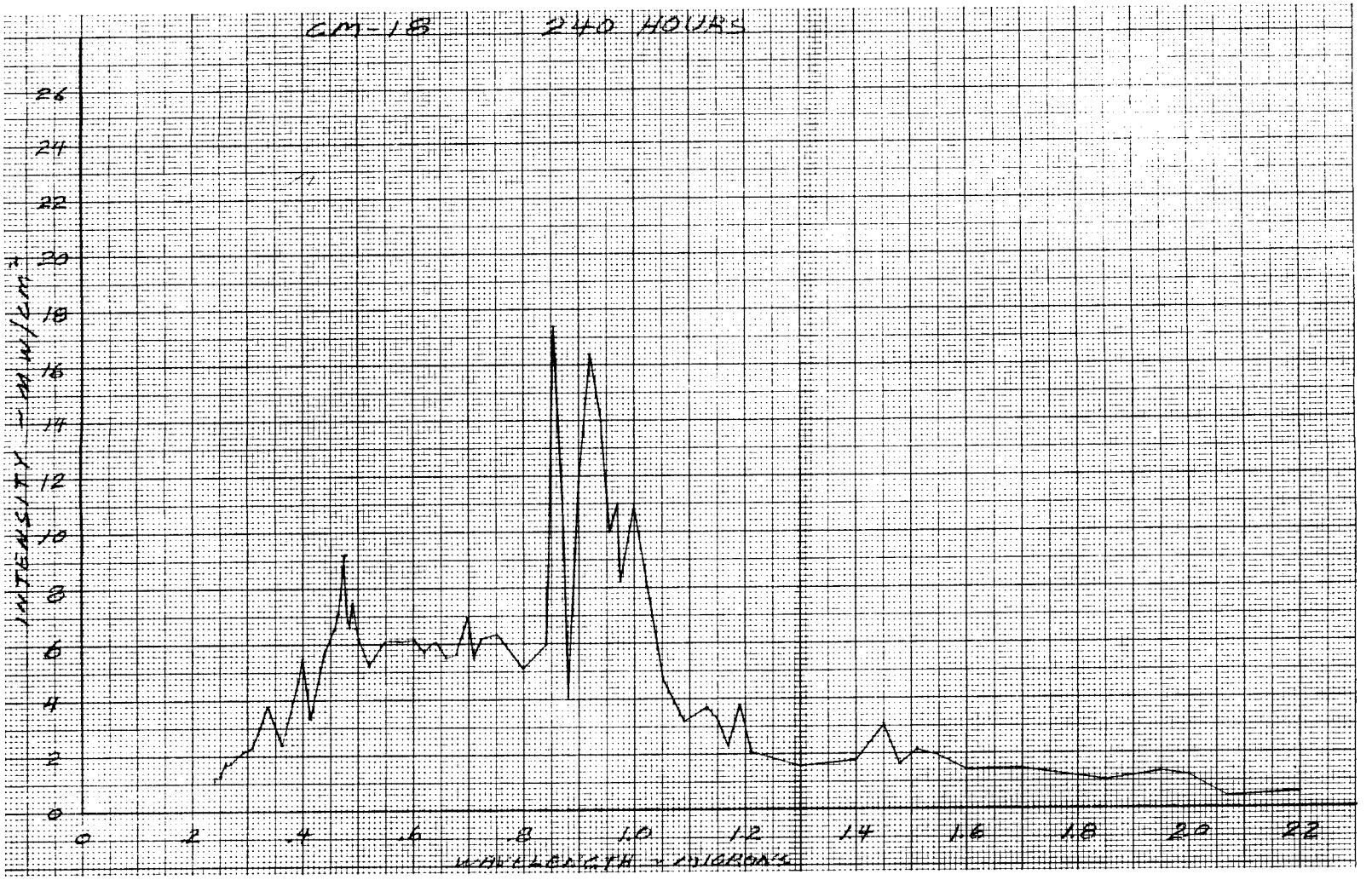


Figure 41. P.E.K. Xenon 7500 Watt Lamp—240 Hours

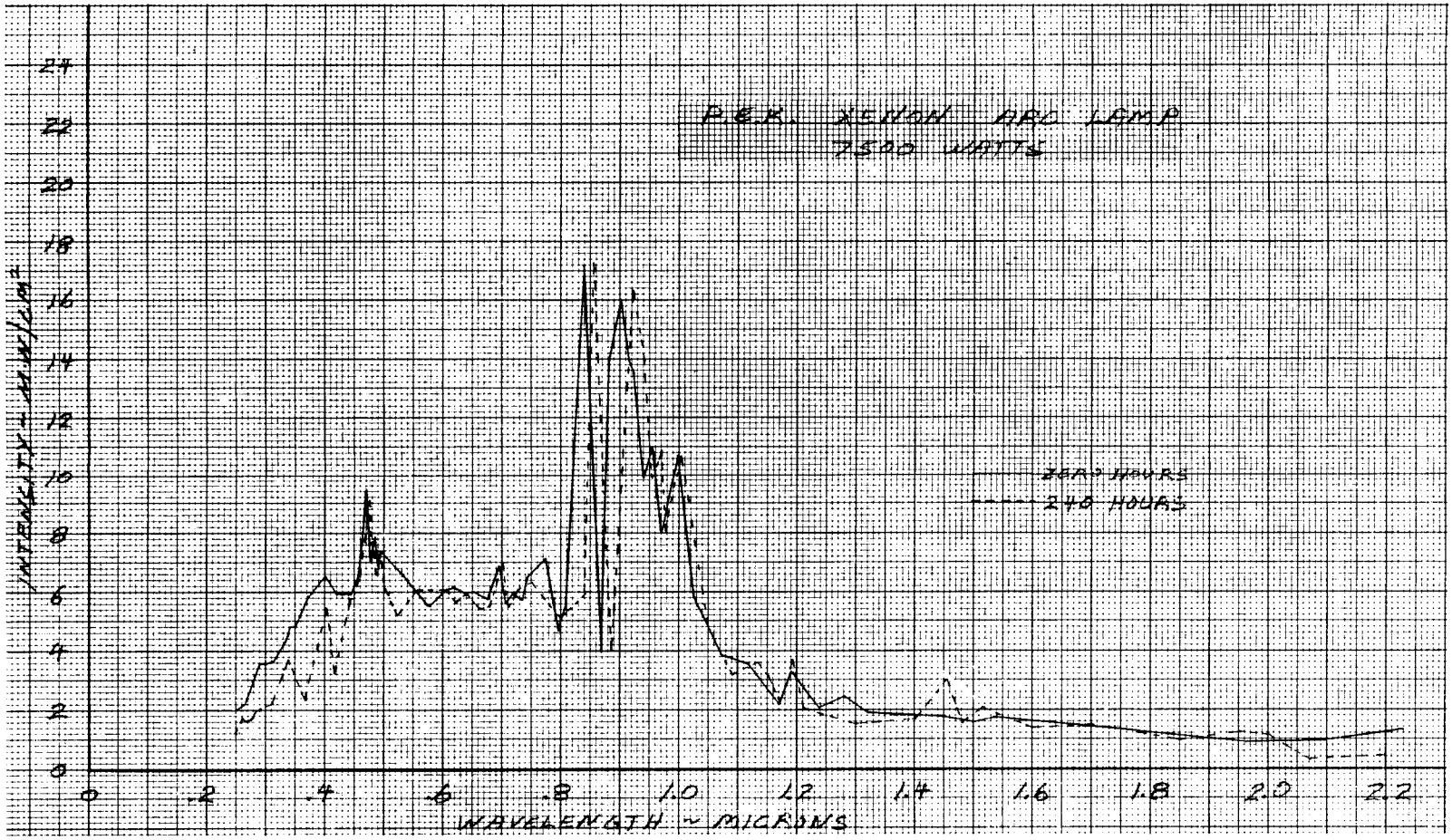


Figure 42. P.E.K. Xenon 7500 Watt Lamp—0 & 2

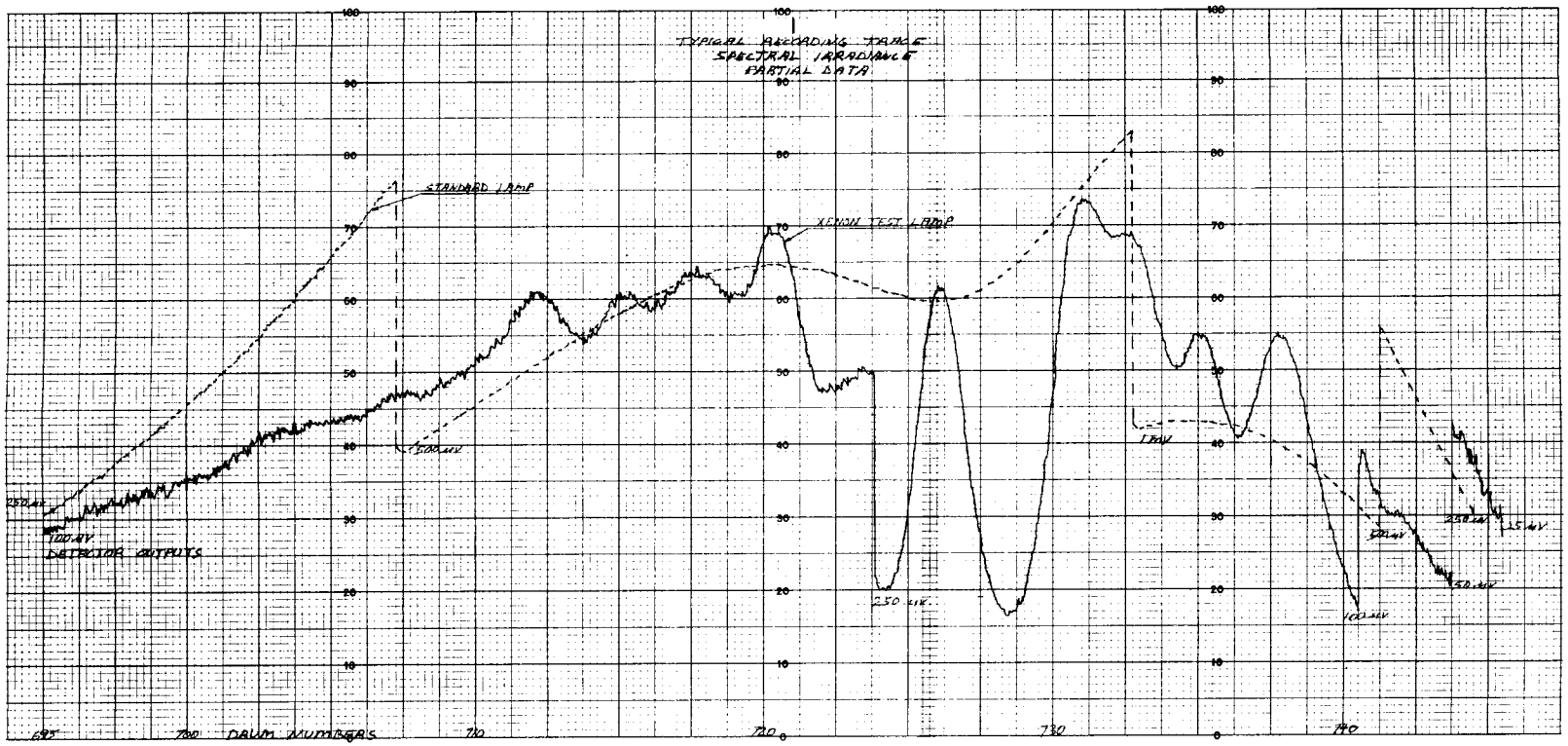


Figure 43. Typical Trace

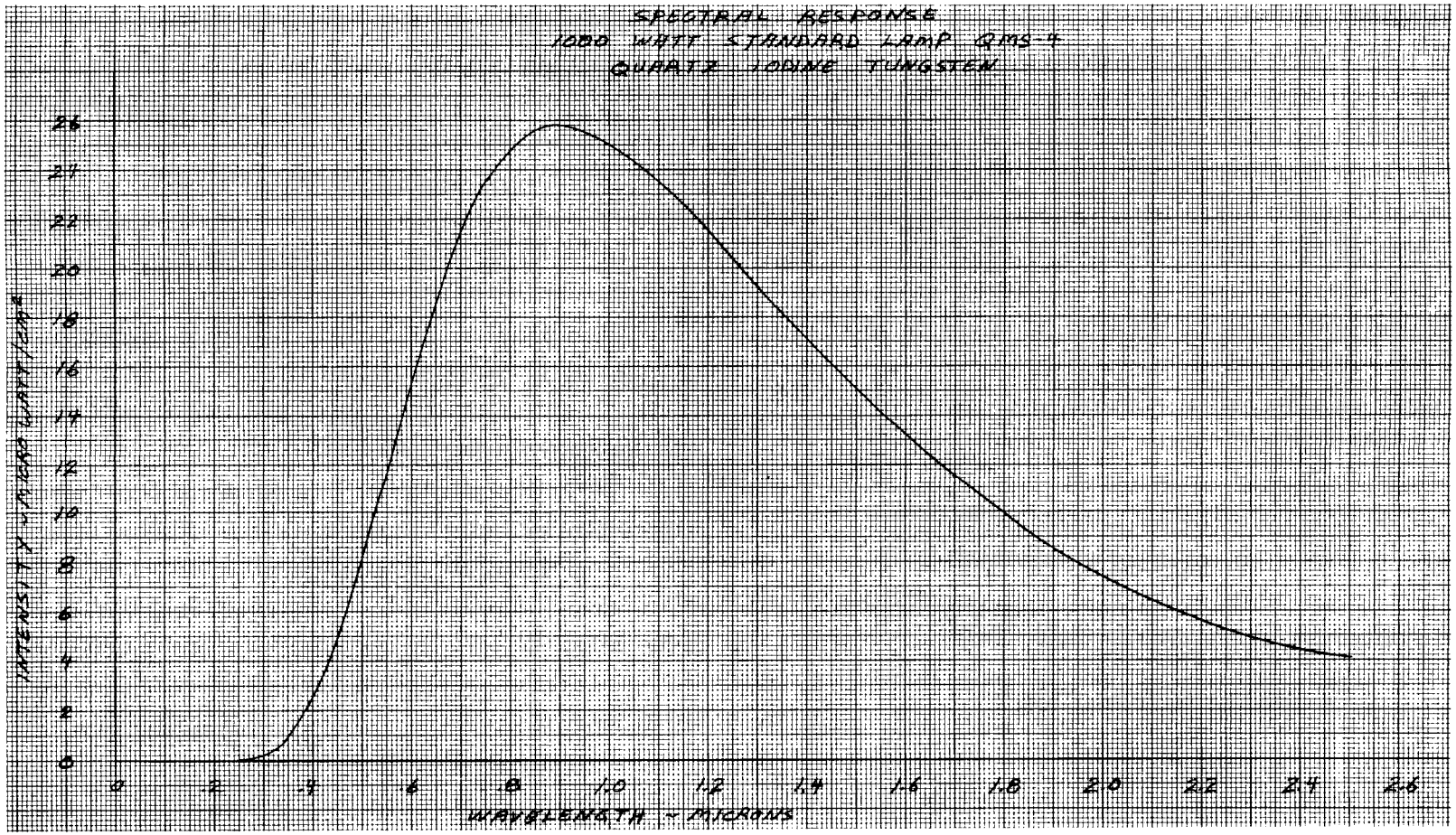


Figure 44. Standard Lamp Energy

Table 15
Schedule of Test Measurements

Lamp: Hanovia 2.5 kw		Lamp: Hanovia 2.5 kw with Aconio Reflector		Lamp: PEK 7.5 kw	
Run No.	Elapse Time	Run No.	Elapse Time	Run No.	Elapse Time
CM-1*	0 hours	CM-6	0 hours	CM-9	0 hours
CM-2*	72	CM-7	54	CM-10	24
CM-3	132	CM-12	106	CM-11	48
CM-4	228	CM-15	202	CM-13	72
CM-5	300	CM-17	274 hours	CM-14	144
CM-8	402			CM-18	240
CM-16	570 hours			Failure at	364 hours

* Painted sphere, remainder with smoked sphere.

MgO smoke for the remaining test measurements. The painted sphere resulted in a reduced signal output in the recording detectors. Please note the change in scale on the graphical plots of the 2.5 kw lamp with reflector. This increase in intensity was due to the partial collimation of the radiant beam.

Unfortunately, the 7.5 kw lamp failed, without warning, at 364 hours. Failure occurred by a crack in the quartz envelope near the positive electrode as shown in Figure 45. Immediately upon failure, the power supply shut off automatically and the lamp electrodes oxidized slightly to coat the internal envelope with a characteristic blue color, tungsten oxide. There was no other evidence of failure. The remaining two lamps are continuing in test.

Temperature

Temperature measurements of lamp electrodes and the aconic reflector obtained during test are shown in Table 16. The temperatures do not vary more than ±2°C during the entire period of testing.

Total Intensity

Total intensity measurements of lamp irradiance is obtained with a calibrated Eppley No. 6767 thermopile detector. Measurements are presented in Table 17 for two of the three test lamps. The remaining lamp, a 2.5 kw with aconic reflector could not be measured accurately due to a non-uniformity distribution in the radiant beam. A small change in location of the detector resulted in orders of magnitude changes in measured intensity with corresponding non-reproducibility. Therefore two total intensity measurements only are presented.

CONCLUSIONS

The test data presented represents an initial evaluation of lifetime characteristics on xenon lamps used in solar simulation. The lamps show a reproducible spectral distribution between the 2.5 kw and 7.5 kw sizes over the entire spectrum from 0.25 to 2.2 microns. The characteristic peaks between 0.80 and 1.0 microns do not appear to alter significantly during the lamp lifetime. Major changes which have some significant value, occur in the ultra-violet and near visible regions between 0.25 and 0.80 microns. These changes are typically the same in both the 2.5 kw and 7.5 kw lamps. Not so though, with the 2.5 kw lamp and aconic reflector. This arrangement of lamp-reflector-mirror optics illustrate a general decrease in intensity across the entire spectrum. This increase in degradation is probably due to reflector and micron changes.

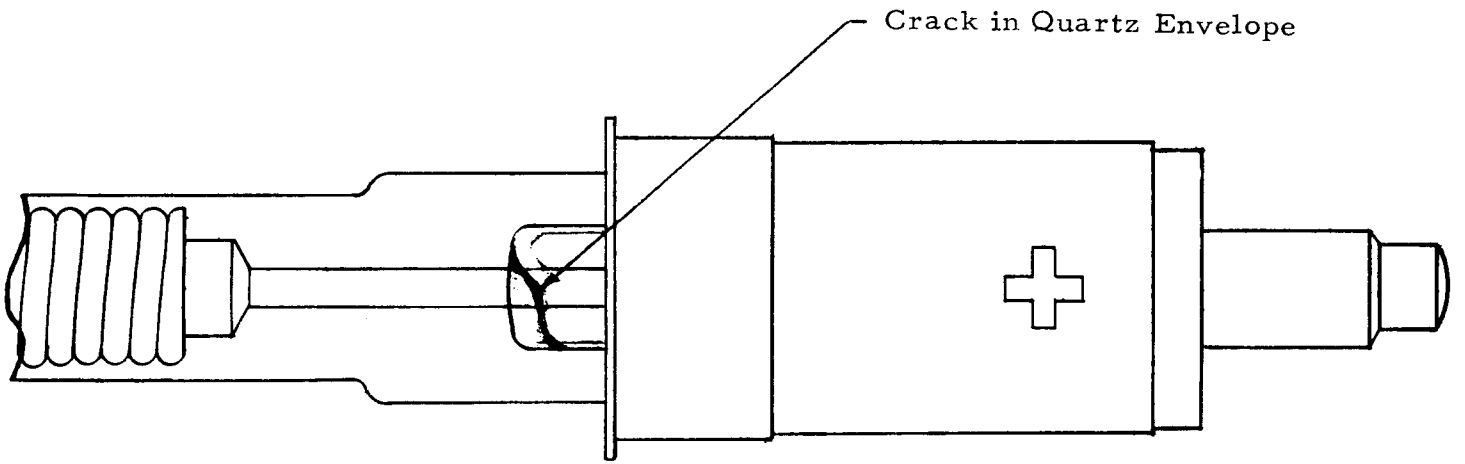


Figure 45. 7.5 kw Lamp Failure

Table 16
Temperature Measurements

T.C. Location	Lamp		
	2.5 kw	2.5 kw/Reflector	7.5 kw
Positive Electrode	150°C	80°C	134°C
Negative Electrode	114°C	75°C	47°C
Reflector 1		140°C	
Reflector 2		85°C	
Reflector 3		63°C	
Reflector 4		100°C	
Reflector 5		60°C	
Reflector 6		55°C	

Note: Room Temperature: 27°C ±5°

Table 17
Total Intensity Measurements

Lamp: 2.5 kw	
No. Hours	MV
0	0.990
72	1.020
132	1.009
300	1.020
400	0.966
450	0.948
550	0.939

Note: Distance from lamp to detector: 37 inches

Lamp: 7.5 kw	
No. Hours	MV
0	1.050
24	1.005
48	0.948
72	0.960
144	0.969
240	0.810
364	Failure of lamp

Note: Distance from lamp to detector: 61 inches

Detector: Epply thermopile with calibration constant: 6.05 MV/139.6 mw-cm^{-2}

These data, although reduced manually, illustrate the level of confidence an investigator might assign to the usage of xenon lamps for solar simulation. Further reduction of the data by a computer program at a later date is not expected to make any significant changes in the overall results.

Testing of the two remaining lamps is in progress and will continue to approximately 1200 hours of operation. The additional data obtained at longer life periods will be added to this report at a later date.

N67-32599

SECTION VI

CONVAIR 990 FLIGHT EXPERIMENT

J. J. Webb

ABSTRACT

Work during the last quarter was concerned primarily with the repair of the Electronic Scanning Spectrometer (ESS). It has not been in operation for several months because of damage to all its circuit boards. After considerable troubleshooting and circuit modification, the instrument is now operating normally. The ESS is presently undergoing wavelength and intensity calibrations, as well as refinements in the data acquisition technique to be used on board the aircraft. The special support structure required to mount the ESS in the plane is now being designed and fabricated, as are the entrance optics.

CONVAIR 990 FLIGHT EXPERIMENT

As reported previously, an internal short on the high voltage power supply circuit board caused considerable damage to the electronics of the ITT Electronic Scanning Spectrometer (ESS). Repairs have been completed on all circuits except the power supply board. The heart of this board is a transformer-coupled feedback oscillator and voltage doubler which converts 20 volts DC to 2500 volts DC to power the image dissector tube. There was apparent damage to the transformer itself which made it necessary to re-wind the entire unit. The requirements for proper oscillation are complex and somewhat critical and as yet the circuit has not been put back into operation.

A simpler type of oscillator was bread-boarded to replace the damaged circuit. This oscillator was a phase-shift type employing only resistors and capacitors. It was designed to operate with a 20 volt input at 8 kc. An emitter follower was also designed and built to match the impedance of the transformer. While laboratory tests indicated that the circuit was very stable, it was eventually decided to abandon this approach since the total components and power requirements made the configuration impractical for the small space available. Therefore, two external power supplies were used as substitutes for the malfunctioning board; a 2500 volt supply for the dissector tube and a 20 volt supply for the amplifier and timing circuits. The ESS now appears to be working normally, and could be used in the flight experiment as is if the power and weight restrictions of the aircraft allow the use of this external equipment.

A circuit was designed and built to manually scan the face of the dissector tube since no equipment is available to permanently record the data in the rapid scanning mode. The data are now recorded on an EAI X-Y plotter whose X-axis is driven by varying the output of a small power supply.

An integrating sphere was originally intended to be used as the diffusing optics of the ESS, but calculations indicate that this may not be feasible. While the sun's energy at 40,000 feet should easily be detected, the UV energy from the 1000 watt quartz-iodine standard lamp is apparently not strong enough to overcome the inefficiency of the sphere. A magnesium oxide block may be used in place of the sphere.

The ESS is presently undergoing electrical alignment and wavelength calibration. The originally computed S-response is also being verified. A rotatable platform is being designed which will allow the ESS to track the sun by manual adjustment.

During the next quarter, the ESS will be readied for the flight experiment both mechanically and electrically. The support structure will be built and the flight configuration will be mocked-up in the laboratory. The project appears to be proceeding more or less on schedule, with a possible delay only in the fabricating of the frames and entrance optics.

N67-32600

SECTION VII

COATINGS QUALITY ASSURANCE

A. J. Hobbs
Ben Seidenberg

ABSTRACT

DEGRADATION EQUIPMENT

1. Eight getter-ion/Titanium sublimation pumps (ULTEK) together with controls and power supplies were received and all units have met specifications.

2. A newer, wider range instrument for accurately measuring the thickness of paint coatings has been ordered by exchanging the old instrument together with a negligible sum of money for this new one (Permascope).

3. Project to manufacture on site (GSFC) lamp housings and holders as designed by our group and S. Hall of EMR or purchase them is reactivated. Housings to accommodate 2.5 kw osrom xenon and Hanovia 5.5 kw xenon source interchangeably.

COATINGS QUALITY ASSURANCE

COATINGS R&D

1. Our group has received another black metallic oxide coating for vacuum chamber interiors. This coating possesses at least one superior physical property as compared to a previous submission. These specimens are being measured optically and will be tested later by our group.

2. Our group has completed an interim study (quantitative) of volatiles emanating from Boeing specimens with some interesting results.

3. We were able to reintroduce our thermal shock coatings array into an empty vacuum chamber, with the cooperation of T&E, for roughly an additional week of thermal shock. Coatings specimens are still intact. Our intention is to expose the array to a still more severe environment in our next exposure. At this writing the array is outside the chamber, stalled again for lack of facilities and support.

4. R. Brown of Boeing may be visiting us at GSFC sometime in March with data from the first test planned on the blueprint (50 kev electron scan at 23°C, exposed and measured in vacuum) under contract NAS-5-9650.

5. Support was provided for N. Ackerman of the Temperature Control Section to aid him in solving a coatings problem on the RAE satellite.

DISCUSSION

DEGRADATION EQUIPMENT

1. A. J. Hobbs of our group and R. McIntosh of EMR represented us at Ultek upon notification by Ultek that the eight "clean" pumping systems ordered were ready for inspection and operation. However, upon their arrival at Ultek's plant in Palo Alto, California they found that this was not the case. Ultek was totally unprepared and they are paying Mr. Hobb's salary and per diem for most of his stay at their facilities. After a thorough inspection job and some advice on the part of Mr. Hobbs, Ultek finally completed the systems to our satisfaction at plant site. The systems were unpacked with the aid of their sales representative, M. Gilbert. This was done to insure any damage that might be noticed was not damage that occurred due to our unpacking operations

(i.e., damage incurred during transit). The sorption pumps were found to be devoid of pellets, some accessory hardware (proper nuts and bolts) were found to be incorrect and some copper gaskets that fit between the eon and sublimation pumps were found to be missing (extra pack). However, all the shortages in hardware have been overcome and the systems have all been checked out by us as to performance. It should be noted that the special set of instructions, booklets, etc. covering the proper operation and maintenance of these systems have not been received by us to date. Our procuring officer, Mr. J. Higgins has been notified. We are at present gearing up to expose some coatings specimens in our systems (metallic oxide coatings).

2. The permascope, an instrument (utlizes induced eddy currents) designed to non-destructively measure the thickness of a paint coating (in this case on a non ferro-magnetic metal substrate), was purchased. The instrument will measure coating thicknesses from 0.001" to 0.100". This transaction was accomplished by forwarding our earlier model, limited range permascope together with approximately $100-$150 to the instrument company in exchange for the newer model.

3. The manufacture or purchase of a lamp housing or housings has been kept in abeyance pending the arrival and checkout of the ion/sublimator pumping systems. This was done so that a better overall design view could be obtained prior to committing additional time and funds. This project has now been reactivated and we are now seeking prices on basic designs.

COATINGS R&D

1. The previous group of black metallic-oxide coatings tested had a normal emittance of approximately 0.62-0.64 which is generally considered low. However, further effort has produced an improved coating with a normal emittance of 0.81-0.82. It will be necessary to expose the two different types of metallic-oxide blacks to simultaneous UV exposure in our own vacuum chambers as we can not again obtain the chamber previously used.

2. Our group designed a test to primarily check the degree, if any, of volatilization upon exposure of the Boeing coating specimens to a vacuum oven. Carmen Nicoletta of our group performed and monitored the work upon this experiment. The alkali silicate paints all exhibited extreme cracking and film disruption. The vapor deposited aluminum on a Logo lacquer undercoating shriveled up badly. The Boeing series P specimen appeared macroscopically and microscopically to have come out best among the white paint specimen candidates. The Boeing series O (Joe Colony's TiO_2 paint) exhibited the

greatest percent volatility under these conditions. Results are shown in Tables 18 and 19 and Figures 46-57.

3. We were able, in spite of many obstacles, to reexpose the thermal shock array in a T&E vacuum chamber for an additional week. The coatings are all still intact. However, we are at present again outside the chamber due to a lack of available facilities and support. We plan to make the extremes of the temperature environment more severe possibly -150° C to +120° C (based on a Boeing series A white in the configuration). We also plan to rephotograph the specimens on the first sign of adhesion failure anywhere in the array.

4. Mr. R. Brown of Boeing indicated he may be visiting our group sometime in March (possibly March 1st) with data concerning the Boeing coatings specimens and the results of their irradiation by 50 kev electrons at 10° C. The irradiation and optical measurements will have been made in-situ. This data will be the result of a contract negotiated by Mr. M. Schach and technically monitored by B. Seidenberg.

5. N. Ackerman has requested our aid and support in determining or certifying a thermal control white paint to be used on a section of the solar cell paddle of the RAE satellite. He could not obtain for us proper testing facilities (vacuum chamber large enough to accommodate specimens together with temperature controls) to test the specimen array our group had designed with an eye towards answering his problem. (We were aided in this endeavor by R. Sheehy and his people.) Our group was forced to design a test that would subject the various specimens of painted aluminum (on 2025 alloy) to severe thermal shock. It was hoped that the results, if favorable, could be relied upon to certainly pass the temperature parameter set-up for it at T&E (namely, -140° C to +89° C). The previous coating, Colony's methyl silicone/TiO_2 applied over General Electric primer failed by losing adhesion in the T&E test. At the writing of this report most of the test has been completed and a full report concerning this work follows:

THERMAL CONTROL COATING ADHESION FAILURE ON RAE SATELLITE SOLAR PADDLE

Our aid was recently requested by N. Ackerman to help solve a coatings adhesion failure that had occurred during testing at T&E.

BACKGROUND

A thermal control white coating had been applied to a section of the solar paddle and had lost adhesion to the substrate material. This substrate, we are

Table 18
Results of Temperature and Low Vacuum on
the Paint Specimens Shown Below

Boeing Series	% Loss after a Total Exposure of 194 hours at 220° F
A-66 Methyl Silicone/TiO_2 (Anatase) over Cat-a-lac White	1.2
B-82 Zerlant S-13 Methyl Silicone/ZnO	0.2
C-118 Methyl Silicone (Dow Corning)/ZnO over Cat-a-lac White	0.5
D_3-162 Potassium Silicate/Al_2O_3	0.8
E_3-170 Potassium Silicate/TiO_2 (Rutile)	1.3
F_3-74 Potassium Silicate/ZnO	0.8
L-183 Methyl Silicone/TiO_2 (Anatase) over Cat-a-lac White Same as A except that Methyl Silicone coating is thicker.	0.5
L'-145 Same as Series L except that surface had strippable material applied to it prior to testing.	0.5
J-126 Vacuum deposited Aluminum over Logo lacquer	1.0
M-131 S-13G - Zerlant Methyl Silicone w/Potassium Silicate mixture/ZnO	0.9
O-93 Over General Electric Primer J. Colony's Methyl Silicone/ TiO_2 (Rutile)	3.1
P-62 Dow Corning XR 3489/Rutile TiO_2 made by B. Seidenberg and A. J. Hobbs	0.8

Table 19

Specimen	Description of Photographs
A-66	Photomicrography failed to show any surface film defects that were due to exposure. Black specks on surface due to unclean environment.
B-82	Exhibited slight dimpling of the surface as compared to original surface. Original surface (initial-prior to exposure reveals an uneven surface).
C-118	No visible film defects were discernible due to exposure.
D_3-162	Reveals a great deal of cracking and uneven surface.
E_3-170	Reveals a great deal of cracking and uneven surface.
F_3-47	Reveals a great deal of cracking and uneven surface.
L′-145	No visible film defects were discernible (line (V-shaped) is residue from strippable coating) due to exposure.
L-183	No visible film defects were discernible due to exposure.
O-93	Slight uneven surface resulted from volatiles.
M-131	No visible defects discernible due to exposure.
P-62	Exhibited smoothest film surface prior to and after exposure.
J-126	Exhibited severe "creep" or shriveling of surface due to exposure.

Figure 46.
A-66
After 194 Hours
at 220°F
30" Vac

Figure 47.
B-82
After 194 Hours
at 220°F
30" Vac

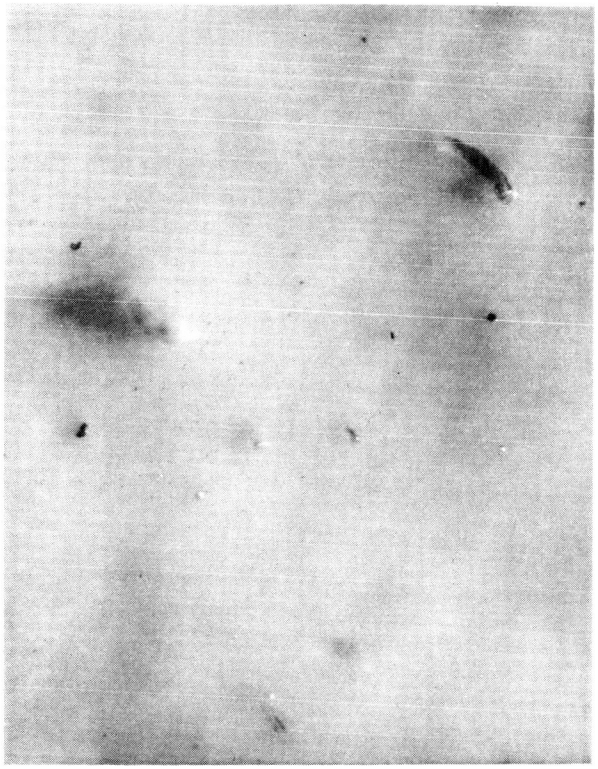


Figure 48.
C-118
After 194 Hours
at 220°F
30" Vac

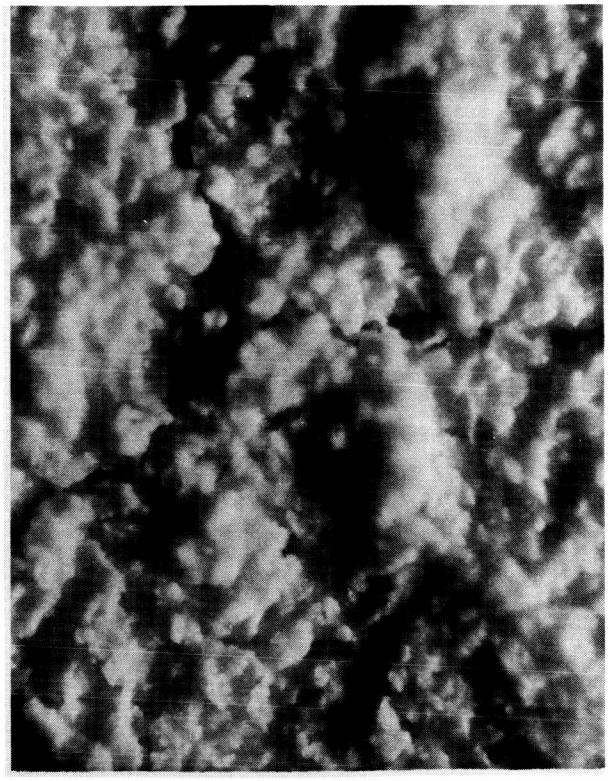


Figure 49.
D-162
After 194 Hours
at 220°F
30" Vac

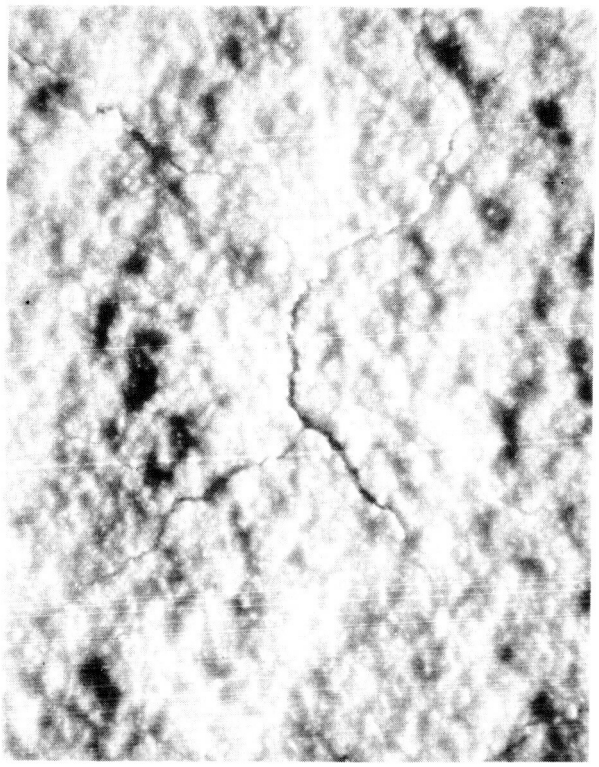


Figure 50.
E_3-170
After 194 Hours
at 220°F
30" Vac

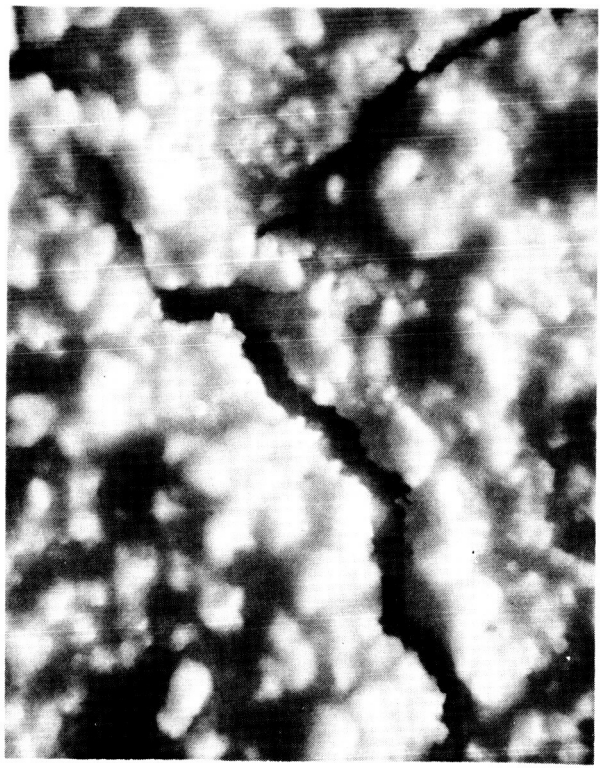


Figure 51.
F_3-47
After 194 Hours
at 220°F
30" Vac

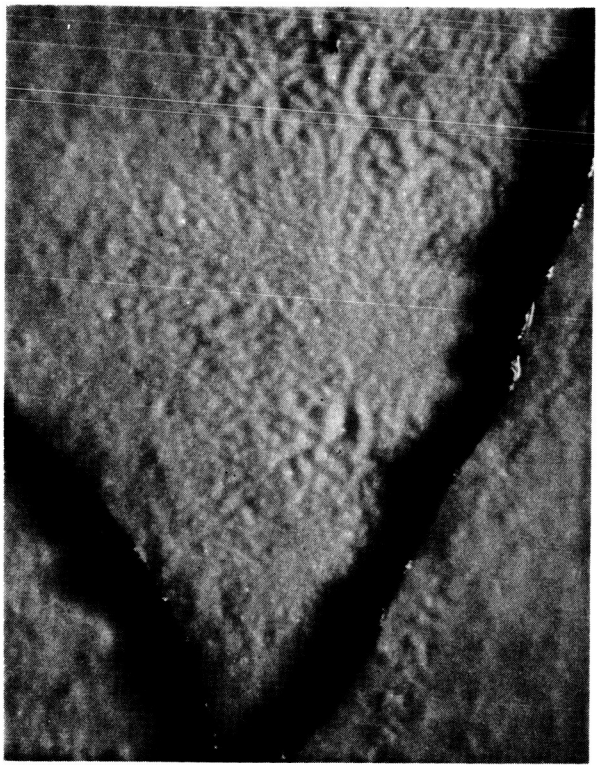


Figure 52.
L'-145
After 194 Hours
at 220°F
30" Vac

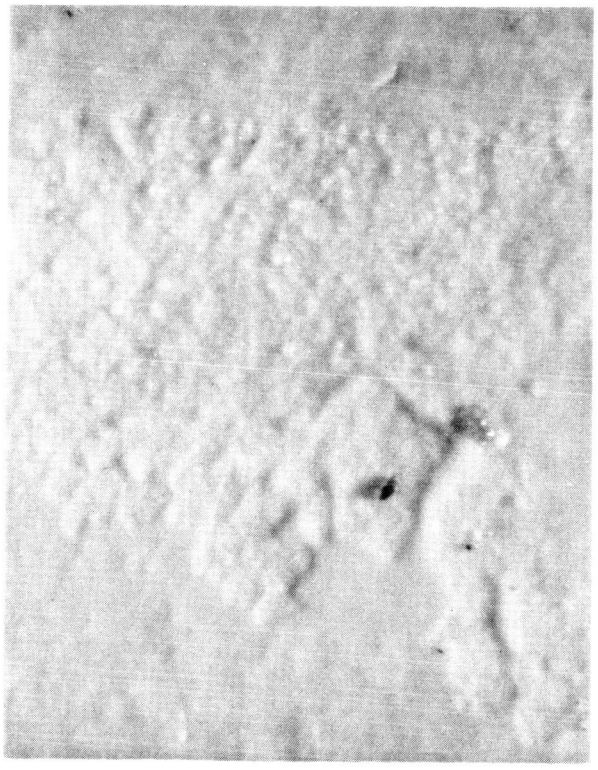


Figure 53.
L-183
After 194 Hours
at 220°F
30" Vac

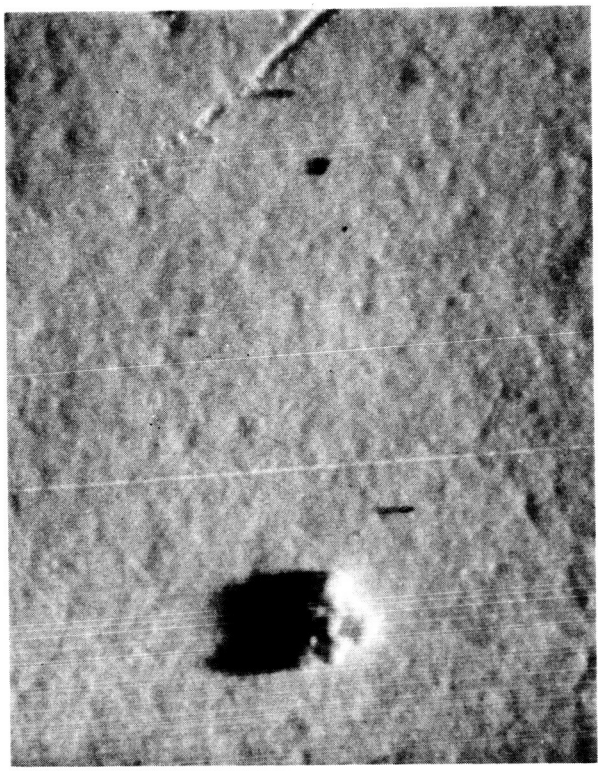


Figure 54.
O-93
After 194 Hours
at 220°F
30" Vac

Figure 55.
M-131
After 194 Hours
at 220°F
30" Vac

Figure 56.
P-62
After 194 Hours
at 220°F
30" Vac

Figure 57.
J-126
After 194 Hours
at 220°F
30" Vac

informed, is a 2025 chromic and anodized aluminum alloy which is shipped from Fairchild Hiller with a protective coating (either a wax or protective polymer). The substrate was prepared for paint application by R. Sheehy's group following standard application procedure to metallic surfaces (abrasion followed by chemical cleansing and degreasing). The thermal control white coating was a paint prepared at GSFC by J. Colony and essentially a mixture of a methyl silicone vehicle and a TiO_2 pigment. This paint was catalyzed and cured at room temperature. The temperature parameters to which the satellite was to be subjected, we are informed, was to be approximately -140°C to +89°C (during an interim period of roughly 24 hours).

DISCUSSION

We requested through Mr. Ackerman but obtained limited amounts of 2025 aluminum alloy from Fairchild. They were:

1. 4"x6" piece of recently processed unsealed chromic acid anodize—metal thickness 0.050"

2. 4"x6" piece NPN unsealed chromic acid anodize—OLD—0.020" thickness, and

3. Unsealed chromic acid anodize—OLD—0.065" metal thickness.

The metal substrates were cut into 1-1/2" square specimens, abraded and cleansed by us according to SOP obtained from R. Sheehy's group. We requested test facilities to simulate precisely the test environment in which satellite failure had already occurred. However, none were available or made available to us so that we resorted to the following test:

1. Complete immersion into a Dewar containing LN_2 for 60 sec. (-195°C)

2. Brought to ambient environment for 30 sec. (25° - 27°C)

3. Onto a hot plate whose surface temperature reads approximately +83°C for 180 sec. (specimen covered by an aluminum dish)

4. Specimen brought back for 30 sec. to ambient environment

5. Specimen is then reintroduced into LN_2 for 1 minute and the specimen is examined.

This test was designed to check adhesion of various coatings and coatings combinations under severe temperature conditions and not as a test to simulate actual conditions.

TEST SPECIMENS

I. Recently processed unsealed chromic acid anodize—0.050"

A. Dupont primer/3M white (2 pt. system)

B. Dupont primer/3M white/GE primer/P paint (methyl silicone TiO_2 paint made by our group)

C. Dupont primer/3M white/GE primer/Colony's ZnO methyl silicone paint

D. Dupont primer/3M white/Colony's ZnO methyl silicone paint

E. Dupont primer/3M white/P paint

F. Cat-a-lac white

In all of the above cases the 3M white was approximately 0.003" thick.

G. GE primer/Colony's methyl silicone ZnO paint

H. GE primer/B. Seidenberg's P methyl silicone TiO_2 paint

II. NPN 9955—0.020" thick

III. Unsealed chromic acid anodize—OLD—0.065" coating applied on both above series as per A-H

IV. Dupont primer/3M white/Dow Corning primer (Sylgard)/0.008" of D.C. Q92-007 TiO_2/ methyl silicone

V. Dupont primer/3M white/GE primer/0.008" of D.C. Q92-007 white

VI. Dupont primer/3M white/0.008" D.C. Q92-007

VII. Cat-a-lac primer/Cat-a-lac white 0.008" D.C. Q92-007 white

VIII. Dupont primer/3M white/Q 92-0090

IX. D.C. primer (Sylgard) 0.008" D.C. Q 92-007 paint

Coatings IV through IX were applied onto 0.025" thick 6061 aluminum as it was the thinnest aluminum available to us on base and the only alloy we could get readily. (There was not enough metal to be had from the 2025 alloy Fairchild forwarded to us.)

TEST RESULTS

The II Series was chosen because it represented a substrate with the thinnest cross section (0.020") and therefore it was correctly felt would give the severest test (flex with temperature shock). Only the Cat-a-lac (II F) and the (II A) 3M white passed the test completely in the series II A through II H. II C exhibited adhesion failure at one corner or edge in all tests (methyl silicone lifted only) and the control specimen II G came away completely from the substrate as in the test at T&E. The composite coating represented by II C exhibited by far a greater adhesion to the substrate than did the control II G and there is a good chance (based on this test) that had the coating been applied as per II C that a coating failure could have been averted. However, under thermal shock conditions this is at best a marginal coating. All specimens IV through IX passed the test completely. At this point I would like also to point out that III E passed while specimen II E failed thereby emphasizing the role of substrate thickness or rigidity. In other words a coating may pass on a substrate that does not undergo flexing due to severe temperature exposure but will or may fail when exposed to dynamic conditions such as substrate flexure.

CONCLUSION

The Q 92-007 Dow Corning white methyl silicone/Rutile TiO_2 paint applied to a 3M white substrate primed with Dow Corning Sylgard primer offers the best solution for averting an adhesion failure on the RAE satellite. However, it should be noted that the results and conclusion are based on a severe, thermal shock experiment carried out in air and does not resemble in any respect the actual failure or test condition the RAE will encounter. We feel that a Sylgard primer applied between the two white coatings will give added insurance against an adhesion failure.

Note: Test specimens retained by Q.C. Assurance Lab.

COMPOSITION OF BOEING SAMPLES

We have launched an investigation into the basic formulae of the Boeing specimens D, E and F series (alkali silicate binders) in an effort to dispel the hearsay, etc. and better understand degradation results when they become available from Boeing.

This work was carried out with Bill Riffle of the Advanced Theoretical Studies Lab employing X-ray analysis.

Specimen #	Al	Ti	Zn	Si	K
D	3.4	1.0	1.1	1.0	1.0
E	1.1	655	1.0	2.1	1.8
F	1.0	484	18.5	2.2	1.8

Conclusions:

Specimen D contains essentially α Al_2O_3

Specimen E contains essentially α Al_2O_3 plus rutile TiO_2

Specimen F contains essentially as much Al_2O_3 as E, less rutile TiO_2 than E and much more ZnO than E.

It would appear, from the analysis, that the paints may have been prepared separately and then mixed in given proportions, that is that a separate Al_2O_3, TiO_2 and ZnO paints all using K_2SiO_3 vehicle, were prepared and then mixed resulting in a culmination of three oxides (Zn, Ti, and Al).

Note: Graphs from X-ray diffractions being retained by Q. C. Lab.

CONCLUSIONS AND RECOMMENDATIONS

We have pointed out in many previous discussions that a serious space shortage exists here for our effort. The need for more space has gotten more acute in view of the arrival and imminent set-up of all vacuum systems. Also, we should have room for the electronic scanner and bench scale experiments.

We again recommend that the suggestions we made for a meaningful Quality Control effort be adopted in line with our memo to M. Schach dated 10/14/66 (Appendix III).

We should also like to point out as we did in our previous quarterly report that prior to the usage of a new paint or coating by another section of our Branch that our group be notified and consulted as it may help to stave off coatings failures.

We conclude as we did in the previous quarter with the suggestion that degradation work and coatings certification be more centralized in the present and emphatically in the future in order to obtain better organization, conserve funds, space, equipment and make the most efficient use of manpower.

N67-32601

SECTION VIII

COATINGS DEGRADATION

Carmen A. Nicoletta

ABSTRACT

1. Present test facilities and plans for new facilities, relating to vacuum chambers and particle sources.

2. Results of current testing and its significance.

3. Future plans regarding proton irradiation and further electron irradiation of thermal control coatings.

RADIATION DAMAGE PERTAINING TO COATINGS QUALIFICATION TECHNIQUES

I. FACILITIES

Presently there are two chambers concerned with particle irradiation of thermal control coatings. The first, an ULTEK chamber capable of 10^{-6} ton, is being used with a Van de Graaff accelerator for electron irradiation. The chamber is pumped by a vac-ion pump and contains a chain-driven wheel assembly, whereby up to 18 samples can be exposed. This chamber does not now have any in-situ capability. Plans are being formulated to re-design it for in-situ optical measurements through Electro-Mechanical Research Co., College Park, Maryland. Figure 58 shows a sketch of the movement to be incorporated. Note the modification still makes use of a wheel assembly for several samples. Three ports allow for particle, ultra-violet and optical measurements. Since this chamber will be used to expose samples to lower energy particles than now available, a turbo-molecular vacuum pump would be used in place of the present vac-ion device.

The second chamber mentioned is now being designed by Fairchild Co. This is a single sample chamber, pumped by a turbo-molecular system, capable of a vacuum of 10^{-8} ton. It allows for in-situ measurements of samples exposed to particles and ultra-violet radiation separately. Figure 59 shows blueprint drawings of the design being currently formed. To be used with this chamber and the re-designed ULTEK chamber, we hope to have our own particle irradiation capabilities. This would be in the low energy range of energetic particles (100 ev - 30 kev). A system for supplying electrons and protons in this range is the ORTEC R-F Ion Source System, Model No. 334, which we hope to purchase soon.

II. TESTING

During the past quarter, in cooperation with J. Hirshfield of the Space Power Technology Branch, samples of paints of both the alkali silicates and methyl silicones vehicles were exposed to electrons in a vacuum of 10^{-6} ton. Runs were made on thirteen samples at three different energy levels and at fluences somewhat higher than would be experienced by the ATS-A satellite during a year in orbit. These energies were 1 Mev, 700 kev, and 400 kev at fluences of 10^{14} electrons/cm^2. Separate samples of the same lettering code were exposed in each of the three runs. The samples were measured optically in the visible region just before and within twenty minutes after irradiation by

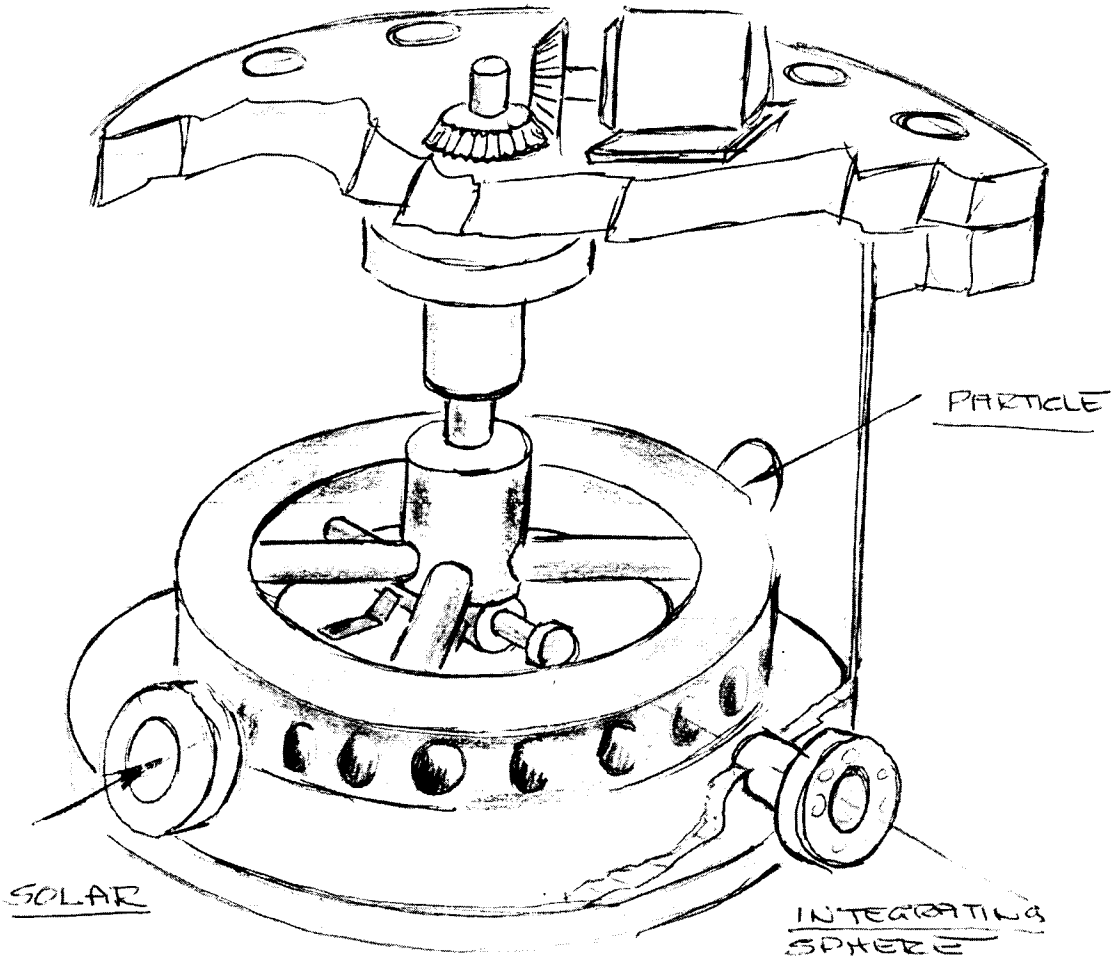


Figure 58. Ultek Chamber Design

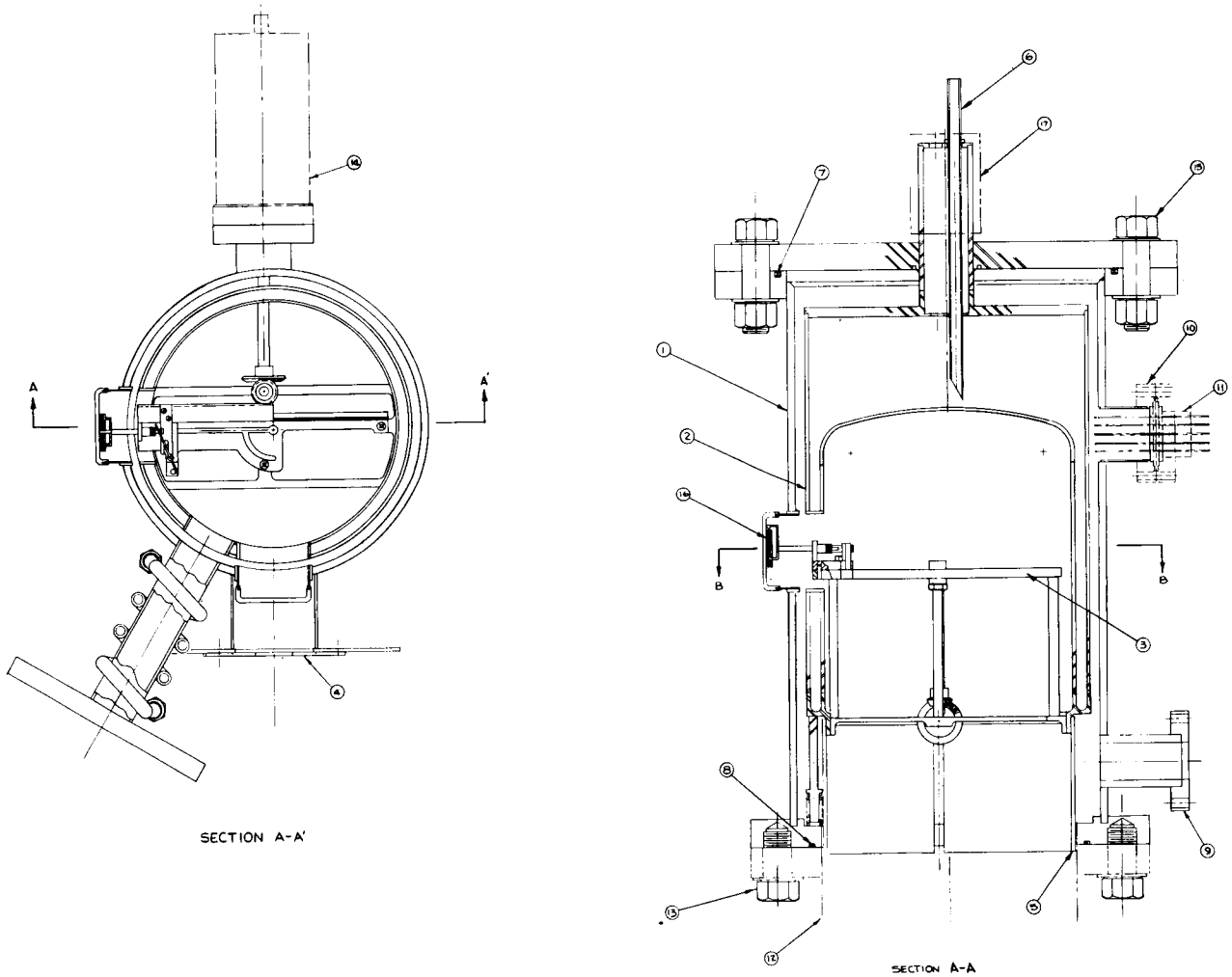


Figure 59. Design of "in-situ" System

J. Heninger. The samples used were B, C, D_3, E_3, F_3, L, M, O, P, Cat-a-lac white, 007, Cat-a-lac black, and 3M black. Samples E_3, P, Cat-a-lac white, and O are shown in Figures 60-71, and as being quite representative of the results found.

At 1 Mev, Figures 60-63 show no change in optical reflectance at all, at 700 kev, a definite change appeared visually, as is shown in Figures 64-67. This was seen immediately upon removing the wheel from the chamber. During this particular run, considerable heating of the vac-ion pump was noticed, causing the entire chamber and wheel to heat up. The temperature was about 30° C. Due to this, it is highly possible that considerable outgassing of the samples could occur. This was found to be the case in experiments carried out on thermal control coatings in a low vacuum, under elevated temperatures. It was found that some of both types of vehicles, methyl silicones and alkali silicates, showed a volatility greater than 1%. A possible mechanism of surface damage might be due to some of these volatile organic molecules being adsorbed on some of the surfaces, very likely on the silicates, to produce optical changes. At 400 kev the change in reflectances is seen to be small, somewhat around 1.0%-3.0%. Since the flux of all energy beams was the same, along with the fluence, it seems unlikely that the change seen at 700 kev was due to the effect of electron bombardment. Table 20 shows the results of the 700 kev run. At this point, it is difficult to know the exact amount of any annealing of defects which might occur, due to the lack of in-situ capabilities.

Theoretically the energy loss by electrons increases, from electrons incident at 1.5 Mev, to a maximum, for electrons at about 2 kev. That is, as the kinetic energy of the incoming electrons decreases, the amount of energy transferred to electrons and atoms of the thermal control coatings increases. This produces an increase in ionization and excitation effects in the coatings. This energy transfer reaches a maximum, when the incident electron, or any other charged particle for that matter, is brought to rest. Therefore maximum ionization and excitation can be made to occur nearer the surfaces, which is more important in our case, if electrons of much lower kinetic energy are used than are now available. At 10 kev, the range of an electron in a substance consisting of approximately the same atomic number to atomic weight ratio, Z/A, as TiO_2 pigment in an alkali silicate vehicle, is $\sim 0.8\mu$. At 400 kev, our lowest attainable energy with the present Van de Graaff, the range is 400μ, which more than penetrates the 250μ thick coatings. Considering that optical changes are surface effects, we would like to have as much energy transferred to electrons and atoms near the surface, rather than in bulk. The dividing line between surface and bulk is not distinct, but electron penetration of 1μ and less should produce more significant results.

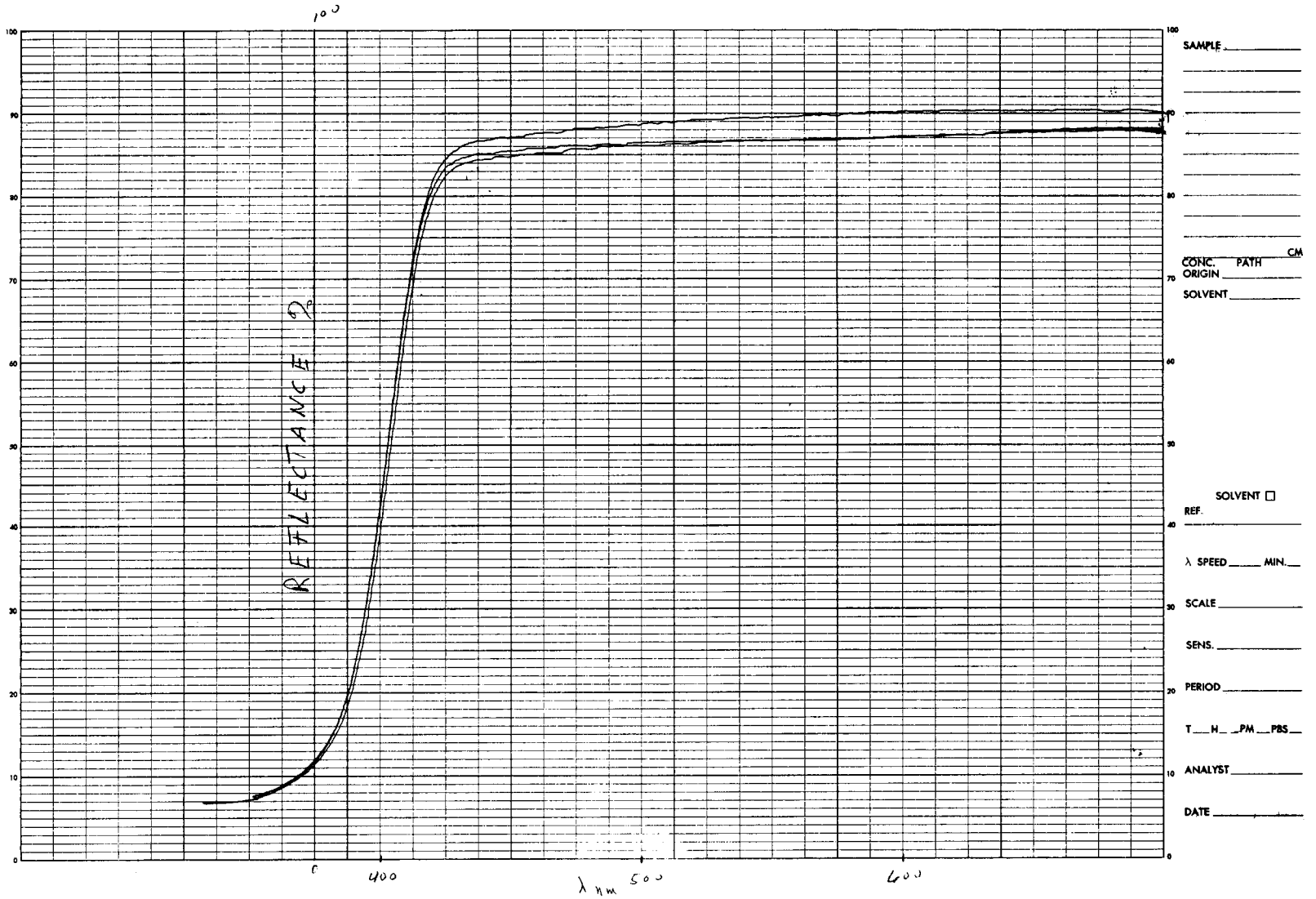


Figure 60. Reflectance Changes with 1 Mev electrons—Sample E_3-137

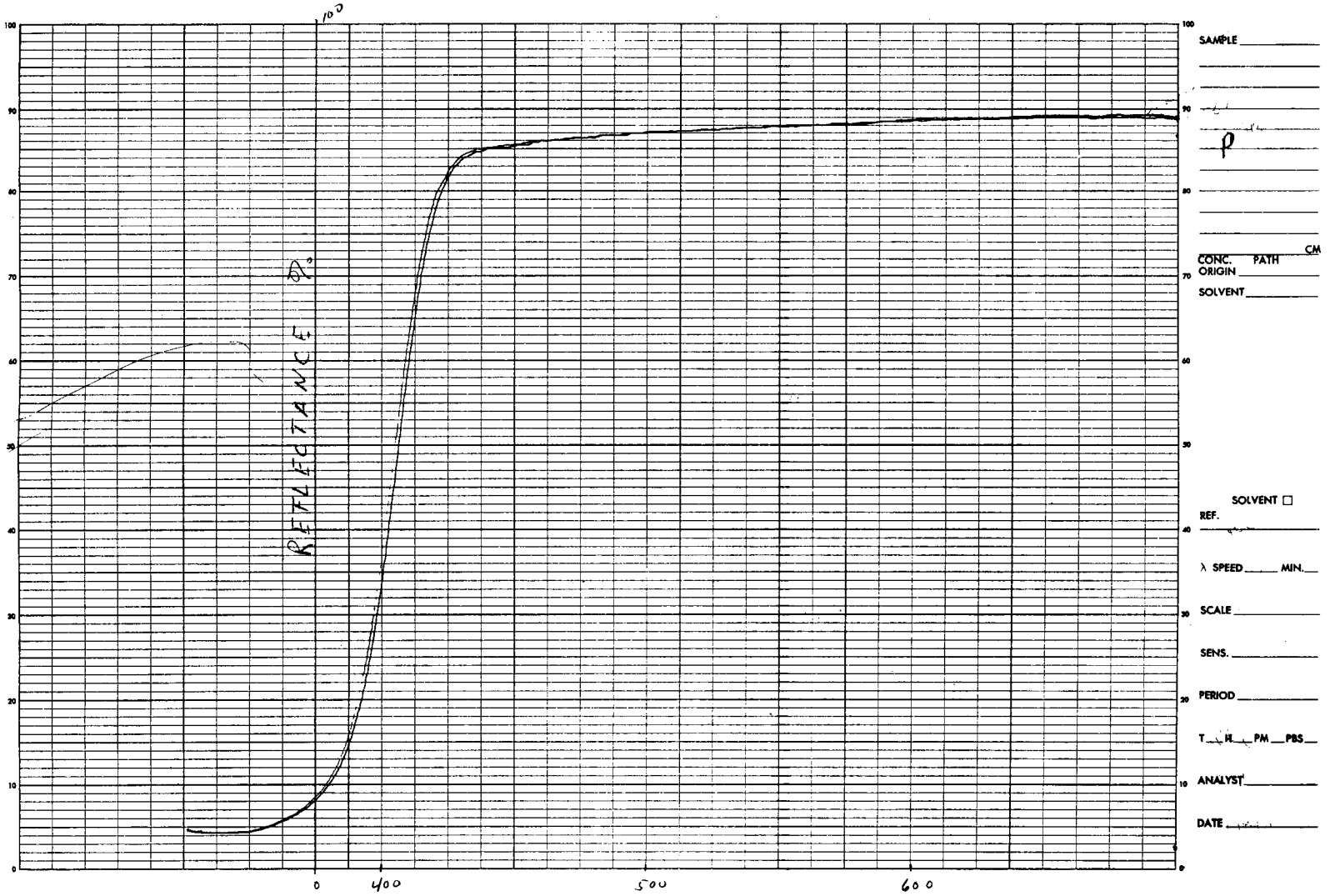


Figure 61. Reflectance Changes with 1 Mev Electrons—Sample P-143

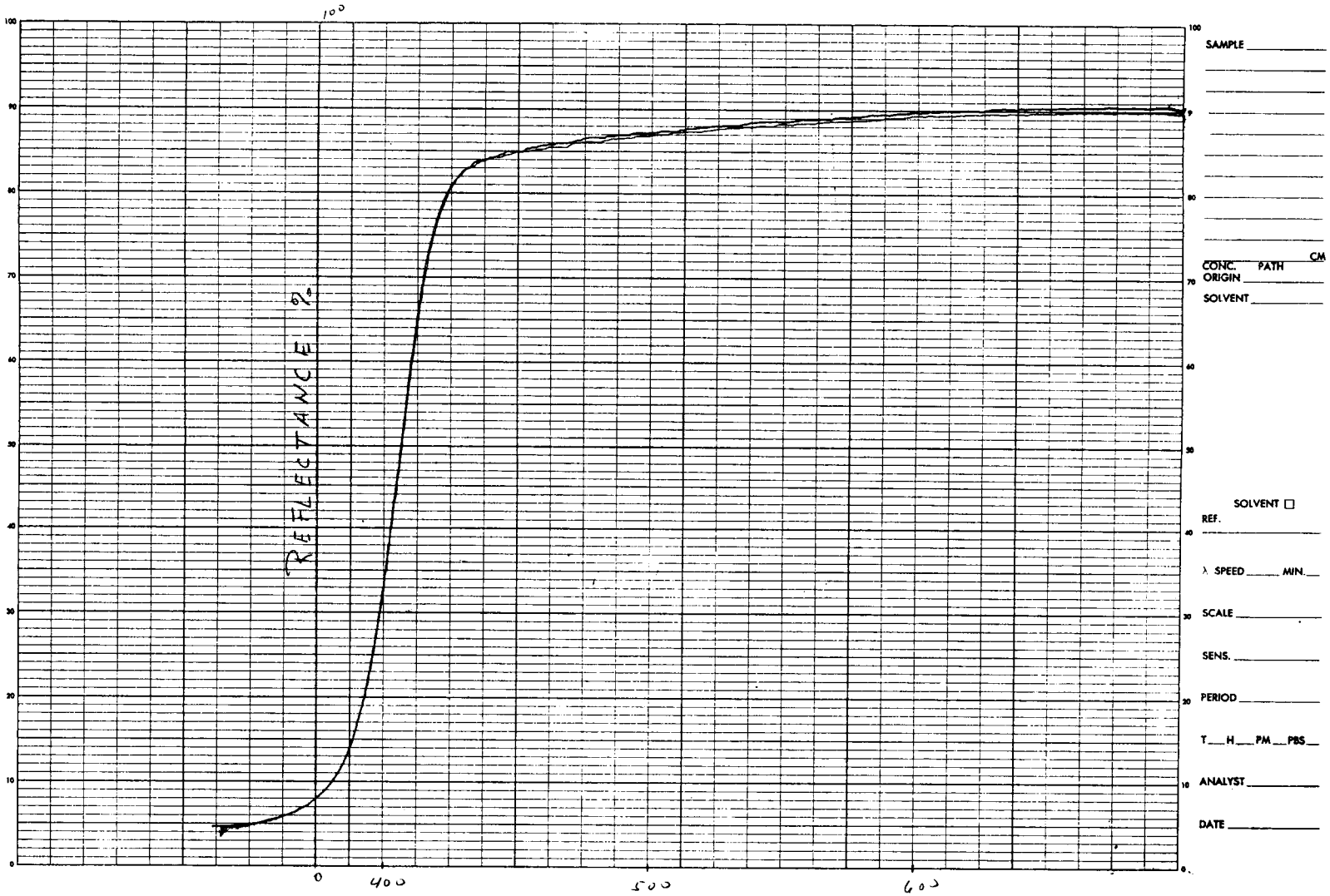


Figure 62. Reflectance Changes with 1 Mev Electrons—Sample Cat-a-lac

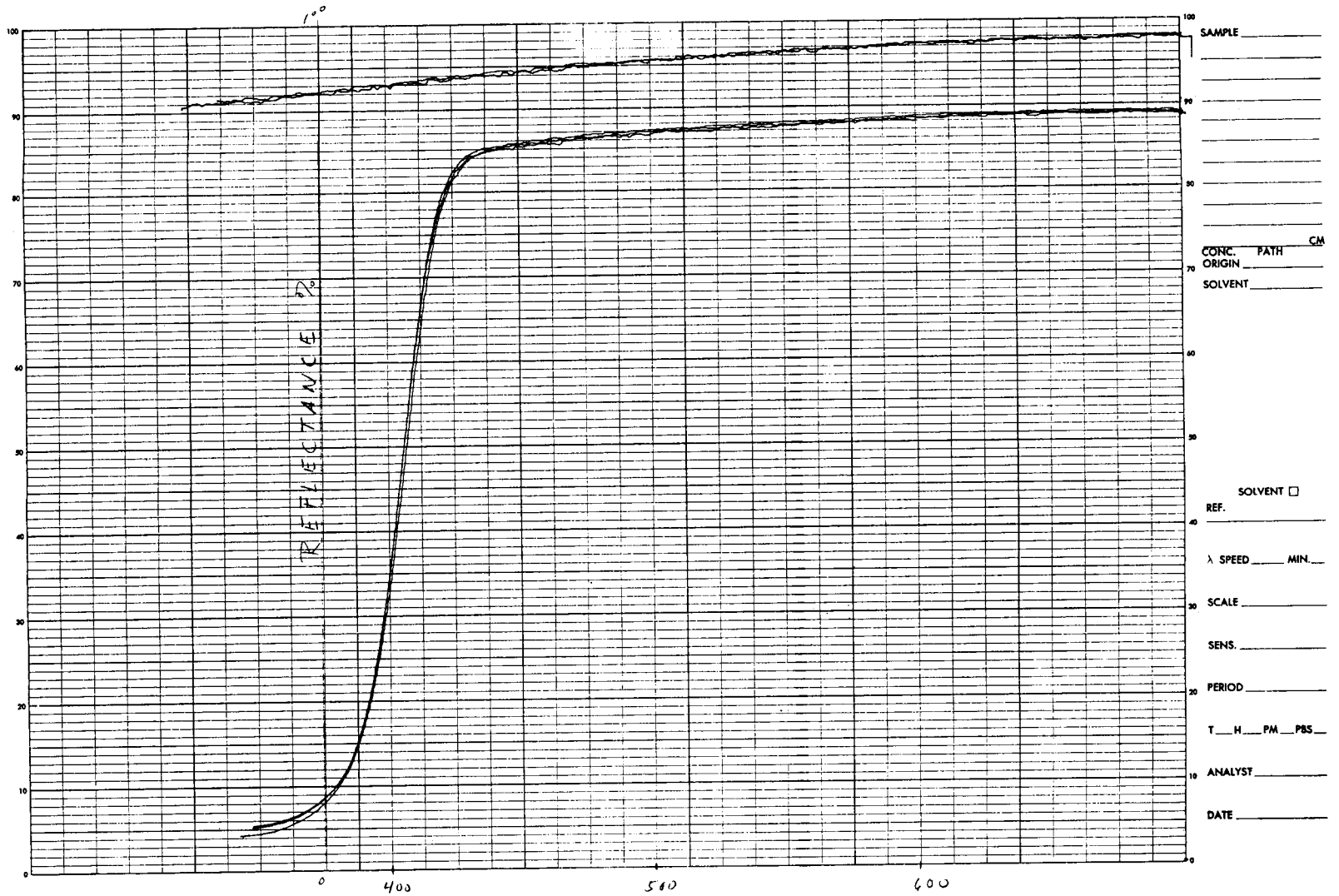


Figure 63. Reflectance Changes with 1 Mev Electrons—Sample O-72

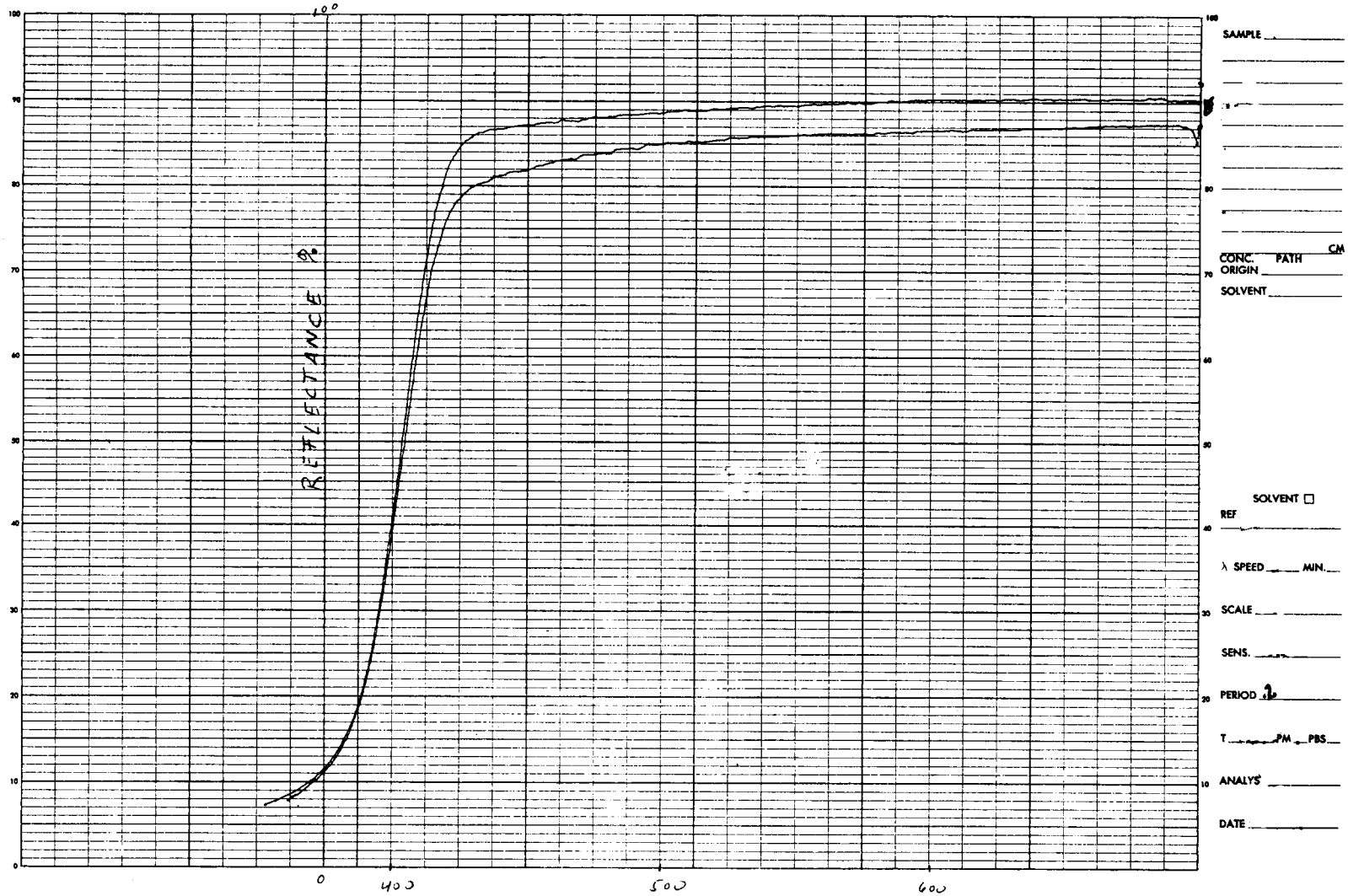


Figure 64. Reflectance Changes with 700 kev Electrons—Sample E_3-194

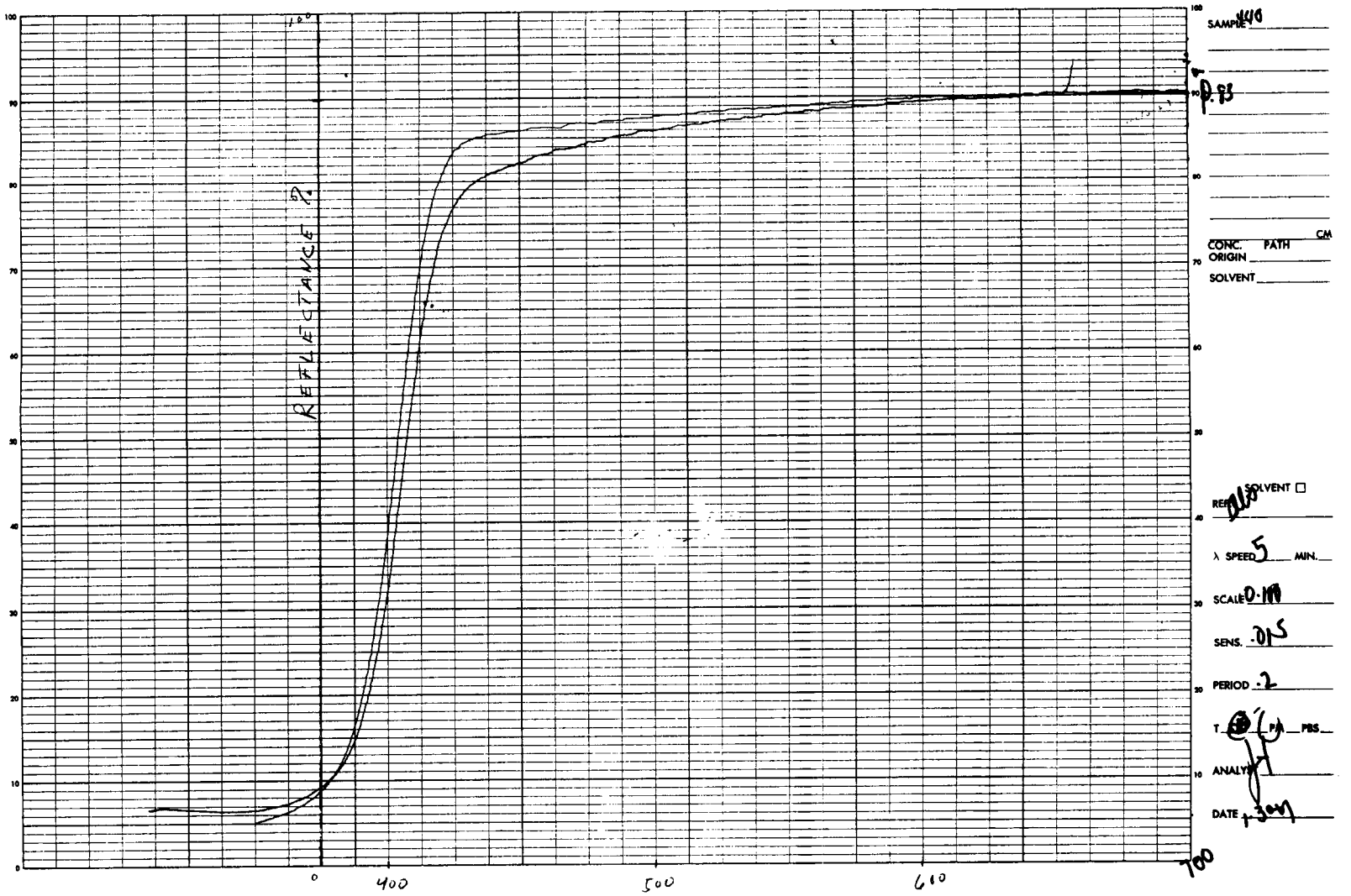


Figure 65. Reflectance Changes with 700 kev Electrons—Sample P-83

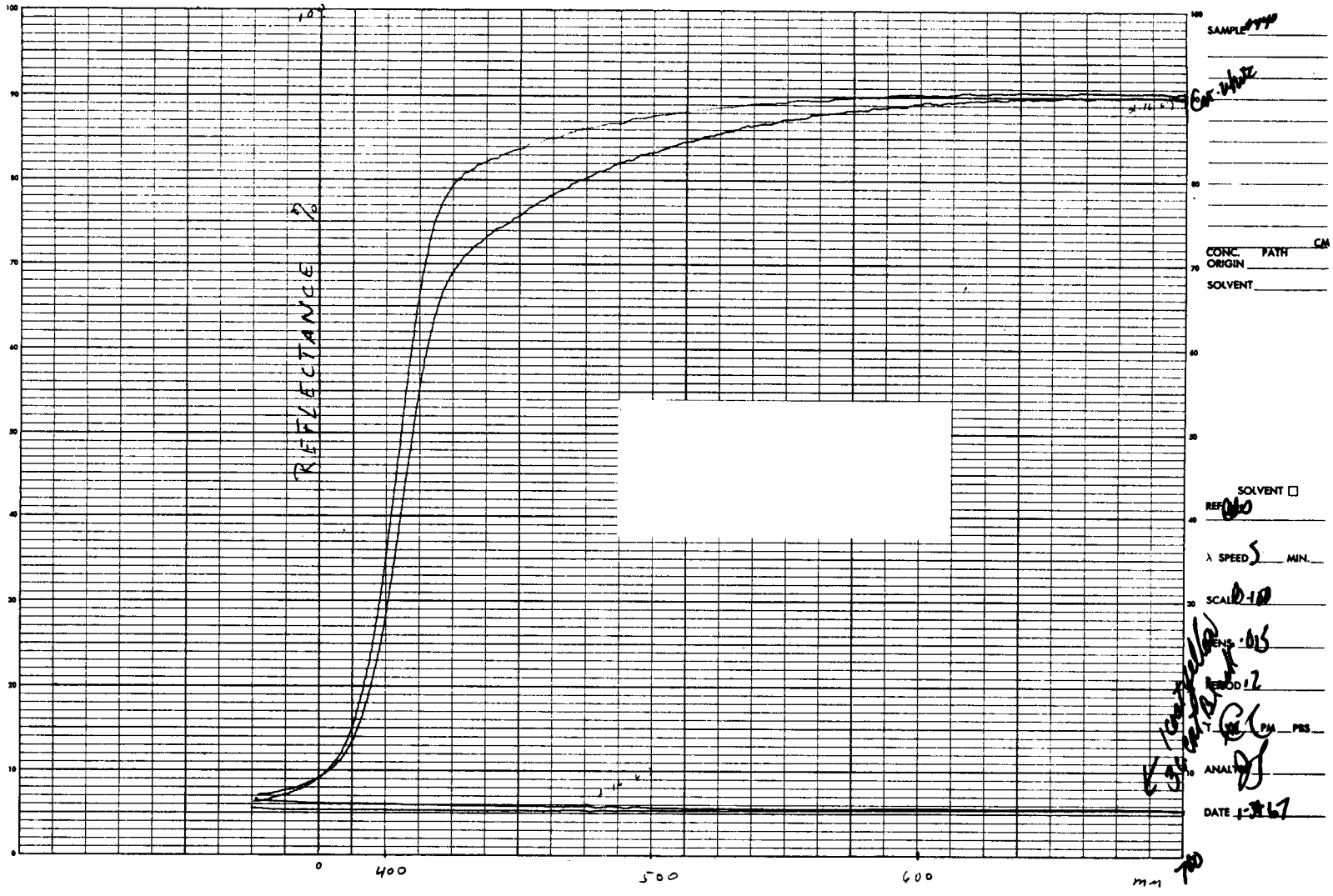


Figure 66. Reflectance Changes with 700 kev Electrons—Sample Cat-a-lac

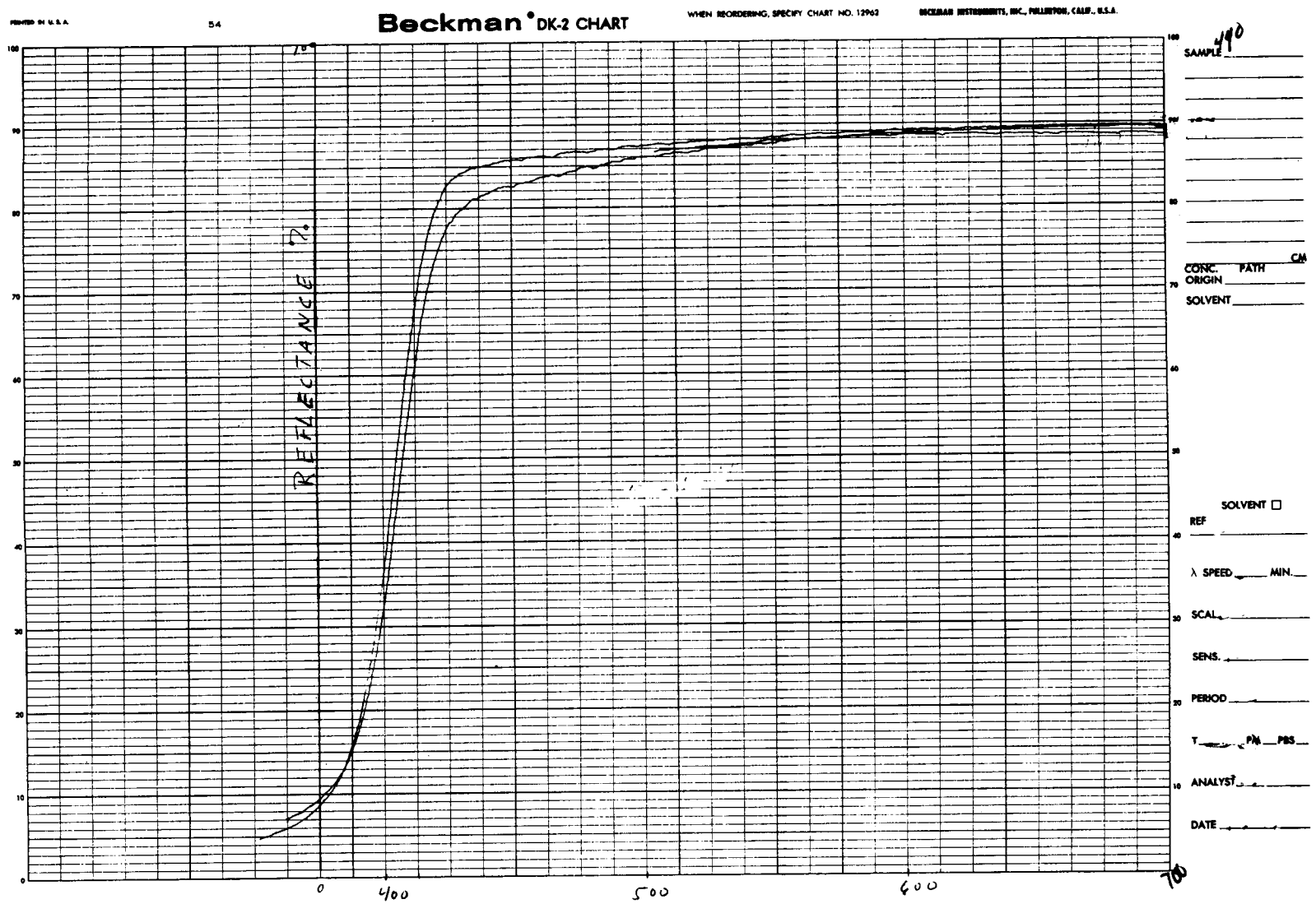


Figure 67. Reflectance Changes with 700 kev Electrons—Sample O-134

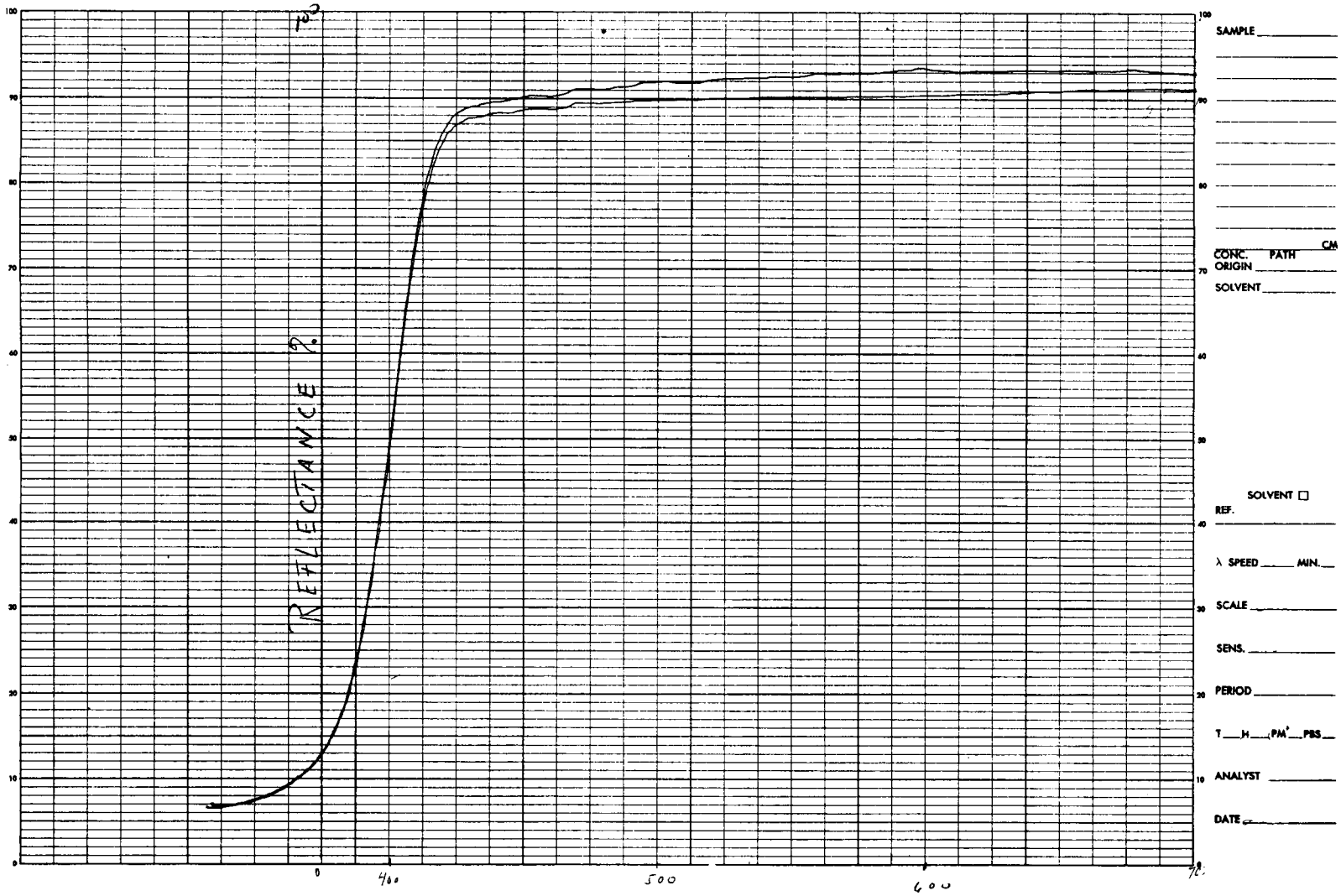


Figure 68. Reflectance Changes with 400 kev Electrons—Sample E_3-171

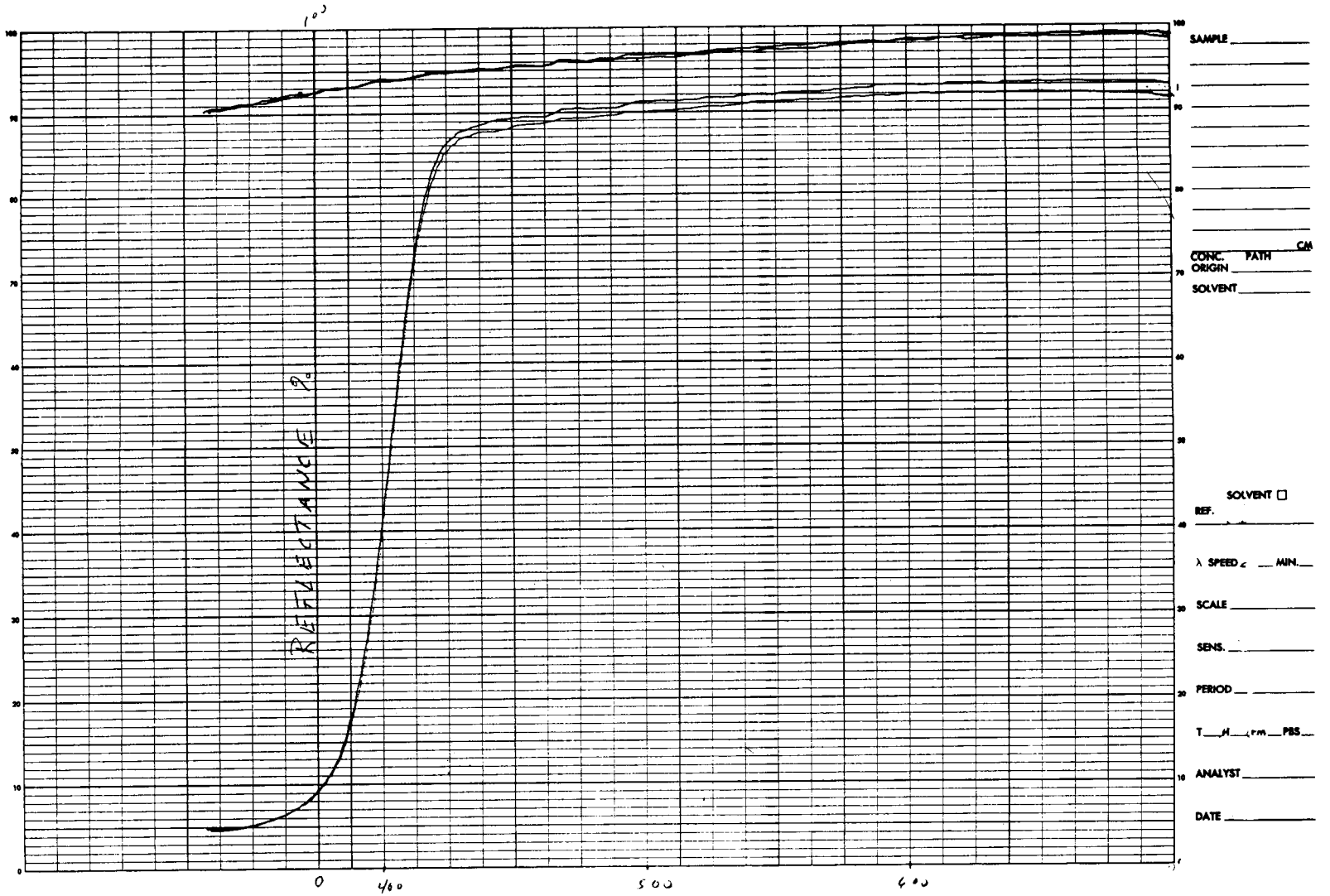


Figure 69. Reflectance Changes with 400 kev Electrons—Sample P-78

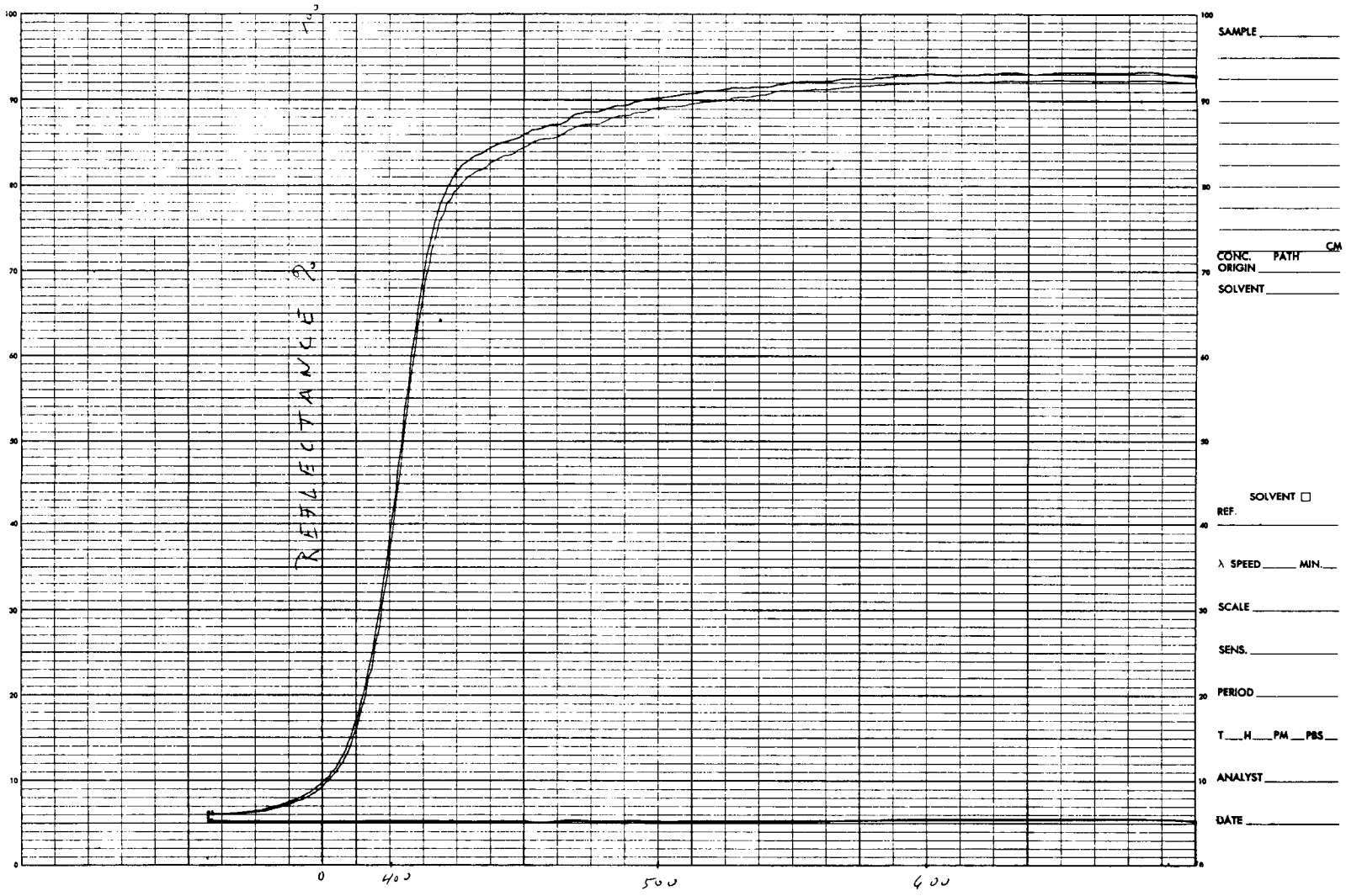


Figure 70. Reflectance Changes with 400 kev Electrons—Sample Cat-a-lac

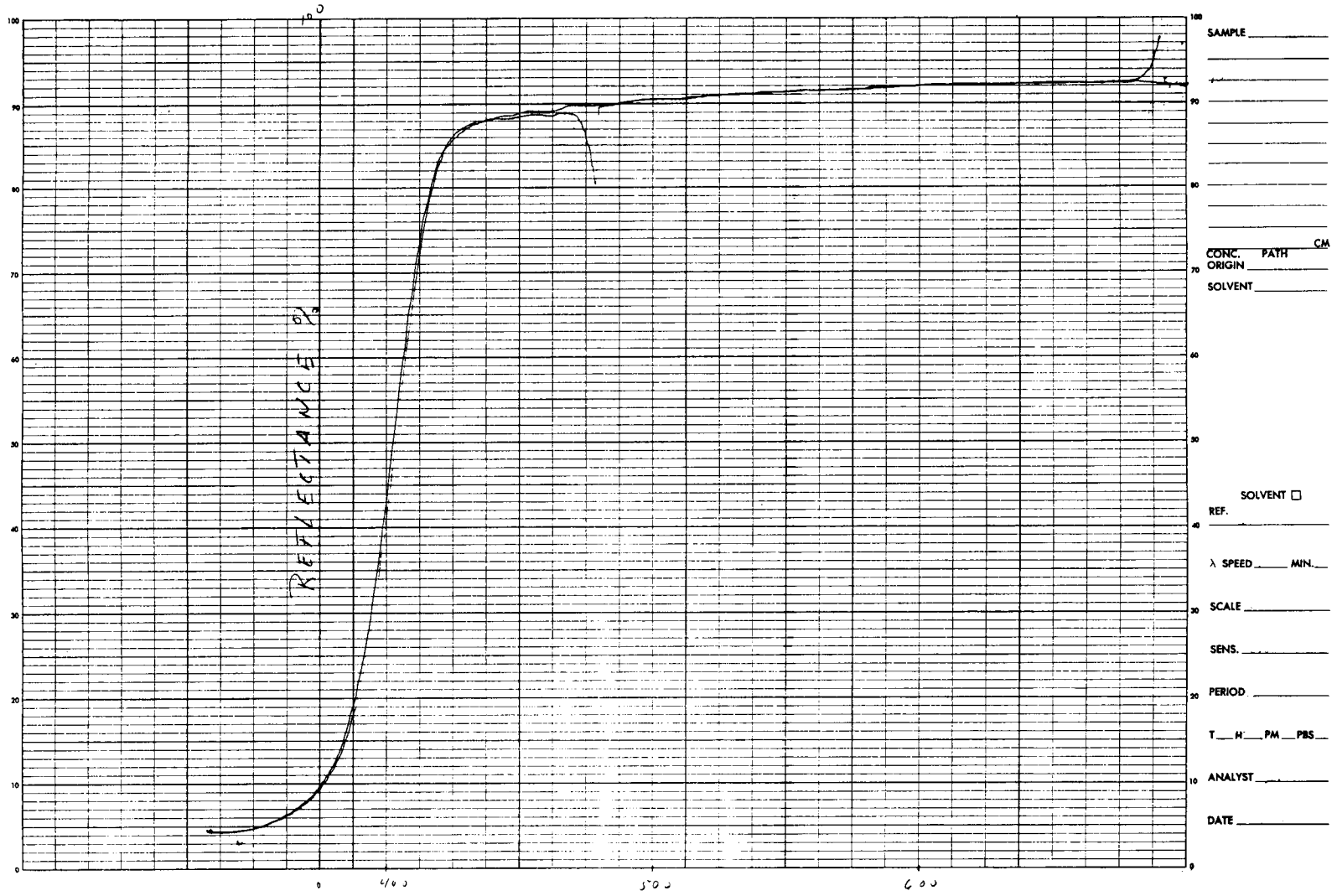


Figure 71. Reflectance Changes with 400 kev Electrons—Sample O-133

Table 20
700 kev Electron Irradiation Induced Changes

Sample	% Change 700 mμ	% Change 425 mμ
L-82	5.4	28.8
E_3-172	12.0	35.7
D_3-150	14.5	24.3
F_3-378	12.3	29.4
O-135	3.3	22.5
P-68	6.0	32.6
007	10.0	35.3
Cat-a-lac black	2.0	5.2
Cat-a-lac white	7.2	32.0
B-109	4.1	26.8
C-144	3.3	23.0
3M black	1.8	4.7
M-96	5.2	35.6

III. FUTURE PLANS

At present, tests are being made on the Van de Graaff accelerator for proton beams. In the coming quarter we hope to run tests on the above mentioned samples in vacuum (10^{-6} ton) using protons in the range of 400 kev-1 Mev at fluences of 2×10^{14} protons/cm^2. Further tests using electrons up to a total dose of 10^{16} electrons/cm^2, will be tried, if they are attainable, to see if damage will occur, aside from the fact that energies will still be high, 400 kev and greater.

During the first week of March, R. Brown of Boeing Co., Seattle, Washington, visited the coatings degradation group. Results of electron bombardment at 50 kev, in vacuum of 10^{-4} ton, and fluences of 2×10^{12} electrons/cm^2, 2×10^{14} electrons/cm^2, and 1×10^{15} electrons/cm^2, were brought. All optical measurements were made in-situ. The data is now being looked over in detail. Most of the coatings sent them showed degradation in the visible and infrared, very little in the ultra-violet. All of the alkali silicates showed degradation in both the visible and infrared.

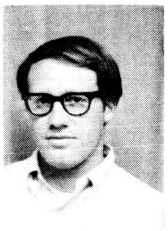
N67-32602

APPENDIX I

EVALUATION OF SEVERAL INTENSE LIGHT SOURCES USED FOR ACTINISM STUDIES

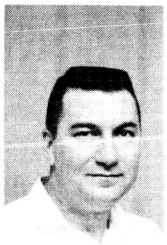
EVALUATION OF SEVERAL INTENSE LIGHT SOURCES USED FOR ACTINISM STUDIES

Malcolm Lillywhite, Roy McIntosh. Electro-Mechanical Research, Inc.*
Charles Duncan, Joe Colony. NASA - Goddard Space Flight Center.

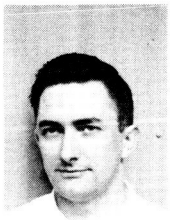


Malcolm Lillywhite

Roy McIntosh



Charles Duncan



Joe Colony

Mr. Malcolm Lillywhite was graduated from the College of William and Mary with a B. S. degree in physics in 1963. He worked in Ionospheric Research as an undergraduate until 1963 and has been working in solar simulation research and thermal control coating qualifications since that time. He is presently supervisor of the Thermal Laboratory working for Electro-Mechanical Research, Inc., performing work on a support services contract with Goddard Space Flight Center.

Mr. Roy McIntosh was educated at Antiock College and George Washington University. He was engaged in radiometric studies, electronic design, and solid state physics before joining Electro-Mechanical Research, Inc. in 1965. His present position is supervisor of the Radiometry Group of EMR at Goddard Space Flight Center.

Mr. Charles H. Duncan received his B. S. degree in physics from the College of William and Mary in 1950 and later did graduate work in physics at the University of Illinois. From 1952-1960 he was engaged in optical and spectrographic studies at the Naval Research Laboratory. He transferred to G.S.F.C. in 1960 and is presently Head of the Radiometry Section which has the responsibility for solar simulation, thermal control coatings qualifications, spectroradiometric measurements, and solar cell calibrations.

Mr. Joe A. Colony was graduated from Reed College with a B. A. in chemistry in 1959, and worked at the Walter Reed Army Institute of Research doing biochemistry research in 1960. In 1962 he joined G.S.F.C. where he is presently engaged in research of surface chemistry and thermal control coating development in the Thermophysics Branch.

Abstract

Several sources used for space environment solar simulation testing are evaluated in terms of (1) their operational characteristics, and (2) the effects of their different spectral irradiance characteristics on several thermal control coatings. Nine sources are discussed: Xe, filtered Xe, HgXe, Kr, Ar, H-Xe, 2.5 KW compact short arc lamps, a medium pressure 500 watt Hg vapor lamp, a carbon arc, and an Ar filled experimental vortex arc lamp. The coatings used are commercially available white paints commonly used on satellites. The spectral irradiance characteristics of the sources are given and discussed in terms of degree of solar spectral mismatch, effective absorptance values of each coating, and the rate and magnitude of the degradation observed. The results of short term (< 200 hours) testing of these coatings, irradiated with different sources, show that for some coatings large errors may result from the use of solar spectral mismatch and for others the rate of degradation is different but the ultimate absorptance value achieved through degradation may not be significantly affected. The "actual absorptance" value is obtained using an optical "in-situ" measurement and the "effective absorptance " values are computed using the relative spectral reflectance of the coating and the spectral irradiance of the source.

Introduction

With the increasing need for dependable passive temperature control of satellites the "long term" radiative characteristics of satellite thermal control coatings are of extreme importance. It is essential that these coatings'properties, both favorable and unfavorable, be well known for temporal considerations approaching that of the flight mission in question so that thermal design limits may be determined. Since the radiative properties of a specific coating will be determined almost entirely by the solar incident irradiance, accurate ground based solar simulation testing is required. This makes it necessary to choose a radiation source for this solar simulation. This paper reports on efforts to evaluate a number of sources that are used for solar simulation and the types of errors that can be expected with each in terms of rate and magnitude of change in absorptances of the coatings. Particular emphasis has been placed on interpretation of the data obtained in degradation testing in terms of actual solar spectral distribution and the degree of solar spectral mismatch of the source in question. Specifically, this means the evaluation of a lamp's spectrum in narrow bandwidths to determine the spectrally selective equivalent solar dose and the consequent degradation in each case. The absorptance values are theoretically computed in this manner for a number of control coatings commonly used on spacecrafts and compared with the absorptance values actually measured "in-situ" during degradation tests using different sources.

*Work performed in part under NASA contract NAS 5-9244

General Discussion

Many solar simulation systems are presently using different types of sources and new types of high intensity sources are under development for potential solar simulation use. These sources have very different spectral and operational characteristics and therefore need a comprehensive evaluation in order to compare the results of solar simulation tests which use different sources. A comparison of the relative spectral irradiance of several of these sources is given in Table 1, "Ratio of Test Lamps Energy to Solar Irradiance". The spectral irradiance measurements are made by directing the light from either a source or the 1000 w NBS traceable standard of spectral irradiance through a chopper (chopped at 11.3 c.p.s.) as it enters a sphere which is coated with magnesium oxide to a depth of 4 mm. This sphere provides the illumination for the slit of a Leiss double prism monochromator. Three detectors are used to cover the spectral range from 250 nm to 2500 nm. These are a 1P28 photomultiplier, a 7102 photomultiplier, and a 2 x 10 mm lead sulfide cell. Suitable overlap regions are covered for these detectors to minimize errors in the regions where the detector sensitivities change rapidly. The signals from the photodetectors are passed through a pre-amplifier and an amplifier which synchronizes the chopper with the signal to minimize the electrical bandwidth and thus the noise. The output signal from the amplifier is recorded on either a strip chart recorder or a magnetic tape data logging system. The wavelength drive of the monochromator is driven by a synchronous motor which in turn drives an absolute shaft position encoder which defines the wavelength of the instrument quite accurately. The data from these irradiance measurements is processed either from punched cards or magnetic tape on a 7040 - 7090 computing system.

Columns 2, 3, 4, 7, 8, and 9 of Table 1 are representative of a 2.5 KW compact arc lamp of that type. Column 5 is a typical high intensity experimental source, Column 6 is a mercury vapor lamp and Column 10 is a typical carbon arc. It should be pointed out that each column contains spectral irradiance data chosen from many sets of measurements to be representative of a typical new source of that type without optics ("0" hours). This data, therefore, may not agree with identical lamps of different ages and/or used in different optical systems. The last column of the table gives the percentage of the solar irradiance in a 10 nm bandwidth whose center wavelength is indicated in Column 1, "Interval Wavelength".[1] The irradiance is calculated for 10 nm intervals over the entire range (250 nm to 2500 nm); the energy is averaged over 100 nm bandwidths over the range 1100 - 2500 nm. The actual solar irradiance, I_s, may be obtained by multiplying a value in Column 11, "Percent Solar Irradiance" by the total solar irradiance (250 nm to 2600 nm). The other nine columns contain data displayed in fractions of a solar constant for the bandwidth indicated in Column 1 when all sources are considered to have a total irradiance of one solar constant. The total irradiance of a specific bandwidth for a specific source is obtained from the product of the indicated value in the source column, the value in the percent solar irradiance column, and the total solar irradiance value. This table gives direct comparison of the energy per bandwidth for several sources in terms of the air mass zero solar spectral irradiance or an equivalent solar dose/bandwidth which can be used to obtain equivalent sun hours of irradiation when these sources are used in degradation testing.

The group of sources studied consists of three basic types: (1) high pressure compact short arc lamps, (2) a medium pressure mercury vapor lamp, and (3) a carbon arc. Each type source has different operational characteristics and each individual source has different spectral characteristics. Consequently, these sources have been evaluated using the following criteria: (1) spectral irradiance - degree of solar spectral match, (2) operational characteristics, (3) efficiency (cost and output) and (4) maintenance.

It is felt by the authors that the most important area of concern for coating degradation work is the spectral irradiance of the source. The closer the spectrum of the source matches that of the solar spectrum the more accurately the solar simulation testing results may be interpreted. The degree of spectral match is considered over the bandwidth 250 nm to 2500 nm with particular emphasis on the ultraviolet spectral region. While the spectrum of the source is considered most important, this assumption is valid only when its spectral irradiance characteristics are known and these characteristics do not change significantly over a reasonable length of testing time. This necessitates the consideration of operational characteristics of each source with specific interest in temporal changes in spectral and total irradiance. The luminous conversion efficiency of the source is of concern because such information is necessary design criteria of multi-module systems and affects the cost per hour operation of such systems. Maintenance of these sources is of concern when the consequence of replacement and optical alignment of a source unit caused by unit failure during test operation is very costly.

The source chosen by the authors as the optimum source is the Xe compact arc lamp. It has a relatively high conversion efficiency ($\approx$ 40-50%), it is temporally stable within acceptable limits, and it lends itself to a minimum of maintenance. The xenon lamp does not possess a satisfactory solar spectral match particularily in the visible and near infrared regions (800 to 1100 nm region, see Column 1, Table 1) but when this source is used with a properly designed band rejection filter or series of filters the resulting spectral irradiance is a good solar spectral match.[2] The xenon lamp used with a spectral filter is the best solar simulation source studied by this laboratory to date. Spectral filters of this type, manufactured by Spectrolab, have been found stable for periods of 1000 hours. No severe changes in spectral characteristics of these filters have been observed. The xenon lamp , when operated properly, experiences a slight initial change in ultraviolet (UV) output during the first 50 hours of operation and then achieves "normal" operational spectral irradiance (see Column 1, Table 1) and does not experience any additional changes until after 500 to 600 hours.

The krypton compact arc lamp possesses essentially the same operational characteristics and basically the same spectral characteristics as xenon lamps with the exception of the expected shift in line structure towards the ultraviolet region. This shift can be seen by comparing the data in Columns 2 and 7 of Table 1. The increase in ultraviolet irradiance seen here is perhaps too great to consider using the source for solar simulation by itself, however, the energy is radiated from

a continuum which is more desirable and easier to evaluate in terms of solar environment than line emission and the lamp can be used in a solar simulator array to boost the UV irradiance of the system[3]. The ultraviolet total irradiance shown in Table 2 is very close to the solar UV irradiance and therefore may be a desirable source to use for steady state radiative property measurements.

The argon lamps used in this evaluation do not possess spectral irradiance characteristics superior to the xenon or krypton lamps (see Column 8 of Table 1) and their operational characteristics are not desirable for solar simulation. The thermal conductivity of argon is greater than that of xenon or krypton and for lamps of equivalent size and rated power the argon lamp bulb runs hotter. This leads to failure of the lamp within 25 hours. To prevent this deleterious heating the lamp design must be modified to enhance cooling or the lamp must be run at a lower power level. The luminous conversion efficiency (i.e., the ratio of total irradiant output to electrical input) of both krypton and argon, under these conditions, is $\approx$ 35% less than xenon, and therefore the total irradiant output is less. This increases the number of modules of this type necessary to obtain a given total irradiance in a test area of a solar simulator producing a less efficient system.

The hydrogen doped xenon lamp poses an interesting academic study but does not appear to be a very good source for solar simulation. The lamp is more difficult to start because of the gaseous mixture. Once started a particular lamp operated initially at 42 volts, 62 amps. However, the hot quartz envelope is porous to hydrogen and the voltage decreases as the hydrogen diffuses through it. As a result, its UV continuum is constantly changing and the lamp becomes less efficient due to a decrease in pressure. The spectral irradiances of such a lamp at zero hours is shown in Column 9, Table 1. The use of such a lamp would require major structural modifications, perhaps, those proposed by Thouret and Strauss.[4]

The mercury xenon (HgXe) compact arc lamp is a rugged lamp and its operational characteristics are suitable for solar simulation use if spectral correspondance is not desired. The spectral irradiance of the lamp is not desirable for coatings work in which close spectral matching is required. The ultraviolet region consists of many mercury emission lines and measurements show that the line intensities are somewhat unstable. This data results in effective absorptance values (for HgXe) that are very different from test to test and a degradation or change in absorptance that is very difficult to interpret in terms of the equivalent solar radiation in space. The spectral irradiance of HgXe lamp operation at 2.2 KW are shown in Column 4, Table 1.

The mercury vapor lamps used in this study were 500 watt Hanovia lamps. These lamps are easy to operate and have a sufficiently long lifetime for testing purposes. However, a mercury lamp is the least desirable of the sources studied, for solar simulation work. The spectral irradiance of the lamp is particularly undesirable. The ultraviolet region contains more than 4.5 times the solar energy for that region and one particular bandwidth (265 nm) has 35.6 times the energy. The remaining portion of the spectrum has very poor spectral matching as shown in Column 6, Table 1. In addition to the spectral problem, a mercury vapor lamp of this type does not have sufficiently high total irradiant output and physical design characteristics to permit radiation collection efficiencies high enough for large solar simulation system use.

The carbon arc used in this study was a Genarco Model ME4 CWM. Recent design improvements to the carbon arc have made it more acceptable for solar simulation; however, it is a difficult unit to combine in an array for multi-module systems, and its short term irradiance stability is still a problem. The spectral irradiance of the carbon arc is the best available considering the entire solar range for a bare source

The experimental arc data shown in Column 5, Table 1, is not very important by itself because the spectral irradiance of such a source can change by varying many parameters (e.g., current, pressure, arc gap, etc.) and a discussion of the possible results would be involved.[5] The point to be made here is that sources of this type are being developed and may be used for solar simulation in the future. The ultimate aim of this arc research is to develop a source with improved spectral characteristics.

The ultraviolet region of the simulated solar spectrum is of greatest concern to the degradation of optical characteristics of thermal control coatings. This region is defined, for solar simulation purposes, as radiation having wavelengths between 250 nm and 400 nm and comprises about 9% of the solar spectrum. The energy of this region is nearly all absorbed by most thermal control coatings, and the absorptances of evaporated metals are determined largely by this portion. This radiation is a major factor in the change of absorptance of these coatings in testing and in space. The use of a solar spectral mismatch in the ultraviolet region can produce quite erroneous results in solar absorptance values and the rate of change in absorptance values or optical degradation. The use of extreme intensities in the ultraviolet region, possibly due to emission lines (e.g., Hg and HgXe sources), results in data that is very difficult to interpret in terms of the actual solar environment. The use of a source deficient in the ultraviolet is equally misleading because the change that might be normal in space would not occur or would occur at a different rate. The errors in absorptance due to the spectral mismatch can be corrected for when analytical calculations are used, but the errors resulting from a different degradation rate due to spectral mismatch cannot be eliminated.

Table 2 points out the criticality of this for the sources being discussed in this paper. This data shows the equivalent total solar irradiance dose in the ultraviolet region below 405 nm for a given total irradiance. Many experimenters use values similar to these to obtain equivalent sun hour dose (ESH) of solar irradiance when one of these sources is being used for irradiation in coating degradation testing. It can be seen from Table 1 that the distribution of spectral irradiance in this region is very different for many of these sources.

It appears, then, that one might expect not only different absorptance values which can be calculated for different sources, but different rates of degradation for which reciprocity may not hold and therefore these rates may not be linearly related. This is, in fact, the case and will be discussed later in this paper.

DIAGRAM OF VACUUM CELL AND OPTICAL "IN SITU" SYSTEM

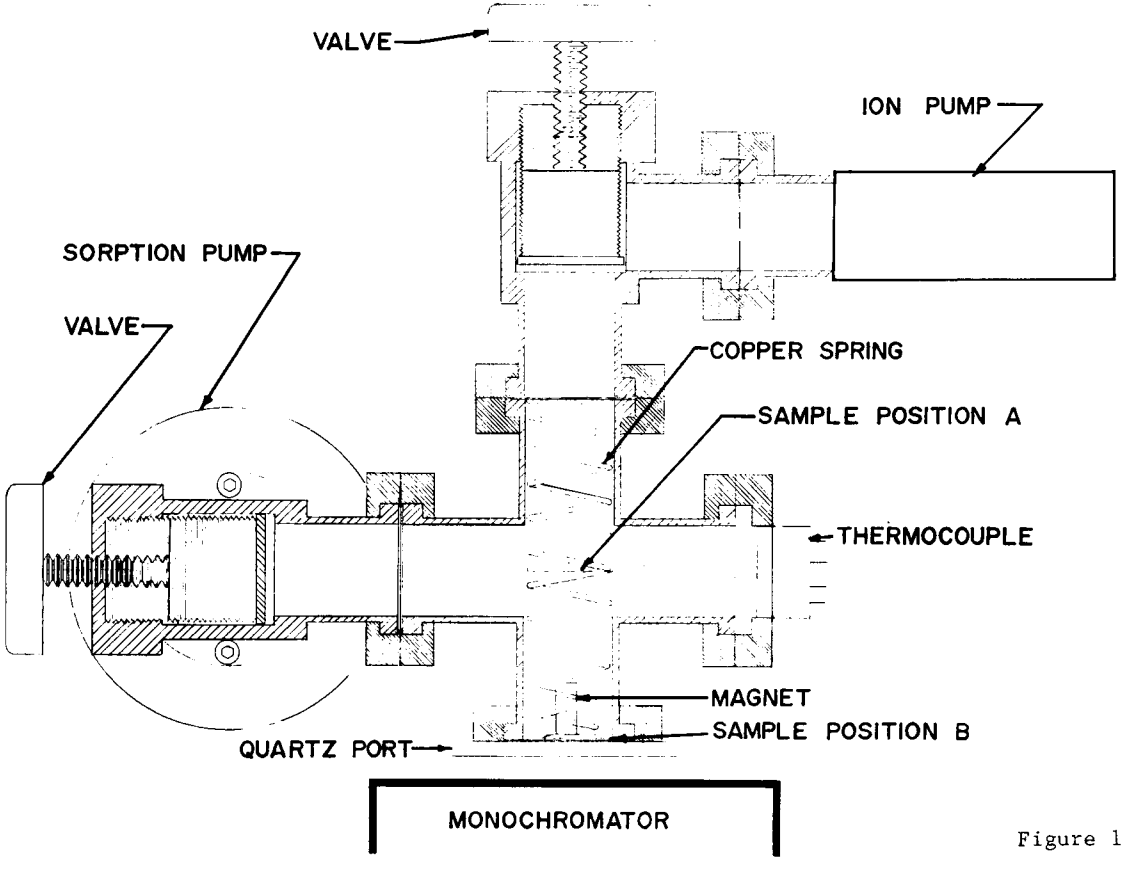


Figure 1.

Table 1

RATIO OF TEST LAMP ENERGY TO SOLAR IRRADIANCE

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
nm Interval Wavelength	Xe	M-13 Filtered Xe X-25L	M-20 HgXe	V-3 Exper. Source	Medium Pressure Hg	M-5 Kr	M-11 Ar	M-9 H-Xe	M-14 Carbon Arc	% Energy Solar
255	0.56	1.09	5.02	13.25		6.18	2.54	4.59		0.072
265	0.45	0.90	1.62	6.34	34.64	3.06	1.29	2.31		0.166
275	0.83	1.43	5.39	6.81	13.64	3.39	1.45	2.60		0.166
285	0.80	1.14	4.55	3.96	5.97	2.06	0.88	1.63		0.290
295	0.71	0.76	4.78	2.65	6.79	1.37	0.58	1.12	0.31	0.456
305	0.85	0.53	7.65	2.53	10.95	1.43	0.59	1.13	0.48	0.476
315	0.78	0.36	5.89	2.04	18.97	1.22	0.49	0.96	0.53	0.590
325	0.72	0.46	0.70	1.65	1.09	0.99	0.40	0.80	0.53	0.746
335	0.72	0.78	1.31	1.54	1.98	0.92	0.37	0.76	0.58	0.828
345	0.79	0.92	0.37	1.56	0.44	0.90	0.35	0.76	0.57	0.870
355	0.83	0.99	0.55	1.62	0.35	0.89	0.37	0.80	0.54	0.870
365	0.73	1.01	6.78	1.41	11.21	0.83	0.36	0.78	0.70	0.922
375	0.73	1.08	1.23	1.36	0.22	0.77	0.34	0.78	1.12	0.942
385	0.92	1.22	0.58	1.45	0.26	0.78	0.37	0.87	1.57	0.859
395	0.89	1.20	0.47	1.28	0.23	0.68	0.35	0.83	1.47	0.942
405	0.63	0.87	1.77	0.88	3.25	0.46	0.25	0.57	1.02	1.346
415	0.59	0.85	0.37	0.93	0.12	0.43	0.29	0.55	0.98	1.429
425	0.63	0.91	0.33	0.98	0.27	0.45	0.29	0.57	0.98	1.357
435	0.64	0.96	2.86	0.96	4.95	0.47	0.26	0.58	0.91	1.336
445	0.56	0.86	0.35	0.69	0.13	0.39	0.20	0.51	0.74	1.564
455	0.60	0.89	0.20	0.65	0.07	0.36	0.20	0.53	0.74	1.615
465	0.66	1.04	0.18	0.67	0.06	0.34	0.19	0.61	0.77	1.605
475	0.73	0.99	0.18	0.67	0.06	0.34	0.19	0.57	0.77	1.595
485	0.66	1.07	0.21	0.69	0.10	0.34	0.20	0.59	0.79	1.522
495	0.67	1.00	0.27	0.67	0.13	0.33	0.20	0.55	0.81	1.522
505	0.67	1.00	0.18	0.68	0.12	0.34	0.21	0.54	0.87	1.450
515	0.66	1.00	0.17	0.64	0.06	0.36	0.21	0.54	0.90	1.429
525	0.65	0.99	0.17	0.60	0.06	0.36	0.21	0.54	0.88	1.439
535	0.63	0.97	0.55	0.57	0.51	0.37	0.19	0.52	0.84	1.470
545	0.59	0.97	2.25	0.54	4.47	0.39	0.20	0.51	0.83	1.460
555	0.60	0.97	0.49	0.54	1.03	0.43	0.20	0.52	0.84	1.439
565	0.62	0.99	0.59	0.56	0.60	0.47	0.20	0.53	0.84	1.408
575	0.61	0.97	3.16	0.53	5.28	0.48	0.19	0.52	0.81	1.429
585	0.62	0.96	1.68	0.54	0.83	0.52	0.20	0.53	0.81	1.408
595	0.63	0.93	0.62	0.56	0.08	0.55	0.22	0.53	0.80	1.398
605	0.66	0.95	0.23	0.56	0.08	0.56	0.23	0.55	0.81	1.336
615	0.67	0.99	0.23	0.53	0.08	0.50	0.22	0.56	0.81	1.305
625	0.69	1.03	0.24	0.53	0.08	0.49	0.21	0.57	0.83	1.284
635	0.69	1.08	0.24	0.54	0.08	0.52	0.22	0.58	0.87	1.253
645	0.68	1.09	0.25	0.57	0.09	0.56	0.22	0.61	0.92	1.232
655	0.68	1.09	0.26	0.58	0.09	0.56	0.23	0.67	0.96	1.212
665	0.68	1.03	0.27	0.57	0.11	0.52	0.24	0.66	0.96	1.201
675	0.71	1.05	0.28	0.65	0.15	0.51	0.25	0.62	0.96	1.170
685	0.75	1.08	0.33	0.74	0.13	0.52	0.29	0.66	0.95	1.139
695	0.78	1.07	0.38	0.87	0.11	0.53	0.43	0.66	0.94	1.108

Table 1.

Ratio of Test Lamp Energy to Solar Irradiance

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
nm Interval Wavelength	Xe	M-13 Filtered Xe X-25L	M-20 HgXe	V-3 Exper. Source	Medium Pressure Hg	M-5 Kr	M-11 Ar	M-9 H-Xe	M-14 Carbon Arc	% Energy Solar
705	0.71	0.99	0.34	0.89	0.11	0.50	0.48	0.62	0.90	1.118
715	0.76	1.02	0.35	0.89	0.10	0.52	0.40	0.66	0.91	1.067
725	0.76	1.03	0.35	0.96	0.10	0.56	0.41	0.66	0.89	1.056
735	0.78	1.02	0.36	1.27	0.10	0.57	0.60	0.70	0.89	1.036
745	0.82	1.06	0.34	1.71	0.11	0.80	0.94	0.71	0.90	1.004
755	0.79	1.05	0.33	1.97	0.11	1.07	0.97	0.71	0.88	1.004
765	0.85	0.93	0.36	1.90	0.12	2.06	1.25	0.77	0.91	0.963
775	0.87	0.81	0.37	1.77	0.12	1.77	0.76	0.73	0.92	0.932
785	0.69	0.57	0.37	1.75	0.12	1.30	0.66	0.65	0.92	0.922
795	0.67	0.54	0.38	2.02	0.11	1.25	1.12	0.67	0.93	0.901
805	0.72	0.67	0.39	2.54	0.12	1.48	1.72	0.73	0.94	0.880
815	0.89	0.98	0.48	2.86	0.12	2.65	1.89	1.31	0.95	0.859
825	1.71	1.01	0.72	2.76	0.12	3.12	1.22	1.98	0.93	0.849
835	2.25	1.06	0.66	2.46	0.13	2.77	1.44	2.06	0.92	0.818
845	1.81	0.41	0.53	2.22	0.13	2.02	1.65	1.37	0.90	0.797
855	1.16	0.39	0.46	1.79	0.14	1.42	1.11	0.75	0.88	0 777
865	0.97	0.38	0.49	0.94	0.14	1.12	1.13	0.47	0.86	0.756
875	1.17	0.83	0.70	0.75	0.14	1.11	0.57	1.28	0.86	0.746
885	1.94	0.93	0.90	0.87	0.14	1.59	0.55	2.31	0.86	0.735
895	2.44	1.10	0.94	0.91	0.15	1.81	0.54	2.73	0.87	0.715
905	3.19	1.10	0.86	0.75	0.16	1.59	0.78	2.58	0.91	0.683
915	3.12	0.94	0.88	0.71	0.16	1.06	1.11	2,30	0.91	0.673
925	2.88	0.92	0.77	0.70	0.17	0.85	1.06	2.15	0.92	0.663
935	2.73	0.88	0.68	0.66	0.18	0.83	0.77	1.91	0.93	0.652
945	2.55	0.92	0.69	0.59	0.18	0.86	0.72	1.78	0.95	0.632
955	2.79	0.89	0.68	0.58	0.17	0.88	0.79	1.75	0.96	0.611
965	2.64	1.11	0.70	0.53	0.77	0.89	0.83	1.65	0.97	0.601
975	2.47	1.11	0.86	0.51	1.13	1.01	0.84	2.07	0.96	0.601
985	2.94	1.20	1.04	0.54	1.19	1.15	0.84	2.32	1.01	0.570
995	3.42	1.16	1.09	0.52	1.22	1.08	0.78	1.92	1.03	0.559
1005	3.46	1.20	1.56	0.52	2.47	0.99	0.80	1.69	1.08	0.538
1015	2.92	1.22	1.82	0.55	2.08	0.92	0.83	1.72	1.11	0.528
1025	2.41	1.25	1.82	0.58	1.66	0.90	0.85	1.64	1.14	0.518
1035	1.73	0.76	1.34	0.59	1.69	0.90	0.90	0.93	1.15	0.507
1045	1.75	0.73	0.98	0.63	0.41	0.92	0.95	0.91	1.15	0.497
1055	1.07	0.73	0.73	0.65	0.20	0.94	1.08	0.93	1.16	0.487
1065	1.09	0.83	0.71	0.66	0.17	0.97	1.12	0.93	1.19	0.476
1075	1.09	0.93	0.70	0.65	0.17	0.98	1.13	0.95	1.19	0.466
1085	1.15	1.10	0.71	0.59	0.17	0.99	1.12	0.96	1.18	0.456
1095	1.21	1.24	0.74	0.53	0.29	0.98	1.05	1.00	1.21	0.445
1150	1.10	1.29	1.13	0.61	0.68	1.13	1.21	0.98	1 28	0.392
1250	0.97	0.92	1.08	1.12	0.24	1.57	1.81	1.03	1.35	0.314
1350	0.65	0.70	1.34	2.08	0.81	1.66	3.01	1.16	1.42	0.253
1450	0.92	1.85	1.34	0.94	0.35	1.87	2.76	1.52	1.49	0.205
1550	1.14	1.44	1.53	0.71	0.60	1.81	2.99	1.61	1.51	0.168
1650	0.95	1.18	1.79	0.60	0.84	2.10	3.11	1.70	1.58	0.139
1750	0.83	1.16	2.41	0.50	1.00	2.18	3.41	1.89	1.63	0.115
1850	0.84	0.80	1.69	0.54	0.60	2.17	4.02	2.07	1.56	0.096
1950		0.88	1.73	0.49	0.70	1.95	4.40	2.26	1.50	0.082
2050		1.28	1.88	0.54	0.74	2.03	4.66	2.33	1.51	0.069
2150		1.24	2.20	0.51	0.82	2.19	4.91	2.46	1.45	0.059
2250		1.51	2.52	0.51	1.72	2.15	5.89	2.81	1.41	0.051
2350		1.61	2.96	0.63	2.11	2.28	6.46	2.65	1.34	0.043
2450		1.84	3.05		1.76	2.26	7.35	1.75	1.21	0.038

Ratio of Test Lamp Energy to Solar Irradiance

	Sources									
	Xe, A-1	Filtered Xe X-25, M-13	HgXe, M-20	Experimental Source, V-3	Med. Pressure Hg.	Kr, M-5	Ar, M-11	H-Xe, M-9	Carbon Arc, M-14
Ratio of test lamp energy to solar irradiance below 405 nm	.79	.91	2.40	1.84	4.56	1.01	.44	.91	.80

Table 2

Table 3 shows the effective absorptance values of different types of coatings commonly used on spacecrafts for the group of sources studied. The effect of the solar spectral mismatch can be seen here by comparing the effective absorptance values in Table 3, Columns 2 - 10 to the solar absorptance values in Column 11. These are values the coatings have at zero hours of irradiation for a specific source and do not indicate that any degradation has occured. It is extremely difficult to compare rates of degradation under similar test conditions for different sources; however, this will be discussed later in the paper.

In calculating the effective absorptances of each of the coatings described here for each of the light sources used the following technique is employed. First the spectral reflectance (250 nm - 2500 nm) for each coating is measured with a DK-2A spectrophotometer with an absolute spectral reflectance attachment. The spectral reflectance curves obtained from the spectrophotometer are divided into 100 wavelength intervals with each interval representing that wavelength interval which contains 1% of the solar spectrum based on data from the Handbook of Geophysics. Next, an average value is determined for the reflectance within each interval. The solar absorptance, α_s, assuming an opaque coating, is obtained by taking the value

$$\alpha_{s\lambda} = (1-P_\lambda) \qquad (1)$$

where P_λ is the spectral reflectance. This data is then punched on IBM cards for insertion in the computer program which calculates the spectral irradiance of the various test lamps as described above which appears in Table 1. The effective absorptances of the coatings are obtained by dividing the spectral irradiance of each lamp into the same 100 intervals representing the solar spectral irradiance from the Handbook of Geophysics data and then by multiplying the solar absorptance, $\alpha_{s\lambda}$, by the ratio of the test lamp to the solar spectral irradiance, obtaining the effective spectral absorptance. The total effective absorptance, α_e, can then be obtained by adding the 100 values of $\alpha_{s\lambda}$ and dividing by 100. The calculated values for several coatings are given in Table 3. In order to determine the degree of accuracy which may be obtained by using this technique the Handbook of Geophysics solar data was input to the computer program in the same way that the test lamp energy is normally inserted. The results of this test indicated that an average error no larger than 2% of the computed absorptance value can be expected. Therefore, the data obtained from these computer calculations should be reasonably valid.

Coatings, Materials, and Applications

Coatings were selected for these tests in order to demonstrate possible large differences in degradation which depend upon exposure environments. For this reason some coatings which are known to be highly unstable were included with some which have been used in space flight experiments and with some which look promising for the future.

The paint formulations tested employ zinc oxide and titanium dioxide pigments in a variety of vehicles which include two types of silicone, an epoxy resin, potassium silicate and a polyester resin. Table 4 is a list of the white paint formulations used.

Paints were applied by a spray technique employing six to eight thin coats resulting in 8 - 10 mils of paint for best reproducibility. In the case of the silicones one to two mils of any of three primers were first applied (Dow Corning's A4094, General Electric's SS4044, or Cat-a-Lac white).

White Paint Formulations
Table 4.

Name	Pigment	Vehicle	Solvent
090	TiO_2 (Anatase)	Methyl Silicone (Dow Corning)	Xylene
007	TiO_2 (Rutile)	Methyl Silicone (Dow Corning)	Xylene
S-13	ZnO (SP-500)	Methyl Silicone (G.E. RTV-602)	Toluene
J.C. #78	TiO_2 (Rutile R-960)	Methyl Silicone (G.E. RTV-602)	Toluene
Cat-a-lac White	TiO_2 (Rutile)	Epoxy (Finch Paint and Chemical Co.)	
3M White	TiO2 (Rutile)	Polyester (M.M.M. Co.)	
ZnO Silicate	ZnO (SP-500)	K_2SiO_3	Water
TiO_2 Silicate	TiO_2 (Rutile R-960)	K_2SiO_3	Water
J.C. #88-S	ZnO (SP-500)	Methyl Silicone (G E. TRV-602)	

The wide variety of characteristics was chosen in order to best demonstrate which parameters are most affected by spectral and total irradiance of these sources and experimental temperature. The anatase (TiO_2) pigment in Q92-090 is known to be unstable in the visible region while the SP-500 zinc oxide is known to be unstable principally in the infrared. The methyl silicone resins are quite stable while the epoxy resin is very unstable and the polyester is questionable. The silicate systems were expected to be very stable from prior test data. The combinations of vehicle and pigment which were chosen would hopefully represent all classes of white coatings to be used on spacecraft in the immediate future

Testing Methods

The optical "in-situ" measurement is made using the ion pumped vacuum system shown in Figure 1. This cell accomodates one sample which is irradiated in

Table 3

EFFECTIVE ABSORPTANCE VALUES FOR VARIOUS SOLAR SIMULATION SOURCES

Name of Coating	Irradiance Sources									
	Xe	M-13 Filtered X-25L	M-20 HgXe	V-3 Ar 5KW	M-24 Hg	M-5 Kr	M-11 Ar	M-9 H-Xe	M-14 Carbon Arc	Solar Energy
Silver	4.0	4.0	13.4	10.1	28.5	6.0	3.2	5.2	3.2	5.0
Aluminum	8.0	7.4	6.5	8.5	7.1	7.3	5.5	7.2	7.1	7.6
J. Colony white 78 - 2 coats over G.E. primer-Methyl silicon-TiO_2 (R960)	14.5	17.6	33.2	24.4	49.4	20.9	22.2	19.8	15.6	18.2
3M white - 8 coats over G.E. primer (Polyester)	17.4	20.5	35.2	27.1	51.1	23.3	24.0	22.3	19.9	
Cat-a-lac white - 8 coats (Epoxy)	18.4	21.3	36.5	28.0	50.9	25.2	27.8	24.1	21.0	
Dow Corning Q007 over Cat-a-lac white-Methyl silicon - TiO_2 (Rutile)	13.2	16.0	31.1	23.3	48.4	18.4	17.9	17.4	15.2	16.2
Dow Corning Q090 over Cat-a-lac white-Methyl silicon - TiO_2 (Anatase)	14.0	16.0	30.3	23.1	46.5	19.3	19.5	18.2	14.9	16.3
S-13 over G.E. Primer-Methyl silicon - ZnO (SP500)	16.5	18.8	34.5	25.8	50.2	22.6	23.7	21.3	18.1	18.9
Gold	14.6	18.6	23.5	22.0	38.5	12.8	7.1	14.0	16.6	19.8
Cat-a-lac black-epoxy	94.9	94.8	94.6	94.7	94.3	94.7	94.7	94.8	94.8	94.8
3M Velvet black	97.2	97.2	97.2	97.2	97.1	97.3	97.3	97.2	97.2	97.2
J. Colony white 88-S over G.E. Primer - Methyl silicon - TiO_2	14.0	16.2	32.1	23.4	46.1	20.1	21.0	18.8	15.4	

RESULTS OF DEGRADATION TESTING WITH VARIOUS SOURCES USING OPTICAL "IN-SITU" MEASUREMENTS

Coatings Tested	α Before	α After	% Change	Total Irradiance mw/cm	Time Irradiated	Source Used	Time of Intermediate Measurement	α Intermediate Measurement	Equivalent UV Sun Hours
Dow Corning Q-090 over Cat-a-lac white - methyl silicone-TiO_2 (Anatase)	14.9	39.8	167.4	140 mw/cm^2	140 hours	HgXe	10 minutes	25.3	336
	16.0	40.0	149.3	140 mw/cm^2	140 hours	Xe	10 minutes	25.5	110
	16.4	41.2	151.3	70 mw/cm^2	280 hours	Hg			638
Cat-a-lac white eight coats (Epoxy)	17.4	27.7	59.1	140 mw/cm^2	36 minutes	HgXe			1.44
	17.6	28.1	60.3	140 mw/cm^2	3½ hours	Xe			2.77
	17.0	21.7	28.0	140 mw/cm^2	30 min.	Carbon Arc			.4
J. Colony 88-S. Same composition as S-13 ZnO SP500 + methyl silicone	17.3	27.5	59.4	140 mw/cm^2	140 hours	HgXe	24 hours	24.2	336
	16.5	28.6	73.3	140 mw/cm^2	140 hours	Xe			110
	13.8	41.9	203.6	70 mw/cm^2	140 hours	Hg	24 hours	23.6	319
Dow Corning Q007 over G. E. Primer - methyl silicone - TiO_2 (Rutile)	15.5	24.1	55.5	140 mw/cm^2	140 hours	HgXe	24 hours	23.3	336
	16.8	25.2	50.6	140 mw/cm^2	140 hours	Xe		23.7	110
	15.8	31.5		70 mw/cm^2	140 hours	Hg	24 hours	26.4	319
J. Colony 78-5B, 2 coats over G.E. primer - methyl Silicone - TiO_2 (R960)	16.8	23.4		140 mw/cm^2	140 hours	HgXe	24 hours	19.3	336
	15.7	22.8		140 mw/cm^2	140 hours	Xe	24 hours	18.8	110
	17.7	29.0		70 mw/cm^2	140 hours	Hg	24 hours	25.2	319

Table 5.

position A and moved to position B where reflectance measurements are made through the quartz port using a Beckman DK-2 Spectrophotometer. The sample is connected to a spring and is moved from position B to A using a magnet. The measurement is precise within ± 1% and its absolute error is less than 4%. The temperature of these samples with one solar constant irradiance ranges from +40°C to +70°C at initial equilibrium conditions. This technique allows measurements to be taken at any time interval. The sample is measured in vacuum before irradiation and a number of times during irradiation to determine change in rate of degradation and after irradiation in vacuum and in air to determine whether the absorptance of the sample has experienced any recovery. This measurement involves physically moving the cell system to be positioned at the integrating sphere port and takes about fifteen minutes.

Results and Conclusions

A summary of the data obtained using four of the sources and some of the coatings discussed herein is shown in Table 5. The absorptance values are integrated total absorptance values measured "in-situ". The "α before" and "α after" values are made at the beginning and at the end of the time interval indicated in the "Time Irradiated" column. The "Intermediate Measurements" are absorptance values taken a short time after irradiation is started (as indicated in "Time of Intermediate Measurement"). This data indicates that there are two types of degradation that are observed, long and short term.

The very rapid initial reflectance changes noted for Cat-a-lac white and Q92-090 provide confirmation for the large initial temperature changes which occur before equilibrium can be reached, and have been observed in testing for these materials. The magnitude of this very rapid initial change in Q92-090 and 88-S is nearly independent of the spectrum, while the rate of degradation is increased by increased short ultraviolet irradiance.

The long term degradation, which can be considered separate from the rapid initial changes, is characteristically most severe in the blue region of the visible spectrum. This type of degradation has been noted to some degree with all of the white coatings tested by the authors. The magnitude of this degradation is related to the intensity of the ultraviolet portion of the spectrum. In order to accentuate this dependence on wavelength it is necessary to consider the rate of reflectance change in the visible region rather than the change in integrated α; otherwise the effect can be largely masked by the initial rapid degradation in the red and infrared.

"In-situ" reflectance measurements indicate that the effect of spectral distribution is minimal with respect to rapid initial reflectance changes which results from surface reactions of pigment; and, maximal with respect to long range, diffusion controlled, bulk reactions of the crystals. Therefore, the choice of source is most important when the effect of rapid surface reaction on reflectance is small, and bulk crystal degradation has the prime effect.

The last column in Table 5 gives the equivalent sun hour dose for the ultraviolet region assuming a constant total irradiance. An inspection of the data indicates the magnitude of degradation is greater when the equivalent sun hour values are greater, but a reciprocity relationship is not obvious. Therefore, a reciprocity rule may not be employed to obtain ultraviolet equivalent sun hours. The use of ultraviolet irradiance to obtain a total effective energy dose presupposes that the actinic absorption and the spectral absorption are identical in the ultraviolet region. Actinic absorption is that absorption which can cause chemical damage and is a function of photon energy (wavelength) and the chemical characteristics of the coating. The actinic absorption curve is probably much different from the spectral absorption curve since it depends upon band gap energy of the pigment material, bonding energies of the vehicle, and activation energies for surface reactions at the pigment vehicle interface, while the spectral absorption curve includes much absorption resulting in thermal response and scattering phenomena. This indicates that different coatings would be characterized by different actinic absorption curves. This is also inferred by the data in Table 5. A valid relationship may exist that will enable an effective total energy dose to be calculated, but such a relationship must consider the actinic absorption curve and the spectral distribution of the irradiance. An actinic absorption curve may be very difficult to obtain but could prove extremely useful in mechanism studies of the separate constituents of the coatings. Considerations of actinic absorption may clarify comparison of data obtained from reciprocity experiments.

Complications arise when different sources are used because the coatings temperatures are inherently different. Even if the substrate temperature is kept constant a problem still exists in determining the actual difference between substrate temperature and coating surface temperature. Any contributions from temperature differences exist in these data. The substrate temperatures measured during these tests were as high as 70°C and as low as 40°C The spectral stability of the system supplying the simulated solar irradiance is a factor which must be considered when evaluating data obtained from long term degradation testing. Degradation of spectrum is inherent with all solar simulation systems and this will change the absorptance of a coating being irradiated. Such degradation of the ultraviolet irradiance generally does not approach an order of magnitude. If periodic spectral and total irradiance measurements are taken and degradation does occur, an average value of irradiance may be obtained for the time interval and used to obtain ultraviolet equivalent sun hours. This is the method used by the authors to obtain the data in the last column of Table 5 ("Equivalent Ultraviolet Sun Hours").

It is the opinion of the authors that testing with different sources and consequently with different

spectra may produce errors in short term or surface degradation and will produce errors in long term or bulk degradation. The type of degradation is dependent upon coating formulation. It was observed that many different rates and magnitudes of degradation occur for various values of (1) spectral irradiance, (2) total irradiance, and (3) temperature. It is proposed, therefore, that valid comparison of coatings optical degradation characteristics may be done only when test conditions (e.g., spectral and total irradiance, temperature, coating formulation, and application) are approximately equal; moreover, environmental testing of thermal coating materials should be conducted using the same conditions that the coatings will experience in space, with emphasis on spectral and total irradiance and temperature.

Footnotes

[1]Johnson, F.S., "The Solar Constant", J. Meteorol., 11 (6) : 431 - 439, December, 1954.

[2]Lillywhite, M. A., McIntosh, R., Lester, D. "Operational Characteristics and Development of a Thermal Vacuum Solar Simulator Used for Spacecraft Thermal Design". Presented at the AIAA/ASTM/IEE Space Simulation Conference, September, 17-19, 1966. AIAA Log. #A1897.

[3]Ibid

[4]Thouret, W. E., Strauss, H. S., "Xenon Compact Arc with Increased Brightness Through Addition of Hydrogen." Illumination Engineering, May, 1963.,p.371

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APPENDIX II

ULTEK TRIP REPORT

Trip to the Ultek Corporation in Sunnyvale, California

During the period 27 December 1966, to 4 January 1967, I made a trip to the Ultek Corporation in Sunnyvale, California, to assist in the preliminary acceptance of eight (8) ultra high vacuum systems which are being purchased by the Thermal Systems Branch, GSFC, in support of its coatings qualification effort. I accompanied Mr. Alfred Hobbs of GSFC. This report represents my activities on this trip.

We arrived at Ultek at approximately 8:45 a.m. on Wednesday, 28 December 1966, and found that although we had been informed by Mr. Bob Moore of Ultek that all eight systems would be ready to be checked out on 28 December, there were no systems completely assembled.

We were told that we could be of no help and it was suggested that we return later that afternoon. We returned at approximately 1:15 p.m., December 28. The two cells, trigger gages, and one power supply were unpacked.

It should be noted here that the cells supplied by NASA - GSFC had been throughly cleaned and baked out in a vacuum oven by Mr. A. Hobbs before we left Washington. The trigger gages were checked against a calibrated gage by myself to 1×10^{-9} Torr before we left.

Ultek was offered the opportunity to clean the cells before either was attached to an Ultek system. The people at Ultek declined indicating that the cleaning which was done at Goddard was satisfactory.

Once everything has been unpacked we found that one system was ready to be checked out. We were told that the other system would not be ready for another day or two.

We attached one cell and one trigger gage to the one system which was ready in the manner described in Ultek's drawings. The system was then evacuated and the large cryocoil in the TSP section was flooded. The system reached a pressure of approximately 2×10^{-6} Torr within 3 hours. The pressure had leveled off and did not appear to be going significantly lower. The specified pressure was 5×10^{-8} Torr in 4 hours. Several explanations were suggested by Ultek's technical staff; however, after discussion it was agreed that these explanations were not technically sound. In an attempt to ascertain what problems did exist, Mr. Charles Brothers of Ultek's research department suggested that they attach a quadrapole residual gas analyzer to the system. This was done on Thursday morning, 29 December.

The residual gas analyzer showed practically no hydrocarbon contamination. There was a large water band, an unbelivable large peak at Mass 20 (neon) and a relatively small series of peaks around Mass 28. This seemed to provide little help in understanding why the systems were not meeting specifications.

It was then suggested that the whole system be baked out. This was done for two hours using heat lamps. I would estimate that the temperature of the system reached perhaps 150°C. When the system cooled and was pumped down with LN_2 in the cryocoil, the largest hydrocarbon contamination I have ever seen appeared on the RGA (residual gas analyzer). The large peak at Mass 20 was still there and the water band was reduced considerably.

Ultek offered the explanation that the cells were really contaminated and asked to clean the cells. We agreed. The cell was removed from the system and the rest of the system was baked out over night to see if the contamination disappeared.

On Friday morning, 30 December, the system was checked, and the contamination was still present. Further, the RGA analyzer tube seemed to be only marginally operational. No explanation was offered by Ultek. However, it seems to me that had the cells caused the contamination this contamination would have been pumped and baked out overnight. It obviously had not been removed. I am forced to conclude that the contamination did not come from the cell but from the Ultek system. Incidentally, if the RGA tube was contaminated the trigger gage tube which was attached to the system was probably contaminated also and readings from this gage would be suspect. The system which had been used for these tests had to be completely disassembled and cleaned.

A second system was ready to be tested at $\approx$ 2:00 p.m. Friday, 30 December. In order to alleviate any suspicions as to any possible contamination from our cell, the system was pumped down with only a trigger gage (a new one). The cryocoil was flooded with LN_2 and after $\approx$ 3 1/2 hours the system reached a pressure of 7×10^{-9} Torr. I would have expected that the system would have reached a pressure of at least 5×10^{-10} Torr with no cell attached since the pumping speed of the system with a cold cryocoil and TSP would be at least a few thousand liters per second. During the pump down it was found that the cryocoil was partially blocked. This would not have greatly affected the pumping speed but it would have to be repaired.

No other systems were completed as of 6:15 p.m. on Friday, 30 December.

On Tuesday morning, 3 January 1967, when we arrived at Ultek we were told that all of the cryocoils would have to be remade since the wrong brazing compound had been used. The brazing compound which had been used apparently had a high vapor pressure.

At this point Mr. Bob Moore of Ultek indicated that the new coils would not be ready for a day and a half.

We returned to the motel and telephoned Mr. C. Duncan at NASA - GSFC who indicated that he was about to have a meeting with Mr. J. Higgins of the Procurement group of GSFC and that he (Mr. Duncan) would call back after his meeting. When Mr. Duncan called back, he said the Ultek would pay Mr. Hobbs salary and expenses, but would not pay mine. Mr. Duncan informed me that I should return on the earliest available flight.

I therefore left San Francisco, California at 5:45 p.m. on Tuesday, 3 January 1967, and arrived in Washington D. C. at approximately 7:00 a.m. the following morning (Wednesday, 4 January, 1967).

I was not present during a single acceptable test of any of the eight systems which are being purchased. Mr. A. Hobbs of NASA - GSFC informed Mr. C. Duncan, Mr. B. Seidenberg, and myself by phone late on Friday, 6 January 1967 that several of the systems has met specifications by rearrangement of the components and attaching the cells directly to the pumping system through a side port without the intervening cross which is specified on the drawings supplied by Ultek as part of this contract.

In my opinion, the vendor(in this case Ultek) should be required to meet the specification (5×10^{-8} Torr in 4 hours) and the agreed date of delivery using the configuration agreed to in the contract. If this is not done we are not being quite fair to the other rejected vendors since all were bidding on the same configuration. Had we specified a different configuration and/or delivery date another vendor might have been able to provide the systems at a reduced price. Further, if the specification (5×10^{-8} Torr in 4 hours) was necessary and the present systems will function only in one configuration it would appear that the system operation may be quite marginal rendering them undesirable for the required applications.

Finally, this experience has again demonstrated the desirability, if not the necessity, to check out all major and/or important equipment which is being purchased at the vendor's facility before the equipment is shipped. If this had not been done in this case it is not clear what sort of systems might have been received at Goddard, nor how much personnel time might have been wasted in trying to make the equipment operational.

N67-32604

APPENDIX III

QUALITY ASSURANCE LABORATORY

APPENDIX III

October 14, 1966

TO: M. Schach
FROM: Benjamin Seidenberg
SUBJECT: Coatings Quality Control

Purpose: To establish an effective area, procedures, and working team along guidelines consistent with good fundamental quality control practice.

I. It is consistent with good quality control practice that we establish an area (a room if you will) in which shelves line the walls. This room have a controlled temperature of 40° -50° F.

This room is needed so that much needed paint samples (uncatalyzed) representing every batch, every paint utilized for a satellite, satellite component, paints transhipped to other areas inside or outside GSFC whether of GSFC or outside manufacture, etc. be stored for a minimum period of one year. That these paint samples bear a specially prepared label noting date of manufacture, date tested, paint type, date of shipment to other areas, etc. An 8 oz. size is recommended as it offers the best compromise between space conservation and utilization for future application study or check. Also, these samples should be cross referenced by a card file showing location on the shelf, duplicate data on the label plus observations concerning end-use, stability, adhesion characteristics, film integrety, etc.

It is necessary that this room be kept cool or refrigerated in order to inhibit or retard polymerization or other possible physical or chemical changes that may occur at room temperatures and more rapidly at elevated temperatures. This room, space permitting, can also be used to house or store certain raw materials such as resins, chemicals, etc. that are more stable at lower than room temperature and therefore better to give reproducible batch results after a period of time.

II. Further, it is recommended that flat 15/16" diameter substrates made of a similar substance to the actual object to be sprayed be prepared at the same time (approximately 10 in number) and retained in another area as a "library" for a future reference, testing, etc. Where flat

specimens are not adequate to exhibit certain characteristics shapes (in miniature) more consistent with the shape actually sprayed should also be included in the "library." Results of reference, tests, etc. on retained specimens be cross referenced with the retained bottle or jar samples and that this card be attached to the above mentioned jar card and placed in the file.

We suggest also that this "library" should include vapor deposited specimens representative of actual objects vacuum deposited by the Thermal Systems Branch. We suggest that the card file include a cross reference as to location of specimens, observations, purpose, procedures, etc. The activities in this area as well as in the paint area to be closely tied in with R. Sheehy's area.

III. To accomplish the above aims we need a technician, full time, assigned to this task. Furthermore, it is urged that the group consist, in the immediate future, of at least three professionals and one technician (under contract) to accomplish the above aims plus many of the task assignments previously outlined for this group.

Also, where evidence, data, etc., retained by this Quality Control group, points to a bad or poor paint batch, bad paint type or where other unsuitable characteristics for end-use obviously exist, that this group have the authority to decline its use after proper notification and consultation.

Lastly, we strongly urge that the above recommendations be seriously considered and adopted substantially in its entirety, so that a meaningful, efficient and continuing quality control effort may be established as soon as possible.