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Low-Cost
Solar Array Project

DOE/JPL 1012-31

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Reactor for Simulation and Acceleration of Solar Ultraviolet Damage

E. Laue
A. Gupta

September 21, 1979

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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16. Abstract

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Details of design and construction and operational procedures are presented along with typical test data.

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The JPL Low-Cost Solar Array Project is sponsored by the Department of Energy (DOE) and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

PREFACE

The work described in this report was performed by the Applied Mechanics Division and the Control and Energy Conversion Division of the Jet Propulsion Laboratory under the cognizance of the Low-Cost Solar Array Project.

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ABSTRACT

An environmental test chamber providing acceleration of UV radiation and precise temperature control (±1°C) has been designed, constructed and tested. This chamber allows acceleration of solar ultraviolet up to 30 suns while maintaining temperature of the absorbing surface at 30°C - 60°C). This test chamber utilizes a filtered medium pressure mercury arc as the source of radiation, and a combination of selenium radiometer and silicon radiometer to monitor solar ultraviolet (295-340 nm) and total radiant power output, respectively.

Details of design and construction and operational procedures are presented along with typical test data.

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I INTRODUCTION

A. Introduction

All hardware deployed in the field for solar energy applications has to be tested for weatherability and long usable life outdoors. The LSA Encapsulation Task is required to demonstrate technical readiness by 1982. This demonstration will include development and validation of a methodology of life prediction of solar cell modules. Validation of any life prediction model requires both real time and accelerated testing. This report describes design and fabrication of an environmental test reactor which allows accleration of stresses such as ultraviolet radiation and temperature. This reactor design can be readily extended to include control of humidity and atmosphere (e.g. oxygen concentration).

Several key design requirements have been identified which control the closeness of correlation of accelerated test data with data obtained in field. A survey indicates that these design requirements are not met by a several commercial weatherometers which may explain why correlation between weatherometer and field data is often so poor. Here we are concerned with the correlation of the effects of aging identical sample in the field and in the test chamber. In theory this correlation should be exact if 1) the dependence of aging/degradation rate on stress levels are known, 2) during acceleration of one or several stresses these dependence relationships hold, in other words, valid limits of acceleration are not exceeded, and 3) stress levels and nature of stresses being applied in the test chamber and those experienced in field are known to a given level of accuracy.

B. Performance Objectives

The design requirements identified are:

1. Wavelength of ultraviolet radiation being used in the reactor. The wavelength should have a sharp cutoff at 295 nm. This cutoff should not be outside the range 294-300 nm. There are many acrylics in which damage occurs at wavelengths in this region and a shorter cutoff (e.g. 280 nm) can damage acrylics or silicones which will not be damaged in field (excluding high mountain tops), while a longer cutoff, e.g. 320 nm, will not duplicate damage on other types of acrylics and silicones observed in field which is caused by short wavelength uv radiation present in AM 1 sunlight. Commercial weatherometers using carbon arcs and xenon arcs with various types of filters often do not meet this requirement. For example, commercially available carbon arc (sunshine arc or violet arc) or high pressure xenon lamp weatherometers may either have significant output in the range 280-290 nm, harmful to many acrylics but not present in AM 1 solar irradiance, or may be deficient in the range 295-310 nm. This problem is particularly acute with xenon weatherometers, since these sources undergo degradation in their uv output over quite short periods of operation. Certain commercial weatherometers generate ozone, e.g. generate 254 nm and shorter wavelength radiation. Obviously these are unsuitable for use as well. Other weatherometers use

coated mercury lamps, and their suitability depends on the fluorescence characteristics and stability of the coatings. In general, it is believed that an uncoated lamp jacketted with a pyrex filter is best suited for this work.

It appeared that if the wavelength cutoff requirement is met, a source emitting radiation containing spikes can be utilized if there is an underlying continuum, and if the spikes are also relatively broad. In other words, use of a source whose intensity certain wavelengths may not produce an expected acceleration of aging of a specimen absorbing at wavelengths away from the spikes, but if the spikes are distributed throughout the spectrum (e.g., Hg arc) this problem is avoided.

2. Temperature control. Temperature control should be maintained not only at the outer surface of the specimen, but at the volume element absorbing radiation. In general this is difficult, since absorbed radiation causes a rise in temperature, and the higher the acceleration level, the greater is this uncontrollable temperature rise. However, this problem is significantly less severe if the infrared part of the exciting radiation is removed. No chemical damage occurs in this region through electronic mechanisms. However, this radiation is generally absorbed by polymers and certain ceramics quite efficiently, and rise of temperature can be quite substantial. Cooling the sample then causes large temperature gradients to form, which may cause new types of failures. Hence this requirement can only be met by filtering out the infrared from the radiation input.

3. UV intensity. These measurements need to be carried out quite frequently until there is confirmation that the radiation source is stable both in total output and in output as function of wavelength. In general, high temperature sources tend to be less stable in terms of uv (295-320 nm) output. Although continuous measurements can provide data which can be used for correcting for this problem, it is clearly preferable to use a lamp which operates at a lower temperature and hence provides a stable output of uv radiation.

II. REACTOR DESCRIPTION

A. Introduction

A single solar cell 7.6 x 7.6 cm (3" x 3") module complete with encapsulant has been selected as an inexpensive method of observing the effects of environmental exposures. A cylindrical 34 cm-diameter reactor using a medium pressure mercury discharge lamp has been fabricated to (Figure 1) to explore the parameters required to simulate exposure to natural environments. This report details the reactor and one sequence of tests using the single cell modules.

B. Reactor Design

A 550 watt Canrad/Hanovia medium pressure mercury A.C. lamp surrounded by a 1 cm thick pyrex water jacket, for cooling and infrared absorption, provided the irradiance, while an electrical heater and fan system was used to adjust the sample's temperature. The lamp was allowed to operate from its standard power supply with no attempt at regulation of the irradiance. Lamp voltage was the only parameter monitored to characterize its performance.

The exposure region was a perforated aluminum cylinder 34 cm in diameter by 23 cm high. This allowed contiguous exposure of approximately 11 1-cell samples. Truncated ones of the aluminum were used to close both ends of the cylinder. The lower cone was permanently attached to the cylinder and supported an electrical heater and muffin fan air circulator. The upper cone merely rested with angle guides on the cylinder. The perforated cylinder walls and easily removed top piece allowed rapid examination or replacement of samples not necessarily of the 7.6 x 7.6 cm size. A 5 cm thick thermal blanket surrounded the assemlby and allowed control of the temperature of a typical sample between 30 to 60°C. Figure 1 is a photograph of the assembled reactor in operation showing that the stray UV light had been reduced to a minimum. Figure 2 shows the internal portion of the reactor. Construction details are found in Fig 3 (JPL DWG #J10093034).

C. System Details

The auxiliary instrumentation needed to monitor the reactor test panel performance is shown in Figure 4 and details are listed in Appendix I. This list of equipments and instrumentation is recommended for use in construction and operation of this test reactor.

A strip chart single channel recorder with an adjustable set point using voltage from one of the copper constantan thermocouples installed on a test module was used as an on-off temperature controller. Gross adjustment of the temperature was achieved by blocking the fan inlet and upper cone air outlet. Fine tuning was accomplished by adjusting the heater current. A cyclical variation of ±1 degree C was the best that could be achieved using the various adjustments. The heater current could be adjusted between 0 to 3 amps (approximately 0 and 85 watts). Temperature control between 30 and 60°C was possible. Sample performance was monitored by measuring the open circuit voltage of each solar cell and the millivolts developed across a 0.131 ohm load (approximately short circuit value). These were recorded at least twice daily and more often if abnormal readings were encountered.

The 200 to 400 nm spectral irradiance was measured using a Gamma Scientific Spectroradiometer. Table I presents data from the October 6, 1978, measurements, and Table II the results of the December 8, 1978, measurements. After it was ascertained that the spectral irradiance of the system had decreased during the initial two month's usage, a selenium photovoltaic cell and Corning 7-45 ultraviolet filter was used to monitor the UV irradiance. A 1 x 2 cm silicon solar cell was used to measure the near-IR irradiance. Measurements were made directly in front of each module. The "effective" spectral sensitivity of the 7-45 filter and selenium cell combination is shown in Figure 5. While this combination adequately covers the UV spectral region of the medium pressure mercury lamp, the stability of the Corning 7-45 filter to continuous ultraviolet exposure and the unknown temperature sensitivity of the selenium photocell made it necessary to minimize the exposure time of the UV meter. On May 9th when the solar irradiance at JPL was at 94 mW/cm^2, the filter Se/photocell combination indicated 2.8 mV. The 1 x 2 cm silicon solar cell, loaded with 0.24 ohms "short circuit", read 13 mV under the same JPL sun. These values were used as the reference one sun throughout the testing. Figure 6 and Figure 7 are plots of the average of the observed UV and near IR measurements made in front of each test sample during the exposure from March 19, to June 12, 1979. The ultraviolet measurements indicate a 40% degradation as measured by the output of the filtered selenium radiometer (Fig. 5) while the near IR decreased only 8%. Either the solarization or staining of the Pyrex water jacket or a decrease in the lamp output could cause the observed results. A preliminary test has indicated that the pyrex water jacket was the primary cause of the observed reduction in the ultraviolet irradiance. A different water jacket and a new 550 watt lamp will be used to further pinpoint the precise nature of the loss in ultraviolet irradiance. Approximately 1900 hours of lamp operation have been logged since the initial tests in October, 1978. Based on these results it is recommended that new lamps and water jacket be installed every 1000 hours of operation.

III REACTOR APPLICATION

A. Introduction

This section describes a typical test run on the reactor using one solar cell modules supplied by Springborn Labs. In one sequence of tests six one cell modules were continuously irradiated in air in the reactor. Temperature, irradiance (UV and near IR), short circuit current and open circuit voltages were monitored. In a second series of tests six one cell modules were exposed in this reactor to ultraviolet irradiance in air at temperatures ranging from 50 to 60 degrees C and three of these modules were periodically soaked in distilled water. The other three modules were maintained in the dark (air) during the soak periods.

B. Results

There was no sign of degradation of electrical performance of the initial set of six modules which were exposed to an equivalent of 55 months incident UV in the 295-320 spectral band.

Starting on March 19, 1979, the Springborn samples 8924-1, 8924-2, 8924-3, 7825-1, 8925-2 and 8925-3 were installed. Also one 7.6 x 7.6 cm fiberboard painted with the Catalac flat Black and one painted Epoxy white were installed with thermocouples to serve as temperature monitors. During the entire test cycle (March 22 through June 9) the Epoxy white remained as the lowest temperature and the Catalac Black the highest temperatures of the test group. Table III is a summary of the Springborn module exposure. The temperatures of the other six samples ranged between the 50 to 60°C. A 12 hour soak cycle of modules of 8924-2, 8924-3, and 8925-1 was initiated on March 26. The nominal test consisted of two days of irradiation followed by two days of soak for three of the six samples. The lamp was off during the soak portion of the cycle.

The open circuit voltage and short circuit current (E. 131Ω) for a typical pair of modules during the test program has been plotted in Figures 8 and 9. On each plot data from one non-soaked has been included as a measure of the "random noise" of the system. In these plots "S" and the brackets indicate the lamp off soak period. The Roman numerals identify the test cycles. When possible, cell temperatures, open circuit voltage and loaded current readings were taken immediately before and shortly (approximately 2 hours) after reinstallation of the modules and lamp start-up. The following is a brief narrative describing the test results for the three modules subjected to the soak sequences.

Sample 8925-1: After soak cycle I, the observed current was 0 and the open circuit voltage was "noisy". Post test analysis indicated that cells were cracked and where cracklines intersected the metallization, intermittent contacts caused the change in short circuit current. In subsequent measurements, the current had recovered 229 mA, then fell back to 15 mA. After soak II the short circuit current remained below 60 mA until the day before soak IV the current was 252 mA only one reading. It was less than 10 mA for the remainder of the test program.

Sample 8924-3 had a normal 260 mA output before the soak tests, but dropped to 183 mA after the second soak. There was a gradual recovery to 237 mA then a decrease to 229 mA just before cycle III. After the soak cycle # III the short circuit current dropped to 145 mA and drifted down on subsequent soaking to 0 mA by cycle number # XI.

The normal output for 8924-2 was 237 mA and remained normal for five soak periods but after cycle number V it dropped to 237 mA. The cell output recovered to 214 mA before soak cycle VI (5-14-79). From 5-16-79 through the remainder of the testing cell output ranged from 191 to 0 mA.

Visual inspections of the modules were made throughout the entire test program. The non-soaked samples, number 8924-1, 8925-2 and 8925-3, did not show any significant change. Since the inspection was not quantitative, subtle changes would not be apparent. After soak cycle number VIII 8924-2 and 8924-3 appeared to have random lines in the encapsulant which were visible only in the silicon solar cell area.

Just before soak cycle IX all three modules had these lines. After soak cycle X, 8924-2 and 8924-3 had large semi-opaque areas between some of these lines. There was no change in 8925-1. The opaque region disappeared during the irradiation of 6-6-79. There was no change in visual appearance after the soak number XI except the opaque region re-appeared on 8924-2 and 8924-3.

After the final soak cycle XI (6-11-79) visual inspection was accomplished on 6-27-79, and the lines were still present on 8924-2, and 8924-3, and 8925-1. The opaque areas were still visible (under diffuse light) on samples 8924-2 and 8924-3 but were greatly reduced in area from previous "wet" inspections.

Figures 10 and 11 indicate that the cells cracked during the test and where cracklines intersect the metallization, there is severe corrosion of the metallization. This crack induced corrosion has been predicted by Rockwell Science Center as a potential failure mode.

IV SUMMARY

An ultraviolet test reactor has been designed, constructed and tested. It appears to meet all the design requirements needed for meaninful simulation and acceleration of photodegradation of polymers observed in the field. The reactor design can be readily modified so as to include atmosphere control and provision for water/fog. It can also be scaled up for samples of the size of minimodules (16" x 12") without major modification in the design. A small reactor (suitable for testing samples 4¼ x 4¼") has already been designed and constructed. This second reactor has provision for atmosphere control and rain/fog. Testing of the reactor indicates that the lamp filter assembly can be used for 1000 hours, and using a new pyrex jacket the same lamp can be used for another 1000 hours, equivalent to approximately 10 years of outdoor exposure. Results of one series of tests have been described and a new failure mode, e.g. corrosion of metallization induced by cell cracking, has been discovered.

APPENDIX I

ITEM	SOURCE	REMARKS
Medium Pressure Mercury Vapor Lamp	Conrad Hanovia Model 673A10	550 Watt
Lamp Power Supply	Conrad Hanovia Catalog #2065-1	
Pyrex Water Cooler/Filter	None	Fabricate from 50mm & 70mm pyrex cylindrical tubes
Heater	Dale Resistor type RH50 50 ohm	Parallel five resistors
Muffin Fan	Rotron MU2B1-2807 or #S5747	
Heater Controller	Omega 800M, 0-350°F.	
Temperature Readout	Omega Model 1 (#2572TC)	
Monitor & Test Cell Readout	Fluke Model 8020 or Texmate RP4500D	Intersil Model ICL 7106 DPM kit may be used if voltage calibration available.
Ultraviolet Monitor		Selenium Photovotaic Cell Approx 1" X 1"
Detector	American Science Center #P-30, 411	
Filter	Corning 7-54, 2" x 2"	
Base		Make from Micarta 2½ x 2½ x ½"
Load Resistor	Approx. 200-300 ohms	Load for ≈ 3 mv in 100 mW/cm² sun
Near IR Monitor		
Detector	Vatec VTS-3020 or Panasonic BP-105 or IRC Type BWH	1cm x 1cm Silicon Solar cell
Load Resistor	IRC type BWH or AMF RCL type BWR	With resistors between .11 to .68 ohms load for ≈ 20 mv in 100 mW/cm² sun

Ref. Figs. 3 and 4

Table I. Duplicate spectroradiometric measurements of irradiance on reactor surface. Measurements were made at two nanometer intervals. Units: $10^{-6} W cm^{-2} nm^{-1}$.

	#1	#2
WAVELENGTH 250.0	0.0111	0.0034
	0.0062	0.0031
	0.0081	0.0020
	0.0120	0.0030
	0.0102	0.0018
WAVELENGTH 260.0	0.0060	0.0005
	0.0042	0.0005
	0.0039	0.0004
	0.0081	0.0012
	0.0033	0.0004
WAVELENGTH 270.0	0.0036	0.0004
	0.0027	0.0000
	0.0009	0.0003
	0.0024	0.0003
	0.0018	0.0000
WAVELENGTH 280.0	0.0034	0.0003
	0.0061	0.0006
	0.0015	0.0003
	0.0021	0.0012
	0.0051	0.0031
WAVELENGTH 290.0	0.0763	0.0562
	0.0690	0.0470
	0.1231	0.0841
	0.5812	0.4553
	3.7224	2.6759
WAVELENGTH 300.0	0.9117	0.6264
	13.1294	10.4841
	25.8742	17.7109
	2.5269	1.9795
	2.9482	2.1951
WAVELENGTH 310.0	4.2039	2.9967
	28.1942	18.1368
	341.5651	237.4398
	112.5851	74.4645
	14.7400	10.3133
WAVELENGTH 320.0	15.3719	10.8996
	17.4075	12.2692
	19.7405	13.7850
	21.8938	15.5349
	23.6849	17.2085
WAVELENGTH 330.0	[illegible].5031	10.7652
	[illegible].5268	20.7971
	[illegible].2160	73.7621
	[illegible].0750	140.7045
	42.6790	28.1997
WAVELENGTH 340.0	37.6132	26.4529
	34.7305	24.1856
	33.5007	23.6611
	32.0065	22.5250
	30.4250	21.3441
WAVELENGTH 350.0	28.4008	18.5217
	25.9203	17.8042
	26.7757	19.5014
	29.5941	20.2568
	23.5505	16.0289
WAVELENGTH 360.0	23.6390	16.4244
	20.8591	15.0039
	156.5257	23.4021
	2050.3163	0.0202
	2450.4391	0.0199
WAVELENGTH 370.0	113.5141	83.8141
	48.4316	36.7170
	20.3567	12.9306
	16.8384	11.2201
	14.5398	9.7039
WAVELENGTH 380.0	22.4273	15.1825
	48.3178	11.9505
	14.4223	9.4973
	11.4542	7.9316
	13.1365	8.5447
WAVELENGTH 390.0	19.8580	16.5447
	71.4244	49.9083
	16.0964	8.8757
	9.4649	6.1999
	10.1375	6.9112

Table II. Spectroradiometric measurement of irradiance at reactor surface when lamp/filter assembly is 1900 hours old; units same as in Table I.

WAVELENGTH 250.0
0.0047
0.0025
0.0077
0.0106
0.0088
WAVELENGTH 260.0
0.0044
0.0024
0.0031
0.0103
0.0028
WAVELENGTH 270.0
0.0037
0.0024
0.0011
0.0024
0.0009
WAVELENGTH 280.0
0.0044
0.0068
0.0010
0.0011
0.0022
WAVELENGTH 290.0
0.0323
0.0289
0.0487
0.5837
1.4856
WAVELENGTH 300.0
0.3666
5.3703
10.8889
1.1102
1.3343
WAVELENGTH 310.0
2.1799
12.2797
181.8883
54.9203
8.1827
WAVELENGTH 320.0
8.7785
10.3850
11.9653
13.4911
15.2879

WAVELENGTH 330.0
16.6527
27.4214
60.5521
136.6586
25.4363
WAVELENGTH 340.0
25.6731
23.8144
24.0454
23.1964
22.3074
WAVELENGTH 350.0
20.9928
19.3797
20.2982
22.4518
18.1553
WAVELENGTH 360.0
18.3948
17.3123
30.0482
2739.2778
1817.5709
WAVELENGTH 370.0
71.6789
33.7511
15.3730
13.1053
11.4773
WAVELENGTH 380.0
17.9265
14.3495
11.6089
9.3684
10.8489
WAVELENGTH 390.0
27.3953
56.6031
14.8723
7.5760
8.4730

Table III. Temperature and ultraviolet measurements data

DATA DATE	REF T°C		7-54/Se		AVG Si		SOAK DATES
	White	Black	m V	"Suns"	m V	Si mW/cm^2	
3-22-79	54	67	17.3	6.2	No Data	-	
3-26-79	53	66	16.0	5.7	5.8	41	3-26 to 3-27
3-27-79	52	65	--	--	--	--	
3-29-79	51	64	--	--	--	--	3-29 to 4-2
4-2-79			16.7	6.0	5.4	38	
4-25-79	51	67	-- 13.1	-- 4.7	-- 5.9	-- 42	4-20-79 4-25-79
4-26-79	52	68					4/25/79 4/26/79
4-30-79	51	65					4-28-79 4-30-79
5-11-79	51	64	12.1	4.3	5.5	39	5-9-79 to 5-11-79
5-16-79	52	64					5-14-79 to 5-16-79
5-25-79	51	64					5-18-79 to 5-21-79 5-23-79 to 5-25-79
6-2-79	53	64	11.1	4.0	5.1	36	5-29-79 5-31-79

Table III. Temperature and ultraviolet measurements data (contd)

DATA BASE	REF T°C		7-54/Se		AVG Si		SOAK DATE
	White	Black	m V	"Suns"	m V	Si mW/cm^2	
6-6-79	53	63					6-4-79 6-6-79
6-12-79	53	65	10.3	3.7	5.3	37	6-9-79 to 6-11-79

NOTE: 7-54/Se UV shows approx 40% decrease UV irradiance from 3-26 to 6-12-79

TOTAL TEST:	84 days
Soak:	23 days
Standby:	4 days
	57 days irradiation

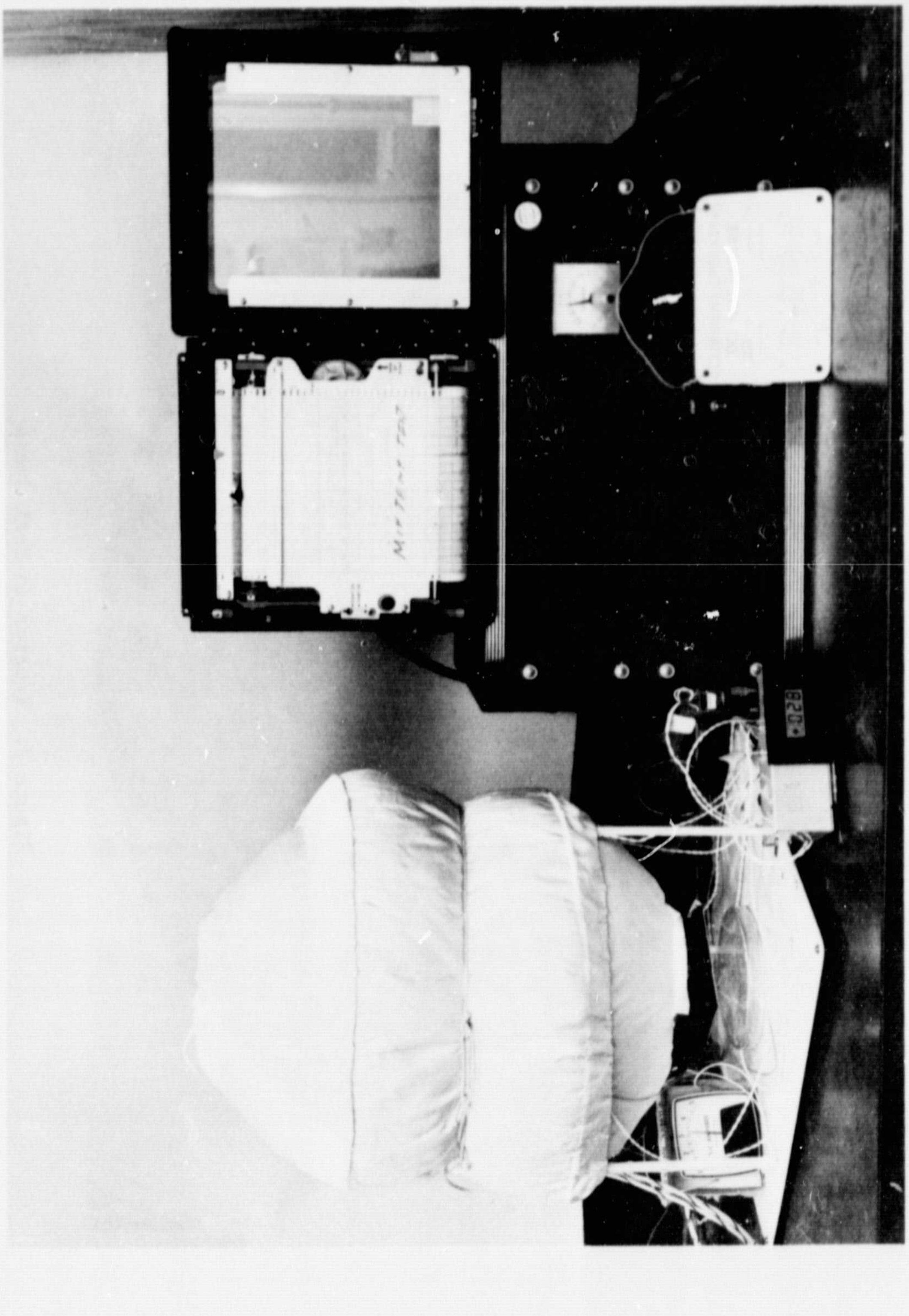


Figure 1. 550-Watt Reactor in Operation

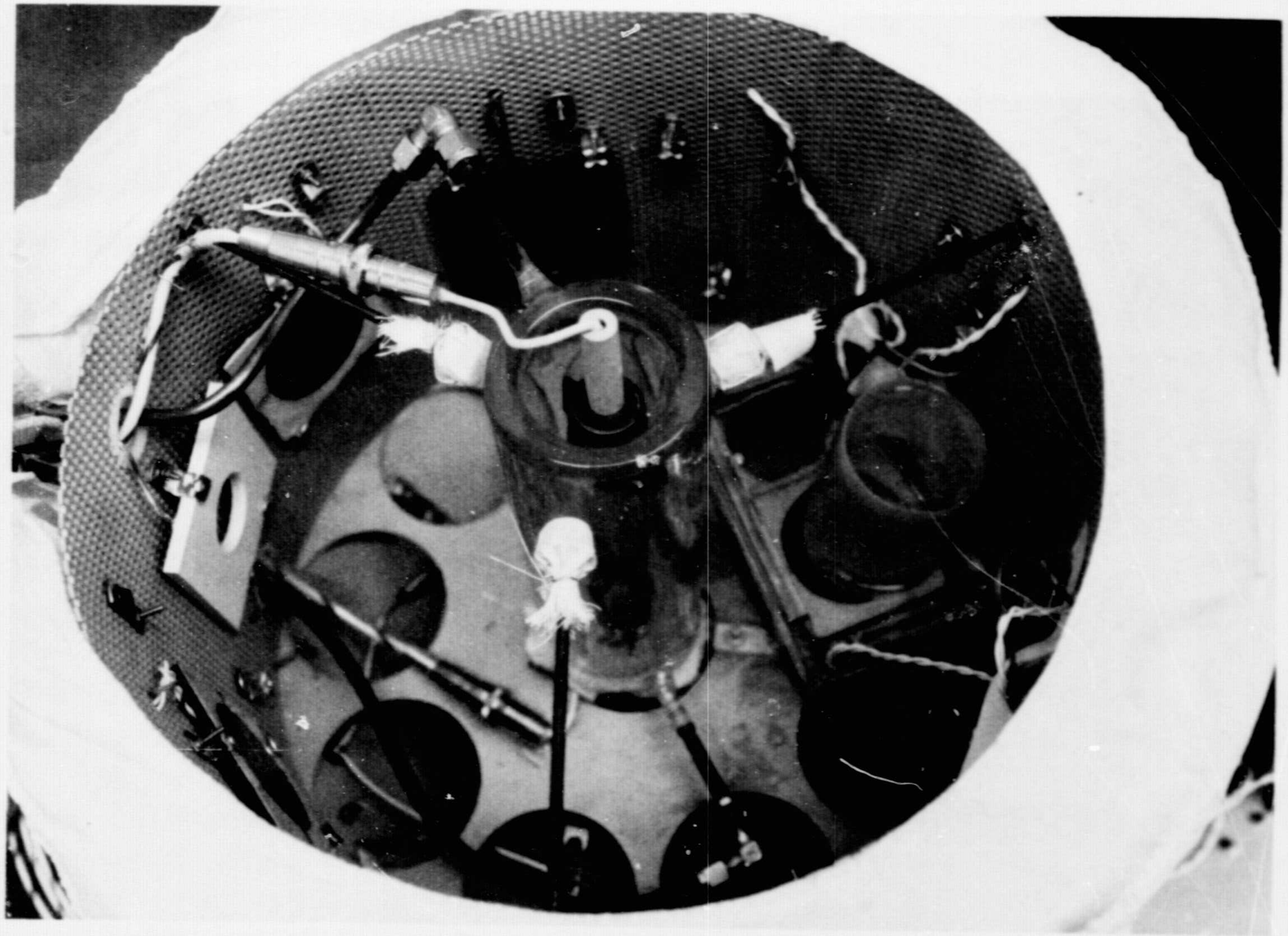
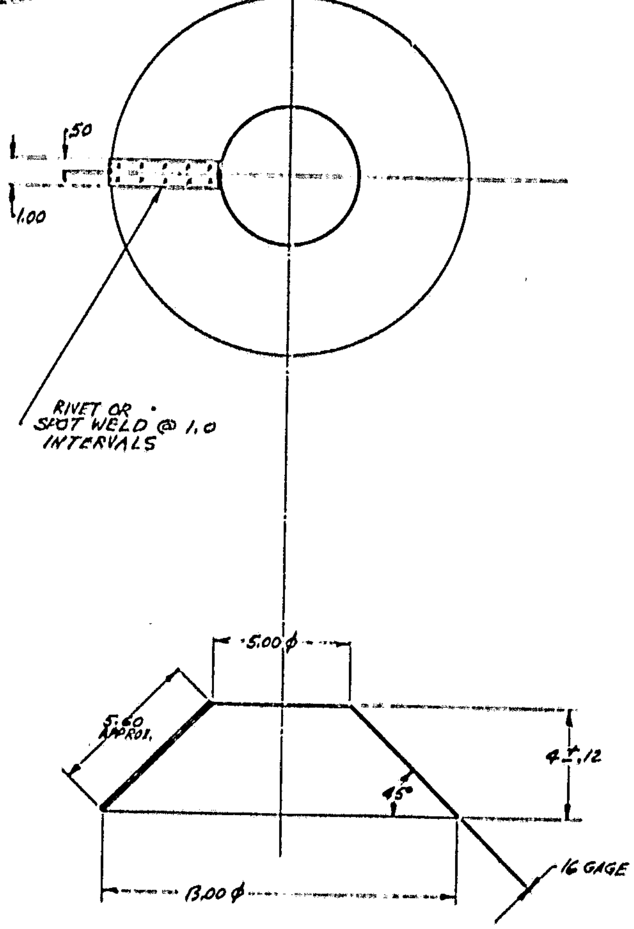
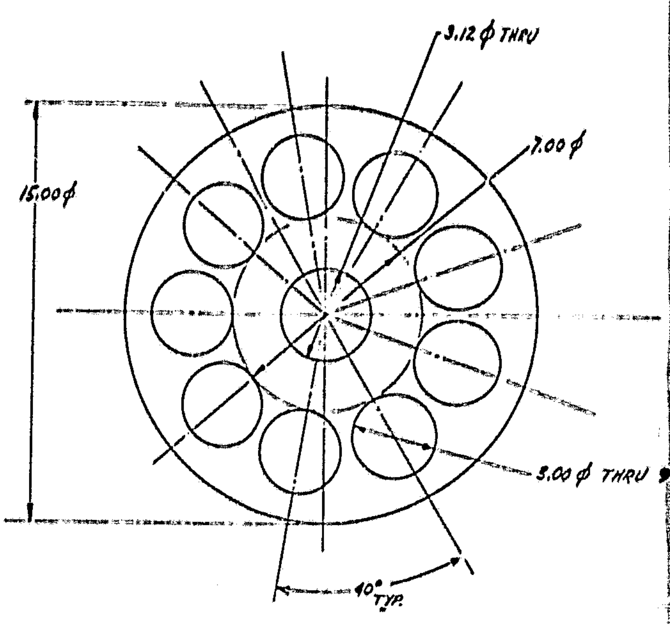


Figure 2. Reactor in Soak Cycle

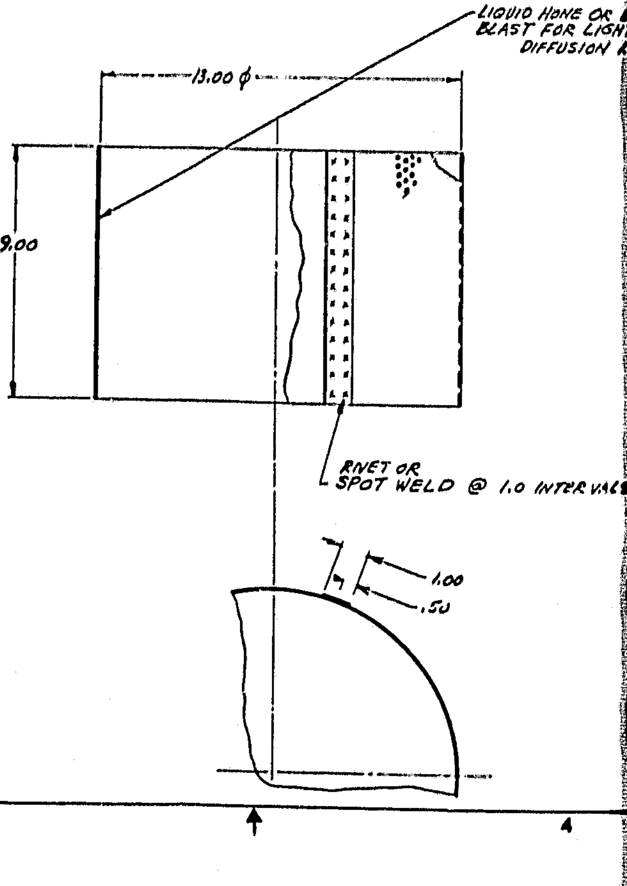


-103 END CONES AL ALY 6061 T6 16 GAGE THK

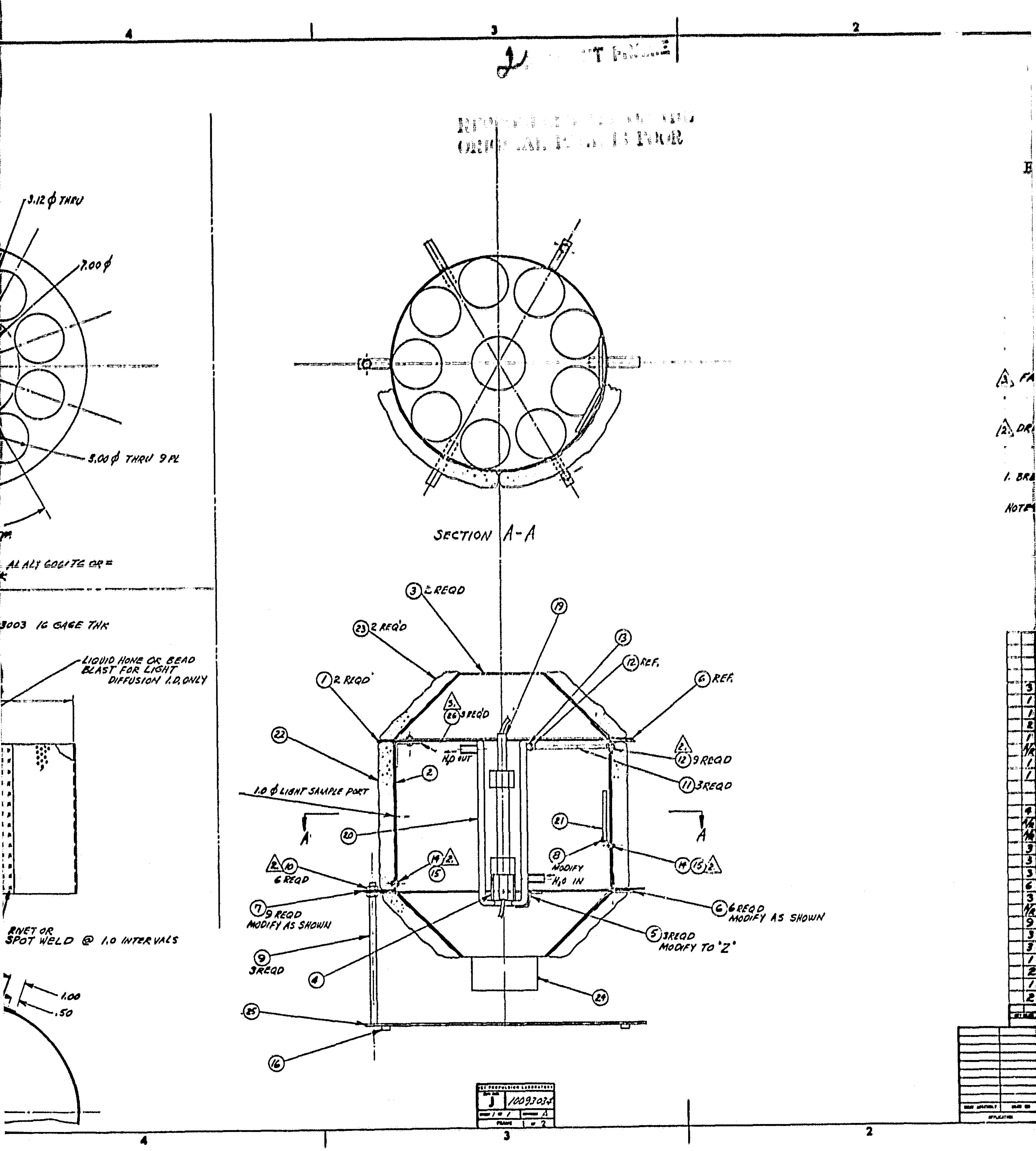


-101 BAFFLE BASE PLATE AL ALY 6061 T6 OR =
14 GAGE THK

-102 HOUSING AL ALY 3003 16 GAGE THK



FOLDOUT FRAME 2



JET PROPULSION LABORATORY

J	10093034
1 of 1	A
FRAME	1 of 2

Figure 3. Advanced Sample UV Exposure Rig

3. UT FRAME

3 FASTEN TO ITEM 1 ONLY.

2 DRILL 1/8 OR 3/16 ϕ HOLES IN ALL BKTS AS REQ'D.

1. BREAK SHARP EDGES.

NOTES: UNLESS OTHERWISE SPECIFIED.

REF.

QD

QD

6 6 REQD
MODIFY AS SHOWN

'Z'

3	26		BKT, COVER ALIGNMENT .75 L x .5 x .09 THK		STL
1	25		BASE PLATE	17.0 [illegible] x .125 THK	AL ALY [illegible]
1	24		MUFFIN FAN 4.0 ϕ		
2	23	CONICAL CAP COVERS [illegible]	BLANKET, GLASS CLOTH COVERED		GLASS WOOL FILLED
1	22	[illegible] COVERS HOUSING	BLANKET, GLASS CLOTH COVERED		GLASS WOOL FILLED
N/R	21		SOLAR CELL PANEL (TYPICAL)		
1	20		IR FILTER COOLER CIRCULATING H_2O (1cm)		PYREX TUBE
1	19	KANRAD HANOVIA MOD 673A10	LAMP	650 WATTS	
	18				
	17				
4	16		PAD	.5 ϕ x .25 THK	RUBBER
N/R	15		NUT, HEX	4-40 NC	STL
N/R	14		SCREW, RD HD	4-40 NC x .5 LG	STL
3	13		BUMPER, RUBBER (6-32 INSERT		GLASS CLOTH COVERED
3	12		NUT, HEX 8-32 NF		STL
3	11		THD'D ROD 8-32 NF x 5.25 LG		STL
6	10		NUT, HEX 5/8-16 NC		STL
3	9		ROD .50 ϕ x 8.0 LG	5/8-16 NC x [illegible]	AL ALY [illegible]
N/R	8		BKT .75 L x .5 x .09 THK		STL
9	7		BKT 1.5 L x .5 x .09 THK		
3	6		BKT 1.5 L x .5 x .09 THK		
3	5		BKT 1.5 L x .5 x .09 THK		STL
1	4		SUPPORT 1.5 OD x [illegible] WALL x 1.5 LG		GLASS
2	3	-103	END CONES		
1	2	-102	HOUSING		
2	1	-101	BAFFLE BASE PLATE		

PARTS LIST

JET PROPULSION LABORATORY

ADVANCED SAMPLE CSSA
U.V. EXPOSURE RIG

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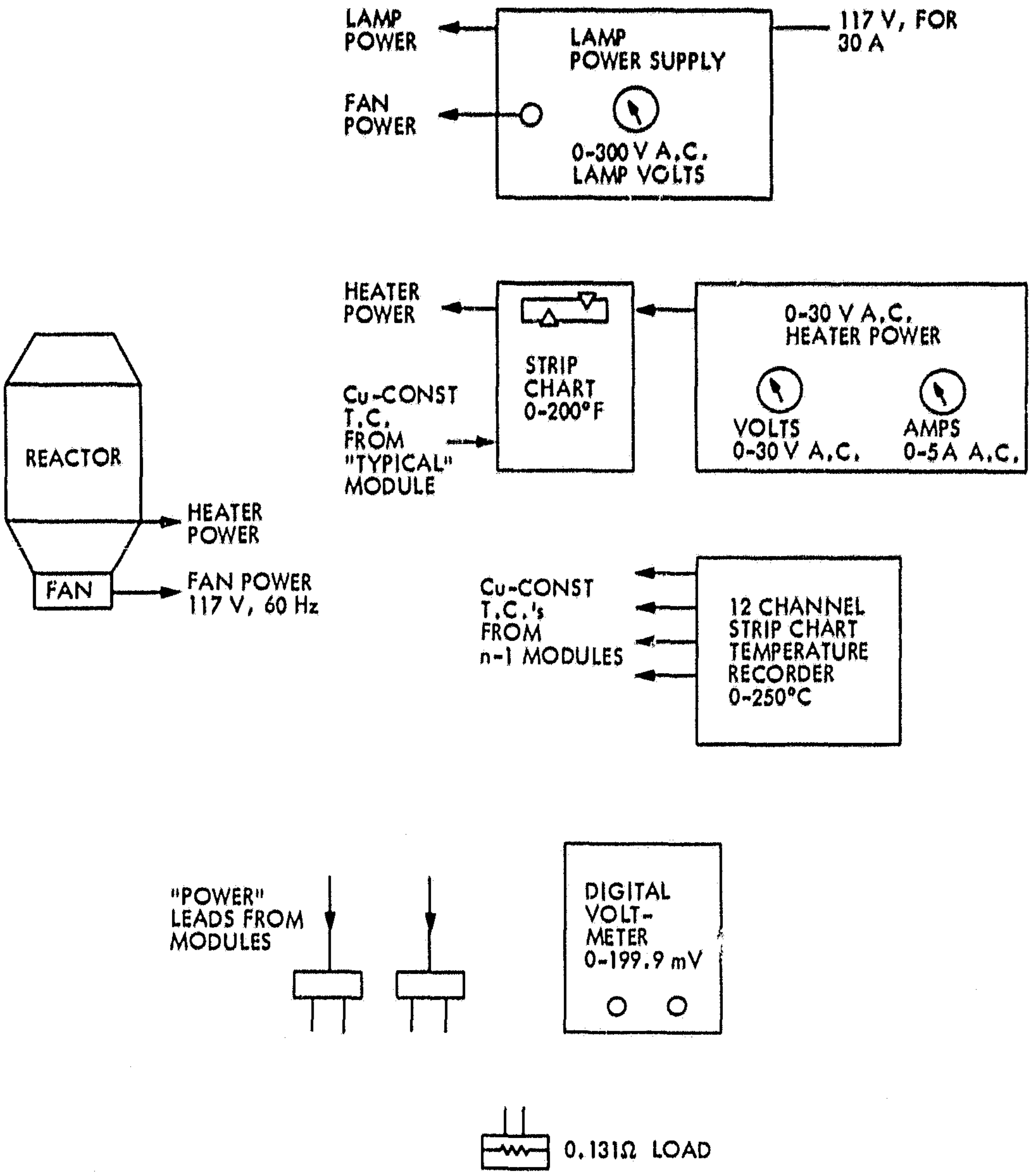

Figure 4. System Block Diagram

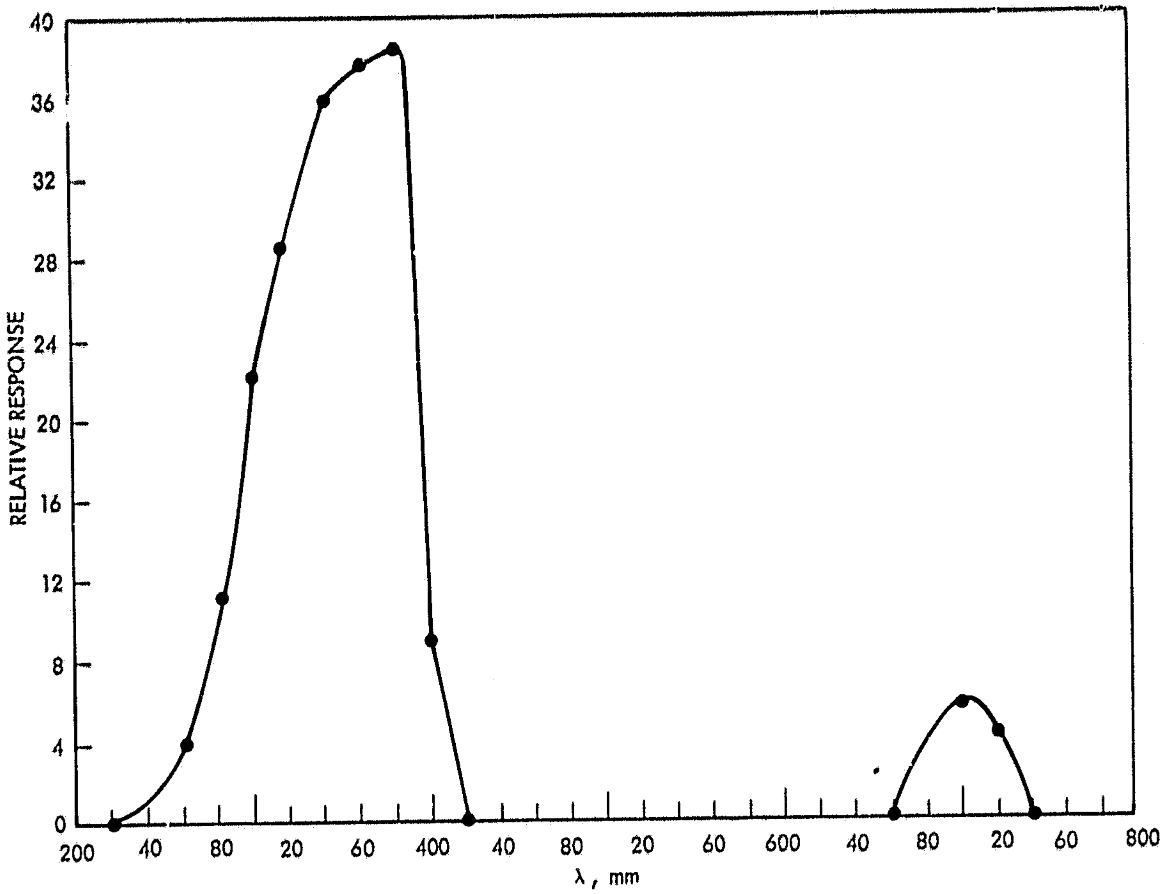

Figure 5. Calculated 7-54 Filter/Se Detector Relative Spectral Response*

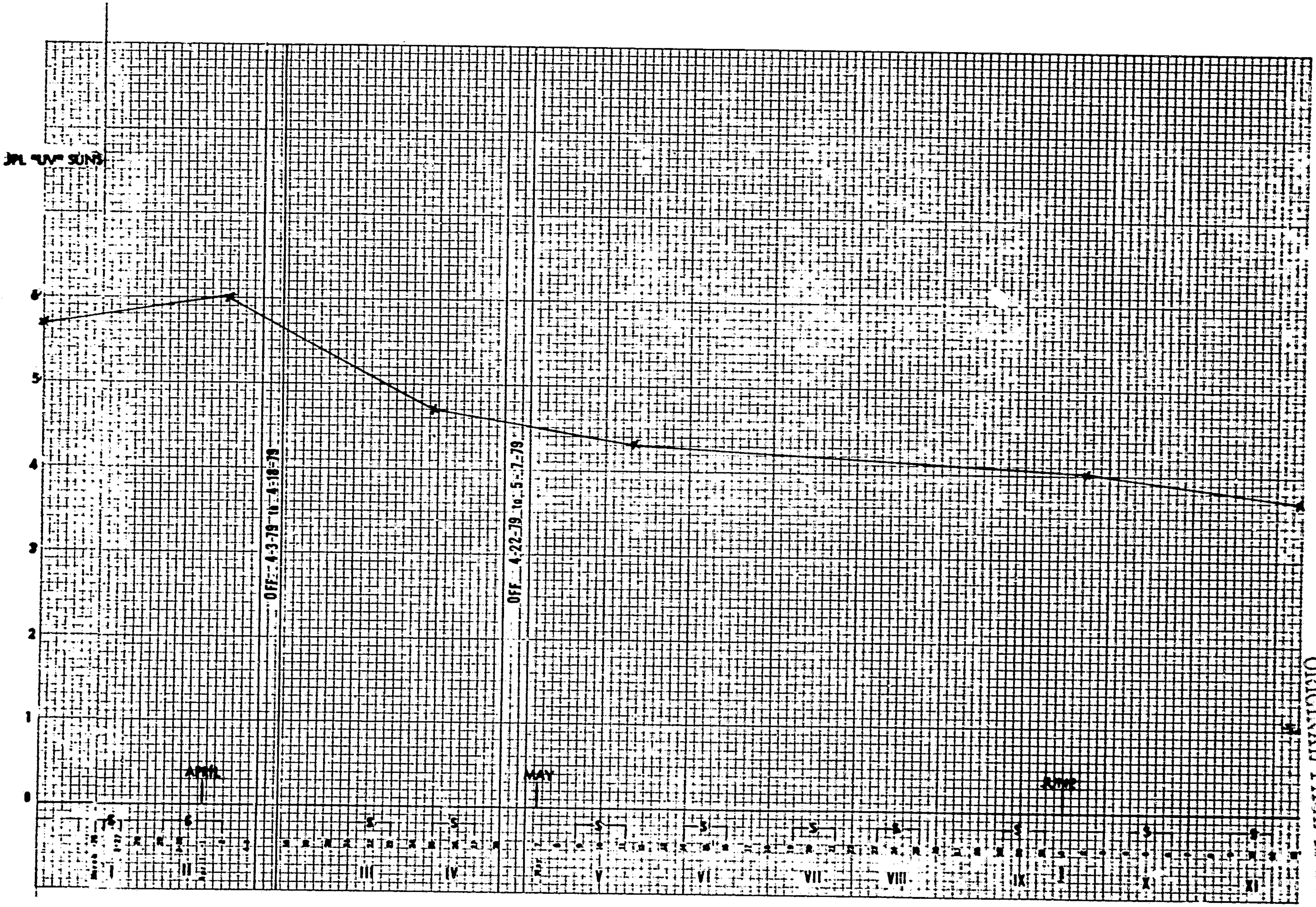

Figure 6. Average JPL "UV" Suns

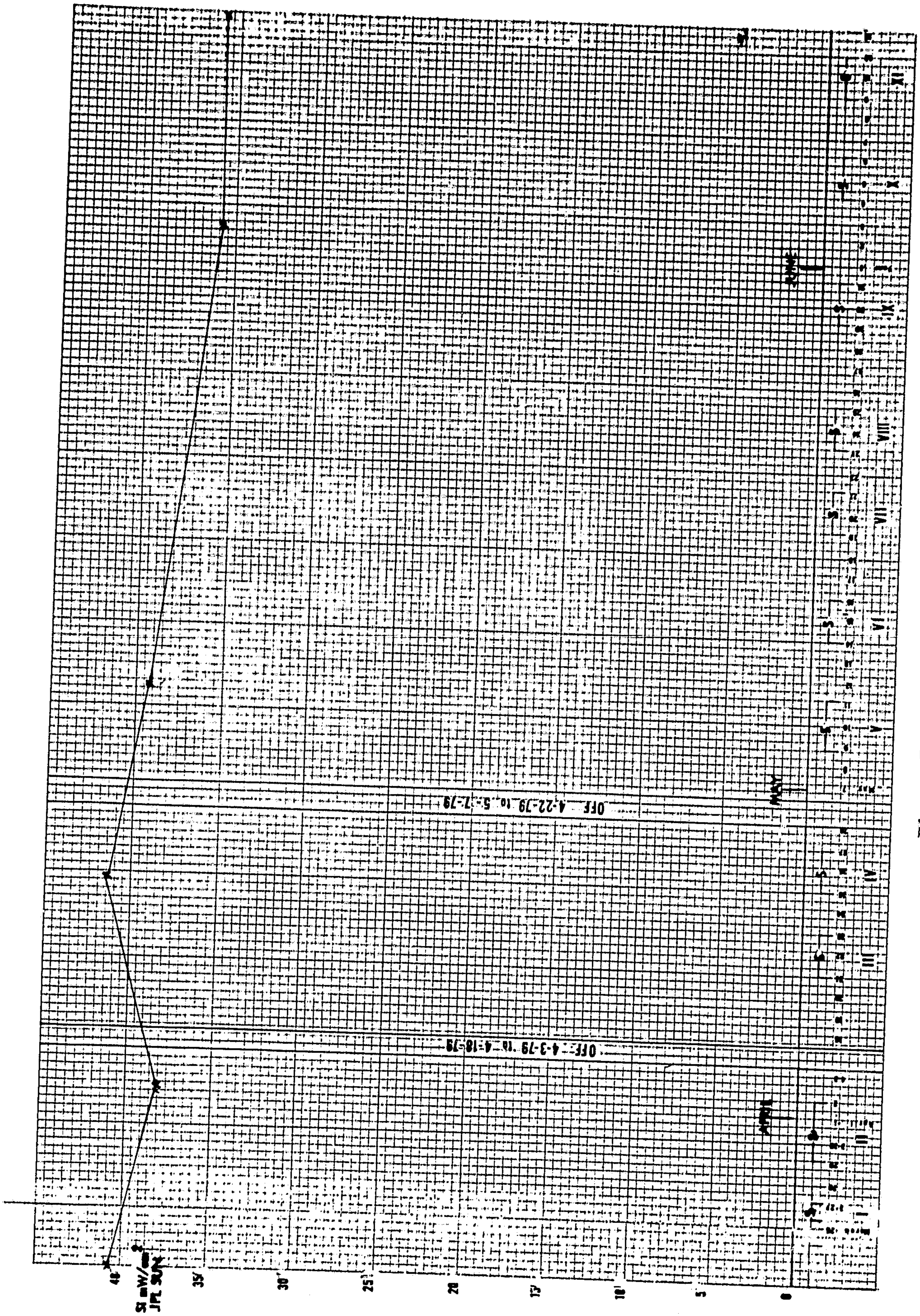

Figure 7. Average Si mW/cm^2

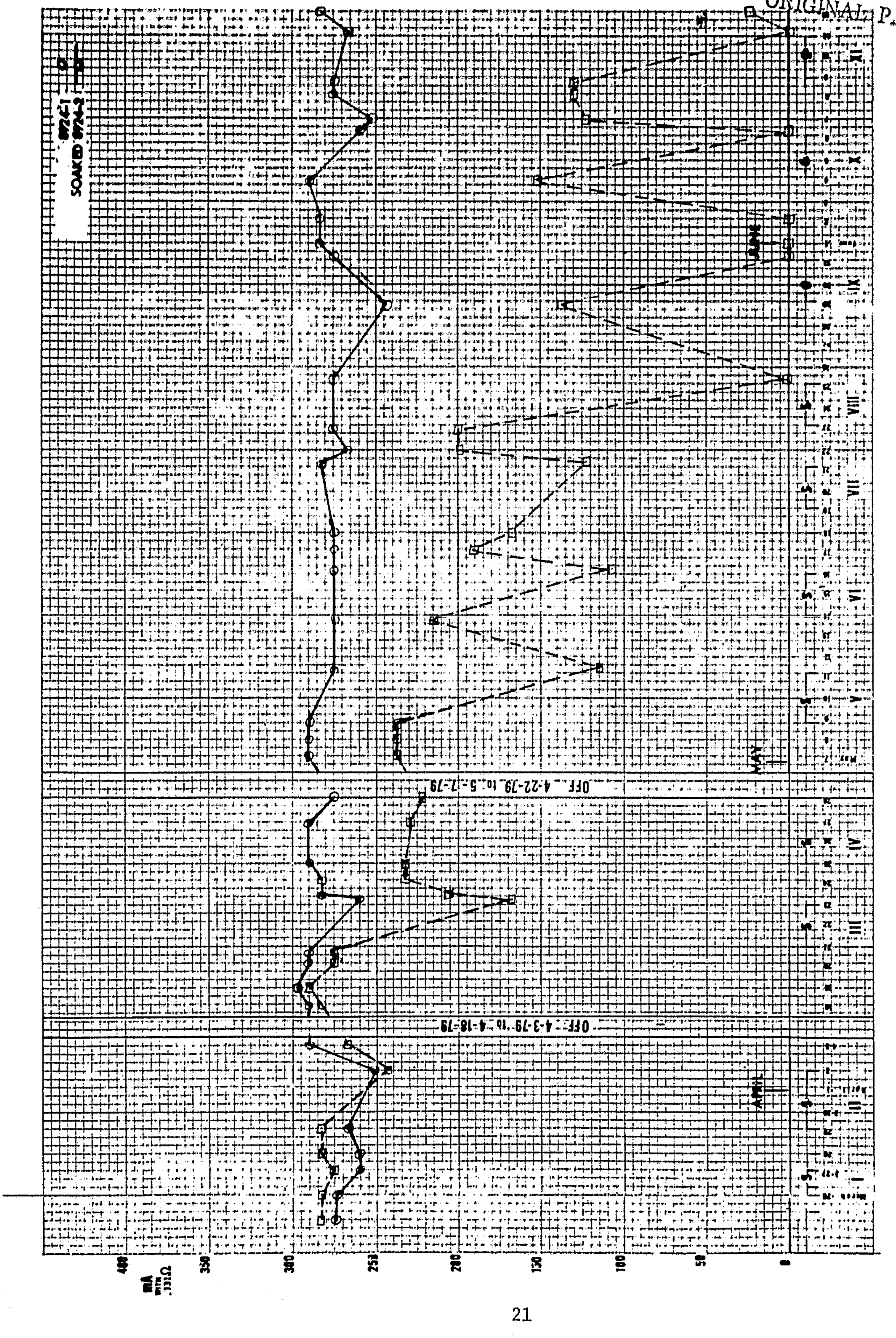

Figure 8. 8924-1 and 8924-2 mA vs Time

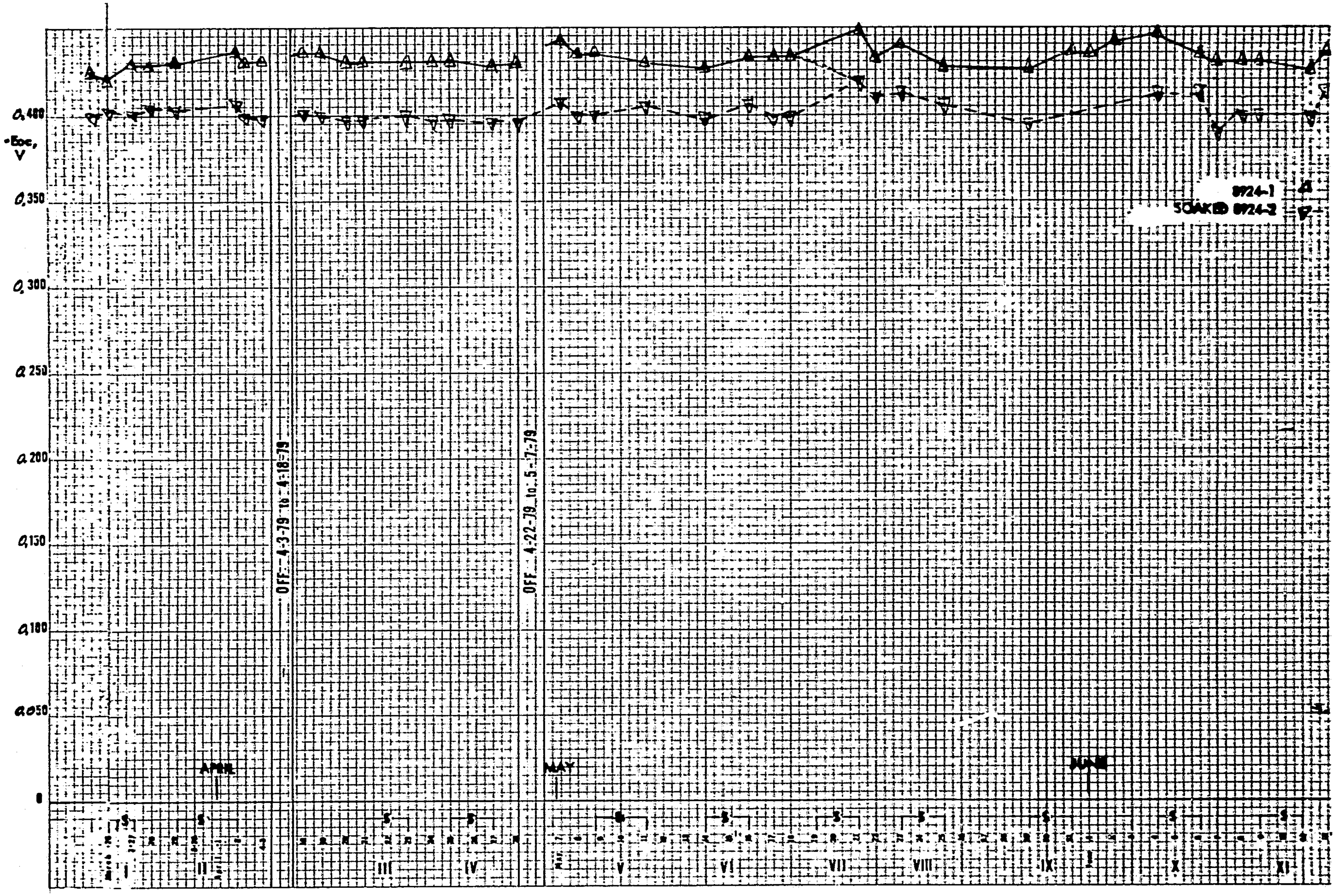

Figure 9. 8924-1 and 8924-2 Open Circuit Volts vs Time

Figure 10. Photograph of Module Exposed to UV/H_2O Soak Cycles

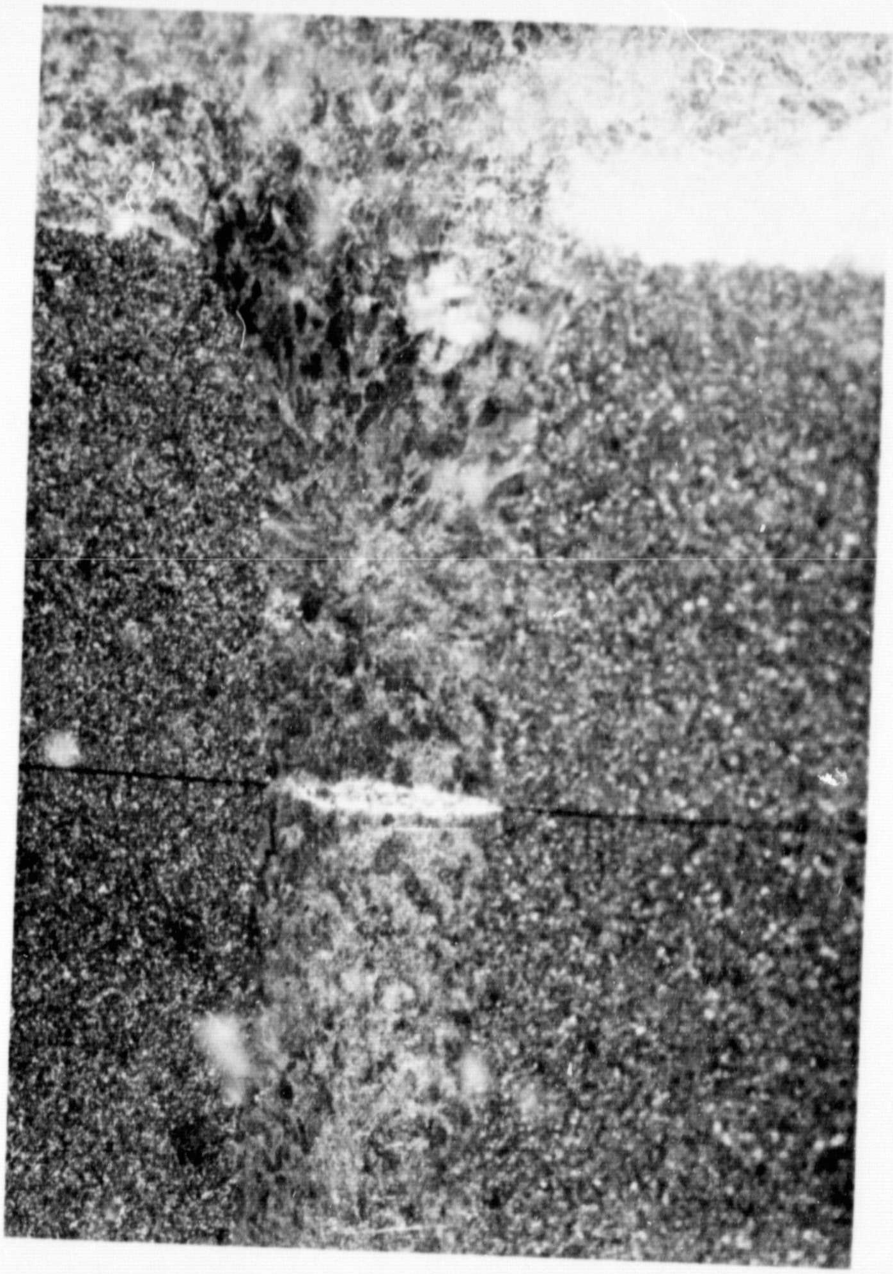

Figure 11. Photograph of One Cell Module Exposed to UV Alone