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LONG TERM SPECTRAL IRRADIANCE MEASUREMENTS OF A 1000-WATT XENON ARC LAMP

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INTRODUCTION

Spectral irradiance measurements over the range of 200 to 1060 nm were made on a 1000-watt xenon arc lamp over a period of 1500 hours. Four sets of measurements were made after periods of 70, 525, 1000, and 1500 hours of operation. The lamp (Hanovia Compact Xenon Arc Lamp, Catalogue No. 976C0010) was mounted in the NASA Solar Irradiation System. When used in the System, the lamp is used as the radiating source for six test stations. Measurements were made of both the long-term stability (or variation of spectral irradiance as a function of time) and the actual spectral irradiance incident on the test specimen.

MEASUREMENT TECHNIQUE

Figure 1 shows an optical layout of the six-station Solar Irradiation System. Each station consists of a light-tight chamber with an adjustable lens (L) for imaging the arc on the sample (S). Typical size for a sample is 4.2 cm^2. In normal operation, a solar cell is placed in the sample position and the lens is adjusted until a reading of one sun is obtained. The use of a lens, however, produces an image which is quite non-uniform in irradiance. In order to eliminate the effects of non-uniformity and, since the positioning of the entrance port of the spectroradiometer system at the sample plane was physically impractical, the lens was removed from the system and the spectral irradiance was measured at a point even with the end of the test chamber.

The irradiance at this point (without the lens in place) was fairly uniform. The exact position of the spectroradiometer was noted and it was possible to realign the instrument and repeat readings to within the stability tolerance of the lamp itself.

Upon completion of the four sets of spectral irradiance measurements, the lens was remounted within the test chamber and adjusted in the normal manner for a reading of one sun. A special filter-radiometer was then positioned in the sample plane and a measurement of the irradiance at 580 nm was made.

Prior to inserting the lens, the spectral transmittance of the lens was measured by NASA Langley. Thus, from a knowledge of the spectral irradiance (without the lens), the spectral transmittance of the lens and the irradiance measurements made with the filter-radiometer, the spectral irradiance over the 4.2 cm^2 sample plane could be calculated.

TEST APPARATUS

Optical Radiation Measurement System

Measurements of spectral irradiance were made with an Optronic Laboratories Model 740 Optical Radiation Measurement System. The basic system includes a rugged, high-efficiency (f/4) single grating monochromator; a stable, ultraviolet enhanced silicon photodetector; and a low-noise electronics unit having a 3-1/2 digit display, reading directly in amperes. The Czerny-Turner design, coupled with the stray light and second order blocking filters, reduces the effect of stray light to less than 0.1% for most wavelengths, with a maximum effect at 300 nm of 2%. Fixed entrance and exit slits (1.25 mm in width), which produce a bandpass of 5 nm, were used over the entire 200 to 1060 nm wavelength region.

The radiation measurement system is normally calibrated in W cm^{-2} nm^{-1} per ampere over the 300 to 1060 nm region. For measurements over the 200 to 300 nm range, the standard grating was replaced with a uv blazed grating and the silicon detector was replaced with a solar-blind photodetector. The use of a solar blind detector, coupled with the uv grating, enabled measurements to be made as low as 200 nm without significant stray light effects. Figure 2 gives the spectral response of the detector.

Filter Radiometer

A specially modified filter radiometer consisting of an Optronic Laboratories Model 730 Radiometer/Photometer with a modified Model 85 Cosine Receptor having a receiving area of 4.2 cm^2, equivalent to the sample area, was used for the final irradiance measurements. For these measurements, the diffuser was replaced with a slightly larger one having a receiving surface equivalent to the sample area (4.2 cm^2). A narrow bandpass interference filter transmitting at 580 nm was used in conjunction with the radiometer and cosine receptor. Figure 3 shows a diagram of the complete detector head.

CALIBRATION PROCEDURE - SPECTRORADIOMETRIC

Calibration of the Optical Radiation Measurement System and the Filter Radiometer was performed using a 1000-watt tungsten-halogen lamp standard of spectral irradiance. Calibration of the lamp standard, designated S-5, over the range of 250 to 1060 nm is based on the new (1973) NBS irradiance scale. Spectral irradiance values for S-5 from 250 to 200 nm were determined through comparison to a similar lamp previously calibrated relative to a 3000° C blackbody reference source. The uncertainty in the calibration of standard S-5 ranges from ± 3.5% at 250 nm to ± 1.25% in the visible and near infrared. The transfer error to the Radiation Measurement System is on the order of ± 1%. Although the uncertainty in the region below 250 nm is not precisely known, the relative calibration is fairly accurate. Thus, any changes in the spectral irradiance of the xenon lamp over the 1500 hour period were accurately determined. All measurements above 250 nm were made on an accurate absolute basis.

Although the stability of the Optical Radiation Measurement System is extremely good, the system was completely calibrated before and after each trip to NASA Langley. A complete calibration was performed as follows:

1) 1000-watt standard S-5 was set up normal to and at a distance of 50 cm from the entrance slit of the spectroradiometer. A Constant Current DC Power Supply was used to supply a set current at 8.30 amp dc to the standard. The accuracy in the operating current is better than ± 0.1%.

2) With the standard uv enhanced silicon detector in place, along with the standard grating, detector output readings in amperes were taken at 10 nm intervals over the range of 300 to 1060 nm. The three standard second order blocking filters were inserted as follows:

Blocking Filter #1	300 to 350 nm
Blocking Filter #2	350 to 650 nm
Blocking Filter #3	650 to 1060 nm

3) The standard grating and detector were replaced with the uv blazed grating and the solar blind diode. Detector signals were then recorded at 10 nm wavelength intervals over the 200 to 300 nm region. A Corning 7-54 blocking filter was used over the 240 to 300 nm region. No blocking filter was used below 240 nm.

4) The spectral responsivity of the system in Watt $cm^{-2} nm^{-1}$ per ampere was then computed.

The above procedure was performed before and after each measurement on the xenon lamp.

The spectral measurements on the xenon lamp were fairly straightforward. The spectroradiometer was set up in the same manner for each of the four sets of measurements. Detector readings were taken at 10 nm wavelength intervals over the 200 to 1060 nm region with the proper gratings, detectors, and filters in place. The operating voltage and current for the xenon lamp are also recorded.

The data reduction consisted of taking the average of the calibration factors before and after the xenon lamp measurements and multiplying these values by the corresponding detector output when looking at the xenon lamp. In most cases, the calibration factors for the eight calibration runs agreed to about $\pm$ 1%. This is within the uncertainty of the standards and also within the actual short-term stability of the xenon lamp.

CALIBRATION PROCEDURE - FILTER RADIOMETRIC

Lamp Standard S-5 was also used to calibrate the Filter Radiometer. The filter radiometer, with the Cosine Receptor attached to the unit (Figure 3) was positioned such that the lamp standard was normal to and at a distance of 50 cm from the cosine receptor. The cosine receptor could easily be removed in order to insert the narrow bandpass interference filter. The calibration was also in units of Watt $cm^{-2} nm^{-1}$ per ampere.

RESULTS AND DISCUSSION

Table I gives the results of the spectral measurements as made with the Optical Radiation Measurement System. Table II gives the irradiance values and the percentage change in the lamp's irradiance after the four sets of measurements.

As shown in Table II, there is a substantial decrease in the spectral irradiance of this xenon lamp after 1500 hours of operation, with most of this decrease occurring in the first 1000 hours of lamp operation.

The purpose of the final irradiance measurement using the filter radiometer was to determine the spectral irradiance of the NASA Solar Irradiation System in a normal sample irradiation configuration. The sample focusing lens was installed and adjusted for one solar constant at approximately 500 nm, using the NASA filtered, solar cell detector so that these measurements could be directly compared to published values of the solar spectrum.* This comparison is made in Table III. Table III shows that the ultraviolet irradiance of the Solar Irradiation System is substantially lower than the published values of irradiance when the filtered, solar cell detector is used for calibration.

* "The Solar Constant and the Solar Spectrum Measured from a Research Aircraft at 38,000 Feet", NASA Goddard Space Flight Center Report X-322-68-304 (August 1968).

TABLE I - Spectral Irradiance of Xenon Arc Lamp with Respect to Hours of Lamp Operation

Wavelength (nm)	Irradiance, $\mu W/cm^2$-nm after 70 hours	525 hours	1000 hours	1500 hours
200	0.133	0.107	0.084	0.081
220	.84	.688	.545	.524
240	1.92	1.56	1.50	1.47
260	3.60	2.90	2.80	2.77
280	5.80	4.89	4.80	4.76
300	11.6	9.09	8.20	7.90
320	18.8	14.9	12.8	12.0
340	28.1	22.7	19.2	17.5
360	35.0	28.5	24.1	22.0
380	50.8	40.7	35.1	31.4
400	68.3	55.9	47.2	41.6
420	90.4	69.4	59.4	51.6
440	103	83.9	71.0	62.0
460	138	111	97.8	85.8
480	155	123	110	95.3
500	155	125	107	92.6
520	169	139	117	102
540	183	149	127	113
560	197	164	138	121
580	211	177	149	130
600	215	182	153	134
620	230	197	166	146
640	230	196	163	142
660	234	198	167	150
680	250	215	185	167
700	245	213	177	159
720	253	223	186	166
740	276	247	211	190
760	273	237	208	189
780	224	193	165	146
800	268	247	207	179
820	584	496	441	435
840	451	395	353	313
860	230	199	165	146
880	1018	918	925	877
900	587	554	447	410
920	873	76	701	558
940	728	698	636	563
960	333	329	256	220
980	970	941	954	910

TABLE I (continued)

Wavelength (nm)	Irradiance, $\mu W/cm^2$-nm after 70 hours	525 hours	1000 hours	1500 hours
1000	427	398	281	241
1020	243	241	184	155
1040	158	153	123	108
1060	160	158	129	111

TABLE II - Change in Spectral Irradiance of Xenon Arc Lamp with Respect to Hours of Lamp Operation

Wavelength (nm)	IRRADIANCE, $\mu W/cm^2$-nm after				% Decrease in Irradiance, after		
	70 hours	525 hours	1000 hours	1500 hours	525 hours	1000 hours	1500 hours
200	0.133	0.107	0.084	0.081	20	37	39
250	2.64	2.14	2.08	2.01	19	21	24
300	11.6	9.09	8.20	7.90	22	29	32
350	33.0	27.0	23.0	19.5	18	30	41
400	68.3	55.9	47.2	41.6	18	31	39
450	124	110	86.7	75.5	11	30	39
500	155	125	107	92.6	19	31	40
550	189	156	133	117	17	30	38
600	215	182	153	134	15	29	38
650	236	207	171	152	12	28	36
700	245	213	177	159	13	28	35
750	268	240	203	182	10	24	32
800	268	247	207	179	8	23	33
850	219	175	151	132	20	31	40
900	587	554	447	410	6	24	30
950	689	666	635	571	3	8	17
1000	427	398	281	241	7	34	44

TABLE III

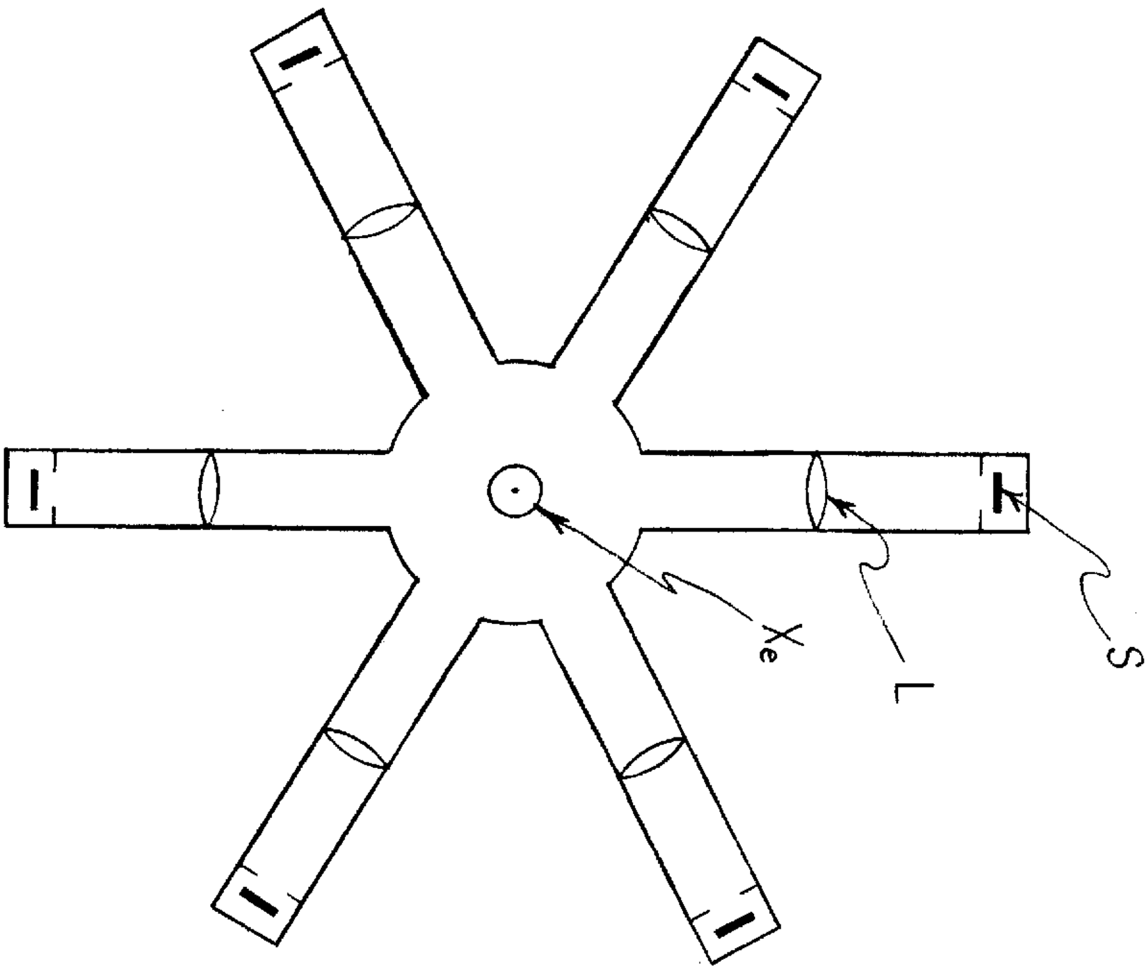
Spectral Irradiance of Xenon Lamp with Lens Adjusted for One Sun and Solar Spectral Irradiance

Wavelength (nm)	($\mu W/cm^2$ nm) Xenon Lamp	Sun*	Wavelength (nm)	($\mu W/cm^2$ nm) Xenon Lamp	Sun*
200	0.161	1.30	660	348	146.8
220	1.17	5.75	680	387	141.8
240	3.41	6.30			
260	6.50	13.0	700	369	136.9
280	11.2	22.2	720	385	131.4
			740	441	126.0
300	18.5	51.4	760	438	120
320	28.5	81.9	780	339	115
340	40.2	105			
360	50.5	105.5	800	415	110.7
380	71.7	111.7	820	1009	106
			840	726	101
400	93.5	143.3	860	339	97
420	115	175.8	880	2035	93
440	138	182.3			
460	190	208.	900	951	88.9
480	210	208.5	920	1295	87
			940	1306	84.5
500	204	194.6	960	510	81
520	225	183.3	980	2111	77.5
540	249	178.3			
560	267	169.5	1000	559	74.6
580	290	170.5	1020	360	72
			1040	251	69
600	303	164.6	1060	258	66
620	334	157.6			
640	329	151.7			

* "The Solar Constant and the Solar Spectrum Measured from a Research Aircraft at 38,000 Feet", NASA/Goddard Space Flight Center Report X-322-68-304 (August 1968).

Figure 1

Optical Layout - Solar Irradiation System



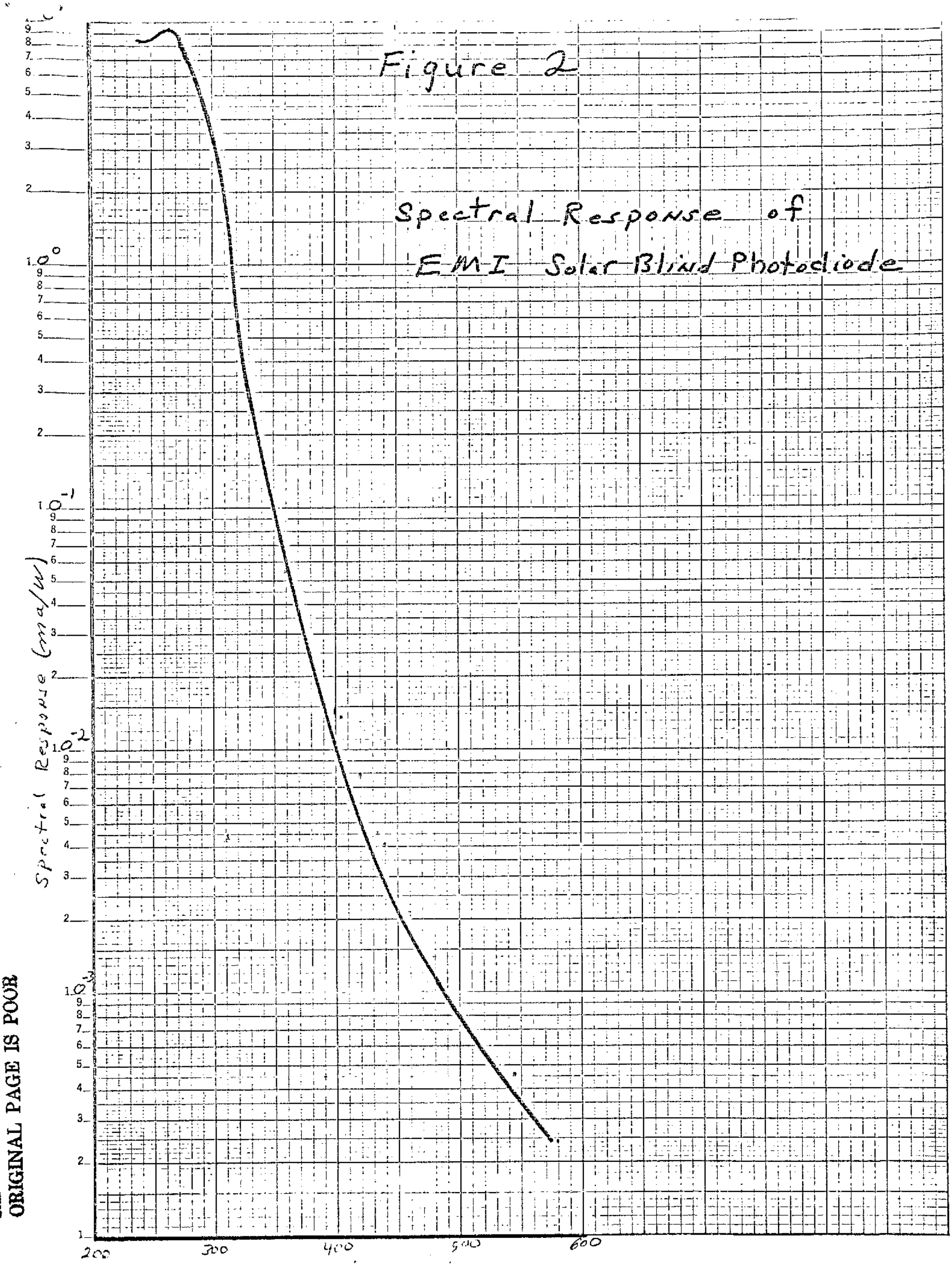


Figure 2
Spectral Response of
EMI Solar Blind Photodiode
Spectral Response (ma/w)
10^0
10^{-1}
10^{-2}
10^{-3}
200
300
400
500
600

Figure 3

Filter Radiometer