NASA CR-72439
DIN 68SD4299

CADMIUM SULFIDE THIN FILM SOLAR CELL ARRAY SUB-PANEL DEVELOPMENT

by

F. A. Blake

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-11821

GPO PRICE $ _____

CSFTI PRICE(S) $ _____

Hard copy (HC) 3.00

Microfiche (MF) _____

ff 653 July 65

FACILITY FORM 602

N68-33207 (ACCESSION NUMBER)

(THRU)

28 (PAGES)

1 (CODE)

(NASA CR OR TMX OR AD NUMBER)

03 (CATEGORY)

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
Valley Forge Space Technology Center
P. O. Box 8555 • Philadelphia, Penna. 19101

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FINAL REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

August 15, 1968

CONTRACT NAS 3-11821

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CADMIUM SULFIDE THIN FILM SOLAR CELL ARRAY
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by F. A Blake

General Electric Co.. Space Systems

SUMMARY

The objectives of this contractual effort were to (1) advance the art of Cadmium Sulfide solar array technology from the module to the sub-panel stage and (2) expand experience in the manufacture of CdS modules to define the learning effect and thereby provide a reliable foundation for array cost projections. The program accomplished these objectives in a 6-week activity period during which 12 modules of 25 CdS solar cells each were fabricated, performance-tested in natural sunlight, and assembled into three sub-panels.

The sub-panel specific weights of 0.0744 lb/ft^2 (0.3633 kg/m^2) for reinforced soldered construction and 0.0688 lb/ft^2 (0.3264 kg/m^2) for conductive epoxy construction approach that which could be expected of a full scale solar array blanket within 2 percent (excluding busbar weight). Consistent performance between 2.82 and 3.19 percent AMO efficiency (referred to silicon standards) was obtained at operating temperatures above 53°C for all 12 modules, and represents an improvement over units manufactured 6 months earlier.

The program verified that construction of solar array sections using CdS solar cells is practical and efficient and involves only modest investment in fabrication equipment.

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ABSTRACT

Advancement of the art of Cadmium Sulfide solar array technology from the module to sub-panel (100 cells) stage was accomplished in the 6-week program described. Twelve modules of 25 cells each were fabricated using both of the previously developed interconnection methods (Reference Final Report DIN 68SD4233 "Thin Film Solar Cell Module Development, Cadmium Sulfide Cell"). These were tested and assembled into three sub-panel units of four modules each. Procedures for sub-panel manufacture together with weight and performance data defining the present state of the CdS solar array technology are presented.

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SECTION 1
INTRODUCTION

Cadmium Sulfide solar cell development programs have resulted in a lightweight flexible cell (Figures 1-1 and 1-2) with sufficiently high performance that near term application of the cells in a spacecraft power system rollup solar array is likely. Concurrent with the present programs advancing and refining the CdS solar cell art, NASA Lewis Research Center sponsored two programs concerned with the development of the basic building block units of a CdS solar array, the module and the sub-panel. The second of these, a program to advance the array fabrication capability to the sub-panel stage was performed under Contract NAS 3-11821 and is the subject of this report. A sub-panel (P/N 47D214886) as fabricated under this program (Figure 1-3) is an assembly of four 25 five-cell CdS solar cell modules, and has an area of 6.692 ft^2 (0.6217 m^2) of the which 86.67 percent is active cell area. In addition to extending the technology to encompass sub-panels, the program had, as a major objective, the extension of the module fabrication experience and cost data from that obtained in the module development program.

Two methods for CdS cell interconnection were developed under Contract NAS 3-10605, the reinforced soldered method (Figure 1-4) and the conductive epoxy bonded method (Figure 1-5). As reported in Final Report DIN 68SD4233 "Thin Film Solar Cell Module Development, Cadmium Sulfide Cell," these methods were used to produce a four-unit pilot run of 25 cell modules (Figure 1-6) of each type.

During the current program, twelve modules per Revision A of drawing 47D214515 were fabricated. These differ from the earlier modules only in the end tab configuration at the positive tabs, which was changed to meet the needs of the sub-panel assembly. Eight of the modules were constructed using the reinforced soldered interconnection method and four were constructed using the conductive bonding method. Upon completion, each of the twelve modules were performance tested in natural sunlight while under a 10-pound (4.536 kg) tension load.

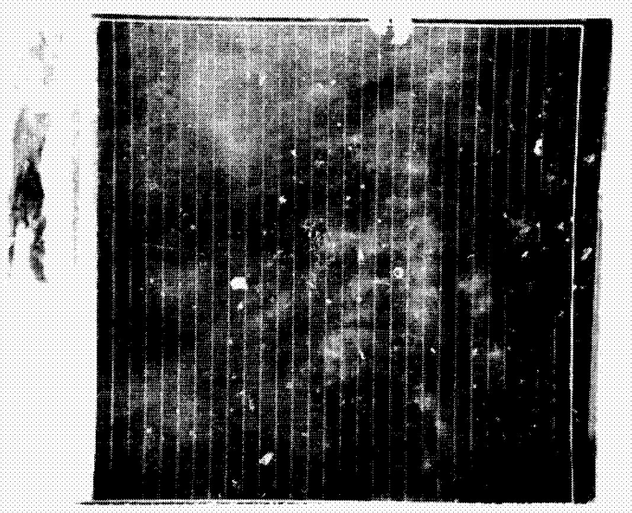


Figure 1-1. Clevite Plastic Substrate CdS Solar Cell

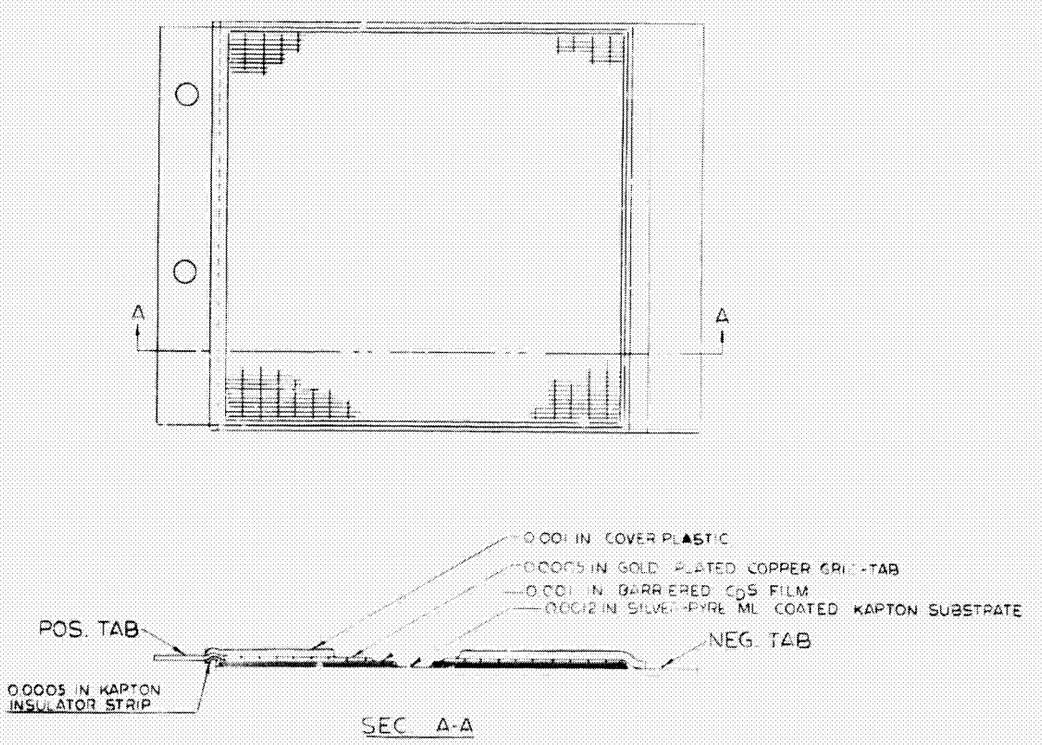


Figure 1-2. Clevite Plastic Substrate Cadmium Sulfide Solar Cell

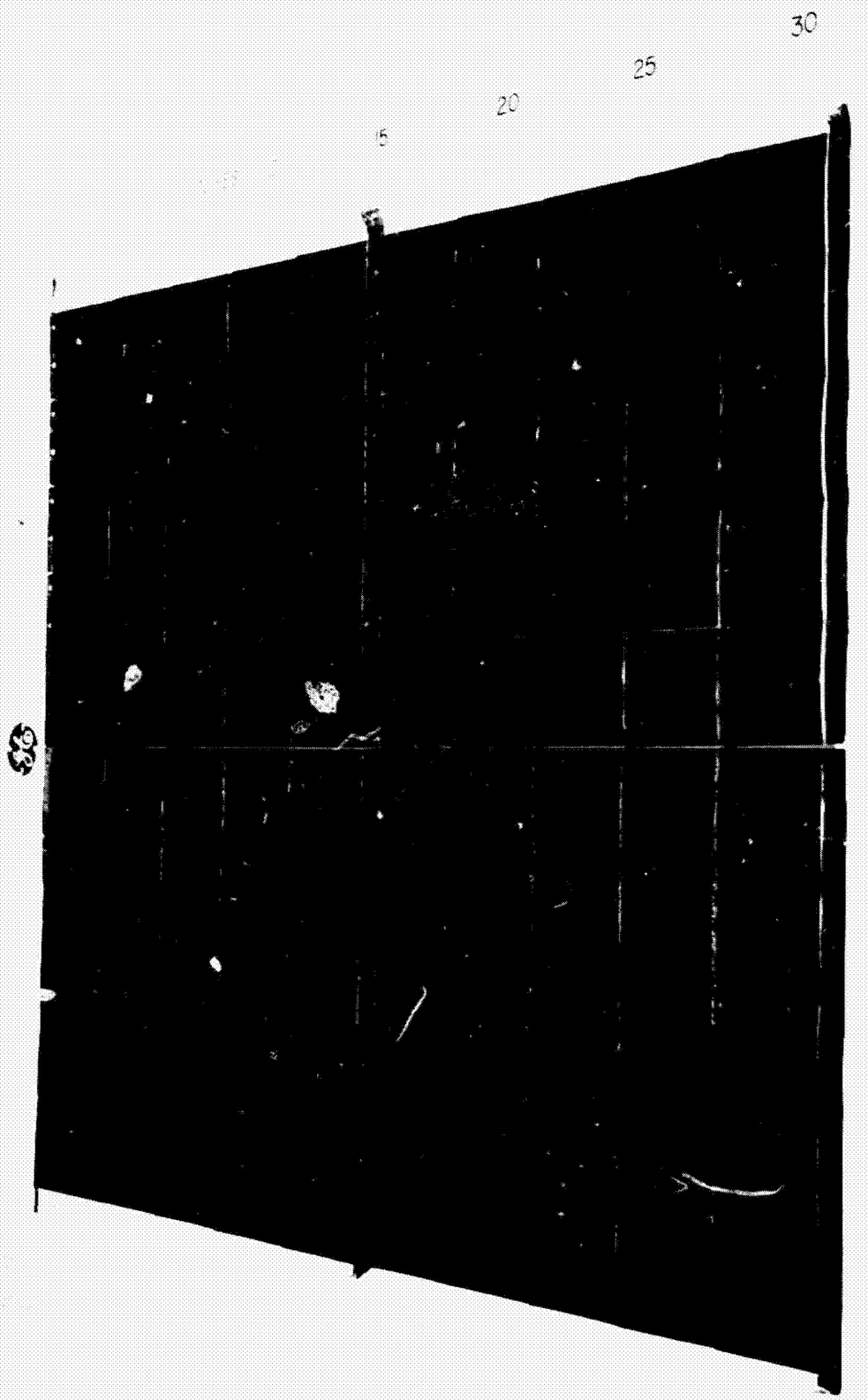


Figure 1-3. Solar Cell Array S[illegible] nit of 100 CdS Cells

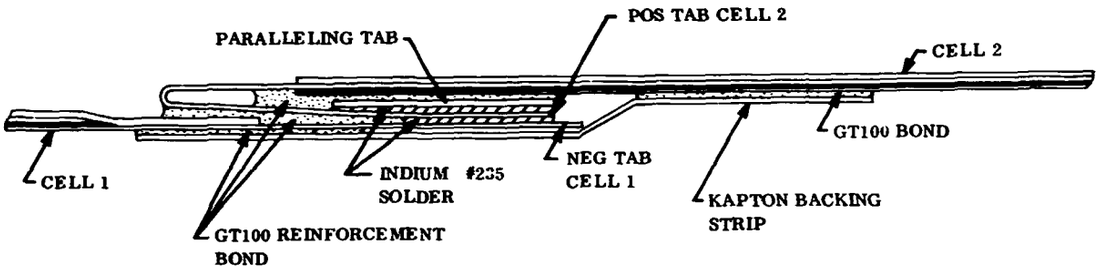


Figure 1-4. Cross Section of Reinforced Soldered Interconnection Method

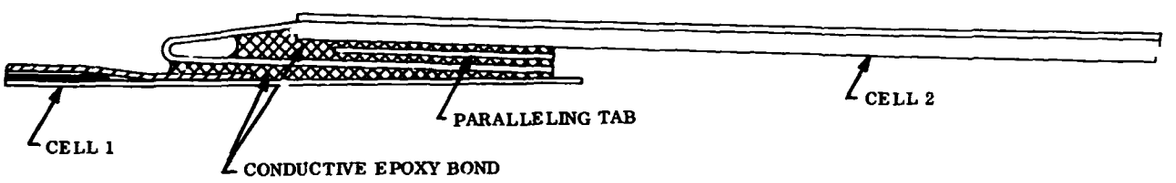


Figure 1-5. Cross Section of Conductive Epoxy Bonded Interconnection Method

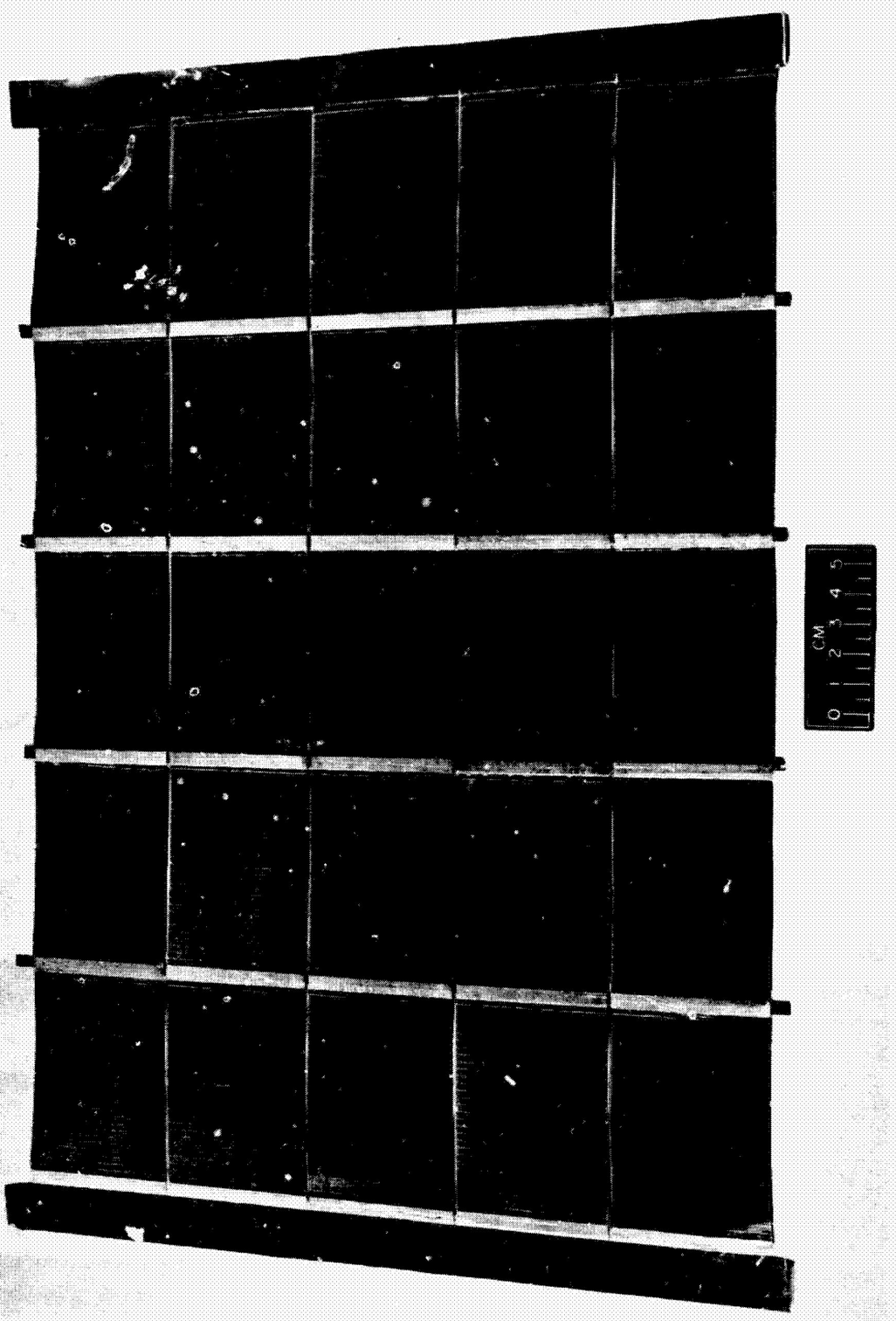


Figure 1-6a. Twenty-Five Cells Cds Solar Cell Module P/N 47D214515, Face Side

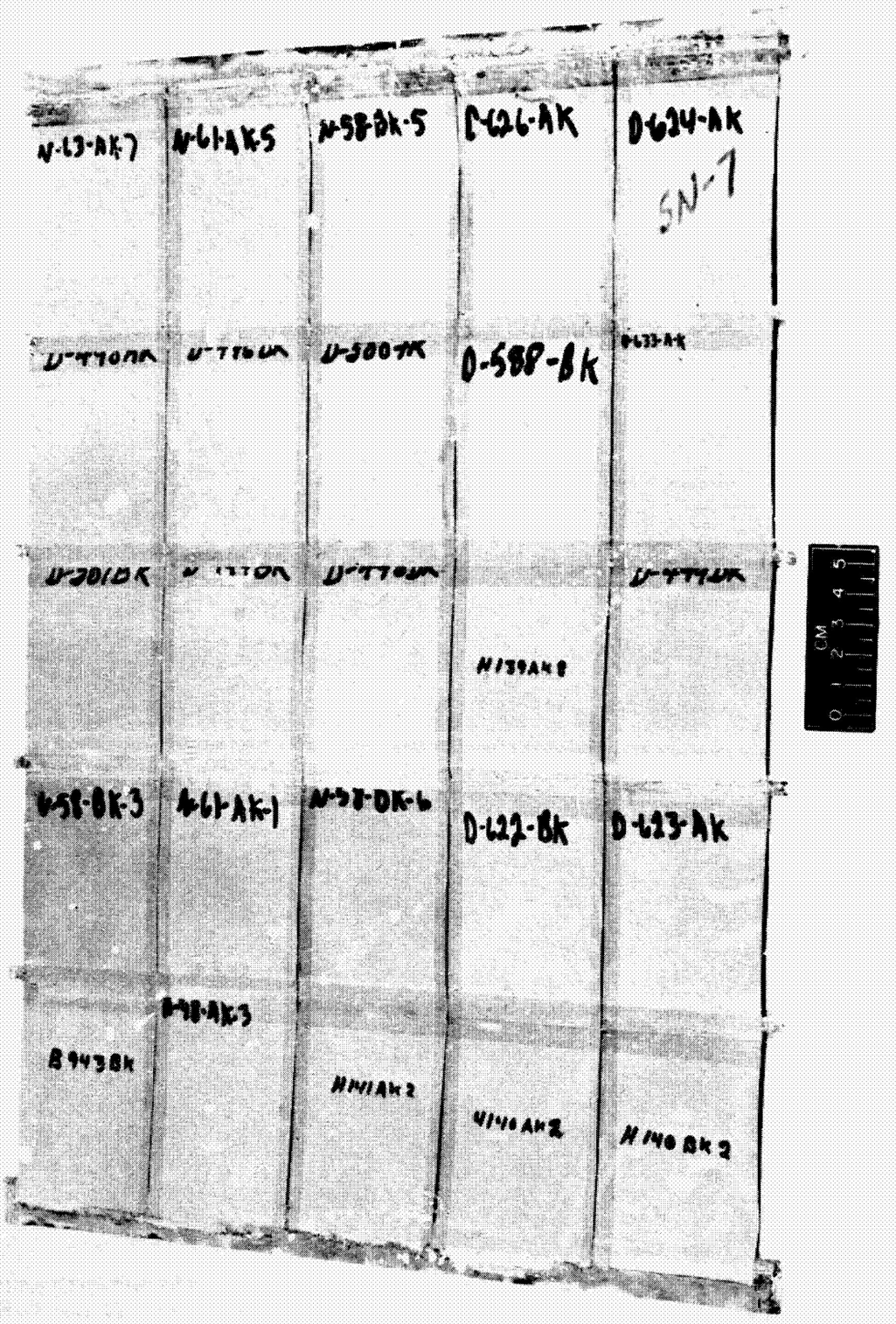


Figure 1-6b. Twenty-Five Cells Cds Solar Cell Module P/N 47D214515, Back Side

The final phase of the program was the assembly of the twelve 25-cell modules into three sub-panels (Figure 1-7). The module fabrication equipment, consisting of the pneumatically actuated soldering/bonding machine and two assembly fixtures, in place as a result of the prior program was utilized for the module manufacture. A modification to the soldered module assembly fixture, the addition of side rollers, was the only change required to extend the capability of the module equipment to encompass the sub-panel fabrication requirements.

The following report covers the physical performance of this program, including the training of a new fabrication technician, during the 6-week period from June 14, 1968, to July 23, 1968, when the three sub-panels were shipped to NASA Lewis Research Center.

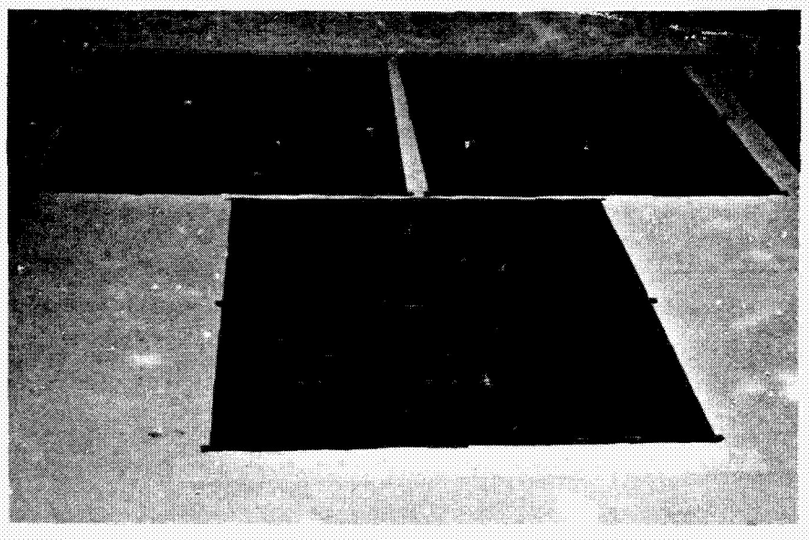


Figure 1-7. Three CdS Solar Cell Sub-panels on Layout Table

SECTION 2

TECHNICAL DISCUSSION

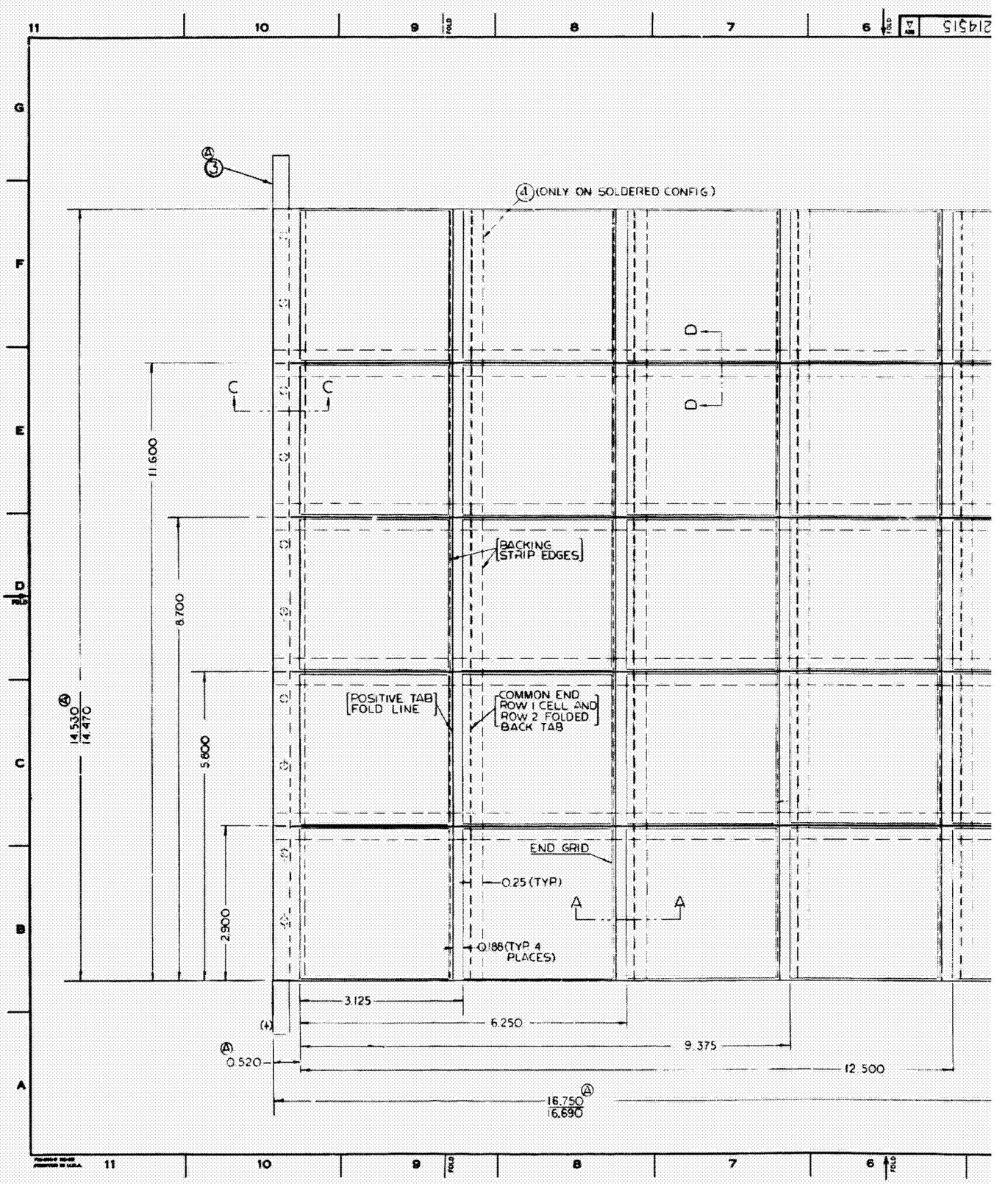
2.1 MANUFACTURE AND TEST OF 25-CELL CADMIUM SULFIDE SOLAR MODULES

In accordance with Contract NAS 3-11821, twelve modules of 25 Cadmium Sulfide solar cells each were manufactured in conformance with GE drawing 47D 214515 Revision A. (Figure 2-1) using the processes developed under the Contract NAS 3-10605 program. Eight of the modules were fabricated by the "Reinforced Soldered" method and four by the "Conductive Epoxy Bonded" method. Following fabrication, the modules were performance-tested in natural sunlight before their incorporation in the next higher assembly, the sub-panel. One of the completed modules is shown in Figure 2-2 mounted on the solar testing fixture. The 10-pound (4.536 kg) load is applied at the positive end of the module and is resisted by anchoring the negative end of the module to the fixture platform. Transmission of both the applied and anchorage loads to the module was through a Kapton leader attached to the back of the end rows of cells.

2.1.1 MODULE FABRICATION TIME - LEARNING EFFECT

The collection of fabrication time data for the 25-cell modules was continued during this program. These data are presented in Figure 2-3 and in Table 2-1 with the data for the predecessor units from the NAS 3-10605 program. Of particular interest is the speed with which a new fabrication technician can acquire the skills associated with both the reinforced soldered and conductive bonding processes. This is evidenced by the fabrication times for the current program falling on a learning curve based in the prior program after one (conductive epoxy) or two (reinforced soldered) training modules have been fabricated.

As the experience with the two processes is expanded, it is apparent that the fabrication times are converging and that neither has a definite time advantage over the other as previously indicated. The last three units of each process required a total of 22 hours or an average of 7-1/3 hours. This also appears to be nearing a limit for a fabrication cycle during which all operations are performed by one man. For a large scale production such as would be needed for a flight array sized in excess of 1 kilowatt, it would be



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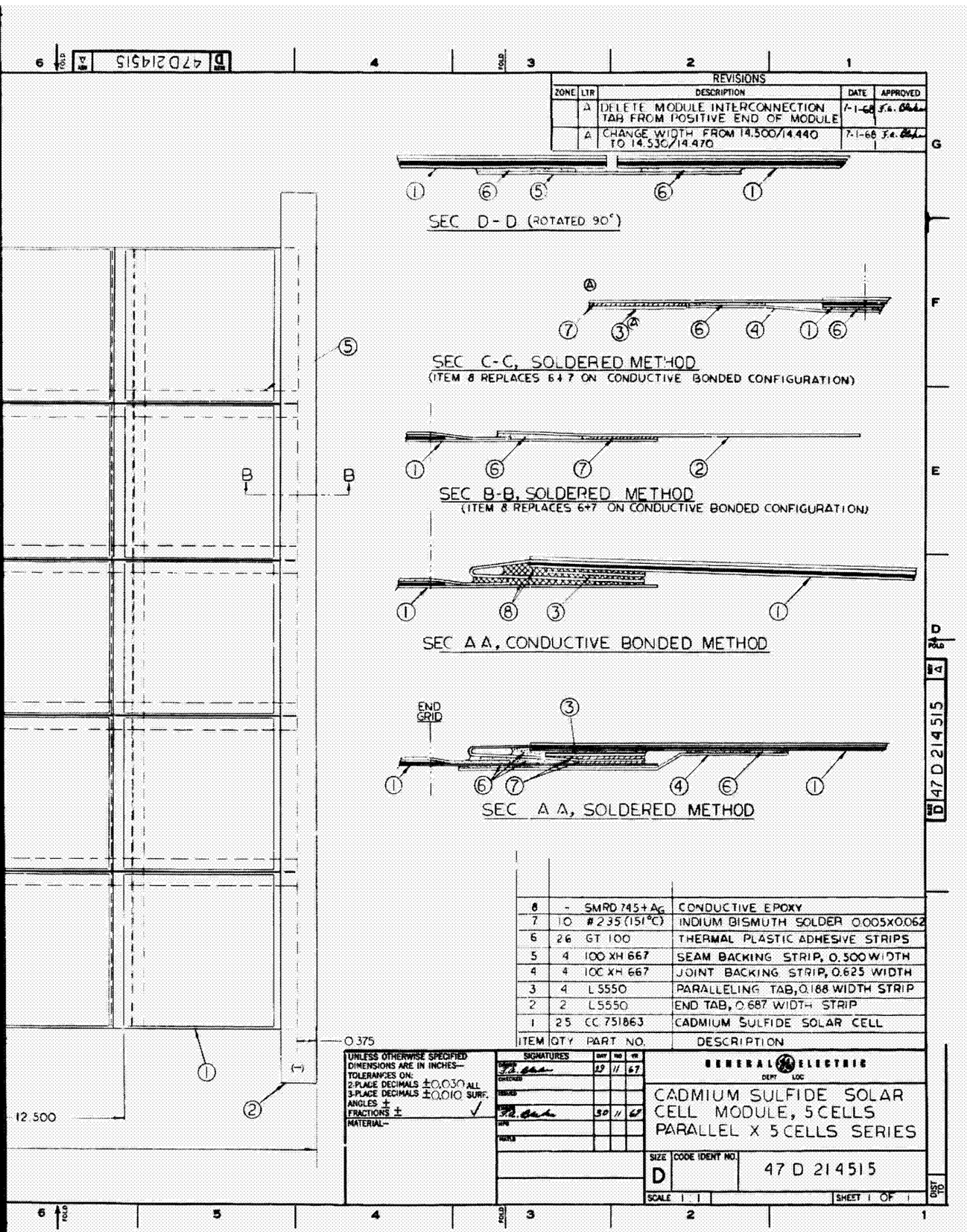

Figure 2-1. Cadmium Sulfide Solar Cell Module, 5 Cells Parallel x 5 Cells Series

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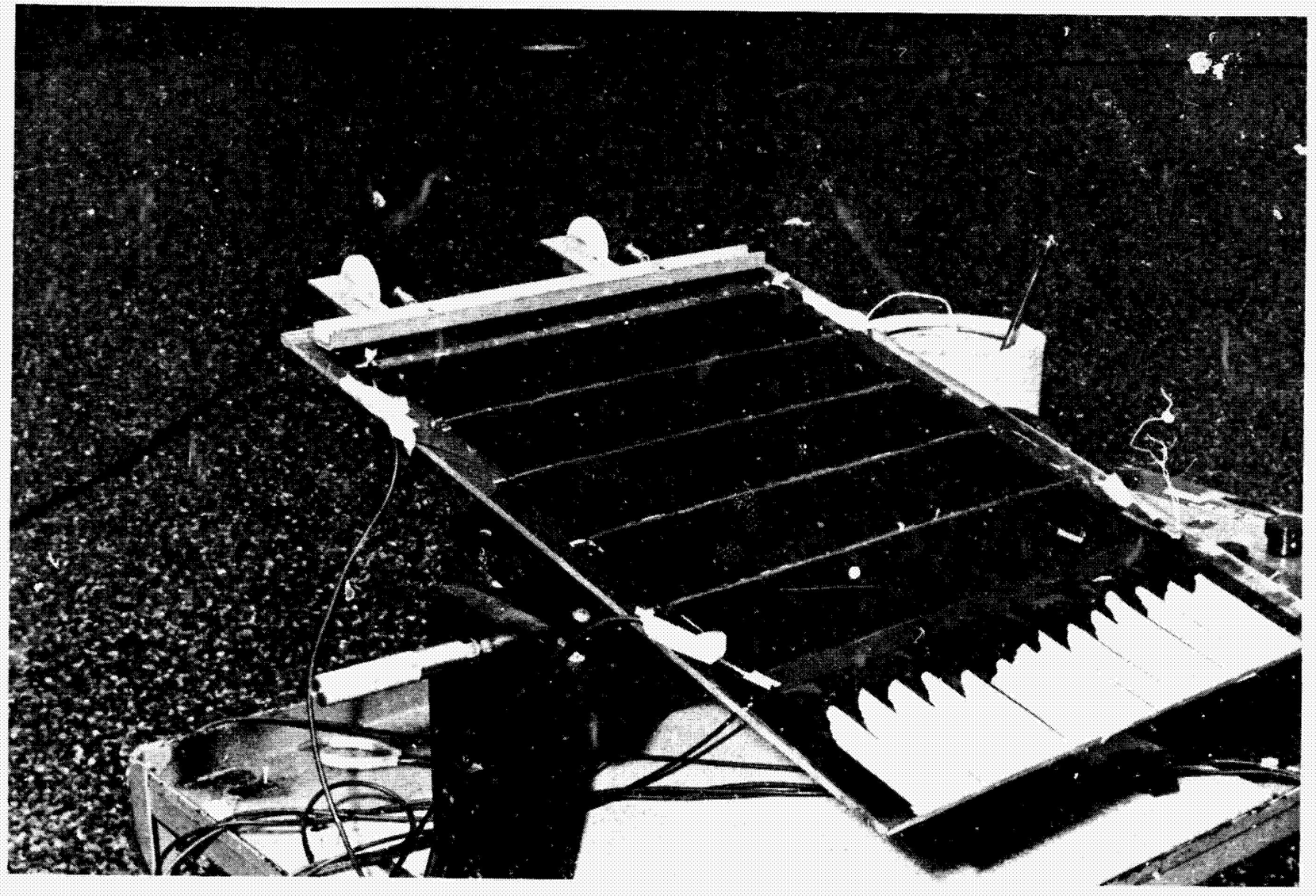
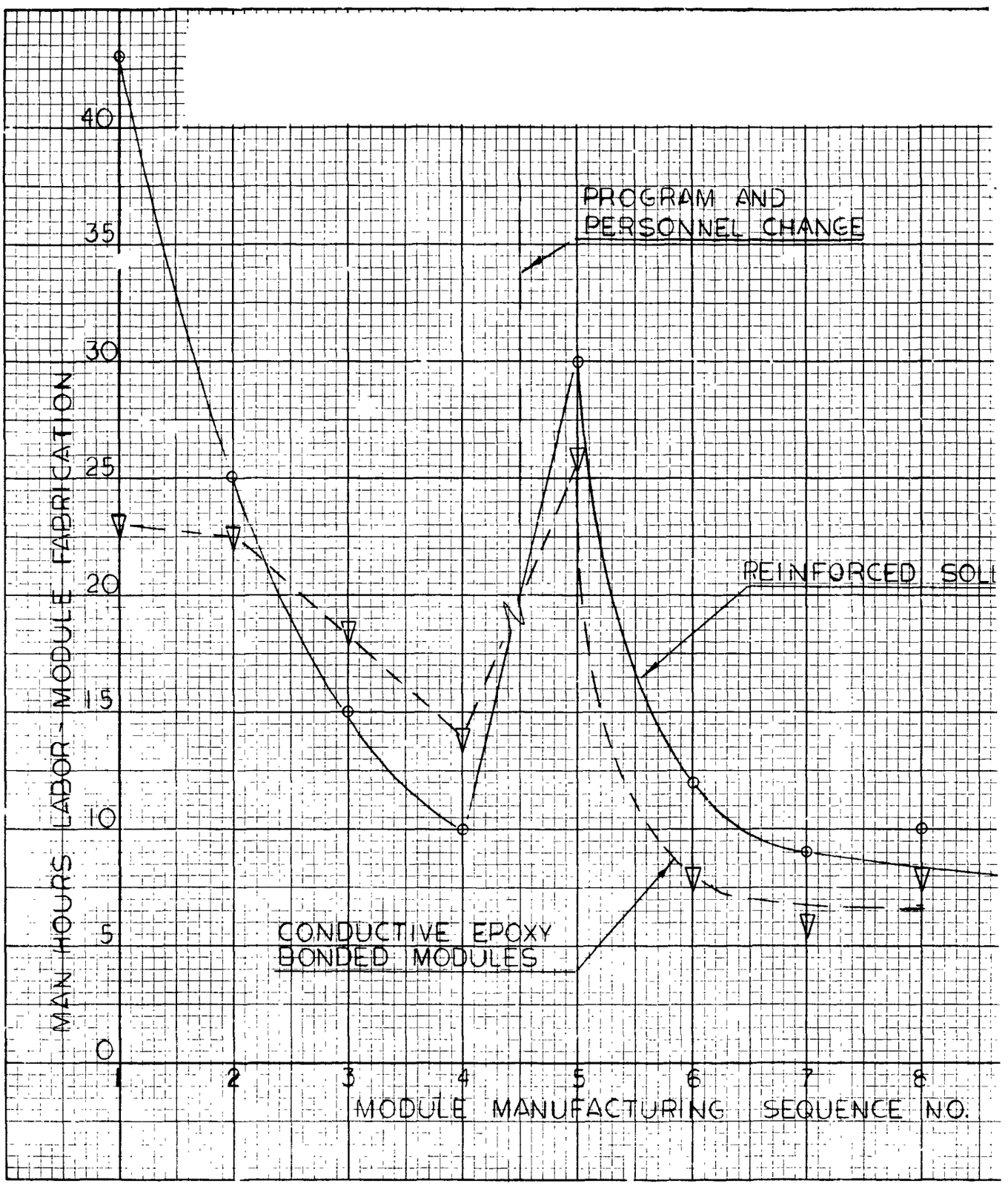


Figure 2-2. Twenty-Five CdS Solar Cell Module Mounted on Solar Test Fixture



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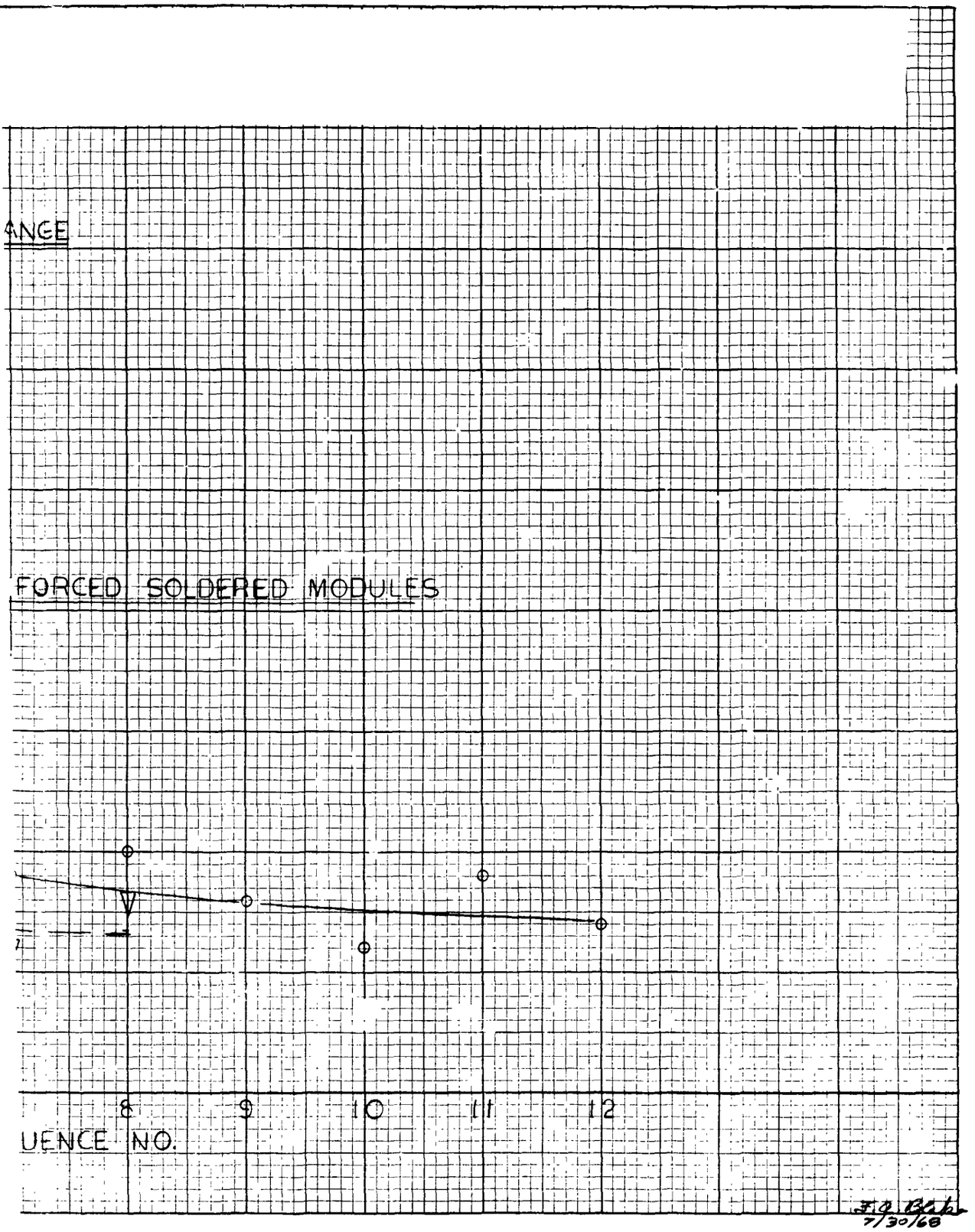


Figure 2-3. Learning Effect on Module Fabrication Time for 25 CdS Solar Cell Modules

FOLDOUT FRAME 2

Table 2-1. Twenty-Five Cell CdS Solar Cell Modules Fabrication Labor Hours

Module Type Sequence No.	Soldered Mods		Conductive Bonded Mods		
	Module No.	Labor Hours	Module No.	Labor Hours	
1	1	43	4	23	
2	2	25	5	22.5	NAS 3 10605
3	3	15	6	18.5	
4	7	10	8	14	
5*	9	30	17	26	
6	10	12	18	8	
7	11	9	19	6	NAS 3 11821
8	12	10	20	8	
9	13	8			
10	14	6			
11	15	9			
12	16	7			

*Training module for new fabrication technician

expected that some improvement could be obtained through establishment of work centers for the specialized operations such as cutting-trimming and soldering and bonding.

2.1.2 MODULE WEIGHT

Details of the weight data taken for the modules fabricated under the NAS 3-11821 program are shown in Table 2-2. As in the previous program, the conductive epoxy bonded modules are lighter than the soldered modules, averaging 50.0 grams versus 55.7 grams for the soldered units. Both these averages are higher than the corresponding values (46.7 grams and 52.6 grams, respectively) obtained during the NAS 3-10605 program. These show a net gain in weight of 3.3 grams for the conductive epoxy bonded modules and of 3.1 grams for the reinforced soldered modules. Comparison of the cell weights observed during the two programs shows that the later cells run heavier than those of the former program, 44.2 grams versus 38.8 grams for a set of 25 cells (a difference of 5.4 grams per set). The reason that the latest modules do not reflect the total cell differences in the modules indicates that the process weight addition was slightly less for the later modules. The probable source of the slightly improved weight is the use of Schjeldahl T320 tape (a layup of Kapton and GT100 adhesive) rather than individual strips of Kapton and GT100 for the cell edge backing seams.

Specific weights for the latest program modules average 0.0729 lb/ft^2 (0.3560 kg/m^2) for the soldered configuration and 0.0654 lb/ft^2 (0.3195 kg/m^2) for the bonded units.

2.1.3 ELECTRICAL PERFORMANCE OF THE MODULES DURING SOLAR TESTS

Each of the twelve modules was performance-tested in natural sunlight in the setup shown in Figure 2-4. The module is mounted under tension of 10 lb (4.536 kg) on a test table capable of elevation angle adjustment. The azimuth angle is compensated for by rotation of the cart on which the test table is located. The tension loading is supplied by two Hunter Negator spring motors mounted below the test platform as shown in Figure 2-5 and is transferred over pulleys to the spreader bar on the top surface. The loading is transmitted between the spreader bar and the module through a Kapton sheet taped to the center of the first row of cells on the positive end of the module. Anchorage to the fixture at the opposite end of the module is similarly obtained.

Table 2-2. Weight Data for 25-Cell CdS Solar Cell Modules

Module No., Type	Module Weight		Added Weight (Mod Wt - 25 Cells Weight)	Module Specific Weight***	
	(Grams)	(Pounds)		(Kg/m^2)	(Lb/Ft^2)
9 Soldered	54.1	0.1193	9.9*	0.3459	0.0709
10 Soldered	57.3	0.1263	13.1*	0.3663	0.0750
11 Soldered	57.9	0.1276	13.7*	0.3701	0.0758
12 Soldered	57.3	0.1263	13.1*	0.3663	0.0750
13 Soldered	54.4	0.1199	10.2*	0.3478	0.0712
14 Soldered	54.8	0.1208	10.6*	0.3503	0.0718
15 Soldered	53.4	0.1177	9.2*	0.3414	0.0699
16 Soldered	56.4	0.1243	12.2*	0.3606	0.0738
17 Bonded	50.0	0.1102	5.8*	0.3196	0.0654
18 Bonded	50.0	0.1102	5.5**	0.3196	0.0654
19 Bonded	50.1	0.1104	6.0**	0.3203	0.0656
20 Bonded	49.8	0.1098	5.8**	0.3184	0.0652
Ave Soldered	55.7	0.1228	11.50	0.3560	0.0729
Ave Bonded	50.0	0.1102	5.77	0.3195	0.0654

*Difference from average of three groups of cells (44.2 gms)
**Difference from cells used in this module
***Area of module = 1.6836 ft^2 (0.1564/m^2)

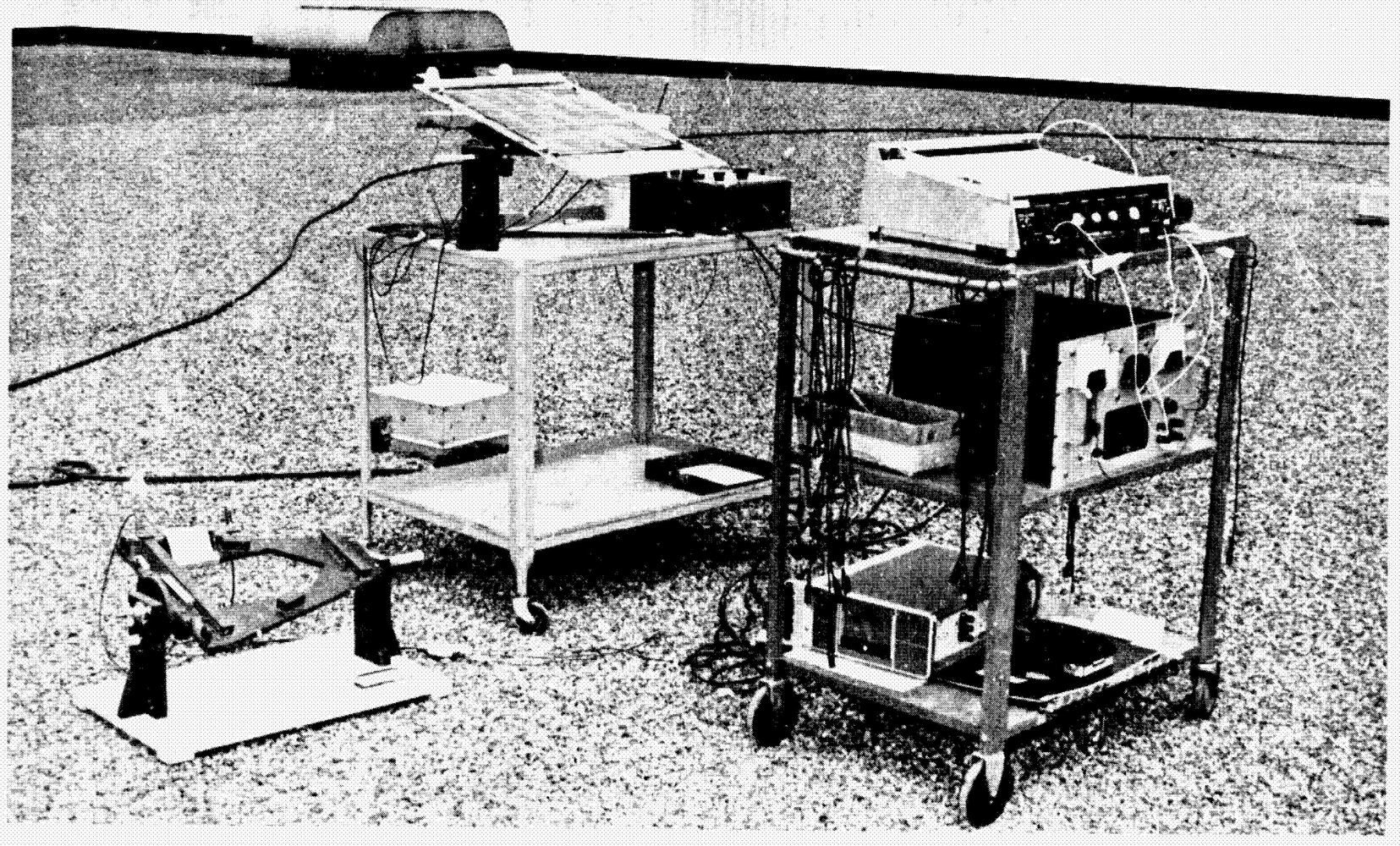


Figure 2-4. Solar Test Setup for 25 Cell CdS Solar Cell Modules

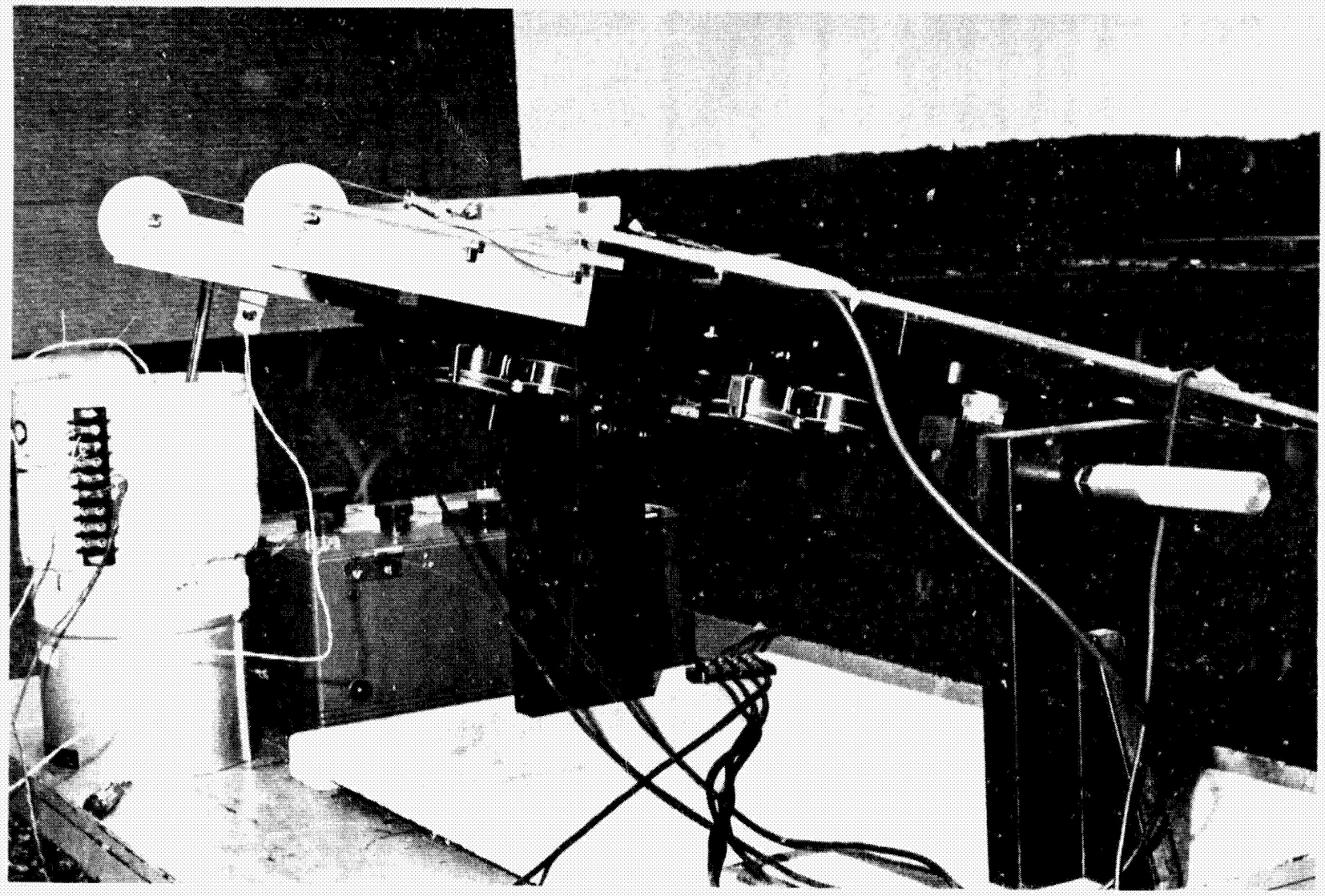


Figure 2-5. CdS Module Solar Test Fixture Closeup Showing the Negator Spring Tensioning System and the Thermocouple Cold Junction Ice Bath

The individual V-I curves of which at least two were taken for each module are included in Appendix B with the computer printout of the data for each curve. The principal results of these performance tests are shown in Table 2-3. All tests were intensity-monitored by short circuit current of the same silicon standard as used during the previous program. An indication that the cells of the current program were consistently of higher quality than those of the first program is clear from comparison of the test results. Although the temperature levels between the two programs varied in accordance with the summer versus winter environments, the operating efficiency of the latest modules at temperatures averaging 56.6^{o}C and 54.6^{o}C (soldered and bonded, respectively) was 3.05 and 2.92 percent (soldered and bonded, respectively). These values are clearly above even the standardized values of efficiency, 2.35 and 2.36 percent, obtained during the earlier program. The trend is also evident in the fill factor values. These averaged 0.639 and 0.632 (soldered and bonded, respectively) for the most recent modules versus 0.614 and 0.622 (soldered and bonded, respectively) for the earlier program.

As with the earlier program, a conversion was made to standard temperature of 25°C on the basis of a voltage shift. These data are included in Table 2-4. Use of this table must be restricted to the category of qualitative because the current variation in the transition from the 55°C range to the 25°C standard temperature was not made. At present, there is not sufficient data available on the current-temperature relationship to enable this correction to be included in the standardization and consequently the error becomes appreciable when the operating temperature is significantly different from the standard temerature. All of the standardized efficiency data points fall between 3.25 and 3.75 percent, testifying to a relatively narrow performance band and consistent cell performance. The cell location maps for each of the modules are included as Appendix C.

Table 2-3. Solar Test Data for 25 Cell CdS Solar Cell Modules

Module (No. Type)		Temperature (°C)	Intensity (mw/cm^2)*	Input Energy (Watts)	Voc (volts)	Isc (amps)	Peak Power (watts)	Efficiency (percent)	Fill Factor, Peak Pwr/ (Isc x Voc)
9	(a)	59.2	95.6	130.8	2.07	3.06	4.030	3.08	0.636
Soldered	(b)	57.5	94.1	128.8	2.06	3.02	3.978	3.09	0.639
10	(a)	58.5	102.2	139.9	2.09	3.33	4.284	3.06	0.615
Soldered	(b)	60.6	98.8	135.2	2.07	3.16	4.004	2.96	0.612
11	(a)	52.5	101.6	139.0	2.07	3.22	4.320	3.11	0.648
Soldered	(b)	52.8	1[illegible].2	138.6	2.07	3.21	4.319	3.12	0.650
12	(a)	59.8	106.4	145.6	2.04	3.37	4.495	3.09	0.653
Soldered	(b)	59.0	108.5	148.6	2.04	3.46	4.631	3.12	0.656
13	(a)	58.8	98.9	135.3	2.08	2.91	3.912	2.89	0.646
Soldered	(b)	56.2	106.4	145.7	2.10	3.23	4.428	3.04	0.653
14	(a)	55.0	102.2	140.0	2.07	3.20	4.134	2.95	0.624
Soldered	(b)	53.3	100.9	138.1	2.10	3.16	4.213	3.05	0.635
15	(a)	57.2	98.2	134.4	2.08	3.15	4.293	3.19	0.655
Soldered	(b)	55.8	97.5	133.4	2.09	3.14	4.253	3.19	0.648
16	(a)	55.3	102.6	140.4	2.07	3.19	4.134	2.94	0.626
Soldered	(b)	54.4	103.1	141.2	2.10	3.21	4.212	2.98	0.625
Average Soldered		56.6	-	-	-	-	-	3.05	0.639
17	(a)	54.2	90.8	124.3	2.075	2.75	3.703	2.98	0.649
Bonded	(b)	54.6	94.6	129.4	2.09	2.855	3.864	2.98	0.648
18	(a)	55.0	88.3	120.9	2.06	2.68	3.440	2.85	0.623
Bonded	(b)	56.5	89.1	121.9	2.05	2.70	3.140	2.82	0.621
19	(a)	52.9	92.5	126.6	2.08	2.74	3.590	2.84	0.630
Bonded	(b)	53.1	90.7	124.2	2.09	2.71	3.564	2.87	0.629
20	(a)	56.2	83.4	114.1	2.10	2.59	3.424	3.00	0.629
Bonded	(b)	53.9	83.6	114.4	2.10	2.62	3.465	3.03	0.630
Average Bonded		54.6	-	-	-	-	-	2.92	0.632

*Referenced to silicon cell short circuit current STD, AMO

Table 2-4. Twenty-Five Cell CdS Solar Cell Module Data Standardized to 25°C Conditions

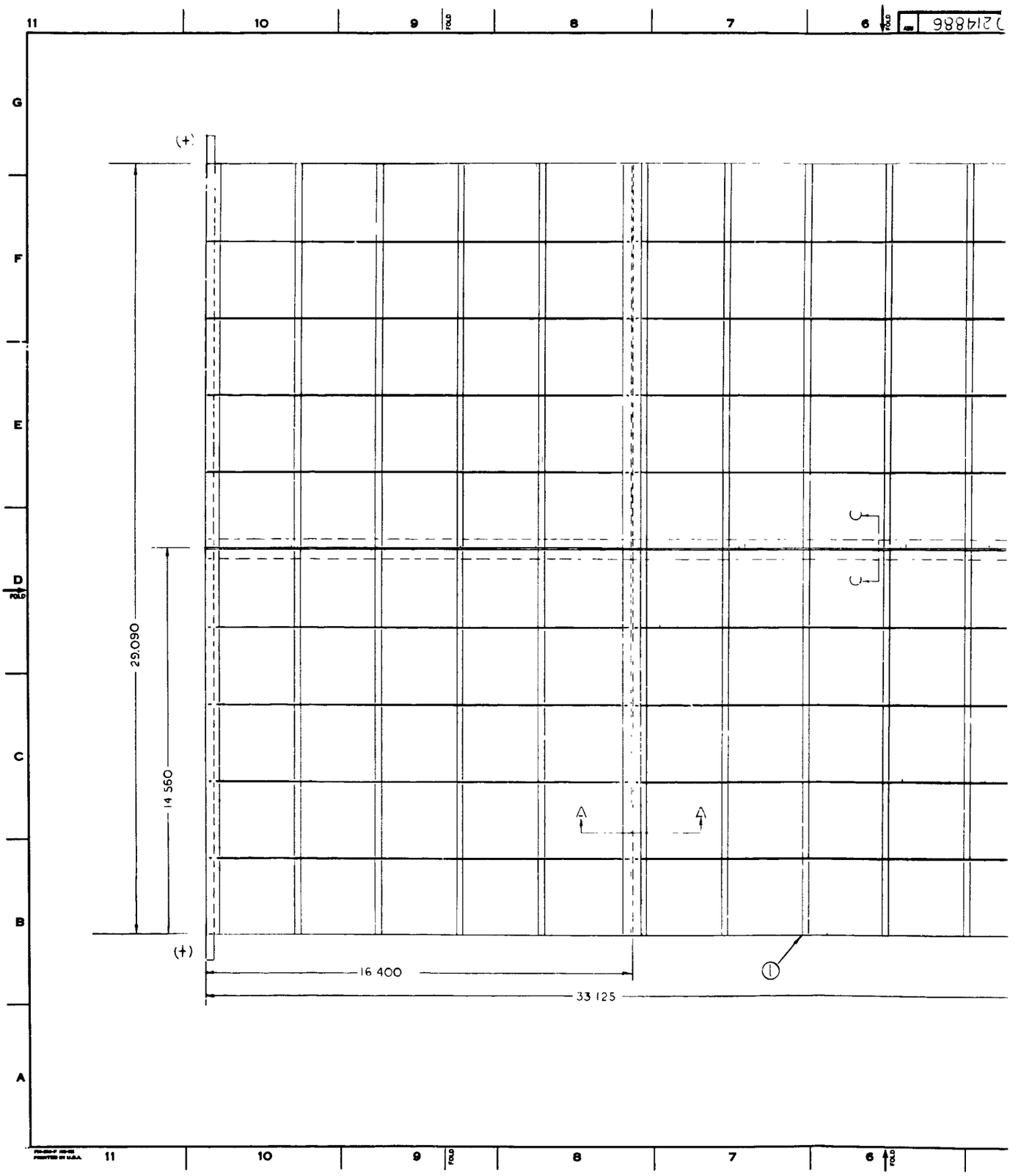
Module No. Type		$I_{Peak\ Power}$ Amps (observed)	$V_{Peak\ Power}$ Volts (observed)	Voltage Correction	Standarized Data -25°C		
					$V_{Peak\ Power}$	Peak Power, w	Efficiency Percent
9	(a)	2.60	1.55	0.299	1.849	4.807	3.67
Soldered	(b)	2.55	1.56	0.284	1.844	4.703	3.65
10	(a)	2.80	1.53	0.293	1.823	5.105	3.65
Soldered	(b)	2.60	1.54	0.311	1.851	4.813	3.56
11	(a)	2.70	1.60	0.241	1.841	4.970	3.57
Soldered	(b)	2.65	1.63	0.243	1.873	4.964	3.58
12	(a)	2.90	1.55	0.304	1.854	5.377	3.69
Soldered	(b)	2.95	1.57	0.297	1.867	5.509	3.70
13	(a)	2.40	1.63	0.296	1.926	4.621	3.41
Soldered	(b)	2.70	1.64	0.273	1.913	5.166	3.55
14	(a)	2.65	1.56	0.262	1.822	4.830	3.45
Soldered	(b)	2.65	1.59	0.248	1.838	4.870	3.53
15	(a)	2.65	1.62	0.282	1.902	5.04	3.75
Soldered	(b)	2.65	1.605	0.270	1.875	4.97	3.72
16	(a)	2.65	1.56	0.265	1.825	4.84	3.44
Soldered	(b)	2.60	1.62	0.258	1.878	4.88	3.46
17	(a)	2.30	1.61	0.255	1.865	4.29	3.45
Bonded	(b)	2.40	1.61	0.259	1.869	4.48	3.46
18	(a)	2.15	1.60	0.262	1.862	4.004	3.31
Bonded	(b)	2.15	1.60	0.276	1.876	4.033	3.31
19	(a)	2.15	1.67	0.244	1.914	4.116	3.25
Bonded	(b)	2.20	1.62	0.246	1.866	4.104	3.31
20	(a)	2.05	1.67	0.273	1.943	3.983	3.48
Bonded	(b)	2.10	1.65	0.253	1.903	3.997	3.49

2.2 MANUFACTURE OF SUB-PANELS

The final activity performed under the NAS 3-11821 program was the fabrication of three sub-panels, P/N 47D214886 (Figure 2-6 and Figure 2-7), using the twelve modules assemblies assembled and tested in the initial stage of the program. The building of the sub-panels represented an advance of the "next higher assembly" stage in the development of a solar array using Cadmium Sulfide solar cells. The electrical configuration for the sub-panel specified by NASA Lewis Research Center was to be two series circuits each having two modules. Isolation was to be maintained between the two series units which were to be mechanically joined along an edge resulting in a generally square configuration. The program did not include provisions for testing of the sub-panels, a function being reserved to the customer.

Manufacture of the sub-panels (step-by-step procedures included as Appendix A) required the joining of modules in series in a manner very similar to the joining required between rows of cells in a soldered module. Consequently, no additional equipment beyond the soldering/bonding machine and the assembly fixture used for module manufacture were required for the series interconnection. A layout table was needed to establish the relative positioning of the modules before fabricating the joint. The second step of the sub-panel assembly, the creation of the mechanical joint between the two module series units, was identical to the joint used in the modules, the seam between cell edges. However, in order to be able to utilize the bonding capability of the soldering/bonding machine, roller attachments were necessary to enable handling the larger area unit.

As specified, two of the sub-panels were fabricated with modules of the "Reinforced Soldered" configuration and one was fabricated using the "Conductive Epoxy Bonded" modules. The sub-panel series joint between modules is of the "Reinforced Soldered" construction for all three sub-panels.



FOLDOUT FRAME 1

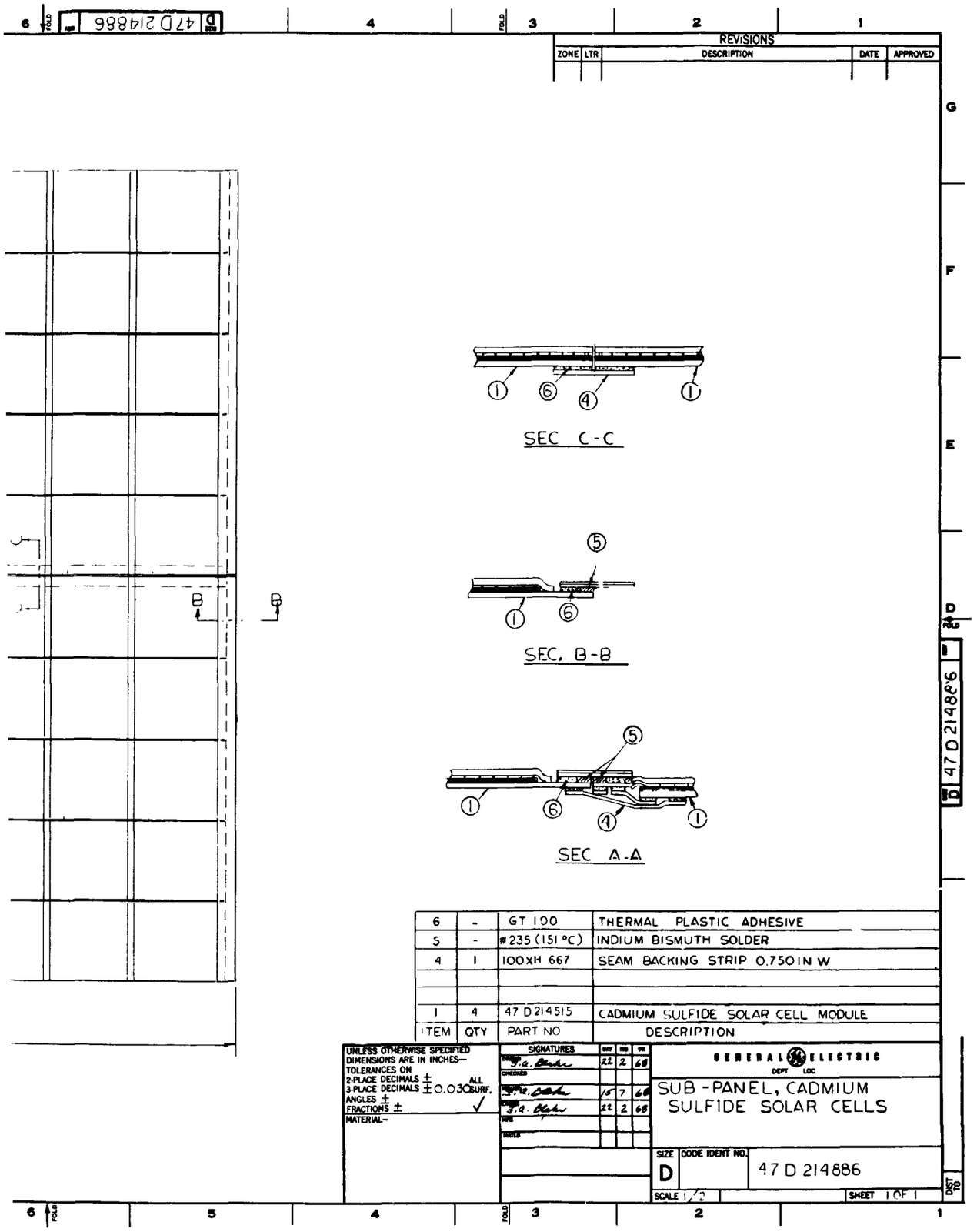


Figure 2-6. Sub-Panel, Cadmium Sulfide Solar Cells

FOLDOUT FRAME 2

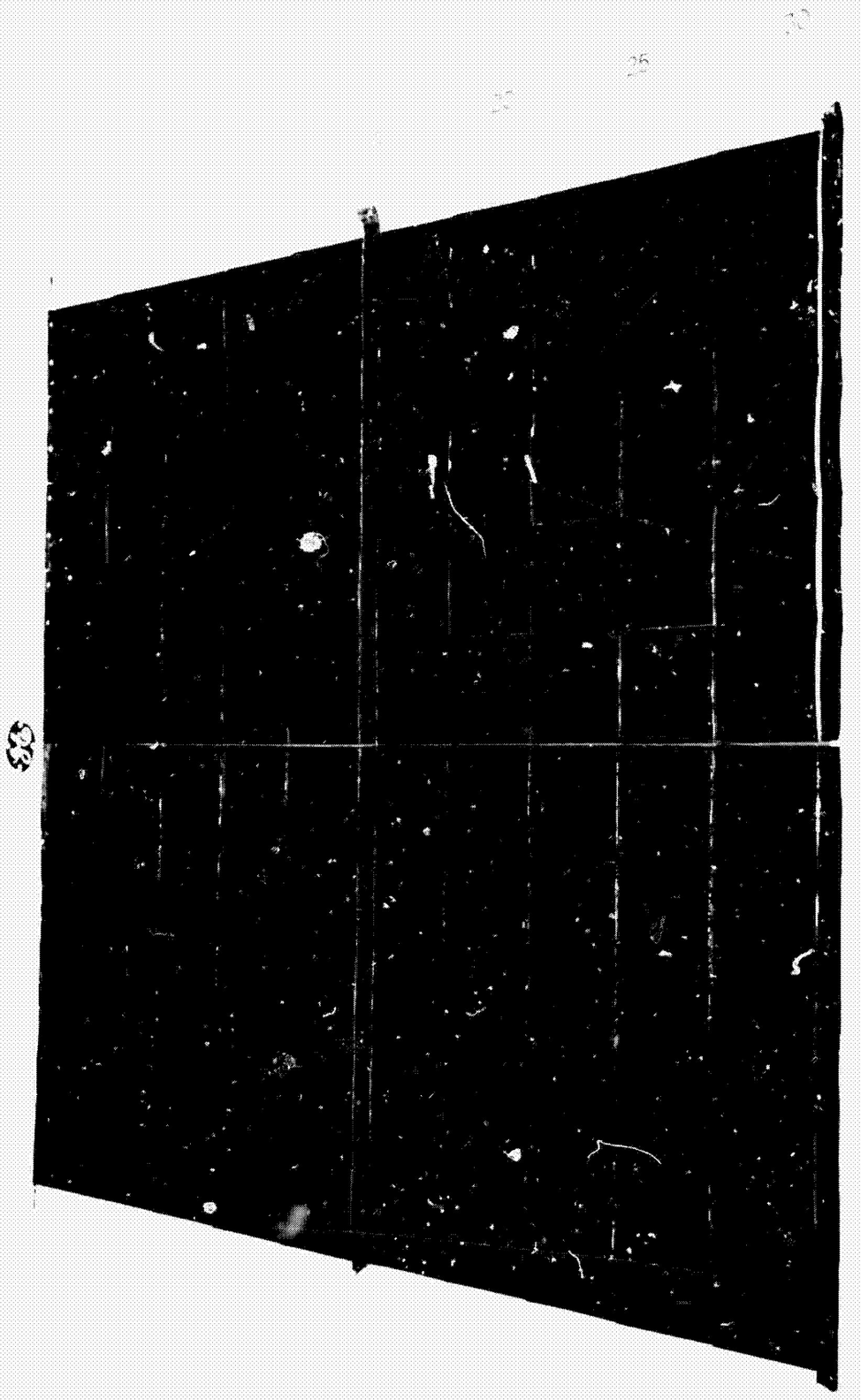


Figure 2-7. Sub-Panel Assembly P/N 47D 214886

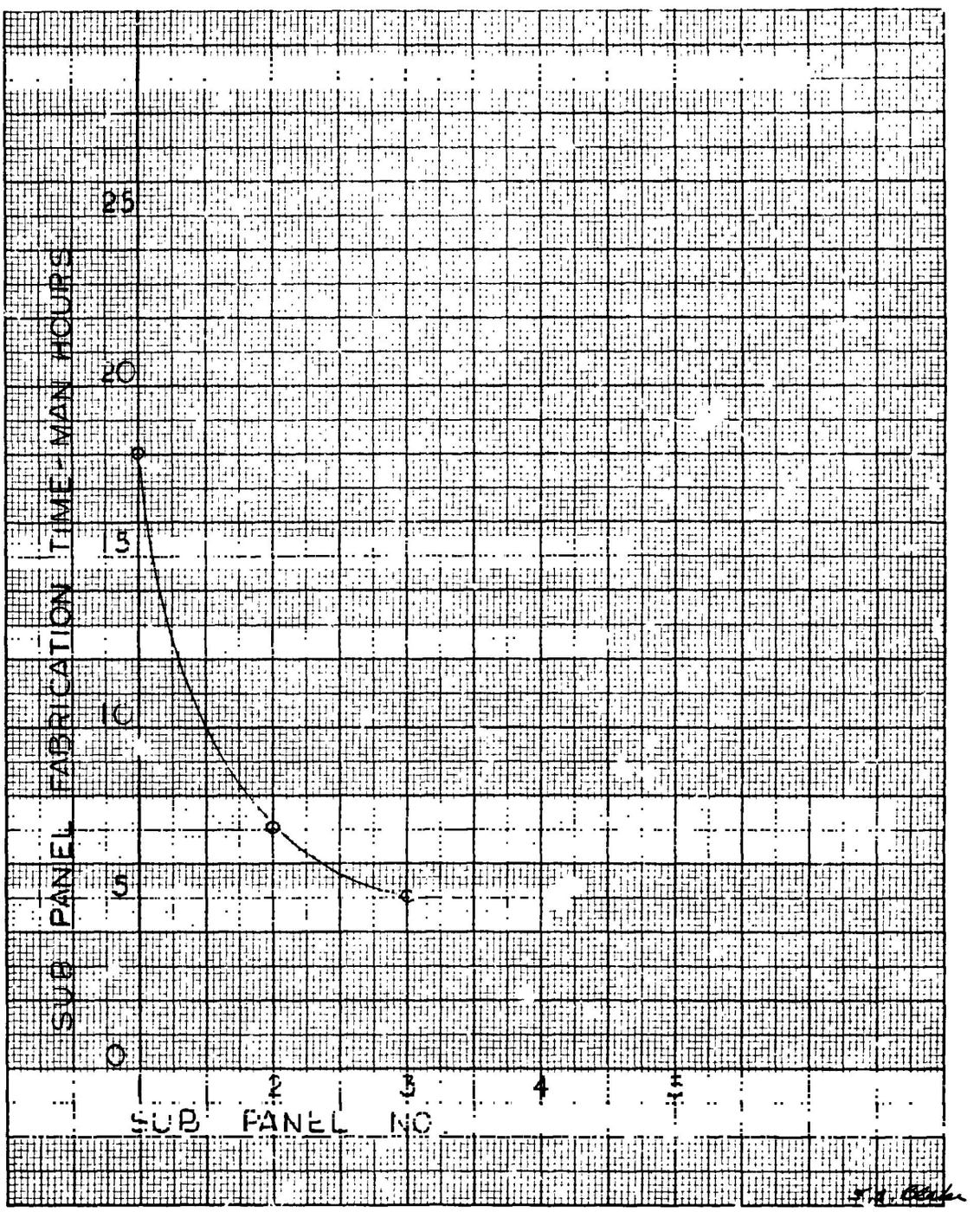


Figure 2-8. Learning Effect for Sub-Panel Fabrication of CdS Cells

2.2.1 SUB-PANEL FABRICATION TIME

As with the modules, a strong learning effect is evident in the initial sub-panel manufacturing. The times for the first three units were 18, 7, and 5 hours, respectively (shown graphically in Figure 2-8). Because the joining operations are virtually routine as a result of the module experience, the learning is predominantly in the "handling" activities associated with the sub-panel assembly. These too had reached routine status by the third unit, and therefore it is not expected that there will be a significant further reduction in the sub-panel fabrication time.

2.2.2 SUB-PANEL WEIGHT

Weight data covering the final sub-panel weights, the summed weights of the modules used in each sub-panel, and the specific weights of the sub-panels on an area basis are shown in Table 2-5. From the specific weight standpoint, the sub-panel operation is one of adding materials while reducing the area due to tab overlapping, both of which increase the specific weight value. For the two sub-panels which used modules of the "reinforced soldered" configuration, the average specific weight is 0.0744 lb/ft^2 (0.3633 kg/m^2); for the ligher unit made with "conductive epoxy" interconnections, the specific weight is 0.0668 lb/ft^2 (0.3264 kg/m^2). The total material added during the sub-panel fabrication operation averaged 4.7 grams. This is 1.7 grams higher than the "net added weight" shown in Table 2-5 because instrumentation tabs which were trimmed off lower the overall weight.

2.2.3 IDENTITY OF MODULES WITHIN SUB-PANELS

Figures 2-9, 2-10, and 2-11 show the positions of the twelve modules within sub-panels 1, 2, and 3, respectively.

2.3 GENERAL COMMENT ON FABRICATION OF CdS SOLAR CELL MODULES AND SUB-PANELS

The program covered in this report demonstrated that construction of solar array sections using Cadmium Sulfide solar cells is practical and efficient and involves extremely modest investments in fabrication equipment. This program has advanced the state of the CdS solar array fabrication one step along the "next higher assembly" trail and leads directly to the next logical stage, the fabrication of full voltage array sections composed of series groups of sub-panels and the return circuit busbar network. As with the sub-panel program, a modest revision of the manufacturing equipment installation aimed primarily at handling the larger area units will expand the capability to encompass the new requirements.

Table 2-5. Weight Data Sub-Panels

Sub-Panel	Sub-Panel Weight (grams)	Sub-Panel Weight (pounds)	Weight of 4 Modules Used (grams)	Added Weight Sub-Panel Fab (grams)	Sub-Panel Specific Weight Kg/m^2 ($A = 0.62168 m^2$)	Sub-Panel Specific Weight lb/ft^2 ($A = 6.6917 ft^2$)
1	229.0	0.5048	226.6	2.4*	0.3684	0.0754
2	222.7	0.4910	219.0	3.7*	0.3582	0.0734
3	202.9	0.4473	199.9	3.0*	0.3264	0.0668

*Net value in that 1.7 grams of instrumentation tabs are trimmed from Modules during sub-panel process. Total material added = Net + 1.7 (grams).

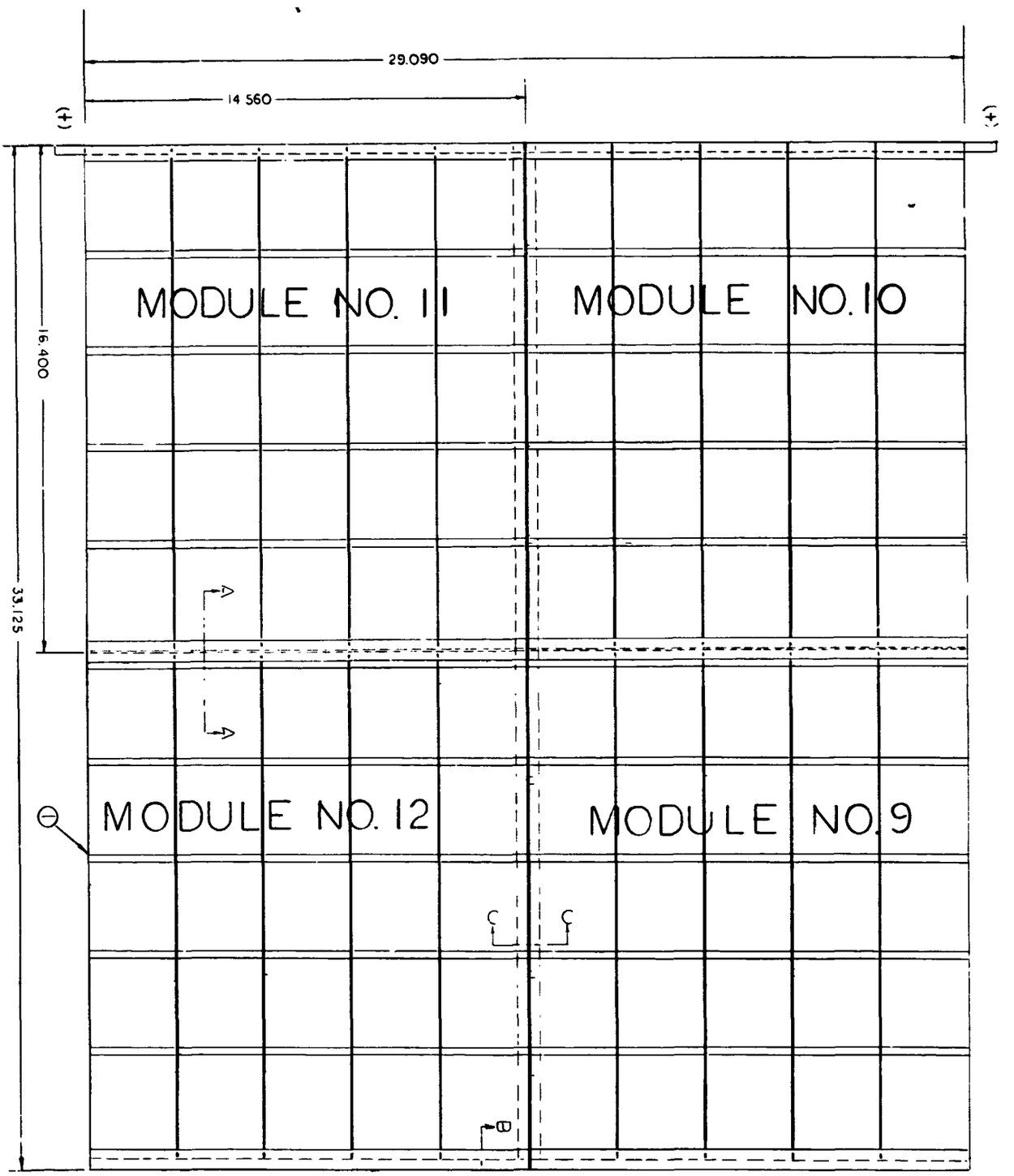


Figure 2-9. Module I.D., S/N 1 Sub-Panel

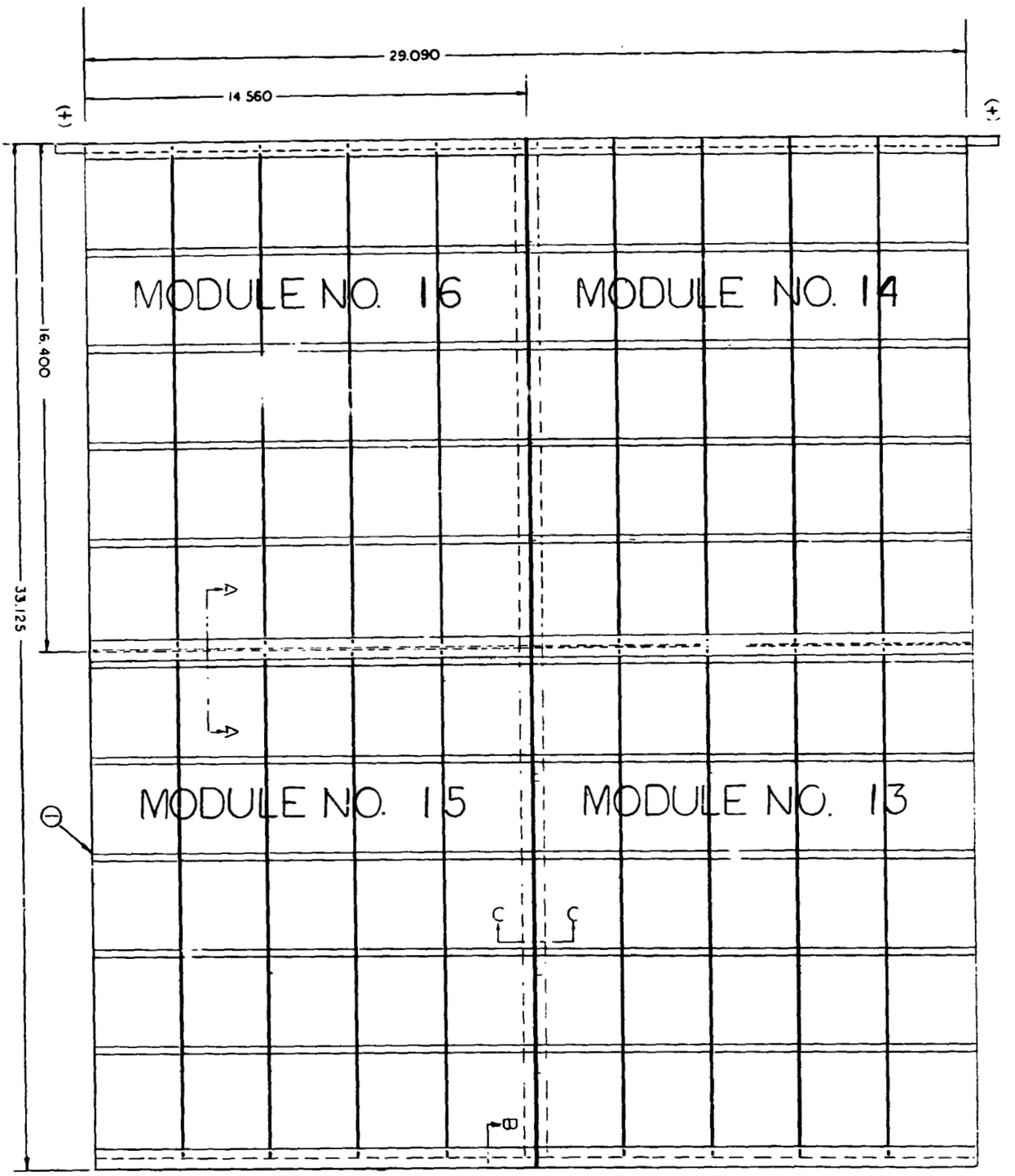


Figure 2-10. Module I.D., S/N 2 Sub-Panel

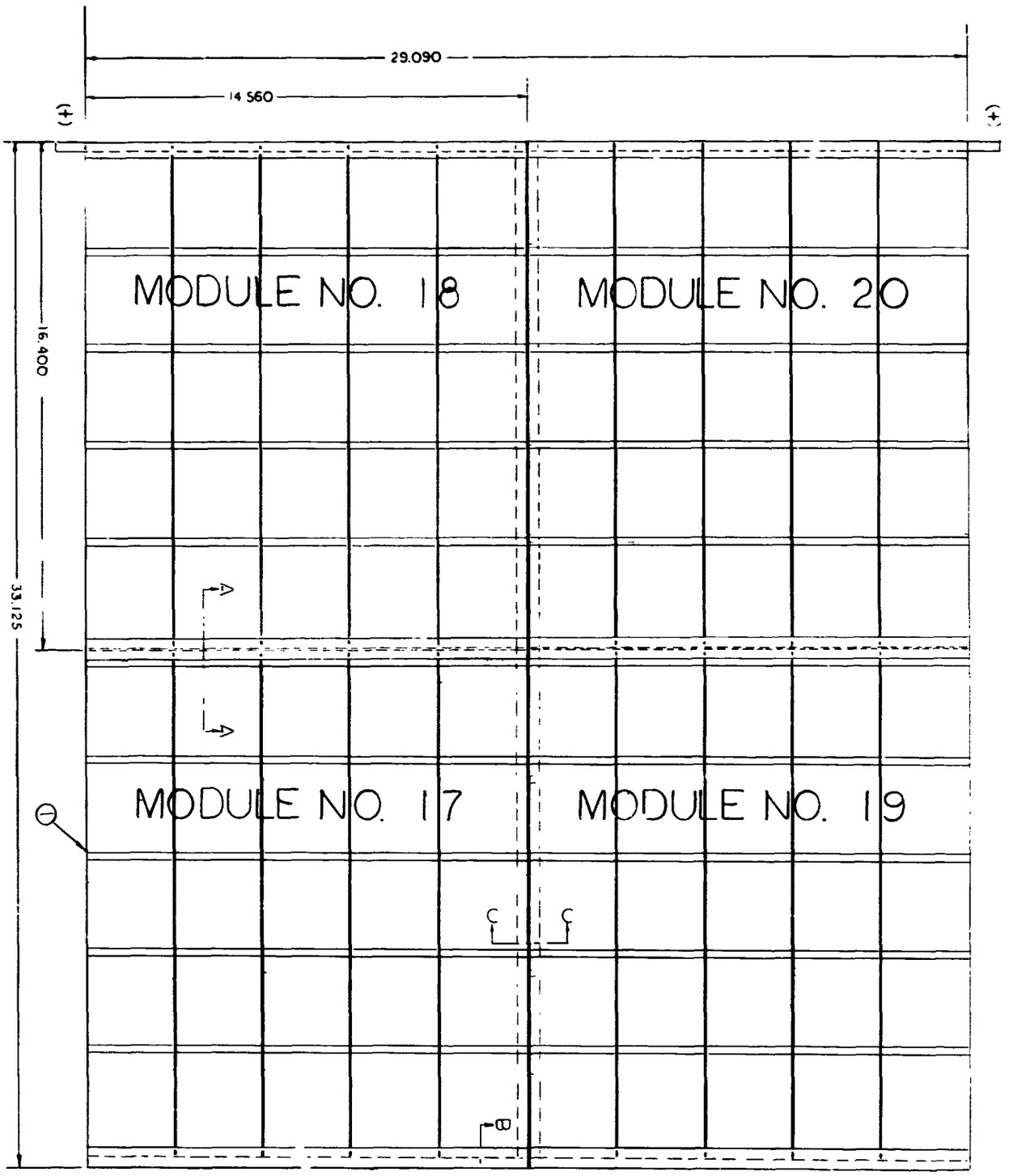


Figure 2-11. Module I.D., S/N 3 Sub-Panel

A.1 EQUIPMENT REQUIRED FOR FABRICATION OF SUB-PANELS FROM MODULES

Because processes for the fabrication of the sub-panels from modules involves the fabrication of joints similar to those used in the module manufacture, it was possible to utilize the principal piece of module fabrication equipment during the sub-panel assembly.

A.1.1 ROLLER MODIFICATION OF SOLDERING/BONDING MACHINE

Fabrication of the sub-panel is a two-step process, (1) the series connection of two modules in series, and (2) the parallel mechanical connection of two series units. The series electrical joint is a mechanically reinforced solder joint between the overhanging Schjelclad L5550 tab of one module to the paralleled positive cell tabs of the row one cells of a second module. The similarity of the process for the series joint to the process for the series joints within the module allowed the use of the soldering/bonding machine to fabricate the joint. Although the parallel mechanical joint was similar to the cell to cell seam joints in the module, the size of the machine relative to the two series units being joined required the incorporation of rollers along the edge of the assembly fixture as shown in Figure A-1. This relatively simple modification to the soldering/bonding machine was the only change needed to expand its capability to include sub-panel fabrication.

A.1.2 LAYOUT TABLE FOR SERIES UNIT AND SUB-PANEL POSITIONING

Before the bonding/soldering operations required for the series units and the bonding operation for the sub-panel, the positioning of the parts to be joined is made on a layout table having baseline and dimension line relationships as shown in Figure A-2. These lines correspond to the configuration control dimensions of drawing 47D214886.

A.2 SUB-PANEL PROCESS PART I, FABRICATION OF TWO MODULE SERIES UNIT

The detail manufacturing steps taken in the preparation of the "Two Module Series Unit," a pair of which are subsequently mechanically joined to form a sub-panel, are listed for reference. A completed Series Unit is shown in Figure A-3.

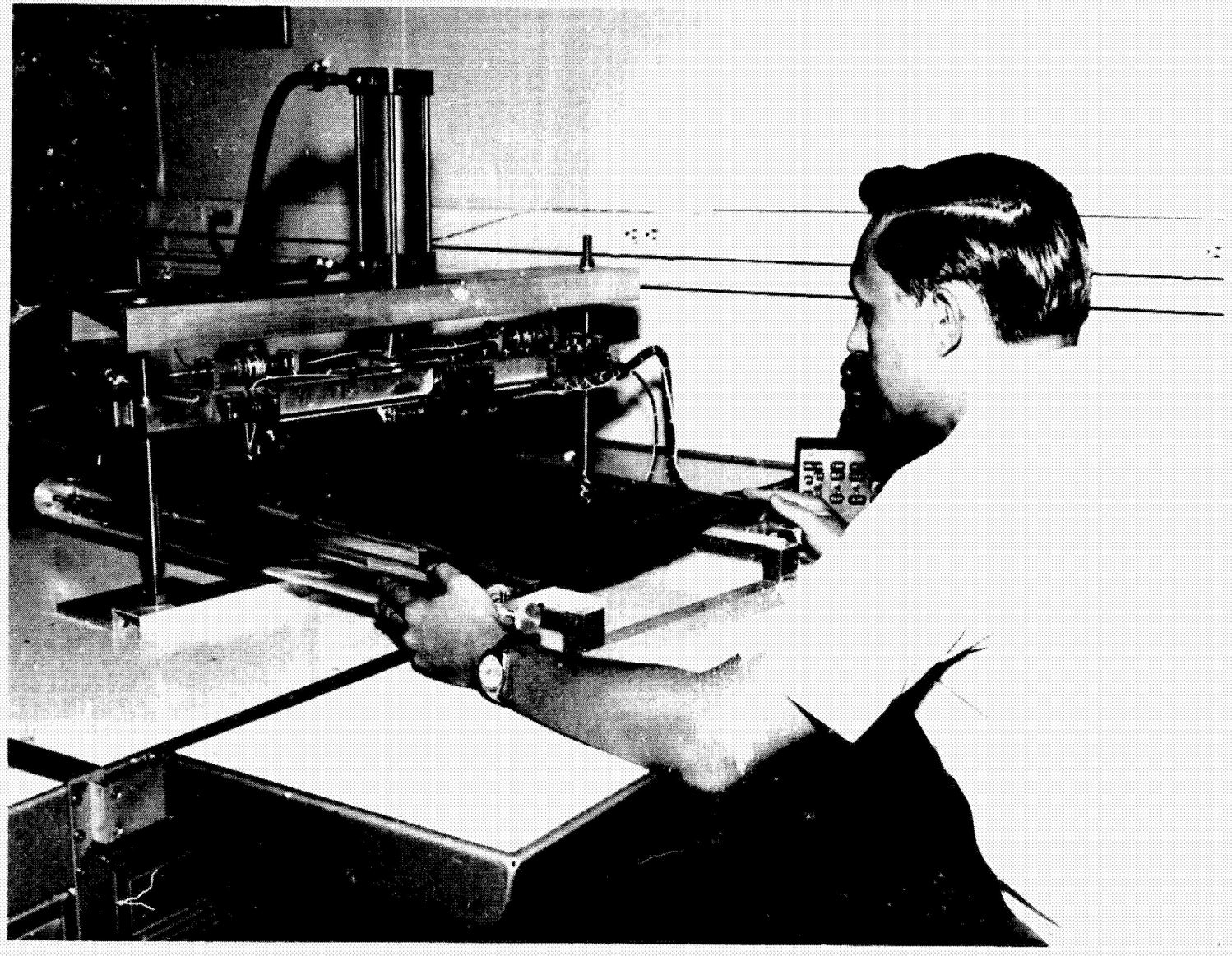


Figure A-1. Soldering/Bonding Machine with Roller Modifications to Enable Bonding of Parallel Sub-Panel Seam Joint

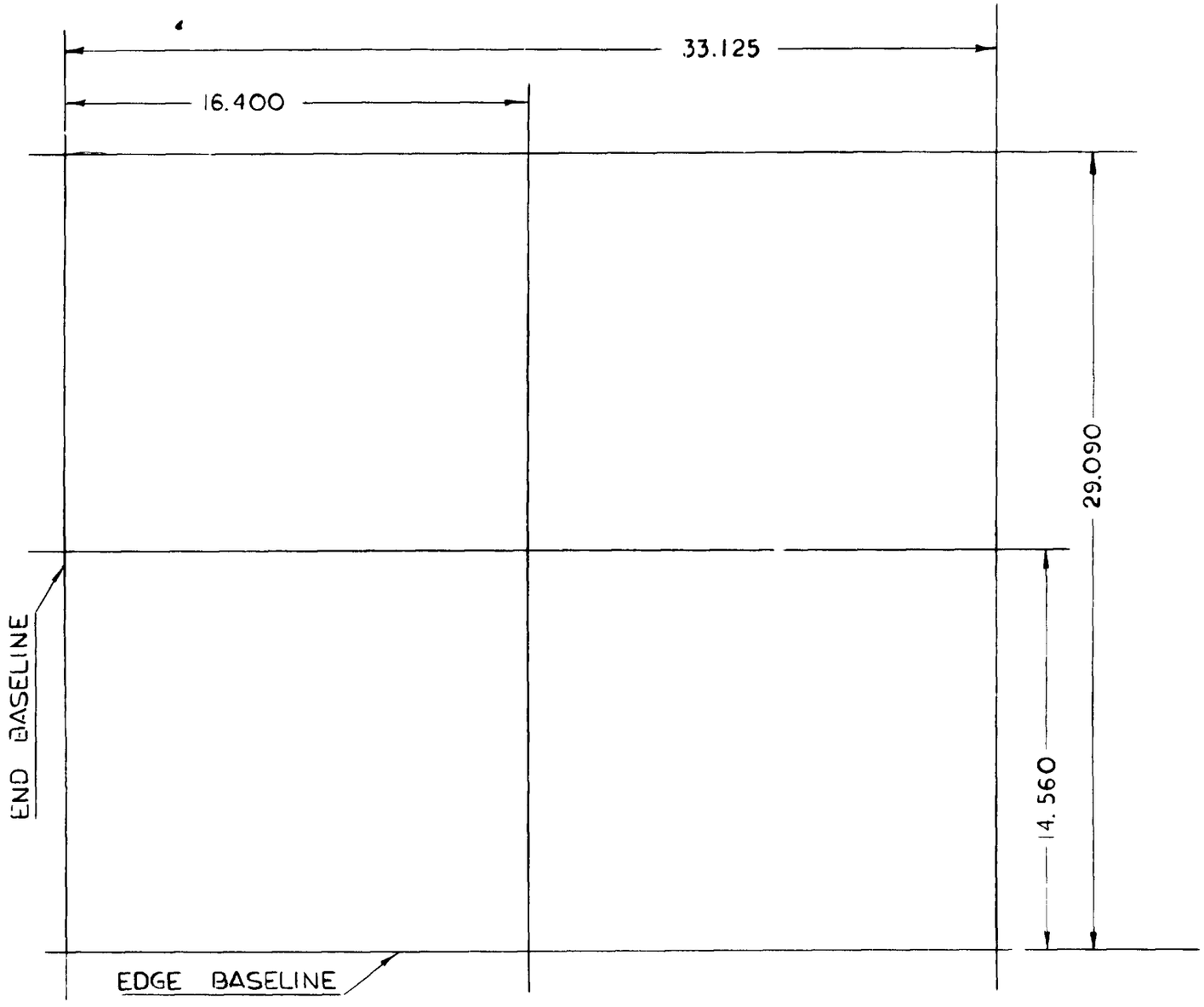


Figure A-2. Layout of Series Unit and Sub-Panel Positioning Table

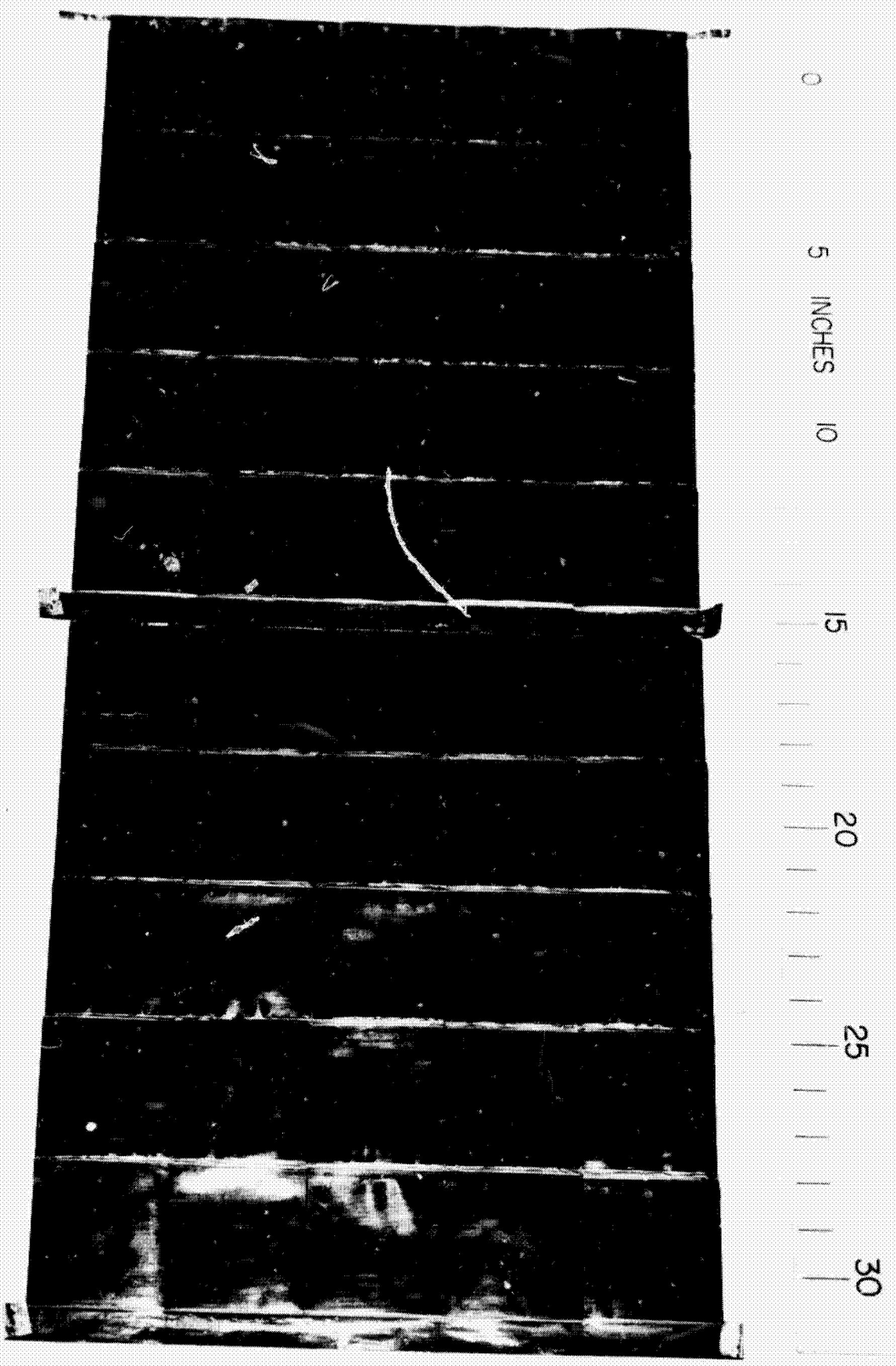


Figure A-3. Completed "Two-Module Series Unit"

A.2.1 MATERIALS AND PREPARATION - SERIES UNIT

a. Twenty-Five Cell CdS Solar Cell Module P/N 47D214515 (2 each)

b. Kapton Film Solder Dam, 2.0 x 16.0 x 0.003 inches (1 each)

c. GT100 Adhesive Strip, 0.188 x 15.0 inches (1 each)

d. GT100 Adhesive Strip, 0.375 x 15.0 inches (2 each)

e. Kapton Film Joint Back Up Strip, 0.75 x 14.5 x 0.001 inches (1 each)

f. Spot tack 0.375 GT100 Adhesive strips side by side on 0.75 wide Kapton strip.

NOTE: Items d., e., and f. can be combined by using a single strip of G. T. Schjeldahl T320 tape 0.75 inch wide.

g. Alpha No. 235 (151^{0}C) Indium Bismuth Solder Preform, 0.005 x 1/16 x 14.5 inches (1 each)

h. Kapton Pressure Sensitive Tape (Mystic 7361 or equivalent) (1 roll 1/2 inch)

i. Pressure Sensitive Masking Tape (1 Roll)

A.2.2 SERIES UNIT MANUFACTURING PROCEDURE

a. The two modules to be joined in series are identified as No. 1 and No. 2, corresponding to the upper and lower modules of Figure A-3, respectively.

b. Install the Kapton Film Solder Dam in position across Row 1 of Module 2 leaving 0.125-inch exposure of the positive tab. (Note: This step is identical to the dam positioning performed during module manufacture.)

c. Position Module 1 face down on layout table. Align positive end with end baseline and edge of module with the edge baseline. Secure the position with masking tape along the module edges. (Reference Figure A-2 for baseline designations.)

d. Position Module 2 face down on the layout table with the positive tab overlapping the Schjelclad tab of Module 1. Align the end of the positive tab with the 16.40-inch line of the layout pattern. Move module laterally until the edge is aligned with the edge baseline. (NOTE: Position of the negative tab of Module 2 must fall within 1/32 inch of the 33.125 line.) Secure position of Module 2 with tape along the edges.

e. Lift positive tabs of Module 2 as shown in Figure A-4, exposing 1/8 section of the negative tab where solder joint is to be made.

f. Spot tack the solder pre-form strip onto exposed tab using hand iron with 500 degrees tip and Alpha 704 flux.

g. Release the positive tabs of Module 2, allowing the module to lay flat on the table. Secure the positioning of the modules relative to each other with short strips of Kapton tape across the joint area at each cell as shown in Figure A-5.

h. Remove the two module assembly from the layout table and mount face up on the module assembly fixture with the joint approximately in the center of the fixture.

i. Apply Alpha 704 flux to the joint.

j. Lower the solder bar onto the joint and hold at 16 lb/in.^{2} and 350°F for 2 seconds.

k. Start forced air cooling of the bar and hold until the temperature of the bar has dropped below 300°F. Raise the solder bar.

l. Remove the Kapton dam strip.

m. Insert the narrow GT 100 strip (0.188 x 15 x 0.0025 inches) in the space between the tabs preserved by the Kapton dam.

n. Switch the heater bar heat controller to the bonding temperature (280°F) position.

o. Lower the heater bar to cure the GT 100 adhesive. Hold the 16 lb/in.^{2} pressure at 280°F for 12 to 14 seconds. Raise the heater bar.

p. Center the 0.750-inch back up strip along back of joint. (Modules positioned face down.)

q. Lower the heater bar and cure the GT 100 adhesive per step o. This step must be repeated three times to cover the area of the back up strip.

The steps a. through q. are repeated for a second set of two modules to provide the two series units needed for the sub-panel assembly.

A.3 SUB-PANEL PROCESS PART II, JOINING OF TWO SERIES UNITS INTO SUB-PANEL

The final sub-panel assembly stage is the mechanical joining of two series units as shown in Figure A-6.

Figure A-4. Series Unit Manufacturing Step e.

Figure A-5. Series Unit on Layout Table Showing Joint Position Secured with Kapton Tape Strips on Each Cell

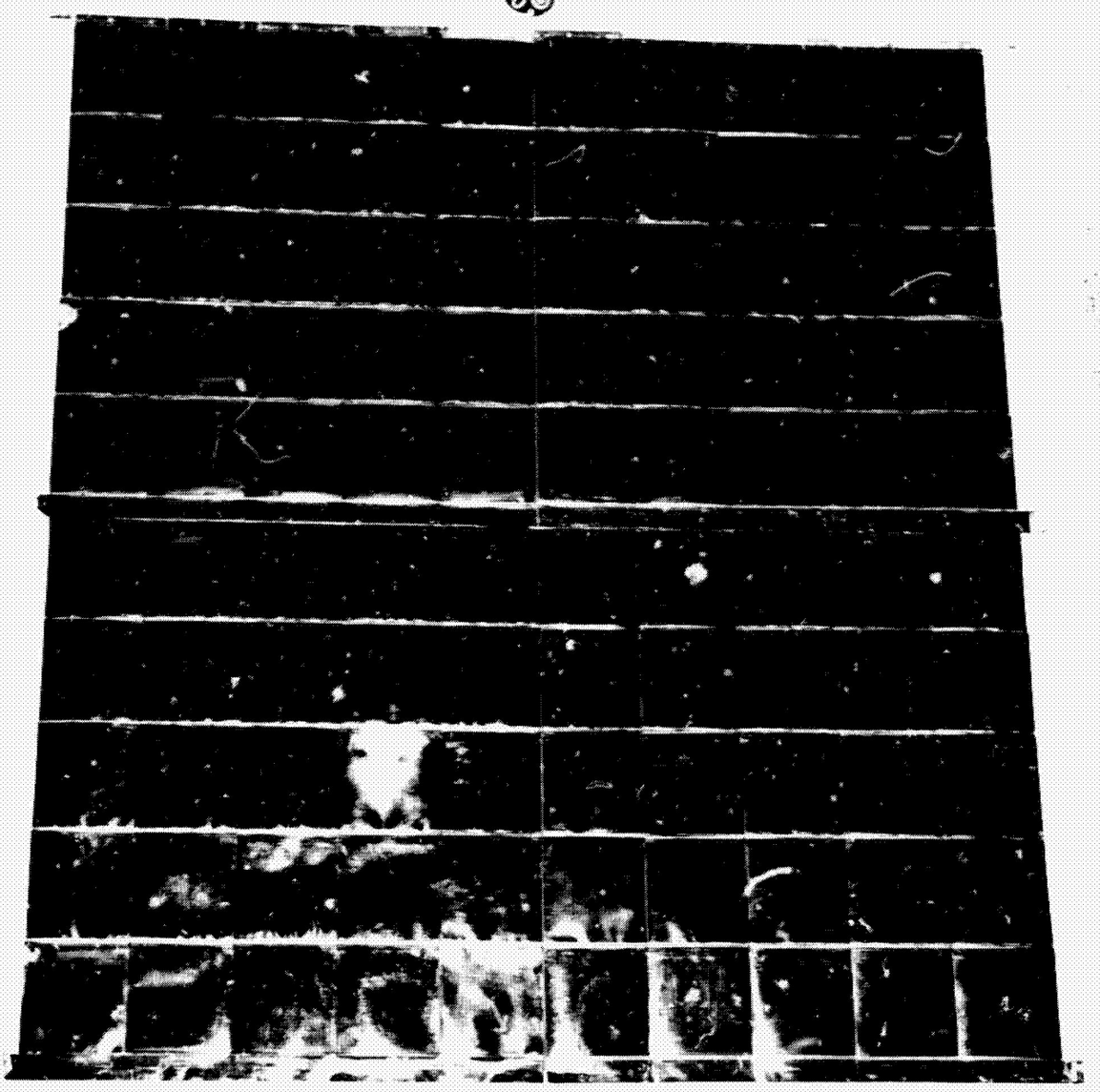


Figure A-6. Completed Sub-Panel P/N 47D214515

A.3.1 MATERIALS AND PREPARATION - SUB-PANEL ASSEMBLY

a. Two series units each of two modules joined in series as described in Section A.2.

b. Schjeldahl T320 Tape (This tape is a factory prepared layup of GT100 and Kapton); 34 x 1/2 inches (1 piece required) 1 1/2 x 1/2 inch (2 pieces required)

c. Kapton Pressure sensitive tape (Mystic 7361 or equivalent) (1 roll)

d. Pressure sensitive masking tape. (1 roll)

A.3.2 SUB-PANEL ASSEMBLY MANUFACTURING PROCEDURE

a. Position one series unit face up on the layout table with the edge aligned with "Edge Baseline" and with the end gaps between the "End Baseline" and the "33.125-Inch Line" balanced. Secure the position with masking tape along the ends and the baseline edge.

b. Trim off test tabs which cross the sub-panel centerline (14.560 line) flush with the edge of the modules.

c. Position second series unit face up on the layout table with edge aligned with the sub-panel centerline (14.560 line) and with end gaps between the end baseline and the 33.125 line balanced. Secure the position with masking tape at the ends and at the edge along the "29.090 line."

d. Repeat Step b., tab trimming, for the second series unit.

e. Secure the position of the series units relative to each other by Kapton tape strips across the centerline joint at each cell row.

f. Lift the four module unit from the table and turn over face down.

g. Center the 36 x 1/2 inch T320 strip over the centerline joint gap and tack at the positive end of the sub-panel by use of a hand soldering iron.

h. Mount the four-module unit on one of the rollers of the module assembly fixture (Figure A-1), starting with the negative end attached to the roller. Cell faces are wrapped inward against the roller and the wrap is such as to result in the unrolling unit lying face down over the work surface of the assembly fixture.

i. Mount assembly fixture in the soldering/bonding machine with the centerline joint directly below the heater bar.

j. Unroll approximately 12 inches of the four-module unit onto the work surface of the fixture.

k. Cure T320 tape to back of modules by lowering the heater bar (280°F) onto joint under 16 lb/in.^{2} pressure for 12 to 14 seconds; lift bar. Repeat with slight position changes under the bar as necessary until the full width of the T320 is cured.

l. Advance the unit across the work surface approximately 12 inches, taking up the finished section on the previously unused roller.

m. Repeat curing Step k. for the newly exposed section of the parallel mechanical joint.

n. Advance the unit until the final section is under the bar and repeat the T320 Tape cure step per k.

o. Remove the sub-panel assembly from the assembly fixture roller and return to the layout table. Remove the Kapton pressure sensitive tape pieces used to secure the joint positioning.

p. Tack the two 1 1/2-inch pieces of T320 across the ends of the T320 seam tape on the back of the sub-panel.

q. Remount the sub-panel on the assembly fixture roller leaving one end exposed on the work surface to enable curing of the end anchorage pieces of T320 tape.

r. Cure the first end anchorage tape per Step k.

s. Advance the sub-panel across the work surface and onto the second roller until the opposite end anchorage tape is under the bar.

t. Cure the second end anchorage tape per Step k., and remove from assembly fixture.

The following listing is of the computer programs used to reduce the Solar Test data taken on modules P/N 47D214515. (FORTAN IV Language)

```
$LIST   DSMOD

07/19/68   15.78

00010 * DATA REDUCTION - CDS MODULE SOLAR TESTS
00020 DIMENSION XIPP(10),VPP(10),PWR(10),ETA(10)
00030 DIMENSION FILFAC(10),VSTDT(10),POWSTD(10),ETASTD(10)
00040 DIMENSION AMOI(10),AMOPWR(10)
00050 40 CONTINUE
00060 PRINT 113
00070 113 FORMAT(//////////)
00080 PRINT 100
00090 100 FORMAT(//,2X," S/N ",2X,"ISC STD",2X,"VOC STD",2X,"TEMP F",//)
00100 READ:SERNO,XISTD,VOCSTD,DEGF
00110 CURSTD=0.345
00120 VSTD=0.549
00130 TOP=XISTD
00140 50 FRACT1=TOP/CURSTD
00150 VFRACT=0.1285*FRACT1
00160 VOCEQ=(0.8715+VFRACT)*VSTD
00170 VCORET=VOCSTD-VOCEQ
00180 TSTDF=82.4-(VCORET/0.0012)
00190 XICORR=0.1366*(VCORET/0.0012)*FRACT1
00200 XICORR=XICORR/1000.
00210 XXISTD=XISTD+XICORR
00220 PRINT:TOP,XXISTD
00230 IF(ABS(XXISTD-TOP)-1.0E-07)51,51,52
00240 52 TOP=XXISTD; GO TO 50
00250 51 FRACT2=XXISTD/CURSTD
00260 XINTEN=FRACT2*139.6
00270 XINPUT=1368.7*XINTEN/1000.
00280 PRINT 101
00290 101 FORMAT(//,2X," I STD  ",3X," V STD  ",3X,"MW/CM2 ",3X,
00300 &"INPUT WATTS",//)
00310 PRINT 102,XXISTD,VOCEQ,XINTEN,XINPUT
00320 102 FORMAT(4F12.4,//)
00330 PRINT 103
00340 103 FORMAT(//,2X,"POWER POINT CURRENT-VOLTAGE",//)
00350 DO 10 I=1,4
00360 READ:XIPP(I),VPP(I)
00370 PWR(I)=XIPP(I)*VPP(I)
00380 ETA(I)=PWR(I)/XINPUT*100.
00390 10 CONTINUE
00400 PRINT 104
00410 104 FORMAT(//,2X,"P.P.CURRENT",2X,"P.P. VOLTS",2X,"POWER-WATTS",
00420 &2X,"EFF-PERCENT",//)
00430 PRINT 105,(XIPP(I),VPP(I),PWR(I),ETA(I),I=1,4)
00440 105 FORMAT(4F12.4,//)
00450 PRINT 106
00460 106 FORMAT(//2X,"MOD ISC",2X,"MOD VOC",//)
00470 READ:XISC,VOCMOD
00480 DO 20 J=1,4
00490 FILFAC(J)=PWR(J)/(XISC*VOCMOD)
00500 20 CONTINUE
00510 PRINT 107
00520 107 FORMAT(//2X,"FILL FACTORS",//)
00530 PRINT 108,(FILFAC(J),J=1,4)
```

B-2. SOLAR TEST V-I CURVES AND DATA

The V-I performance curves obtained from modules 9-20 during the solar tests are included as Figures B-1 to B-24. The computer data reduction print-out for each curve is included as the page following the curve. Two curves and print outs are included for each module.

```
00540 106 FORMAT(F10.4,//)
00550 DEGC=(DEGF-32.0)/1.8
00560 DELTA=DEGC-25.0
00570 VPCELL=0.00175*DELTA
00580 VPMOD=5.0*VPCELL
00590 PRINT 109
00600 109 FORMAT(//2X,"MOD TEMP DEG CENT")
00610 PRINT 108,DEGC
00620 PRINT 110
00630 110 FORMAT(//2X,"VOLTAGE CORRECTION ")
00640 PRINT 108,VPMOD
00650 DO 30 K=1,4
00660 VSTDT(K)=VPP(K)+VPMOD
00670 POWSTD(K)=VSTDT(K)*XIPP(K)
00680 ETASTD(K)=POWSTD(K)/XINPUT*100.
00690 30 CONTINUE
00700 PRINT 104
00710 PRINT 105,(XIPP(K),VSTDT(K),POWSTD(K),ETASTD(K),K=1,4)
00720 SPACEI=XISC/FRACTI
00730 AMODLI=SPACEI-XISC
00740 DO 60 L=1,4
00750 AMOI(L)=XIPP(L)+AMODLI
00760 AMOPWR(L)=AMOI(L)*VSTDT(L)
00770 60 CONTINUE
00780 PRINT 111
00790 111 FORMAT(//,2X," AMO I  ",2X," AMO V  ",2X," AMO POWER",//)
00800 PRINT 112,(AMOI(L),VSTDT(L),AMOPWR(L),L=1,4)
00810 IF(I.EQ.4)GO TO 40
00820 112 FORMAT(3F12.4,//)
00830 STOP
00840 END
```

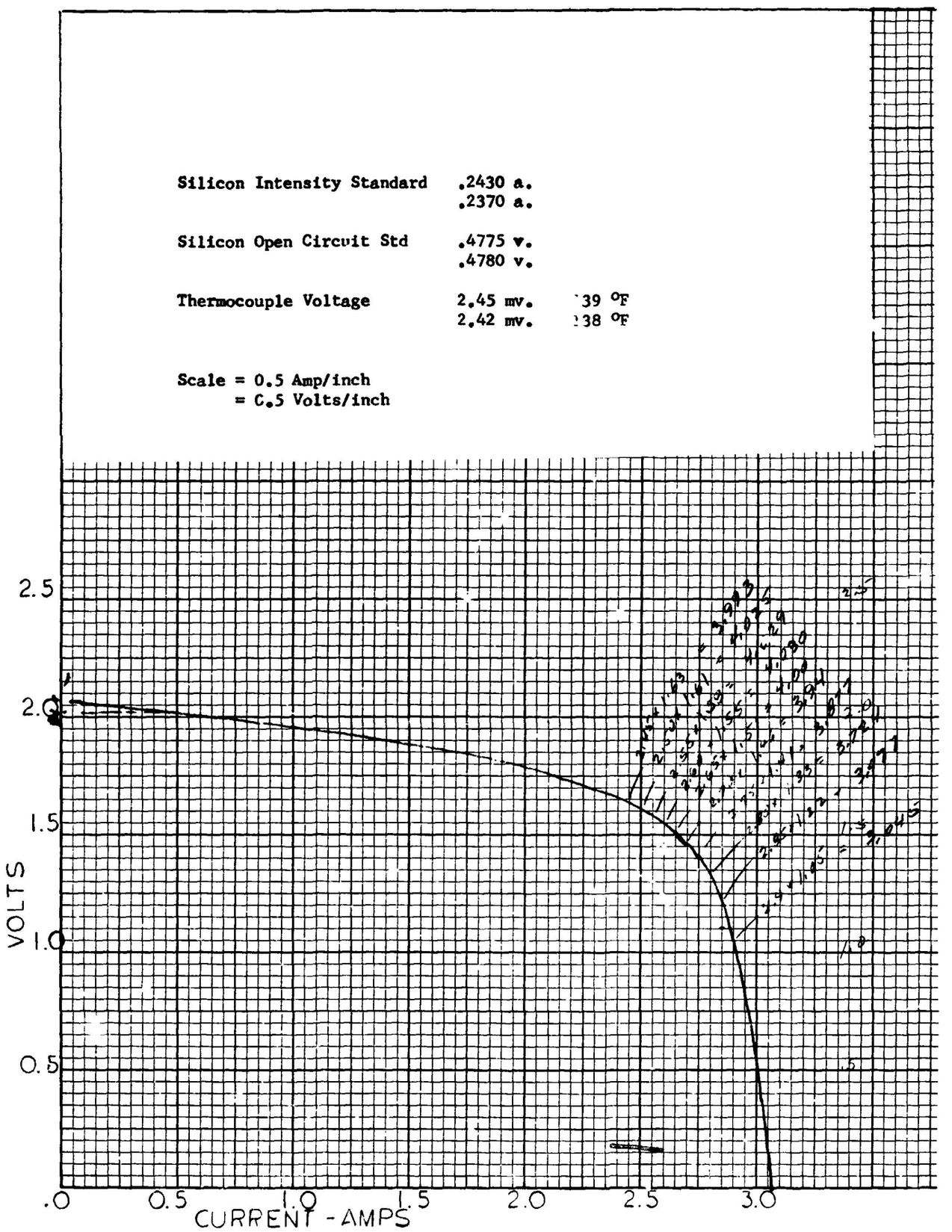


Figure B-1. Solar Test V-I Curve - Module 9 Test A - 7/2/68

```
 S/N    ISC STD   VOC STD   TEMP F
=9A   .2400,    .4777,    138.5
```

2.4000000E-01	2.3605409E-01
2.3605409E-01	2.3618181E-01
2.3618181E-01	2.3617771E-01
2.3617771E-01	2.3617784E-01
2.3617784E-01	2.3617784E-01

ITERATION TO ESTABLISH STANDARD TEMPERATURE CURRENT OF SILICON STANDARD

I STD	V STD	MW/CM2	INPUT WATTS
0.2362	0.5267	95.5665	130.8018

POWER POINT CURRENT-VOLTAGE

=2.50, 1.61

=2.55, 1.58 VALUES READ DIRECTLY FROM V-I CURVE

=2.60, 1.55

=2.65, 1.51

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.5000	1.6100	4.0250	3.0772
2.5500	1.5800	4.0290	3.0802
2.6000 *	1.5500 *	4.0300 *	3.0810 *
2.6500	1.5100	4.0015	3.0[illegible]2

MOD ISC MOD VOC
=3.06, 2.07

FILL FACTORS

0.6354

0.6361

0.6362 *

0.6317

MOD TEMP DEG CENT
59.1667

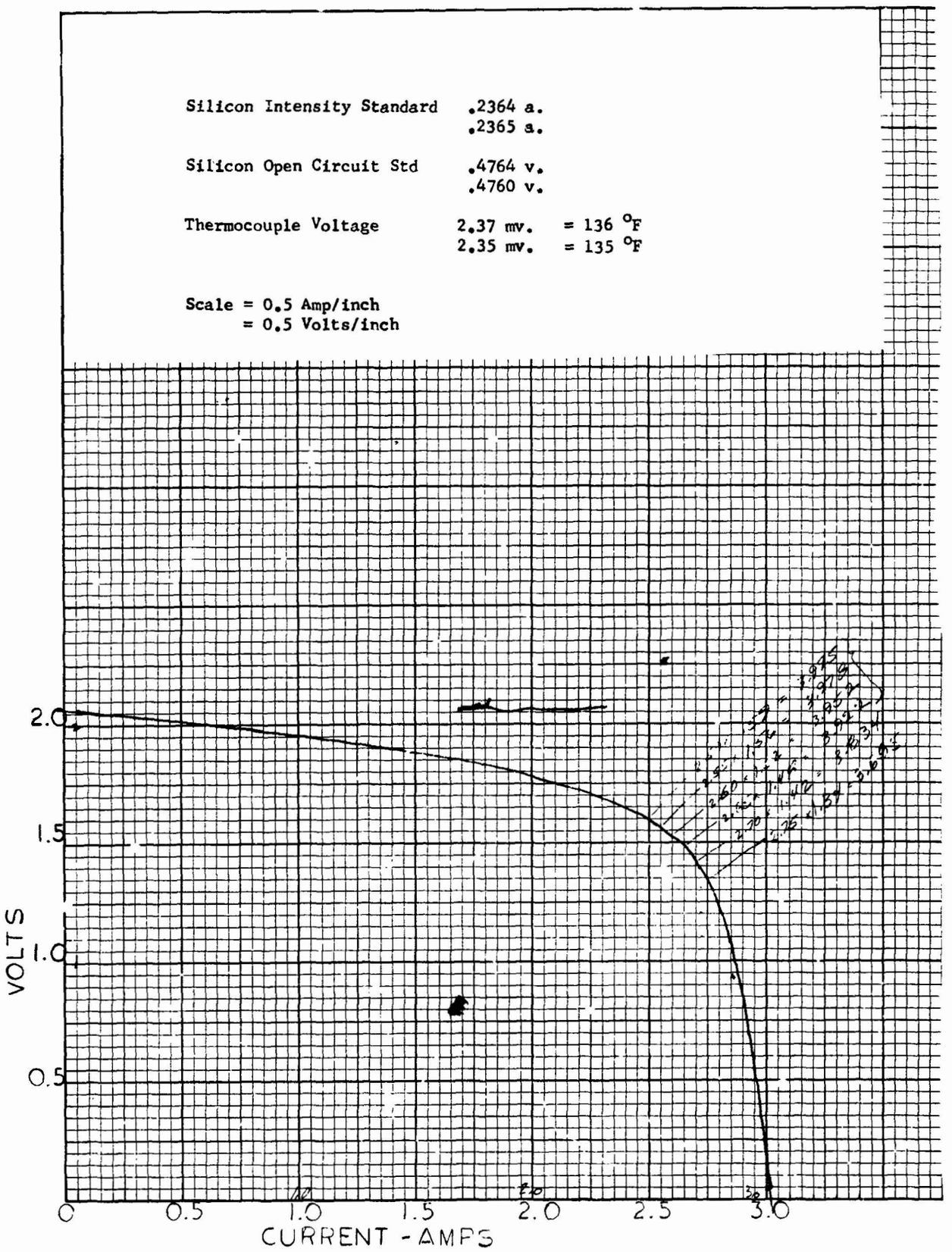


Figure B-2. Solar Test V-I Curve - Module 9 Test B - 7/2/68

S/N ISC STD VOC STD TEMP F
=9,3 .2365, .4762, 135.5

2.3650000E-01	2.3255044E-01
2.3255044E-01	2.3267836E-01
2.3267836E-01	2.3267425E-01
2.3267425E-01	2.3267439E-01
2.3267439E-01	2.3267438E-01
2.3267438E-01	2.3267438E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2327	0.5230	94.1488	128.8615

POWER POINT CURRENT-VOLTAGE
=2.50, 1.59

=2.55, 1.56

=2.60, 1.52

=2.65, 1.48

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.5000	1.5900	3.9750	3.0847
2.5500	1.5600	3.9780 *	3.0870 *
2.6000	1.5200	3.9520	3.0669
2.6500	1.4800	3.9220	3.0436

MOD ISC MOD VOC
=3.02, 2.06

FILL FACTORS

0.6389

0.6394 *

0.6352

0.6314

MOD TEMP DEG CENT
57.5000

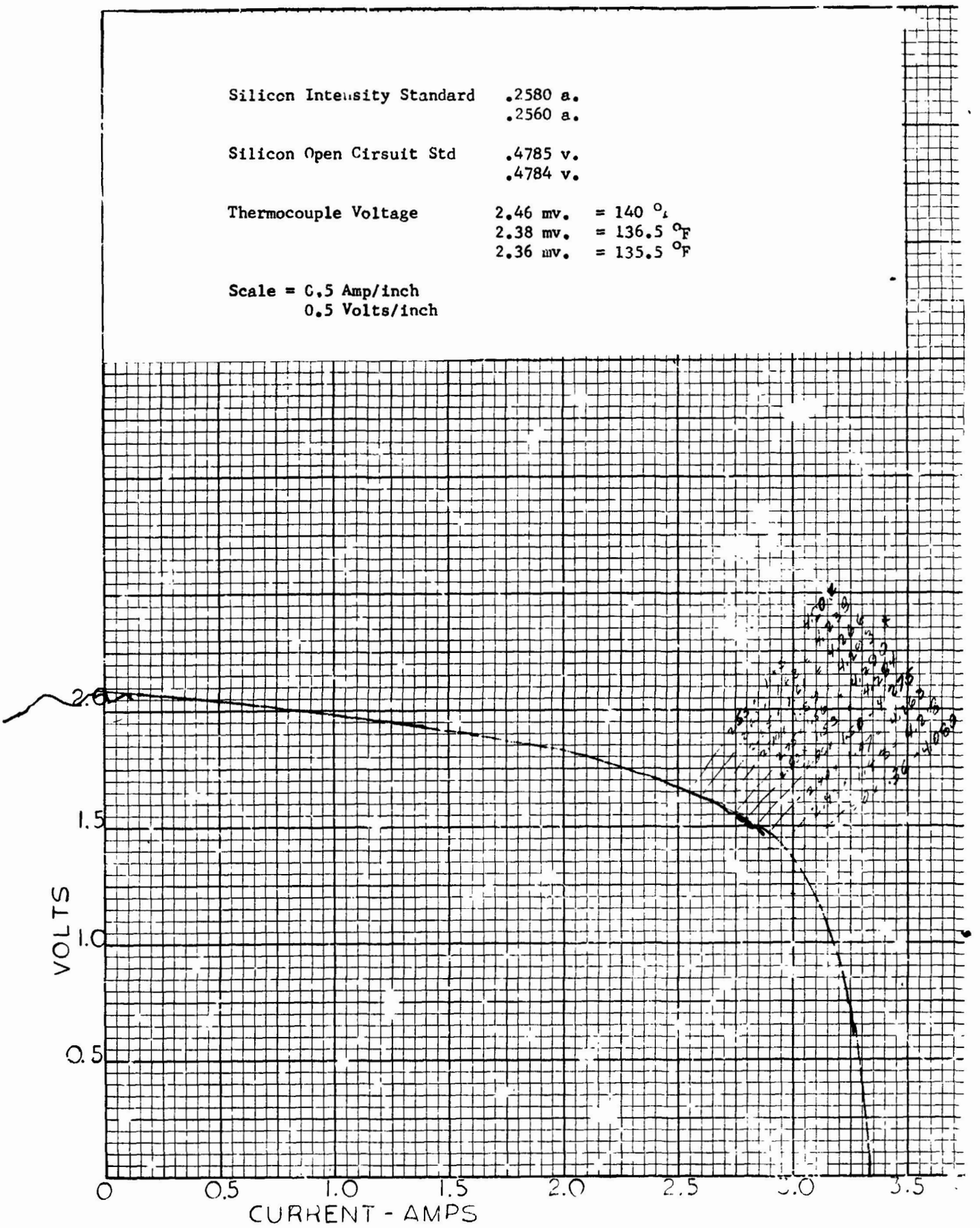


Figure B-3. Solar Test V-I Curve - Module 10 Test A - 7/2/69

```
 S/N   ISC STD  VOC STD  TEMP F
=10A   .2570,   .4784,   137.3

  2.5700000E-01   2.5253918E-01
  2.5253918E-01   2.5269261E-01
  2.5269261E-01   2.5268738E-01
  2.5268738E-01   2.5268755E-01
  2.5268755E-01   2.5268755E-01
  2.5268755E-01   2.5268755E-01

 I STD       V STD      MW/CM2     INPUT WATTS

    0.2527      0.5301    102.2469    139.9453


 POWER POINT CURRENT-VOLTAGE
=2.80,  1.53

=2.85,  1.50

=2.90,  1.47

=2.95,  1.43


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

    2.8000      1.5300      4.2840 *     3.0612 *

    2.8500      1.5000      4.2750       3.0548

    2.9000      1.4700      4.2630       3.0462

    2.9500      1.4300      4.2185       3.0144


 MOD ISC  MOD VOC
=3.333,  2.09


 FILL FACTORS

   0.6150 *

   0.6137

   0.6120

   0.6056


 MOD TEMP DEG CENT
  58.5000
```

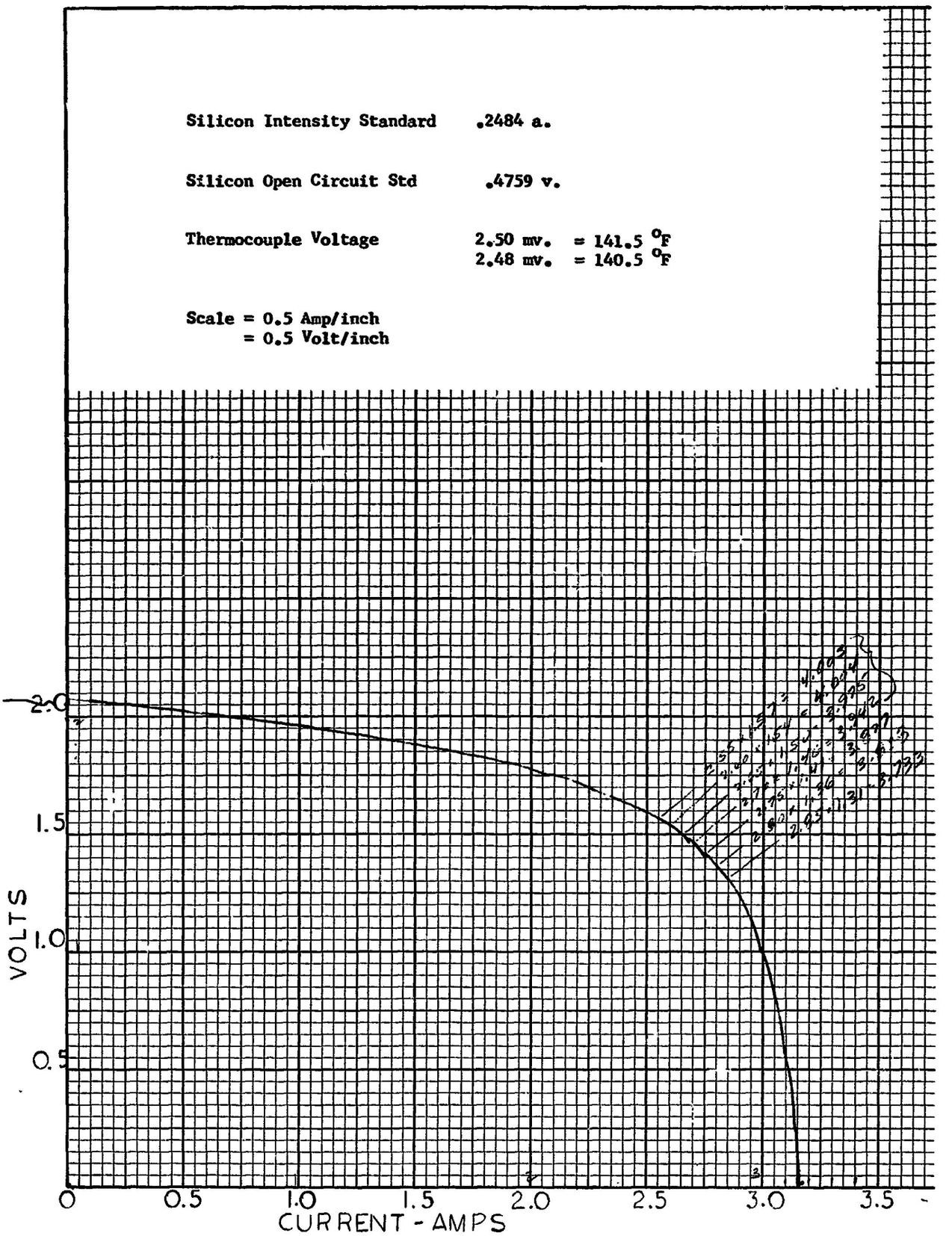


Figure B-4. Solar Test V-I Curve - Module 10 Test B - 7/2/68

S/N	ISC STD	VOC STD	TEMP F
=10.B	.2484.	.4759.	141.0

2.4840000E-01	2.4402768E-01
2.4402768E-01	2.4417663E-01
2.4417663E-01	2.4417160E-01
2.4417160E-01	2.4417177E-01
2.4417177E-01	2.4417176E-01
2.4417176E-01	2.4417176E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2442	0.5284	98.8011	135.2291

POWER POINT CURRENT-VOLTAGE

=2.55. 1.57

=2.60. 1.54

=2.65. 1.50

=2.70. 1.46

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.5500	1.5700	4.0035	2.9605
2.6000	1.5400	4.0040 *	2.9609 *
2.6500	1.5000	3.9750	2.9395
2.7000	1.4600	3.9420	2.9151

MOD ISC	MOD VOC
=3.16.	2.07

FILL FACTORS

0.6120

0.6121 *

0.6077

0.6026

MOD TEMP DEG CENT

60.5556

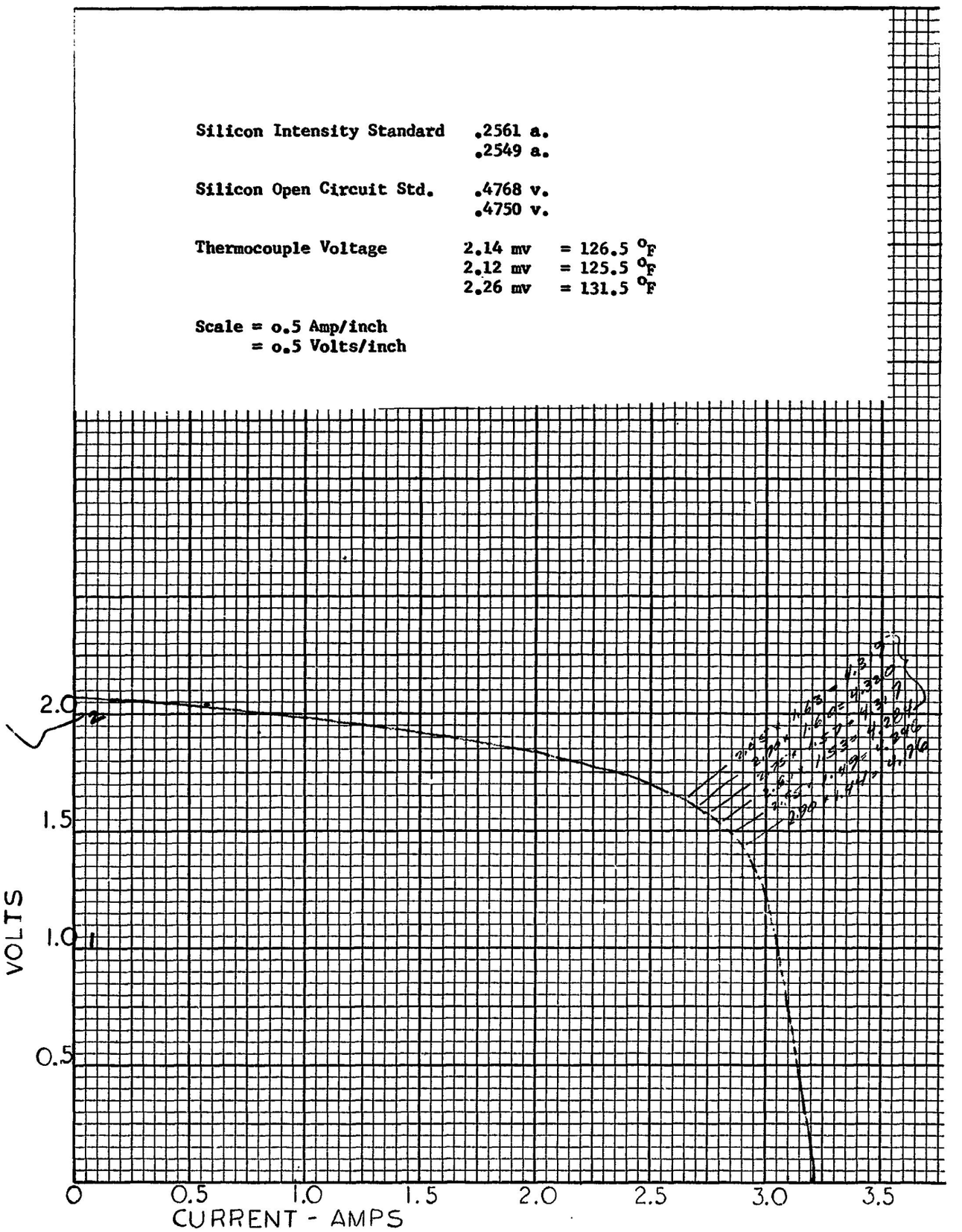


Figure B-5. Solar Test V-I Curve - Module 11 Test A - 7/2/68

```
 S/N   ISC STD  VOC STD  TEMP F
=11,   .2555,   .4759,   126.5

   2.5550000E-01   2.5088032E-01
   2.5088032E-01   2.5104204E-01
   2.5104204E-01   2.5103642E-01
   2.5103642E-01   2.5103662E-01
   2.5103662E-01   2.5103661E-01
   2.5103661E-01   2.5103661E-01

  I STD       V STD      MW/CM2     INPUT WATTS

     0.2510      0.5298    101.5789    139.0310


 POWER POINT CURRENT-VOLTAGE
=2.65,  1.63

=2.70,  1.60

=2.75,  1.57

=2.80,  1.53


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.6500      1.6300      4.3195      3.1069

     2.7000      1.6000      4.3200 *    3.1072  *

     2.7500      1.5700      4.3175      3.1054

     2.8000      1.5300      4.2840      3.0813


 MOD ISC  MOD VOC
=3.22,  2.07


 FILL FACTORS

   0.6480

   0.6481 *

   0.6477

   0.6427


 MOD TEMP DEG CENT
  52.5000
```

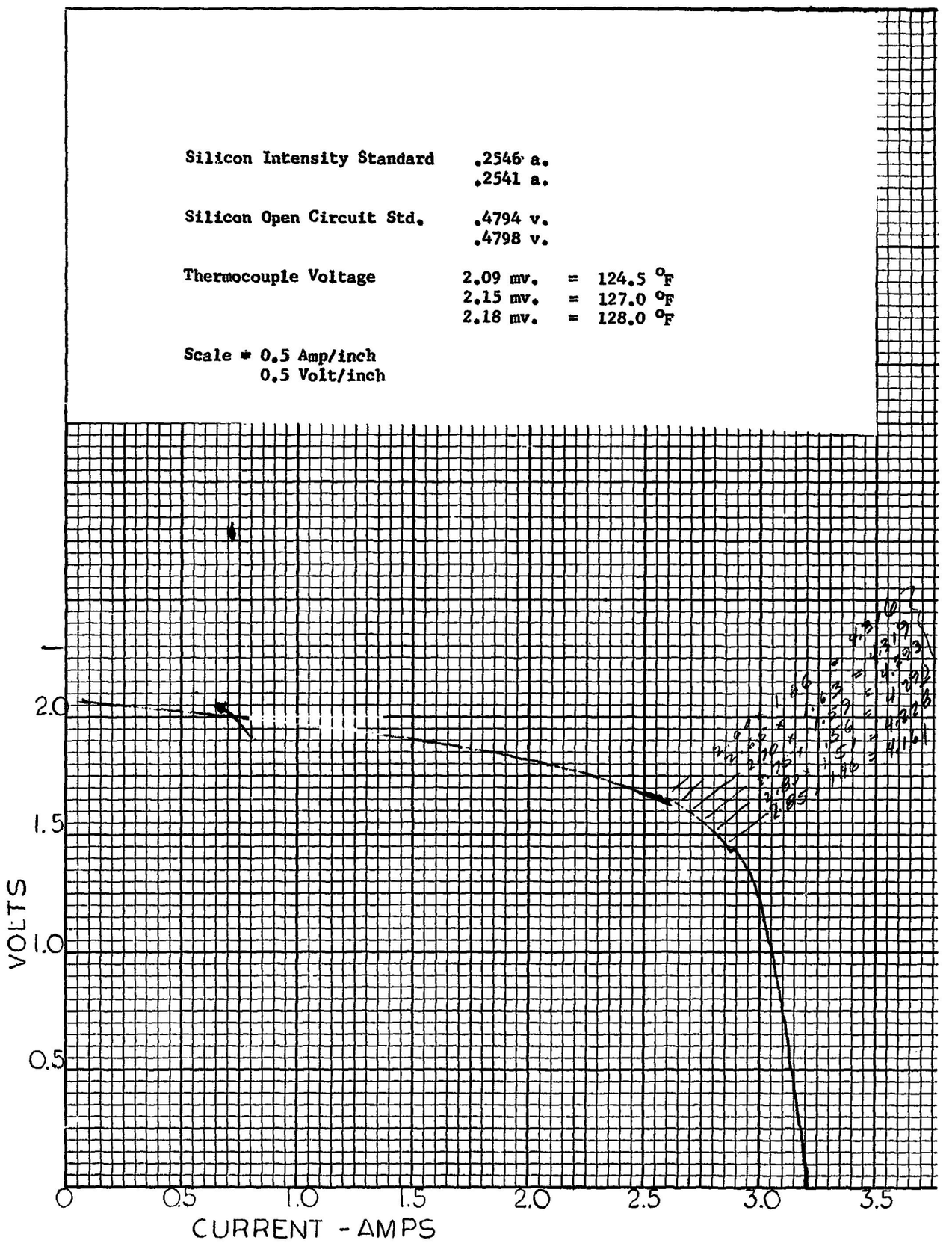


Figure B-6. Solar Test V-I Curve - Module 11 Test B - 7/2/68

```
  S/N    ISC STD   VOC STD   TEMP F
=11B   .2543,    .4796,    127.0

   2.5430000E-01    2.5003305E-01
   2.5003305E-01    2.5017663E-01
   2.5017663E-01    2.5017184E-01
   2.5017184E-01    2.5017200E-01
   2.5017200E-01    2.5017199E-01
   2.5017199E-01    2.5017199E-01

  I STD        V STD      MW/CM2     INPUT WATTS

     0.2502       0.5296     101.2290     138.5521


 POWER POINT CURRENT-VOLTAGE
=2.60,  1.66

=2.65,  1.63

=2.70,  1.59

=2.75,  1.56


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.6000       1.6600       4.3160       3.1151

     2.6500       1.6300       4.3195 *     3.1176 *

     2.7000       1.5900       4.2930       3.0985

     2.7500       1.5600       4.2900       3.0963


 MOD ISC  MOD VOC
=3.21,  2.07


 FILL FACTORS

   0.6495

   0.6501 *

   0.6461

   0.6456


 MOD TEMP DEG CENT
  52.7778
```

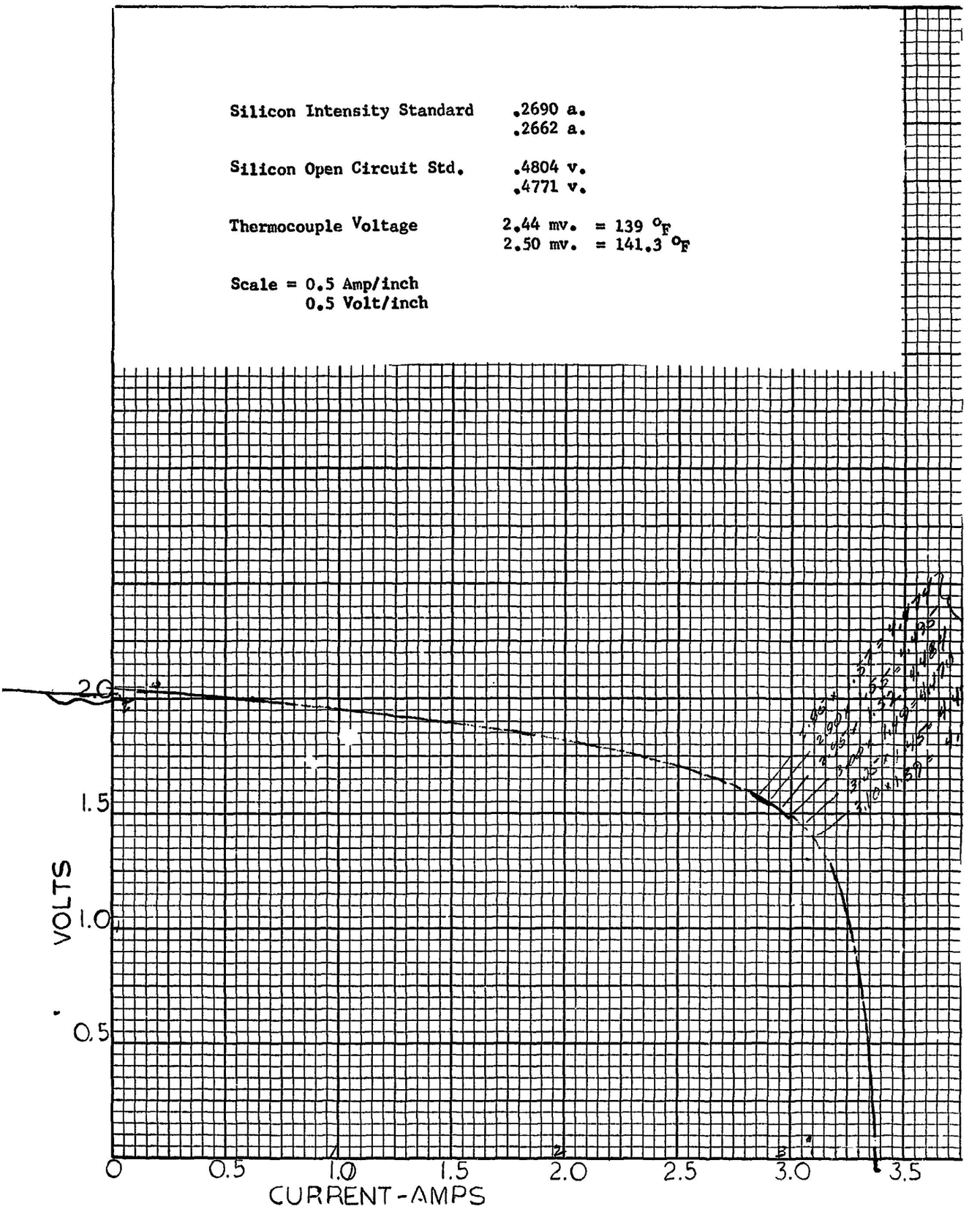


Figure B-7. Solar Test V-I Curve - Module 12 Test A - 7/2/68

S/N	ISC STD	VOC STD	TEMP F
=12	.2676,	.4787,	139.6

2.6760000E-01	2.6279030E-01
2.6279030E-01	2.6296202E-01
2.6296202E-01	2.6295594E-01
2.6295594E-01	2.6295616E-01
2.6295616E-01	2.6295615E-01
2.6295615E-01	2.6295615E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2630	0.5322	106.4020	145.6324

POWER POINT CURRENT-VOLTAGE

=2.85, 1.57

=2.90, 1.55

=2.95, 1.52

=3.00, 1.49

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.8500	1.5700	4.4745	3.0725
2.9000	1.5500	4.4950 *	3.0865
2.9500	1.5200	4.4840	3.0790
3.0000	1.4900	4.4700	3.0694

MOD ISC MOD VOC

=3.375, 2.04

FILL FACTORS

0.6499

0.6529

0.6513

0.6492

MOD TEMP DEG CENT

59.7778

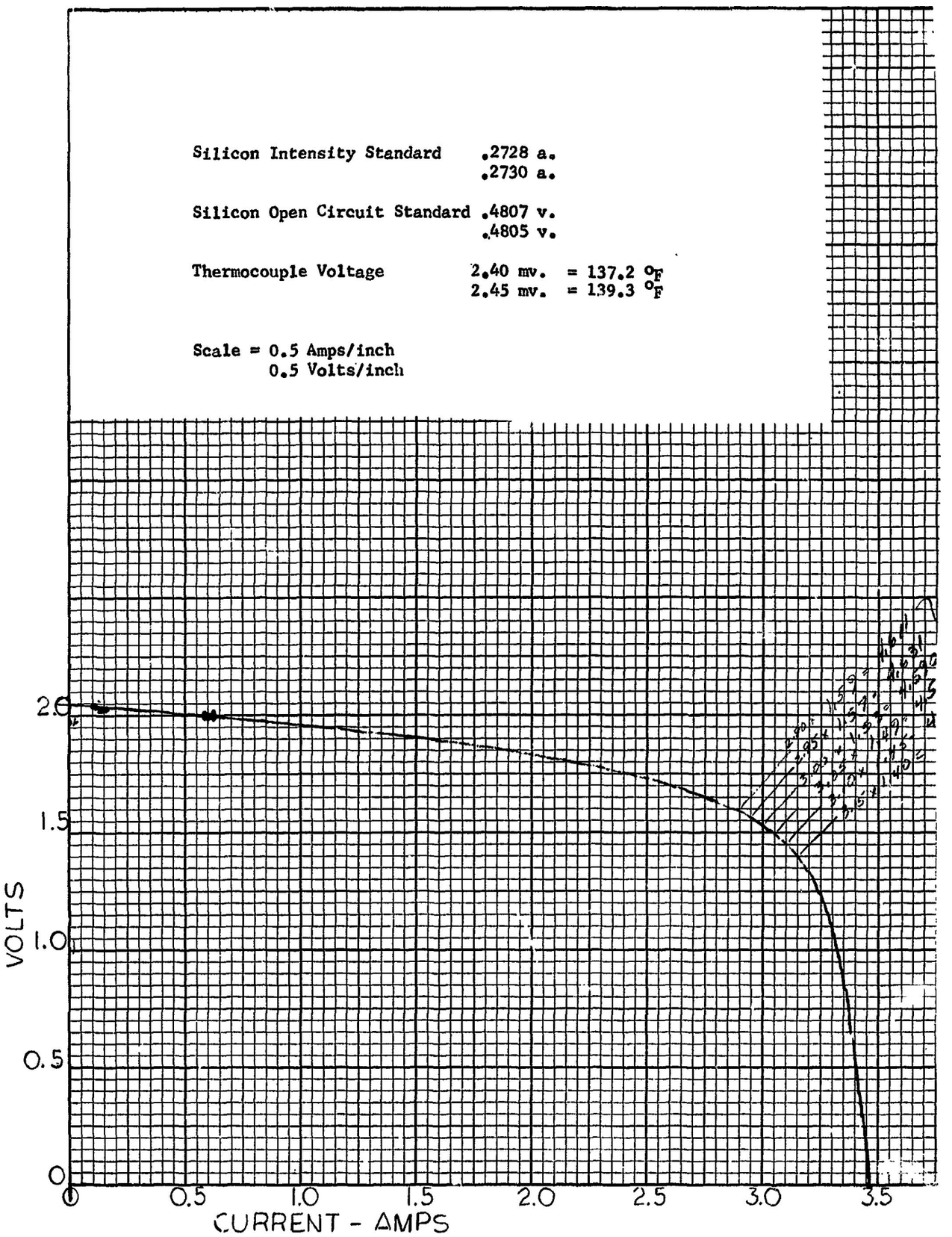


Figure B-8. Solar Test V-I Curve - Module 12 Test B - 7/2/68

S/N	ISC STD	VOC STD	TEMP F
=12	.2729,	.4806,	138.2

2.7290000E-01	2.6806854E-01
2.6806854E-01	2.6824146E-01
2.6824146E-01	2.6823532E-01
2.6823532E-01	2.6823554E-01
2.6823554E-01	2.6823553E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2682	0.5333	108.5382	148.5562

POWER POINT CURRENT-VOLTAGE

=2.90, 1.59

=2.95, 1.57

=3.00, 1.53

=3.05, 1.49

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.9000	1.5900	4.6110	3.1039
2.9500	1.5700	4.6315 *	3.1177 *
3.0000	1.5300	4.5900	3.0897
3.0500	1.4900	4.5445	3.0591

MOD ISC MOD VOC

=3.46, 2.04

FILL FACTORS

0.6533

0.6562

0.6503

0.6438

MOD TEMP DEG CENT

59.0000

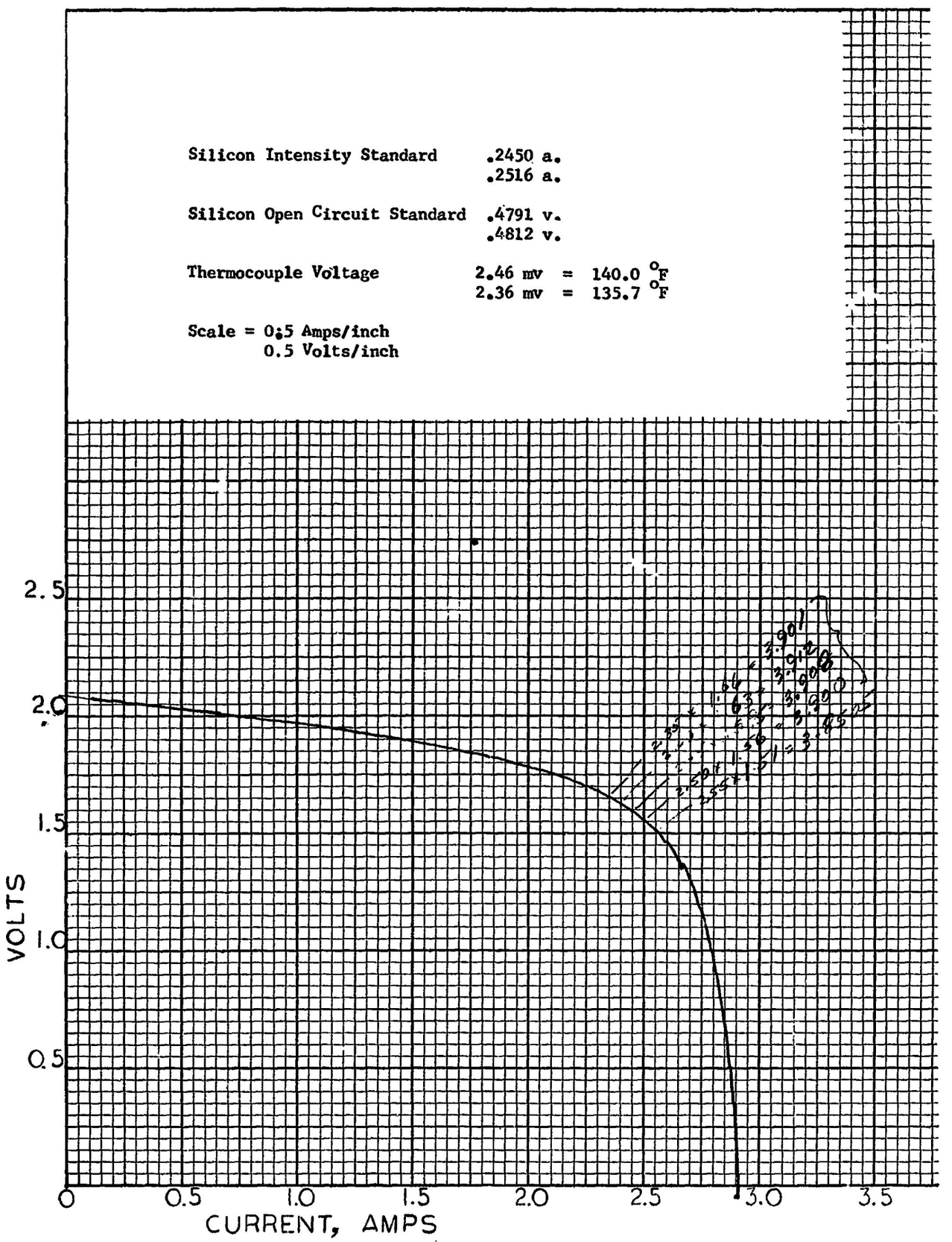


Figure B-9. Solar Test V-I Curve - Module 13 Test A - 7/2/68

```
  S/N    ISC STD   VOC STD   TEMP F
=13A      .2483,    .4801,    137.8

   2.4830000E-01    2.4427521E-01
   2.4427521E-01    2.4440678E-01
   2.4440678E-01    2.4440251E-01
   2.4440251E-01    2.4440265E-01
   2.4440265E-01    2.4440265E-01


  I STD        V STD       MW/CM2     INPUT WATTS

     0.2444       0.5284      98.8945     135.3569


 POWER POINT CURRENT-VOLTAGE
=2.35,    1.66
=2.40,    1.63
=2.45,    1.595
=2.50,    1.56


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.3500       1.6600       3.9010       2.8820

     2.4000       1.6300       3.9120       2.8901

     2.4500       1.5950       3.9077       2.8870

     2.5000       1.5600       3.9000       2.8813


 MOD ISC  MOD VOC
=2.91,  2.08


 FILL FACTORS

   0.6445

   0.6463

   0.6456

   0.6443


 MOD TEMP DEG CENT
  58.7778
```

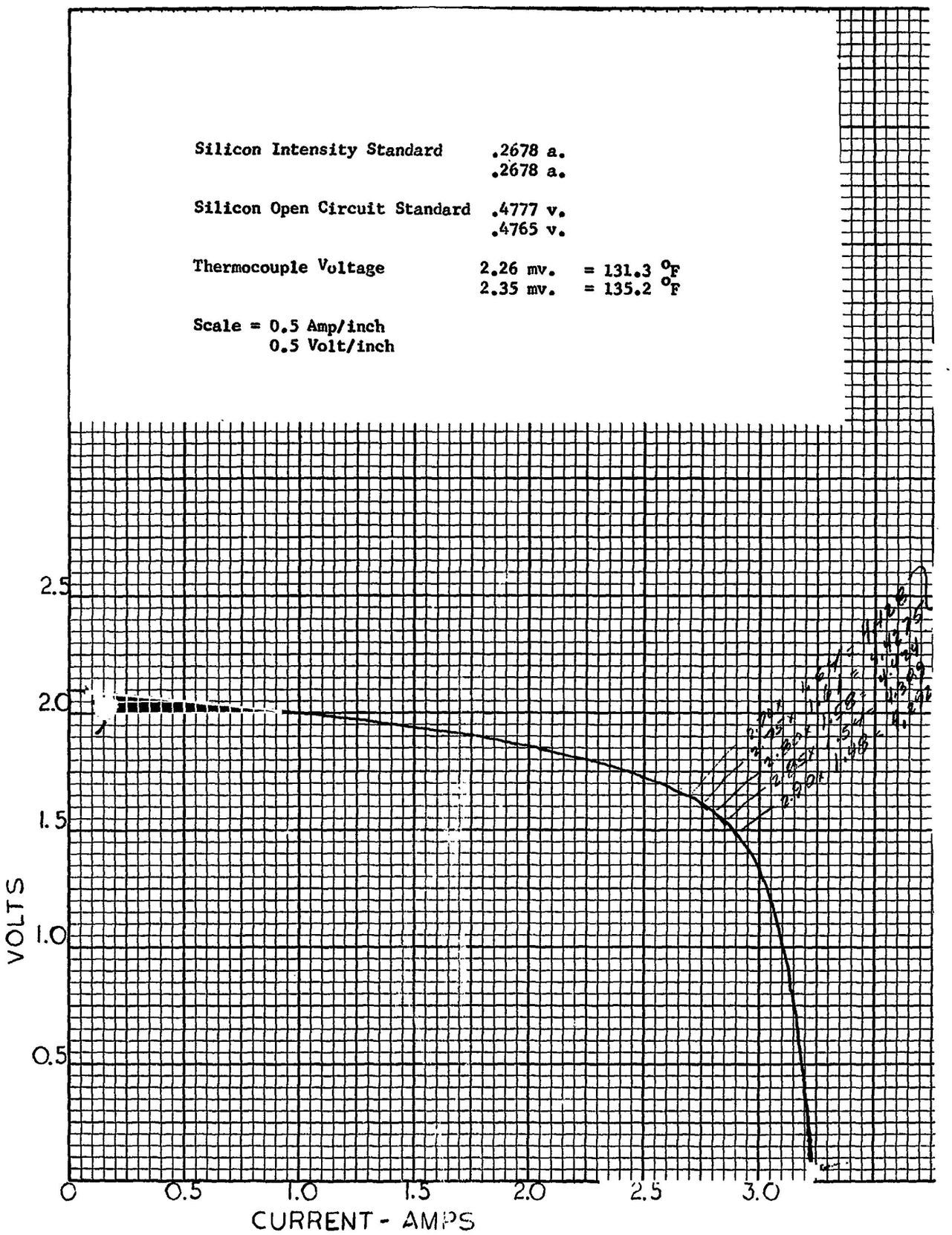


Figure B-10. Solar Test V-I Curve - Module 13 Test B - 7/2/68

S/N ISC STD VOC STD TEMP F
=13B .2678, .4771, 133.2

2.6780000E-01	2.6284171E-01
2.6284171E-01	2.6302144E-01
2.6302144E-01	2.6301499E-01
2.6301499E-01	2.6301522E-01
2.6301522E-01	2.6301521E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2630	0.5322	106.4259	145.6651

POWER POINT CURRENT-VOLTAGE
=2.70, 1.64

=2.75, 1.61

=2.80, 1.58

=2.85, 1.54

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.7000	1.6400	4.4280 *	3.0399
2.7500	1.6100	4.4275	3.0395
2.8000	1.5800	4.4240	3.0371
2.8500	1.5400	4.3890	3.0131

MOD ISC MOD VOC
=3.23, 2.10

FILL FACTORS

0.6528

0.6527

0.6522

0.6471

MOD TEMP DEG CENT
56.2222

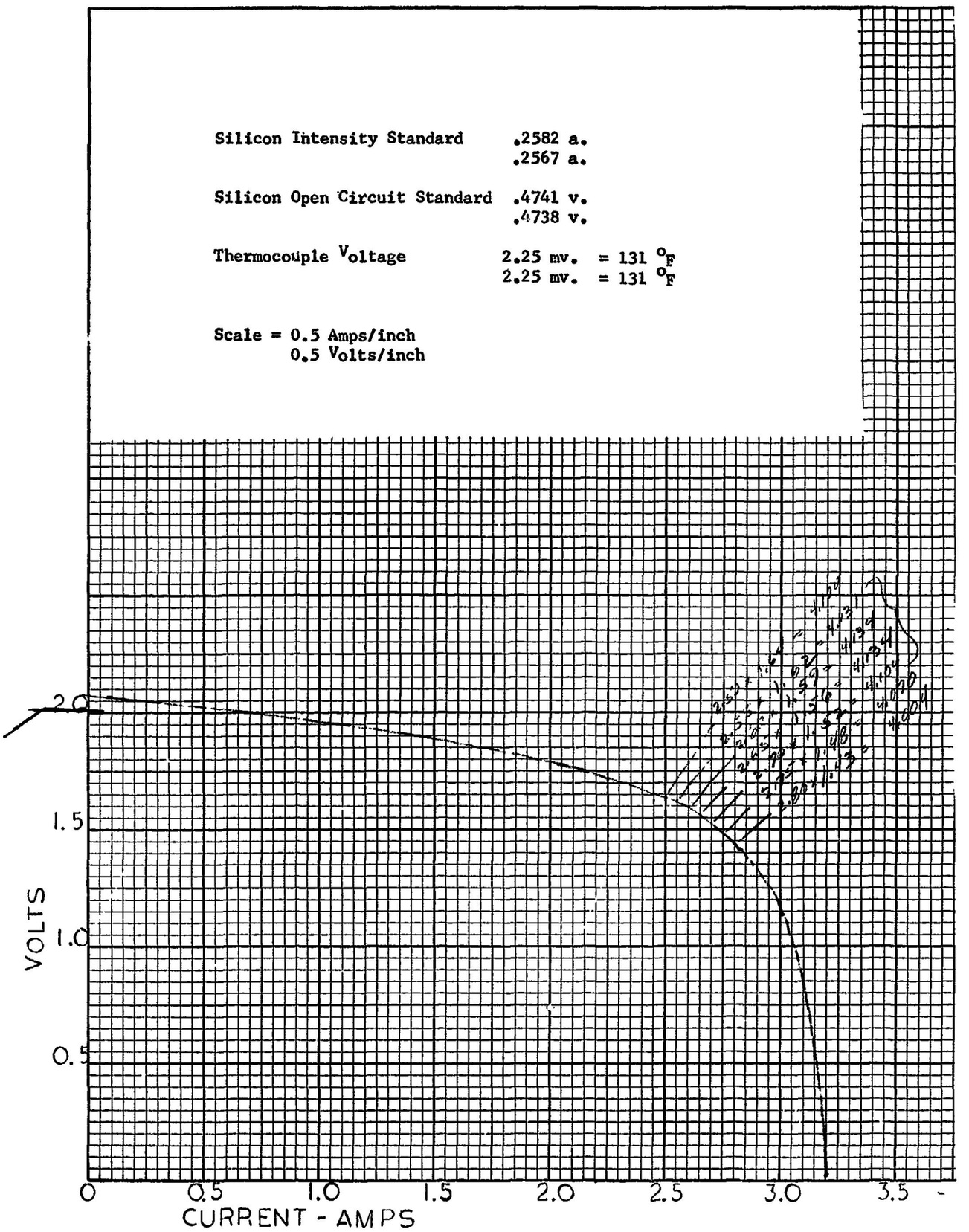


Figure B-11. Solar Test V-I Curve - Module 14 Test A - 7/2/68

```
  S/N    ISC STD   VOC STD   TEMP F
=14A   .2574,   .4739,   131.0


   2.5740000E-01    2.5254310E-01
   2.5254310E-01    2.5271751E-01
   2.5271751E-01    2.5271130E-01
   2.5271130E-01    2.5271152E-01
   2.5271152E-01    2.5271151E-01


  I STD        V STD       MW/CM2     INPUT WATTS

     0.2527       0.5301     102.2566     139.9586


 POWER POINT CURRENT-VOLTAGE
=2.55,   1.62

=2.60,   1.59

=2.65,   1.56

=2.70,   1.52



 P.P.CURRENT   P.P. VOLTS   POWER-WATTS   EFF-PERCENT

     2.5500       1.6200       4.1310       2.9516

     2.6000       1.5900       4.1340       2.9537

     2.6500       1.5600       4.1340       2.9537   *

     2.7000       1.5200       4.1040       2.9323


 MOD ISC   MOD VOC
=3.20,   2.07



 FILL FACTORS

   0.6236

   0.6241

   0.6241

   0.6196


 MOD TEMP DEG CENT
  55.0000
```

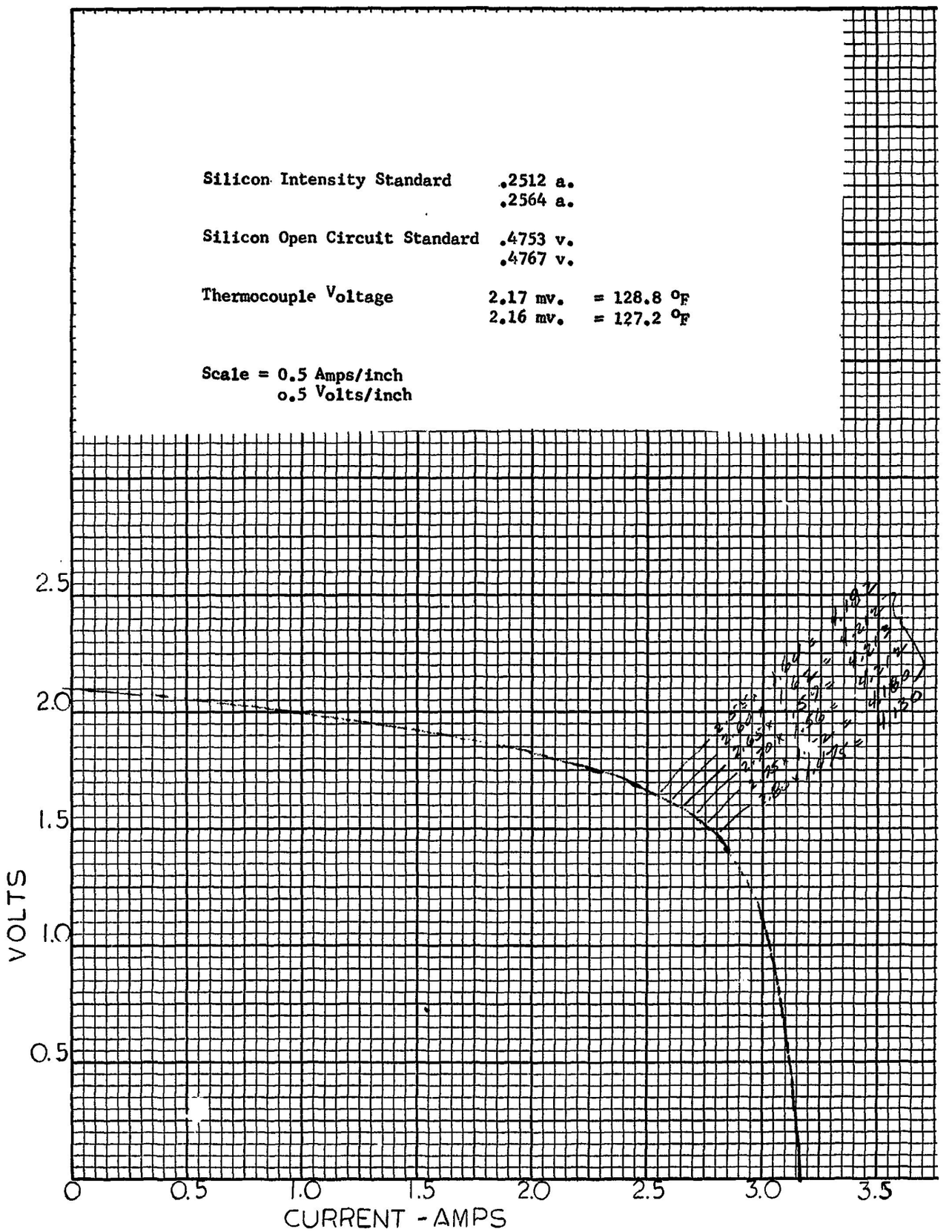


Figure B-12. Solar Test V-I Curve - Module 14 Test B - 7/2/68

```
  S/N    ISC STD   VOC STD   TEMP F
=140   .2538,    .4760,    128.0

   2.5380000E-01   2.4924854E-01
   2.4924854E-01   2.4940670E-01
   2.4940670E-01   2.4940125E-01
   2.4940125E-01   2.4940144E-01
   2.4940144E-01   2.4940143E-01

  I STD        V STD       MW/CM2     INPUT WATTS

     0.2494       0.5295     100.9172     138.1254


 POWER POINT CURRENT-VOLTAGE
=2.60,  1.62

=2.65,  1.59

=2.70,  1.56

=2.75,  1.52



 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.6000       1.6200       4.2120       3.0494

     2.6500       1.5900       4.2135       3.0505

     2.7000       1.5600       4.2120       3.0494

     2.7500       1.5200       4.1800       3.0262


 MOD ISC  MOD VOC
=3.16,  2.10



 FILL FACTORS

   0.6347

   0.6349

   0.6347

   0.6299


 MOD TEMP DEG CENT
  53.3333
```

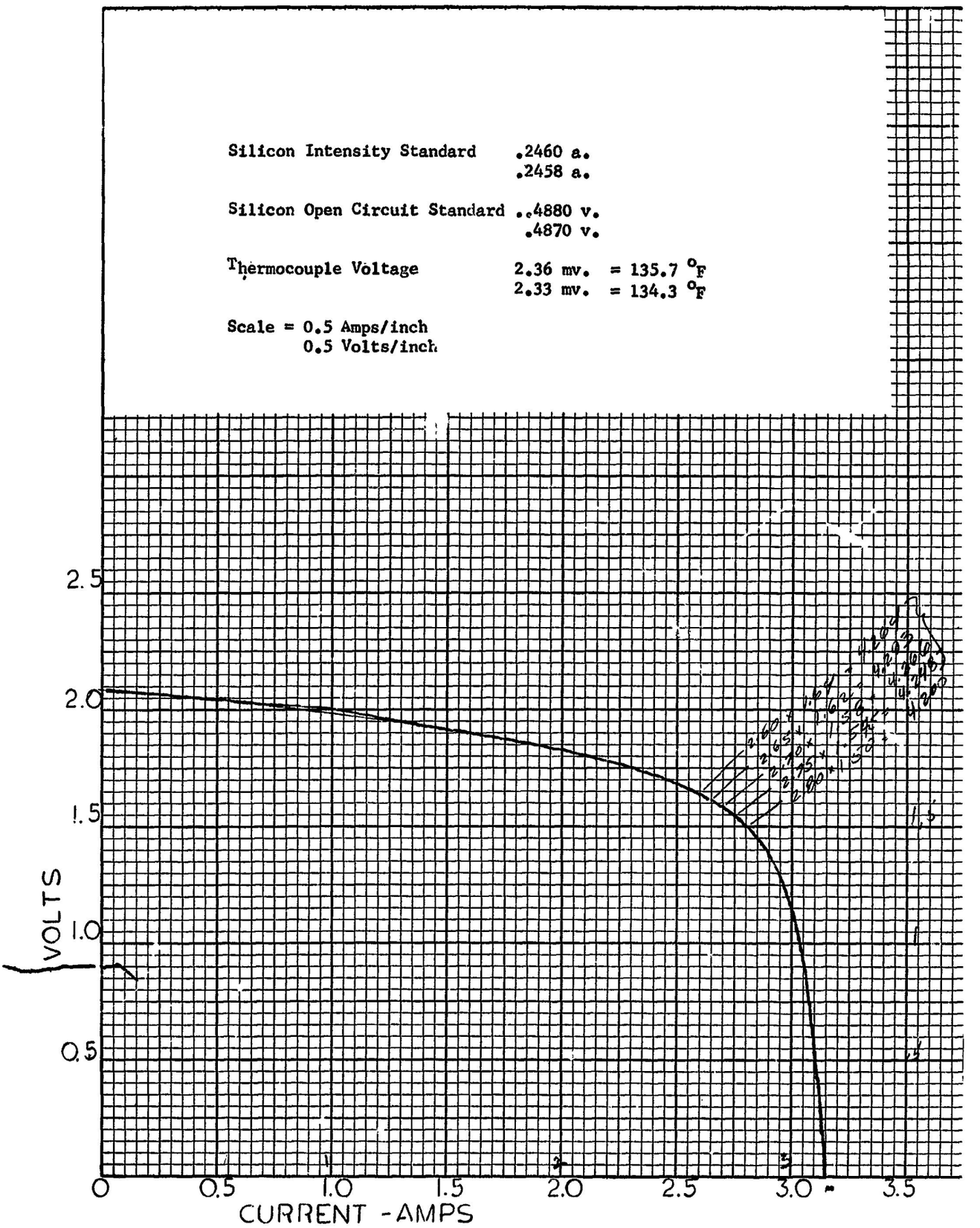


Figure B-13. Solar Test V-I Curve - Module 15 Test A - 7/2/68

S/N ISC STD VOC STD TEMP F
=15 .2459, .4875, 135.0

2.4590000E-01 2.4255433E-01
2.4255433E-01 2.4265460E-01
2.4265460E-01 2.4265162E-01
2.4265162E-01 2.4265171E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2427	0.5281	98.1860	134.3872

POWER POINT CURRENT-VOLTAGE
=2.60, 1.64

=2.65, 1.62

=2.70, 1.58

=2.75, 1.545

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT	
2.6000	1.6400	4.2640	3.1729	
2.6500	1.6200	4.2930	3.1945	*
2.7000	1.5800	4.2660	3.1744	
2.7500	1.5450	4.2487	3.1616	

MOD ISC MOD VOC
=3.15, 2.08

FILL FACTORS

0.6508

0.6552

0.6511

0.6485

MOD TEMP DEG CENT
57.2222

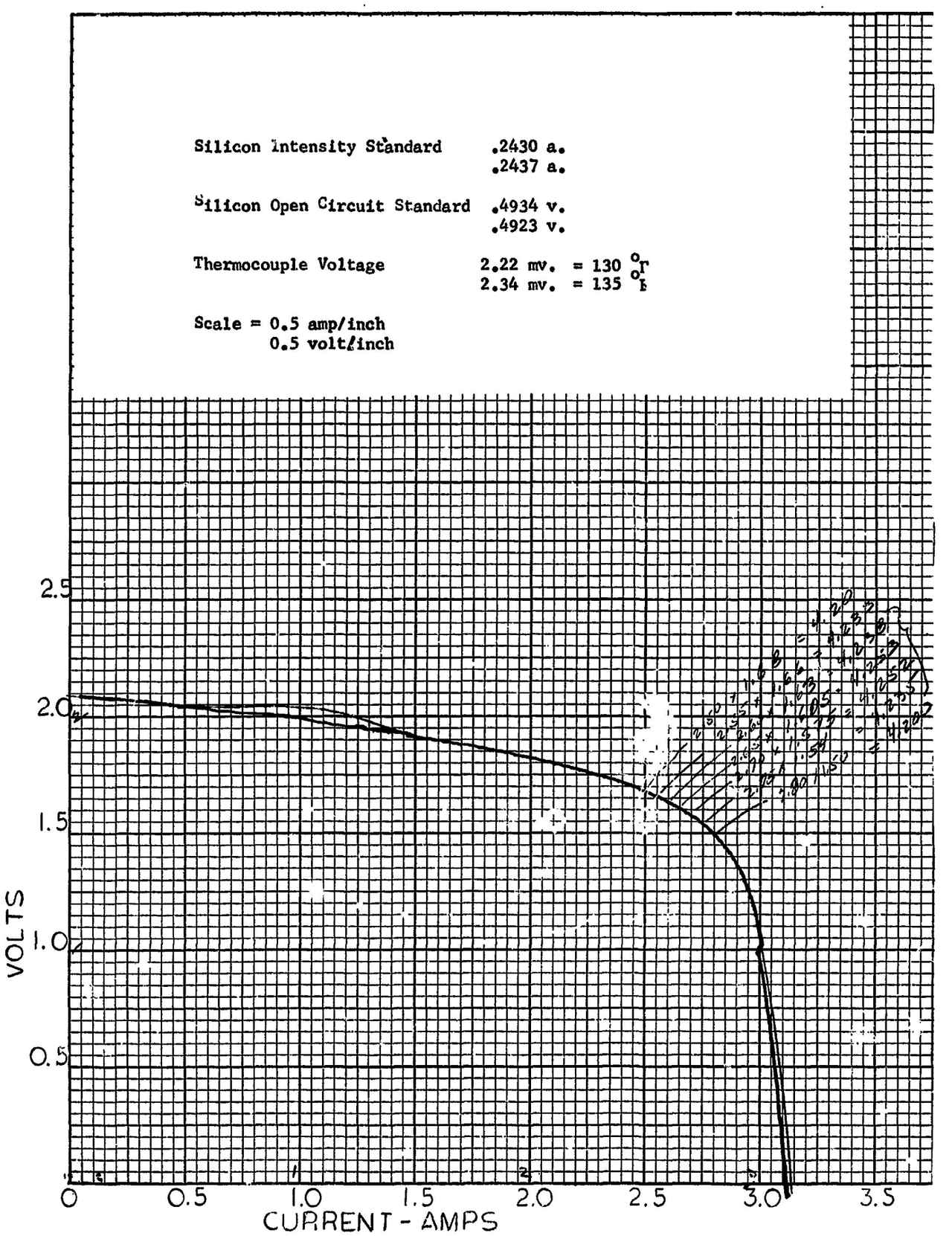


Figure B-14. Solar Test V-I Curve - Module 15 Test B - 7/2/68

S/N	ISC STD	VOC STD	TEMP F
=15B	.2437,	.4928,	132.5

2.4370000E-01 2.4084661E-01
2.4084661E-01 2.4092638E-01
2.4092637E-01 2.4092417E-01
2.4092417E-01 2.4092[illegible]3E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2409	0.5277	97.4870	133.4305

POWER POINT CURRENT-VOLTAGE
=2.60, 1.63

=2.65, 1.605

=2.70, 1.575

=2.75, 1.54

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT	
2.6000	1.6300	4.2380	3.1762	
2.6500	1.6050	4.2533	3.1876	*
2.7000	1.5750	4.2525	3.1871	
2.7500	1.5400	4.2350	3.1739	

MOD ISC MOD VOC
=3.14, 2.09

FILL FACTORS

0.6458

0.6481

0.6480

0.6453

MOD TEMP DEG CENT
55.8333

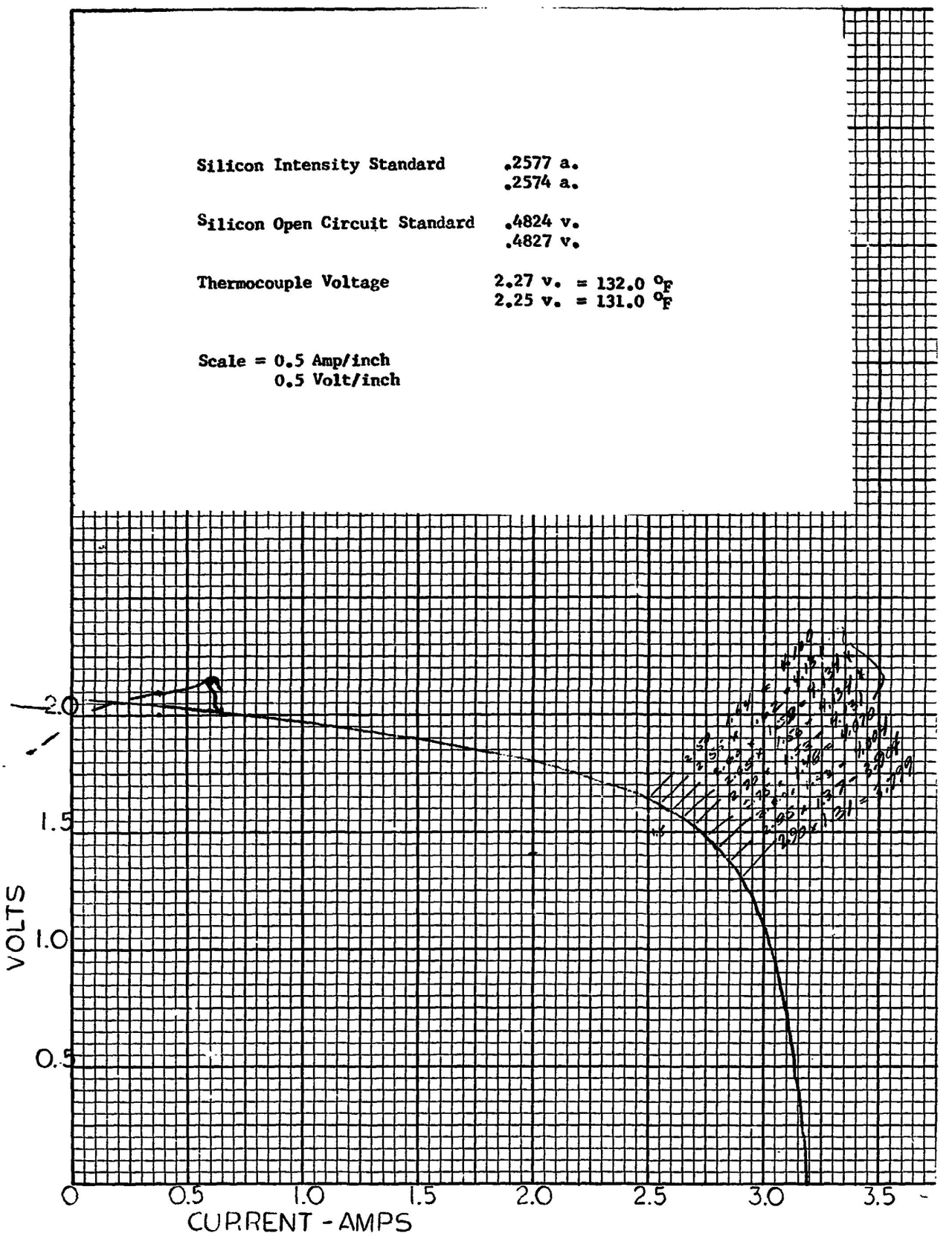


Figure B-18. Solar Test V-I Curve - Module 16 Test A - 7/2/68

```
  S/N    ISC STD   VOC STD   TEMP F
=16A  .2575,   .4825,   131.5


   2.5750000E-01    2.5337016E-01
   2.5337016E-01    2.5350699E-01
   2.5350699E-01    2.5350250E-01
   2.5350250E-01    2.5350264E-01
   2.5350264E-01    2.5350264E-01


  I STD        V STD      MW/CM2     INPUT WATTS

     0.2535       0.5303     102.5767     140.3968


 POWER POINT CURRENT-VOLTAGE
=2.55,  1.62

=2.60,  1.59

=2.65,  1.56

=2.70,  1.53


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.5500       1.6200       4.1310       2.9424

     2.6000       1.5900       4.1340       2.9445

     2.6500       1.5600       4.1340       2.9445

     2.7000       1.5300       4.1310       2.9424


 MOD ISC  MOD VOC
=3.19,  2.07


 FILL FACTORS

   0.6256

   0.6261

   0.6261

   0.6256


 MOD TEMP DEG CENT
  55.2778
```

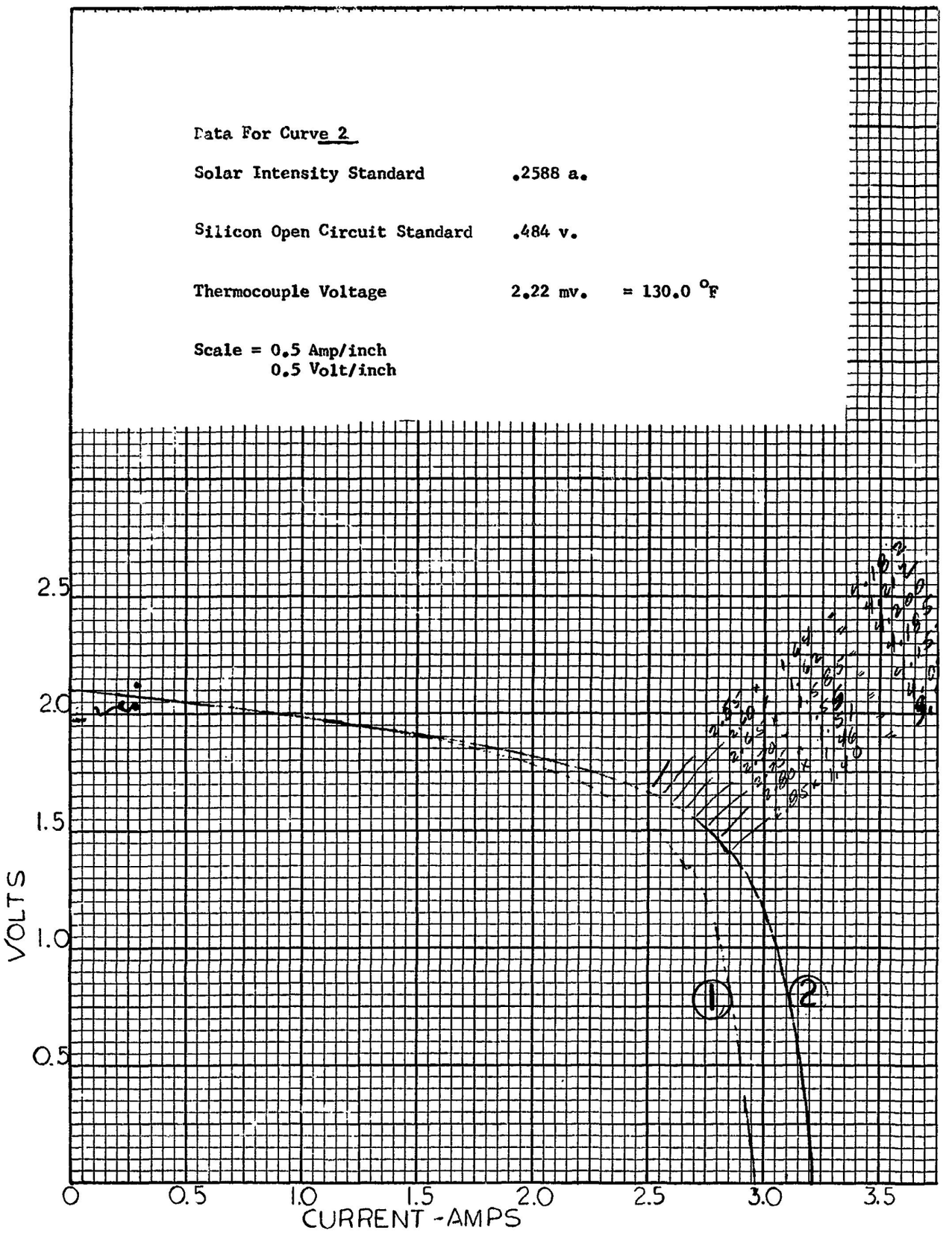
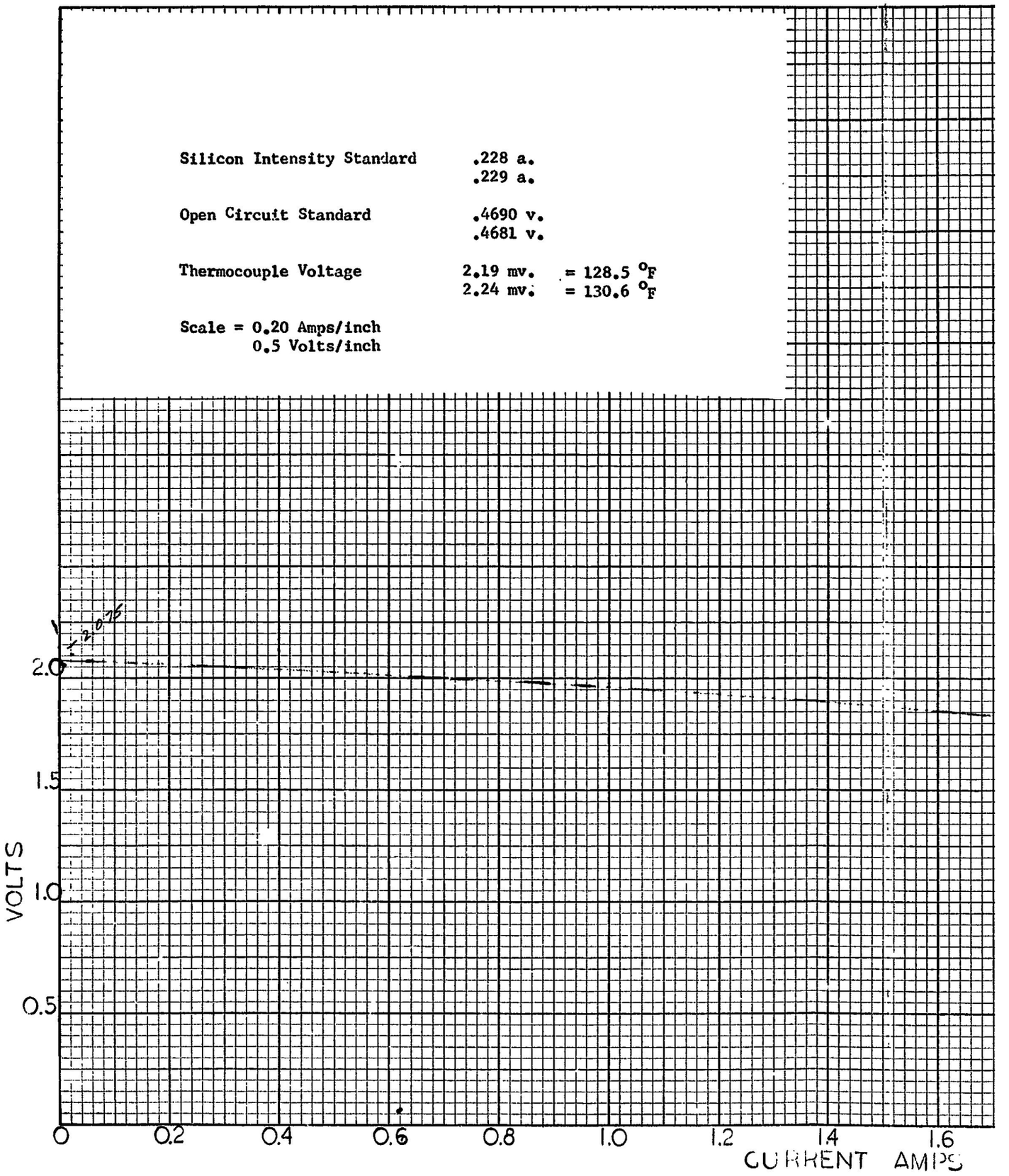


Figure B-16. Solar Test V-I Curve - Module 16 Test B - 7/2/68

```
 S/N   ISC STD  VOC STD  TEMP F
=16B  .2588,  .4840,  130.0

   2.5880000E-01   2.5475470E-01
   2.5475470E-01   2.5488746E-01
   2.5488746E-01   2.5488314E-01
   2.5488314E-01   2.5488328E-01
   2.5488328E-01   2.5488327E-01

  I STD       V STD      MW/CM2     INPUT WATTS

     0.2549      0.5306    103.1354    141.1614


 POWER POINT CURRENT-VOLTAGE
=2.55,  1.64

=2.60,  1.62

=2.65,  1.585

=2.70,  1.55


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.5500      1.6400      4.1820      2.9626

     2.6000      1.6200      4.2120      2.9838   *
    ------------------------------------------------
     2.6500      1.5850      4.2002      2.9755

     2.7000      1.5500      4.1850      2.9647


 MOD ISC  MOD VOC
=3.21,   2.10


 FILL FACTORS

   0.6204

   0.6248

   0.6231

   0.6208


 MOD TEMP DEG CENT
  54.4444
```



FOLDOUT FRAME 1

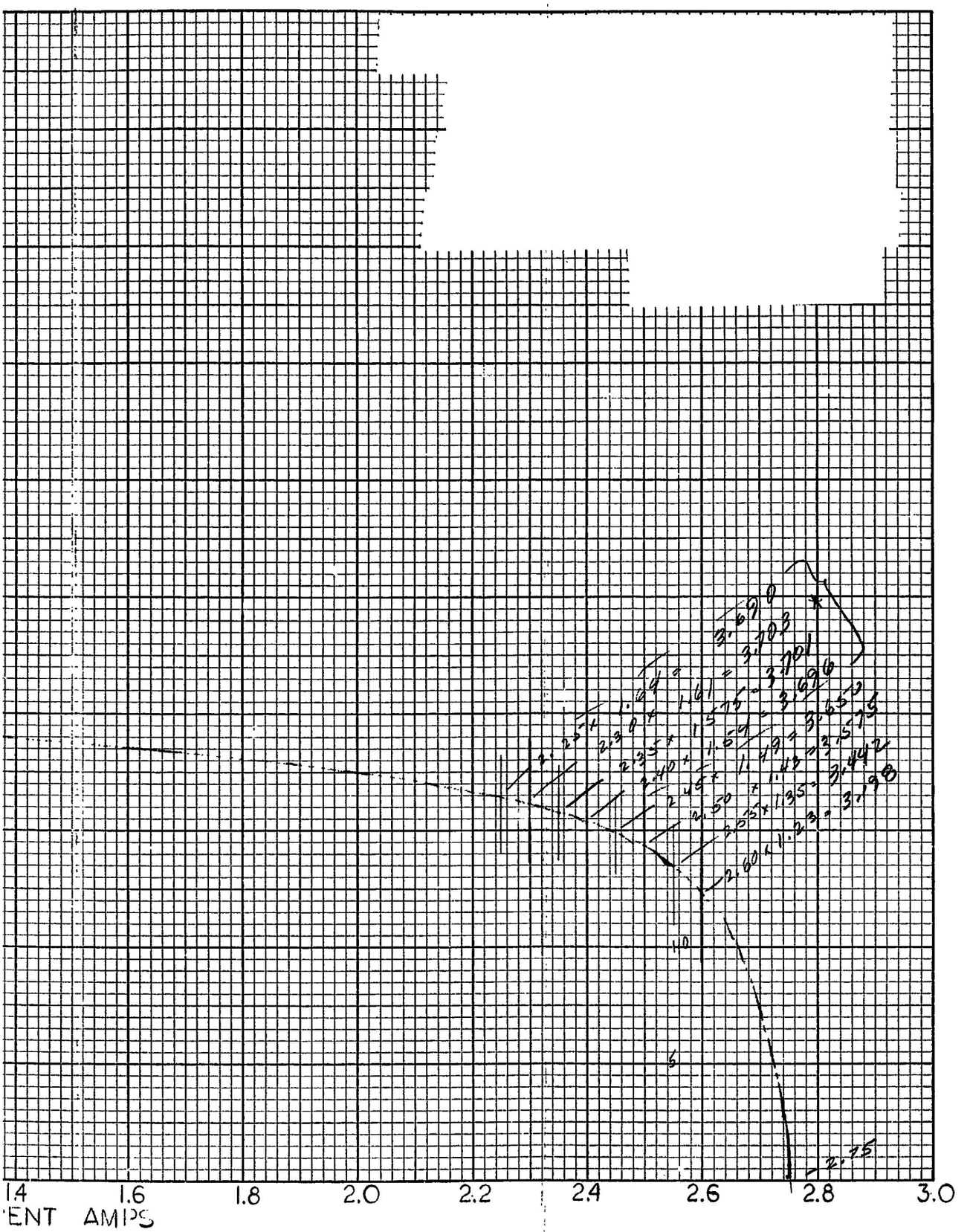


Figure B-17. Solar Test V-I Curve - Module 17 Test A - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=17A	.2285,	.4686,	129.5

2.2850000E-01	2.2423438E-01
2.2423438E-01	2.2437854E-01
2.2437854E-01	2.2437371E-01
2.2437371E-01	2.2437387E-01
2.2437387E-01	2.2437387E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2244	0.5243	90.7901	124.2644

POWER POINT CURRENT-VOLTAGE

=2.25, 1.64
=2.30, 1.61
=2.35, 1.575
=2.40, 1.54

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.2500	1.6400	3.6900	2.9695
2.3000	1.6100	3.7030	2.9799
2.3500	1.5750	3.7012	2.9785
2.4000	1.5400	3.6960	2.9743

MOD ISC MOD VOC
=2.75, 2.075

FILL FACTORS

0.6467

0.6489

0.6486

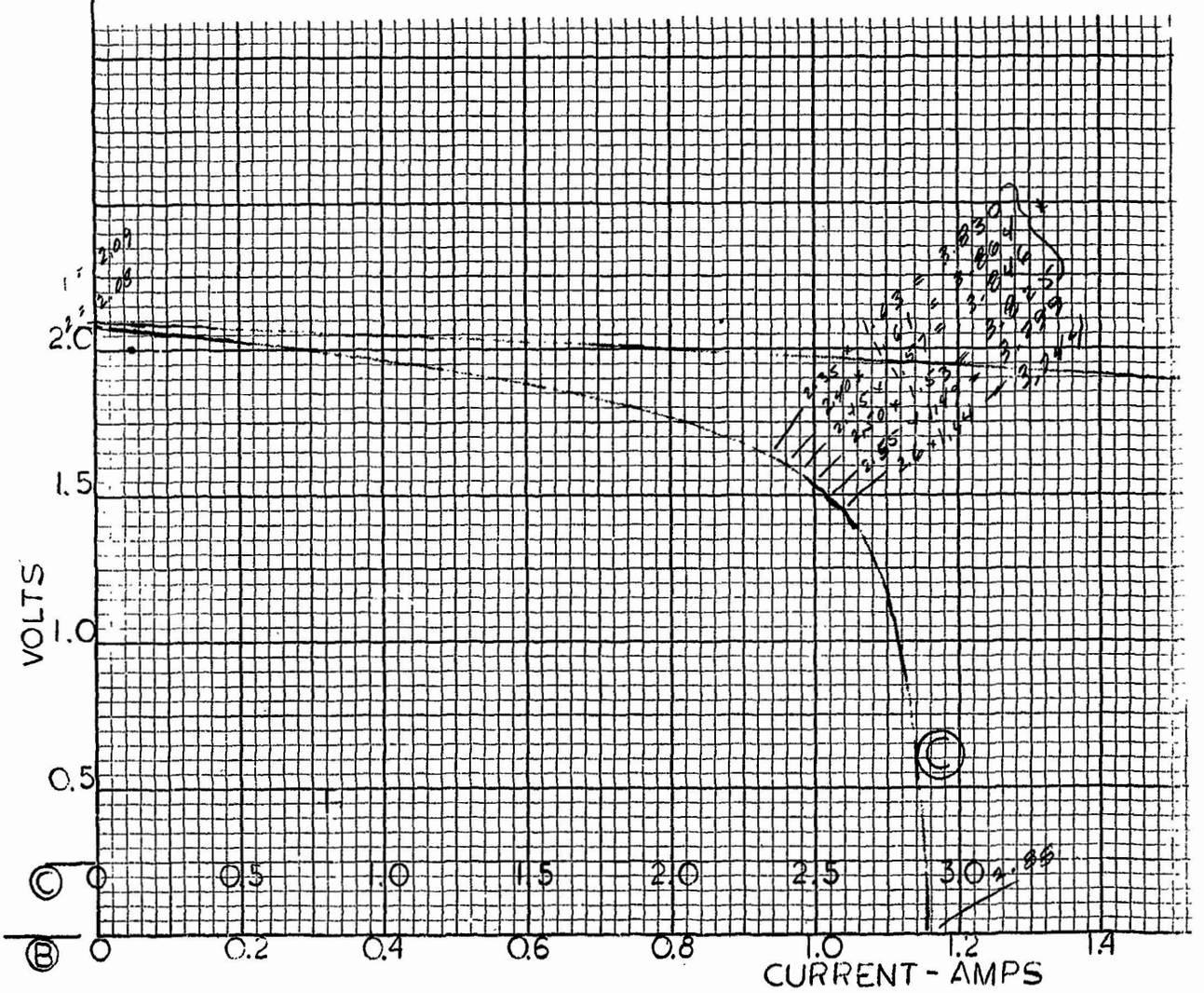
0.6477

MOD TEMP DEG CENT
54.1667

Test B

Silicon Intensity Standard	.238 a.	
	.238 a.	
Silicon Open Circuit Standard	.4704 v.	
	.4715 v.	
Thermocouple Voltage	2.22 mv.	= 129.7 °F
	2.25 mv.	= 121.0 °F
	2.23 mv.	= 130.2 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

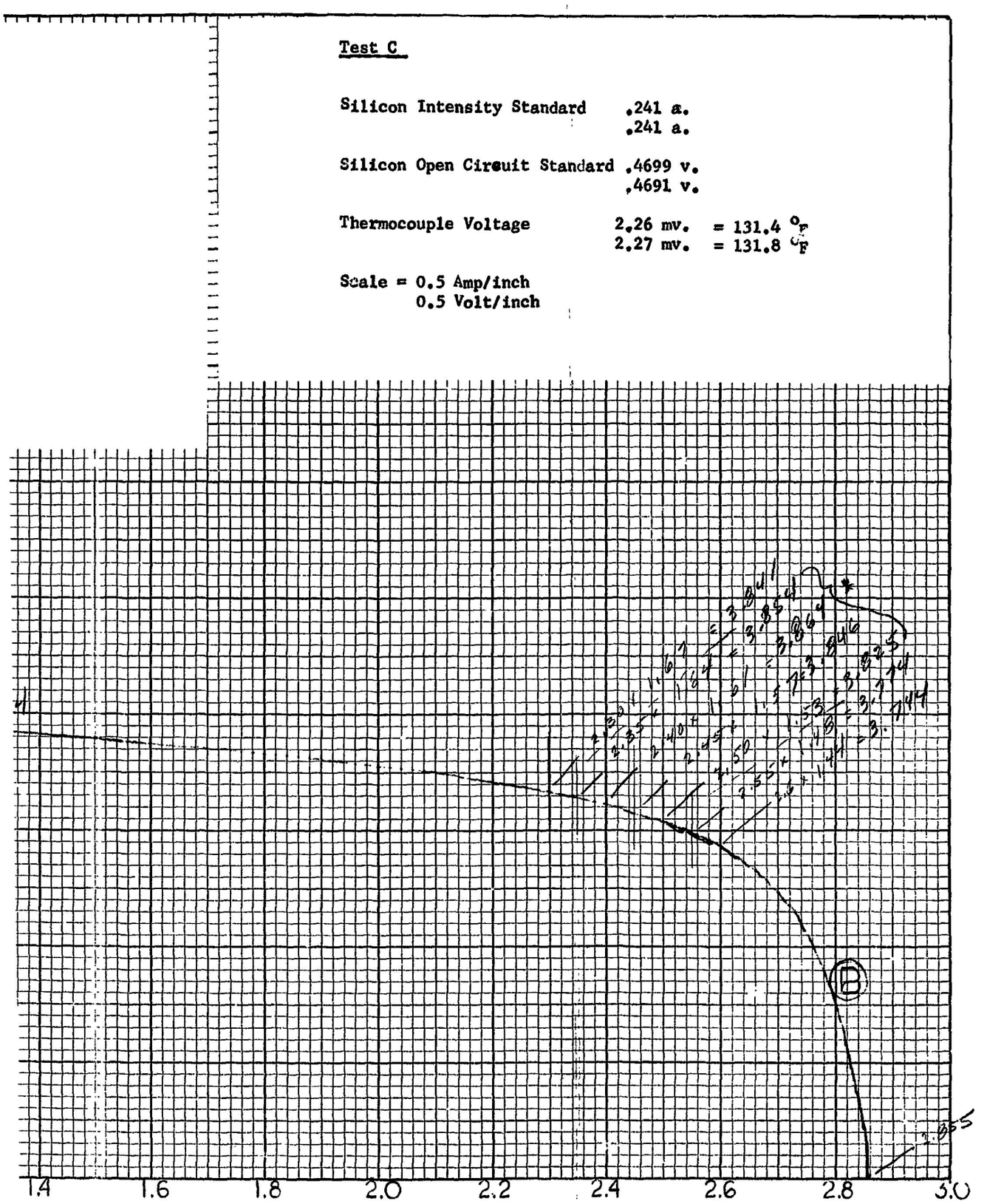


Figure B-18. Solar Test V-I Curve - Module 17 Tests B & C - 7/17/68

FOLDOUT FRAME 2

```
  S/N    ISC STD   VOC STD   TEMP F
=17,B   .238,    .4709,     130.2

   2.3800000E-01    2.3358510E-01
   2.3358510E-01    2.3373657E-01
   2.3373657E-01    2.3373142E-01
   2.3373142E-01    2.3373160E-01
   2.3373160E-01    2.3373159E-01


  I STD        V STD       MW/CM2     INPUT WATTS

     0.2337       0.5262      94.5766     129.4470


 POWER POINT CURRENT-VOLTAGE
=2.35,  1.64
=2.40,  1.61
=2.45,  1.57
=2.50,  1.53


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.3500       1.6400       3.8540       2.9773

     2.4000       1.6100       3.8640       2.9850

     2.4500       1.5700       3.8465       2.9715

     2.5000       1.5300       3.8250       2.9549


 MOD ISC  MOD VOC
=2.855,   2.09


 FILL FACTORS

   0.6459

   0.6476

   0.6446

   0.6410


 MOD TEMP DEG CENT
  54.5556
```

S/N	ISC STD	VOC STD	TEMP F
=17,	.241,	.4695,	131.6

2.4100000E-01	2.3636934E-01
2.3636934E-01	2.3653217E-01
2.3653217E-01	2.3652649E-01
2.3652649E-01	2.3652669E-01
2.3652669E-01	2.3652668E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2365	0.5268	95.7076	130.9950

POWER POINT CURRENT-VOLTAGE

=2.35, 1.63
=2.40, 1.61
=2.45, 1.57
=2.50, 1.53

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.3500	1.6300	3.8305	2.9242
2.4000	1.6100	3.8640	2.9497
2.4500	1.5700	3.8465	2.9364
2.5000	1.5300	3.8250	2.9200

MOD ISC MOD VOC

=2.88, 2.08

FILL FACTORS

0.6394

0.6450

0.6421

0.6385

MOD TEMP DEG CENT

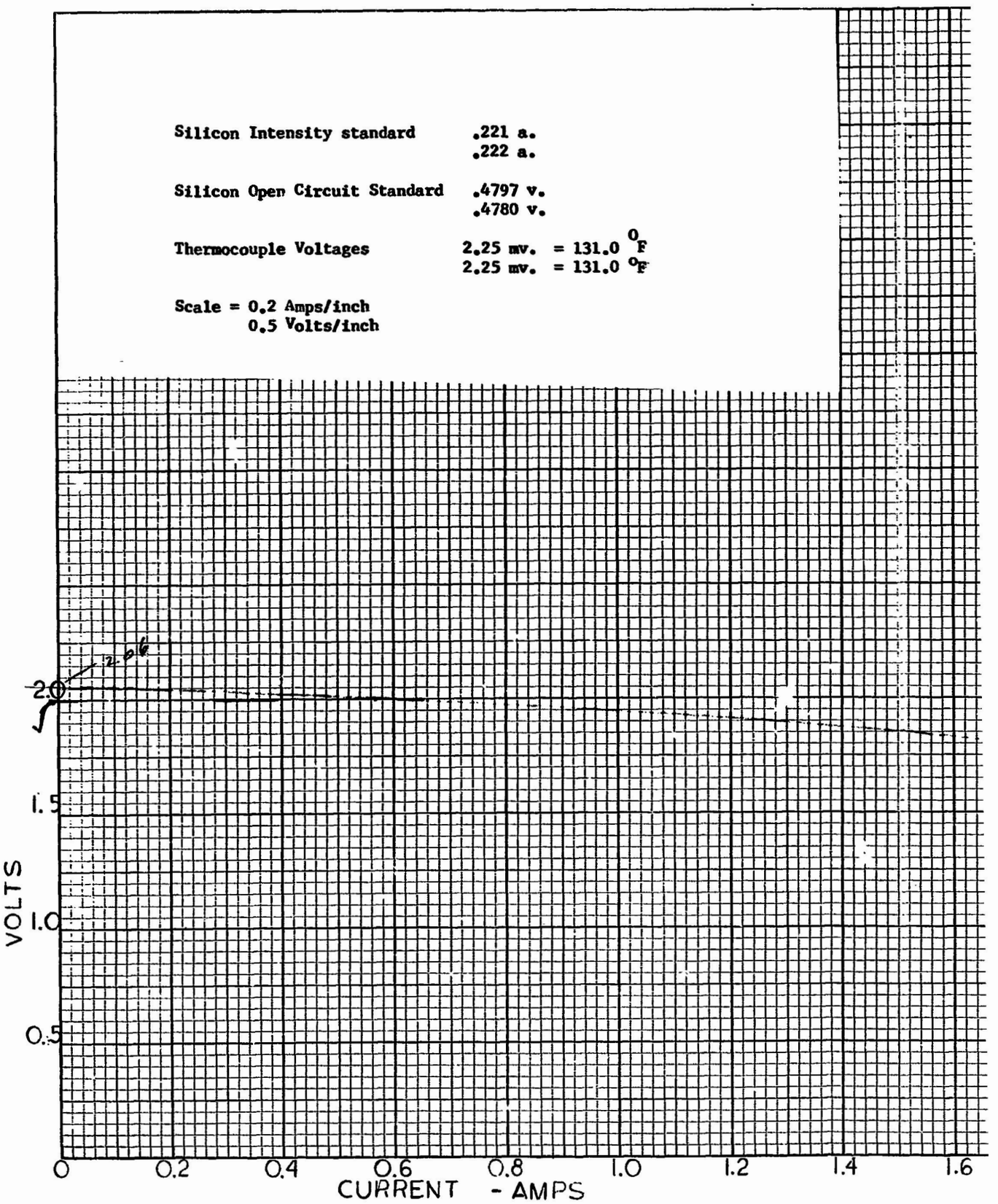
55.3333

Silicon Intensity standard .221 a.
.222 a.

Silicon Open Circuit Standard .4797 v.
.4780 v.

Thermocouple Voltages 2.25 mv. = 131.0 °F
2.25 mv. = 131.0 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

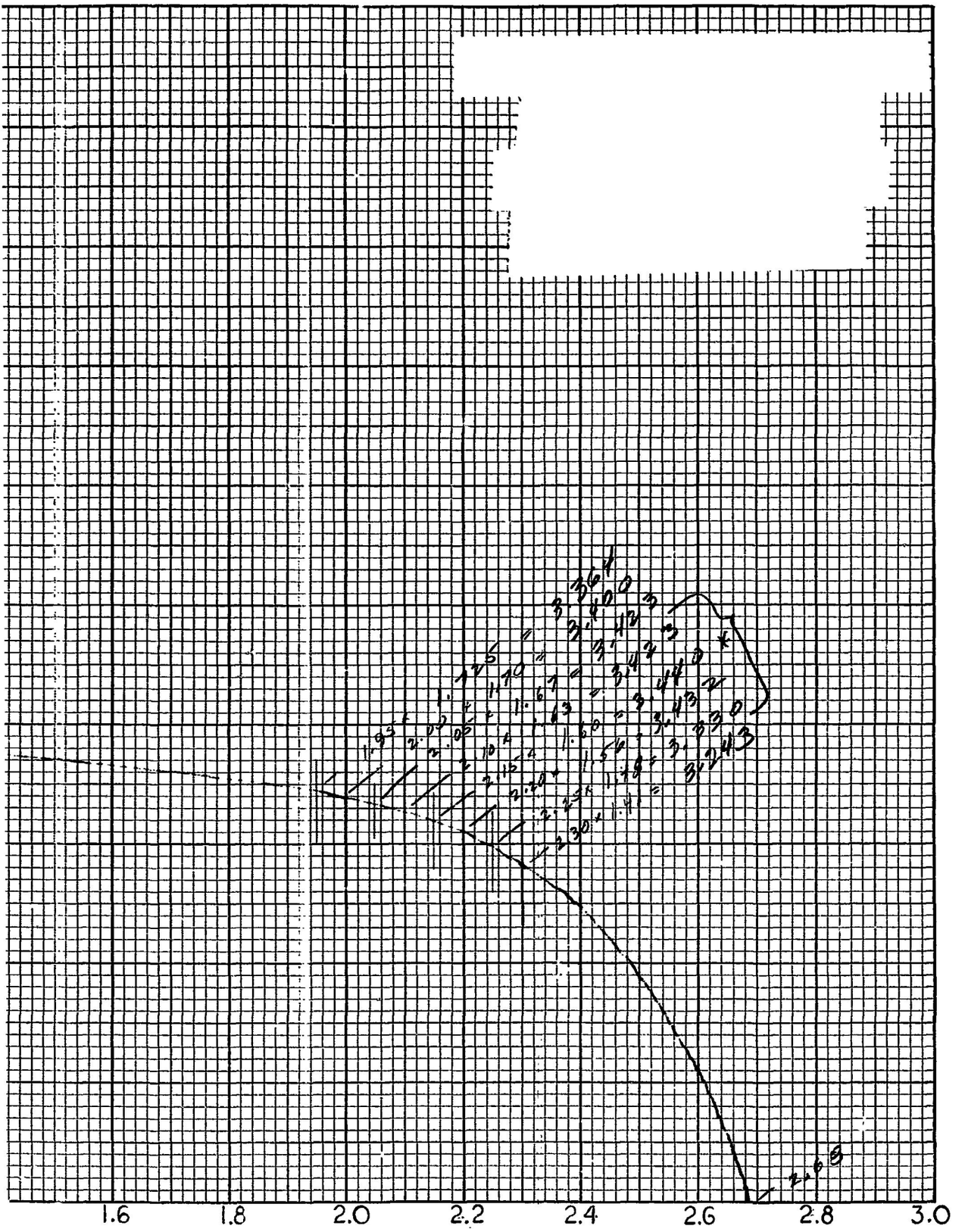


Figure B-19. Solar Test V-I Curve - Module 18 Test A - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=18A	.2215,	.4788,	131.0

2.2150000E-01	2.1821512E-01
2.1821512E-01	2.1831220E-01
2.1831220E-01	2.1830935E-01
2.1830935E-01	2.1830944E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2183	0.5231	88.3362	120.9058

POWER POINT CURRENT-VOLTAGE

=2.10, 1.63
=2.15, 1.60
=2.20, 1.56
=2.25, 1.48

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.1000	1.6300	3.4230	2.8311
2.1500	1.6000	3.4400	2.8452
2.2000	1.5600	3.4320	2.8386
2.2500	1.4800	3.3300	2.7542

MOD ISC MOD VOC
=2.68, 2.06

FILL FACTORS

0.6200

0.6231

0.6216

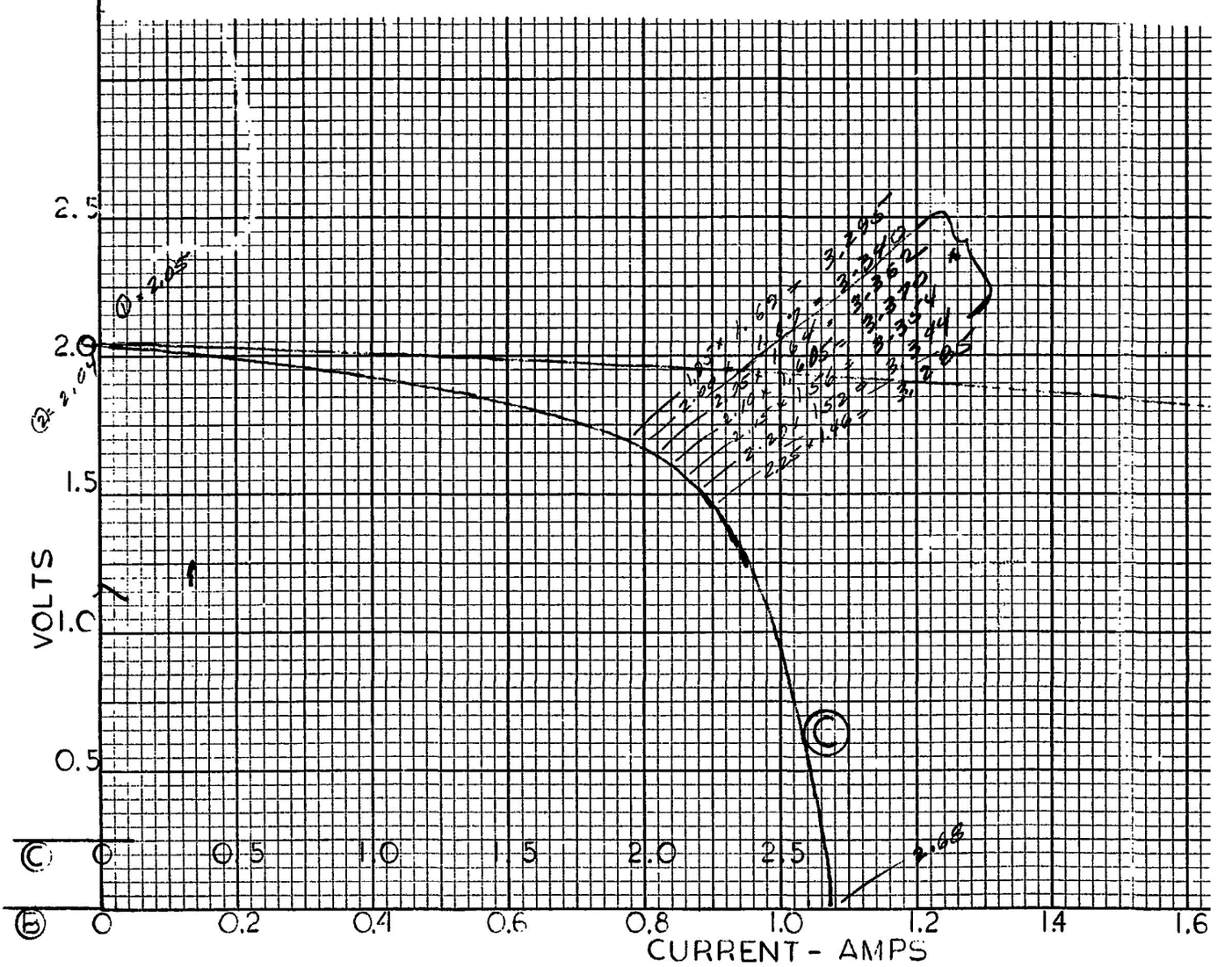
0.6032

MOD TEMP DEG CENT
55.0000

Test B

Silicon Intensity Standard	.223 a.	
	.224 a.	
Silicon Open Circuit Standard	.4789 v.	
	.4770 v.	
Thermocouple Voltage	2.33 mv.	= 134.3 °F
	2.29 mv.	= 132.7 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

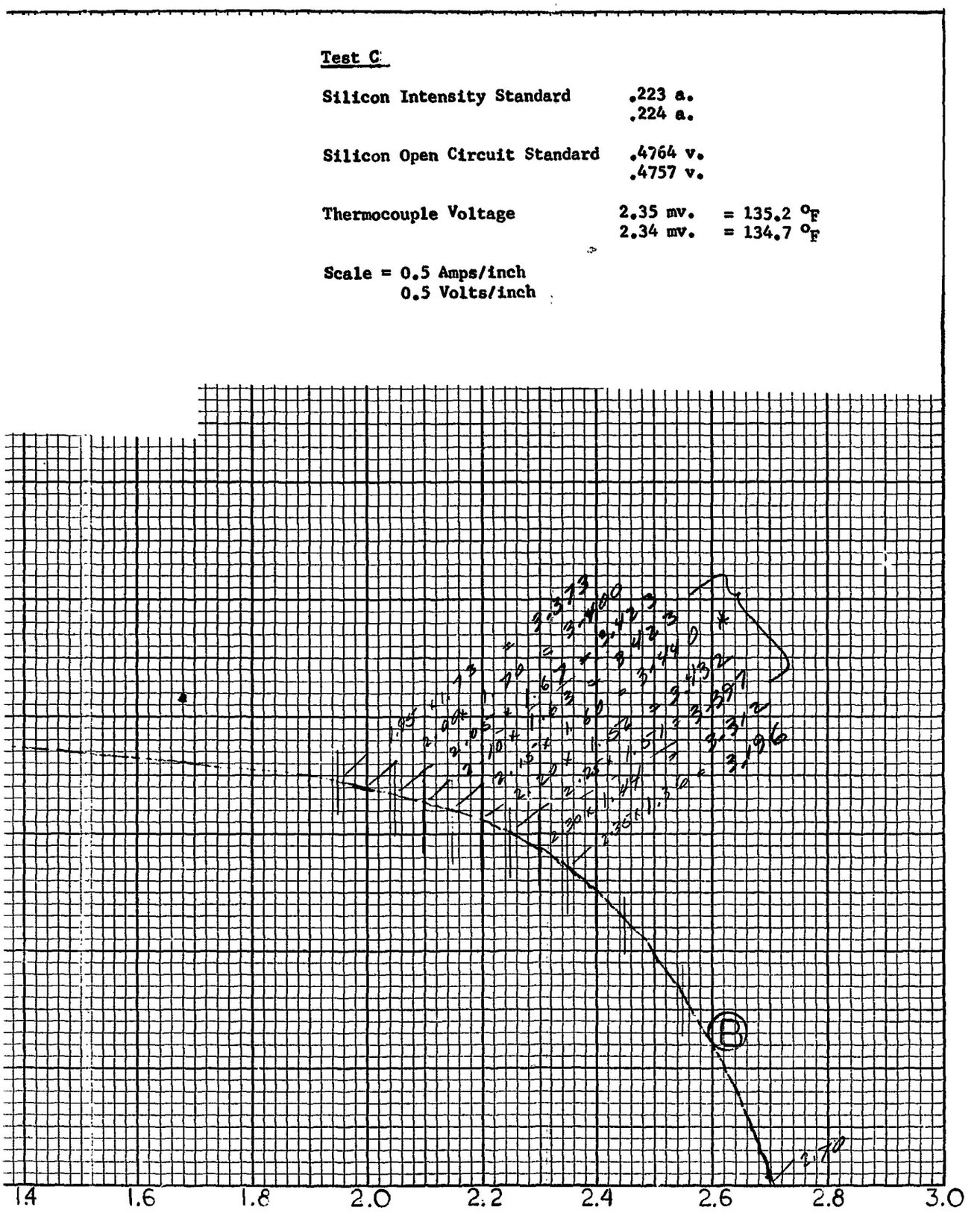


Figure B-20. Solar Test V-I Curve - Module 18 Tests B & C - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=18.B	.2235,	.4779,	133.7

2.2350000E-01	2.2008894E-01
2.2008894E-01	2.2019165E-01
2.2019165E-01	2.2018858E-01
2.2018858E-01	2.2018867E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2202	0.5235	89.0966	121.9466

POWER POINT CURRENT-VOLTAGE

=2.10, 1.63
=2.15, 1.60
=2.20, 1.56
=2.25, 1.51

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.1000	1.6300	3.4230	2.8070
2.1500	1.6000	3.4400	2.8209
2.2000	1.5600	3.4320	2.8143
2.2500	1.5100	3.3975	2.7861

MOD ISC	MOD VOC
=2.70,	2.05

FILL FACTORS

0.6184

0.6215

0.6201

0.6138

MOD TEMP DEG CENT
56.5000

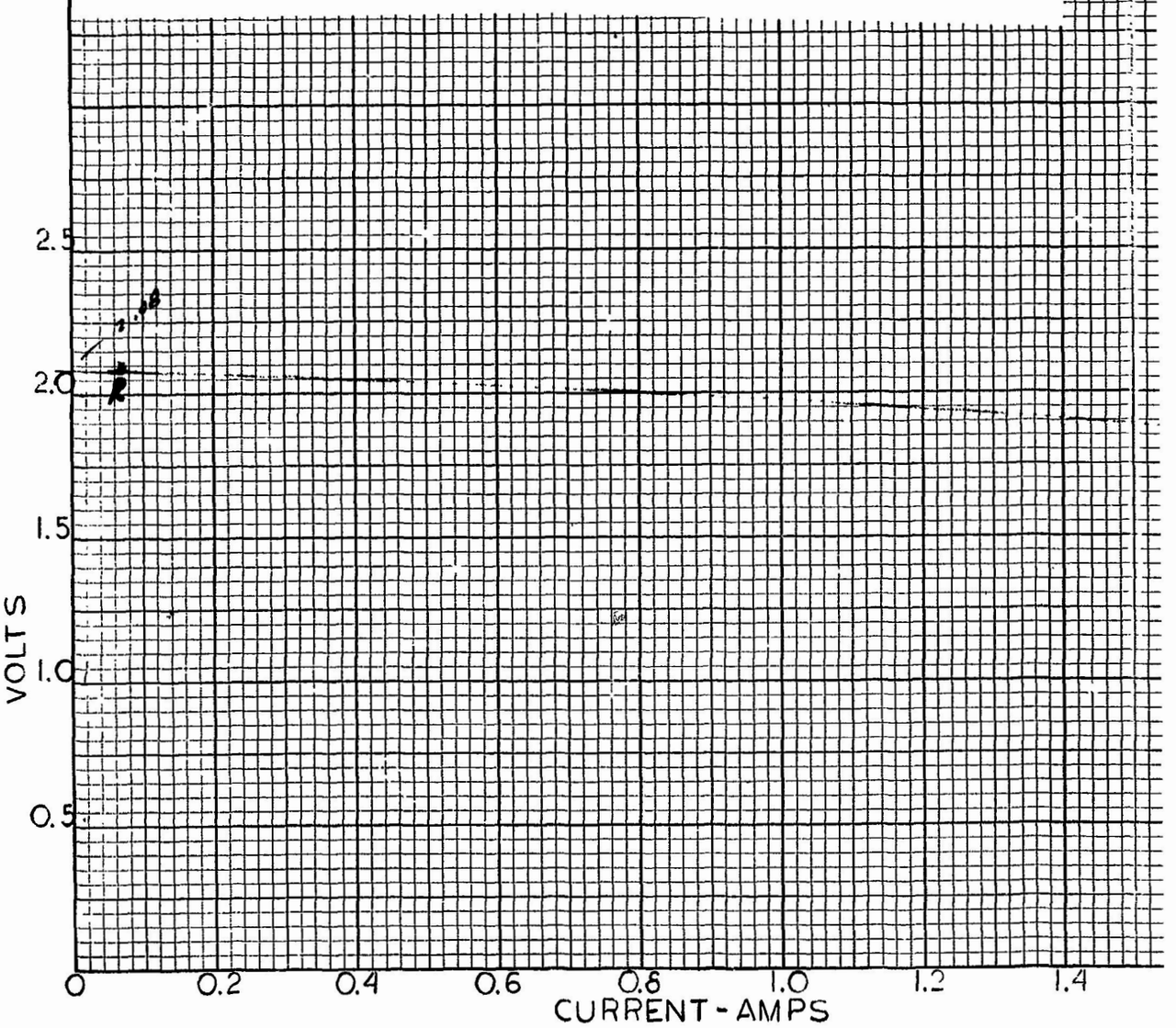
```
  S/N    ISC STD   VOC STD   TEMP F
=18,C   .2235,     .4760,     135.0

   2.2350000E-01    2.1994882E-01
   2.1994882E-01    2.2005795E-01
   2.2005795E-01    2.2005462E-01
   2.2005462E-01    2.2005472E-01
   2.2005472E-01    2.2005472E-01


  I STD        V STD      MW/CM2     INPUT WATTS

     0.2201       0.5235      89.0424     121.8724


 POWER POINT CURRENT-VOLTAGE
=2.05,  1.64
=2.10,  1.605
=2.15,  1.56
=2.20,  1.52


 P.P.CURRENT  P.P. VOLTS  POWER-WATTS  EFF-PERCENT

     2.0500       1.6400       3.3620       2.7586

     2.1000       1.6050       3.3705       2.7656

     2.1500       1.5600       3.3540       2.7521

     2.2000       1.5200       3.3440       2.7439


 MOD ISC  MOD VOC
=2.68,   2.04


 FILL FACTORS

   0.6149

   0.6165

   0.6135

   0.6116


 MOD TEMP DEG CENT
  57.2222
```

Silicon Intensity Standard .232 a.
.233 a.

Silicon Open Circuit Standard .4734 v.
.4721 v.

Thermocouple Voltage 2.15 mv. = 126.8 °F
2.17 mv. = 127.7 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

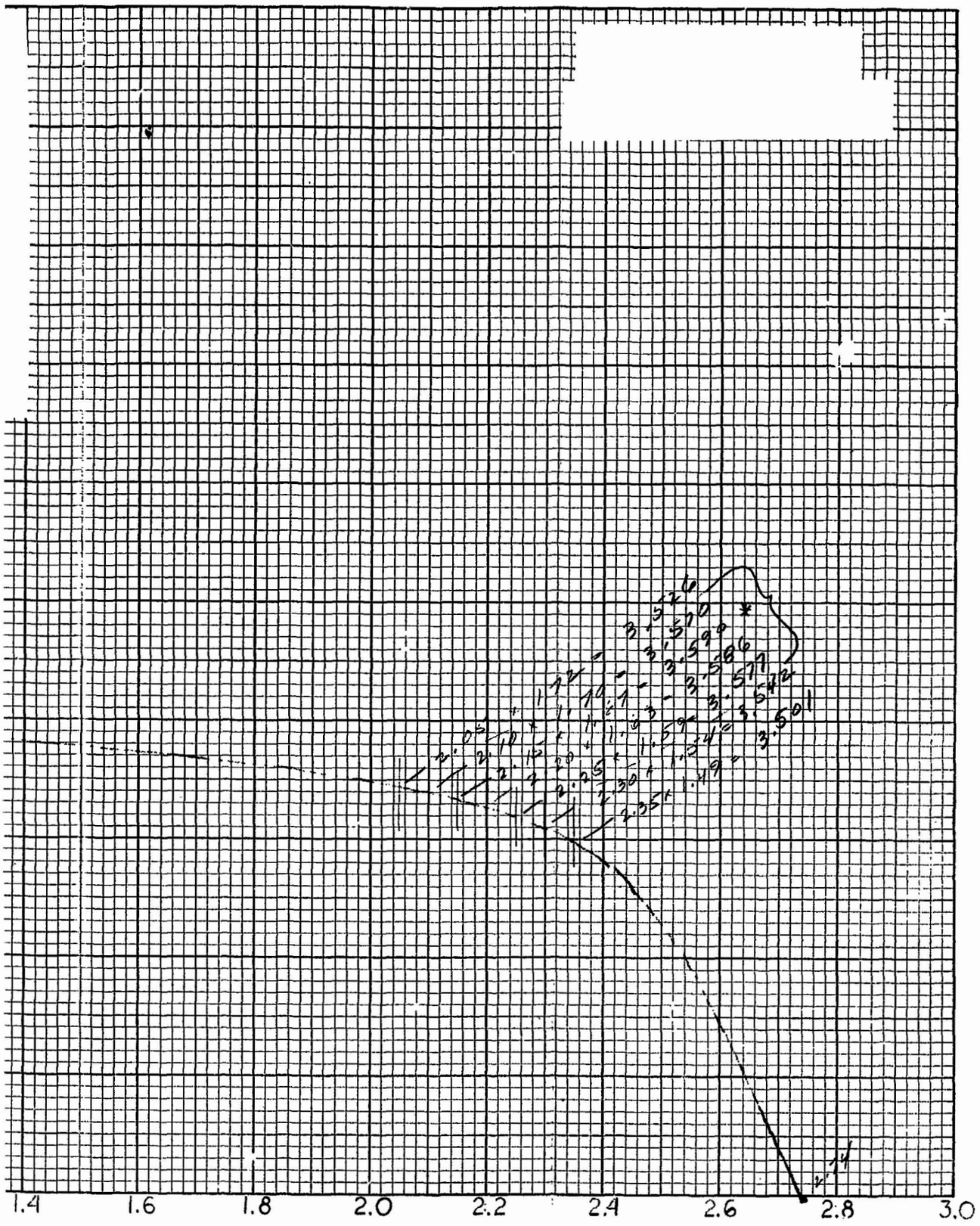


Figure B-21. Solar Test V-I Curve - Module 19 Test A - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=19,	.2325,	.4727,	127.25

2.3250000E-01	2.2841149E-01
2.2841149E-01	2.2854639E-01
2.2854639E-01	2.2854197E-01
2.2854197E-01	2.2854212E-01
2.2854212E-01	2.2854211E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2285	0.5252	92.4767	126.5729

POWER POINT CURRENT-VOLTAGE

=2.10,	1.70
=2.15,	1.67
=2.20,	1.63
=2.25,	1.59

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.1000	1.7000	3.5700	2.8205
2.1500	1.6700	3.5905	2.8367
2.2000	1.6300	3.5860	2.8331
2.2500	1.5900	3.5775	2.8264

MOD ISC	MOD VOC
=2.74,	2.08

FILL FACTORS

0.6264

0.6300

0.6292

0.6277

MOD TEMP DEG CENT
52.9167

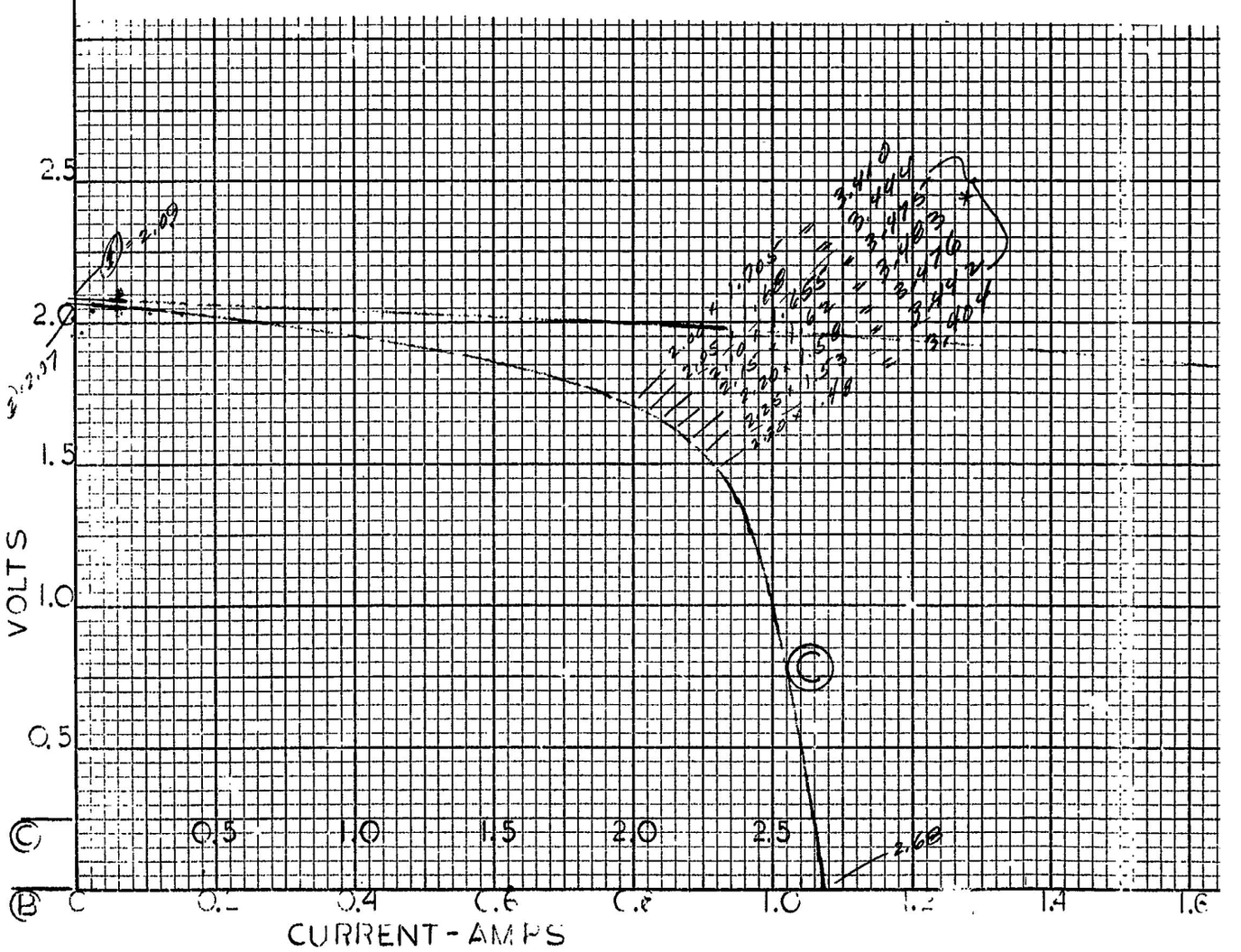
Test B

Silicon Intensity Standard .230 a.
.226 a.

Silicon Open Circuit Standard .4728 v.
.4731 v.

Thermocouple Voltages 2.17 mv. = 127.7 °F
2.16 mv. = 127.2 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

Test C

Silicon Intensity Standard	.226 a. .226 a.	
Silicon Open Circuit Standard	.4727 v. .4724 v.	
Thermocouple Voltages	2.13 mv. 2.20 mv.	= 126.0 °F = 128.9 °F

Scale = 0.5 Amps/inch
0.5 Volts/inch

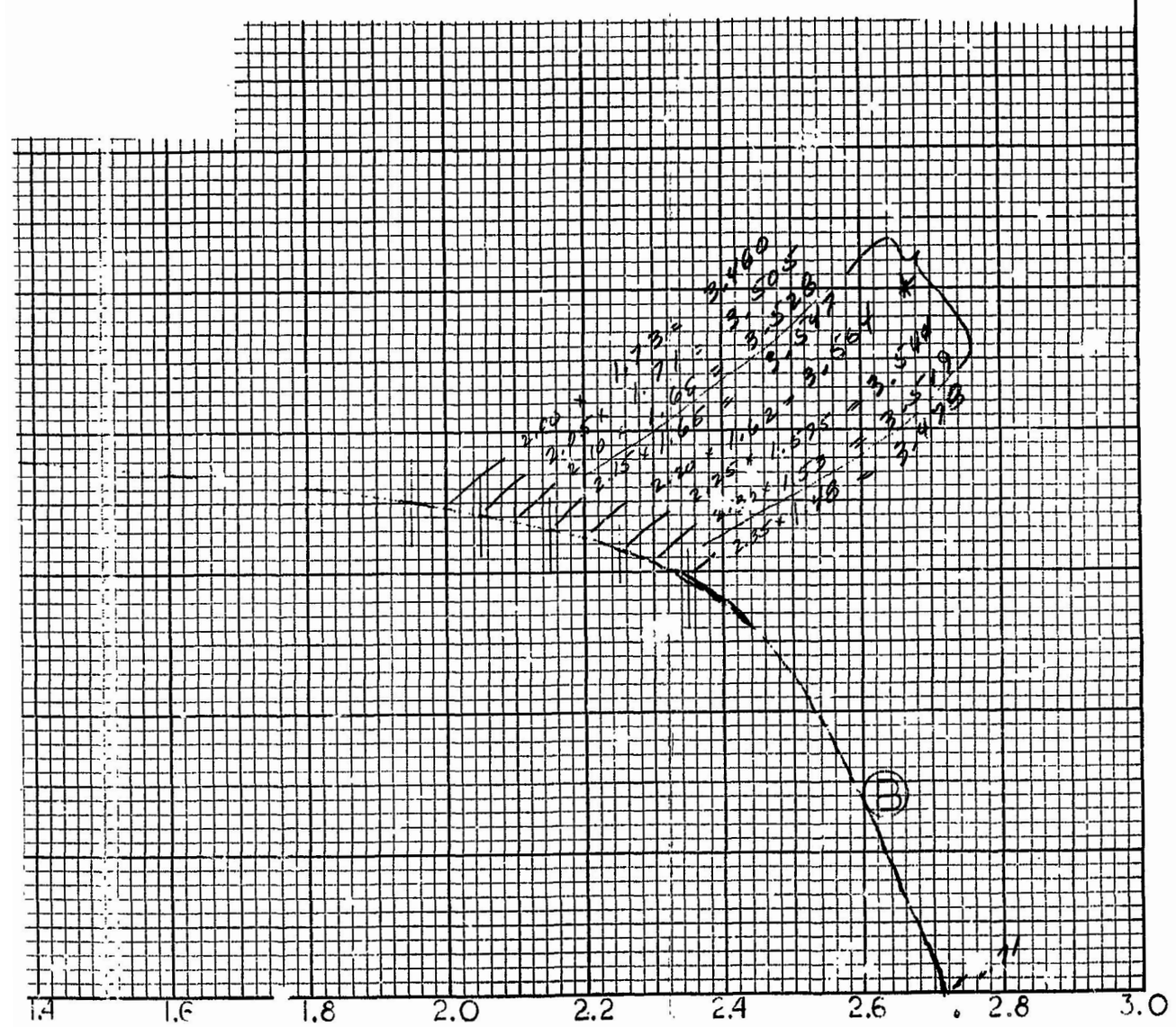


Figure B-22. Solar Test V-I Curve - Module 19 Tests B & C - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=19,	.228,	.4730,	127.5

2.2800000E-01	2.2408241E-01
2.2408241E-01	2.2420895E-01
2.2420895E-01	2.2420490E-01
2.2420490E-01	2.2420503E-01
2.2420503E-01	2.2420502E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2242	0.5243	90.7218	124.1709

POWER POINT CURRENT-VOLTAGE

=2.15,	1.65
=2.20,	1.62
=2.25,	1.575
=2.30,	1.53

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.1500	1.6500	3.5475	2.8569
2.2000	1.6200	3.5640	2.8702
2.2500	1.5750	3.5437	2.8539
2.3000	1.5300	3.5190	2.8340

MOD ISC	MOD VOC
=2.71,	2.09

FILL FACTORS

0.6263

0.6292

0.6257

0.6213

MOD TEMP DEG CENT
53.0556

S/N	ISC STD	VOC STD	TEMP F
=19,	.226,	.4725,	127.5

2.2600000E-01	2.2210999E-01
2.2210999E-01	2.2223524E-01
2.2223524E-01	2.2223124E-01
2.2223124E-01	2.2223136E-01
2.2223136E-01	2.2223136E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2222	0.5239	89.9232	123.0779

POWER POINT CURRENT-VOLTAGE

=2.10,	1.655
=2.15,	1.62
=2.20,	1.58
=2.25,	1.53

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.1000	1.6550	3.4755	2.8238
2.1500	1.6200	3.4830	2.8299
2.2000	1.5800	3.4760	2.8242
2.2500	1.5300	3.4425	2.7970

MOD ISC	MOD VOC
=2.68,	2.07

FILL FACTORS

0.6265

0.6278

0.6266

0.6205

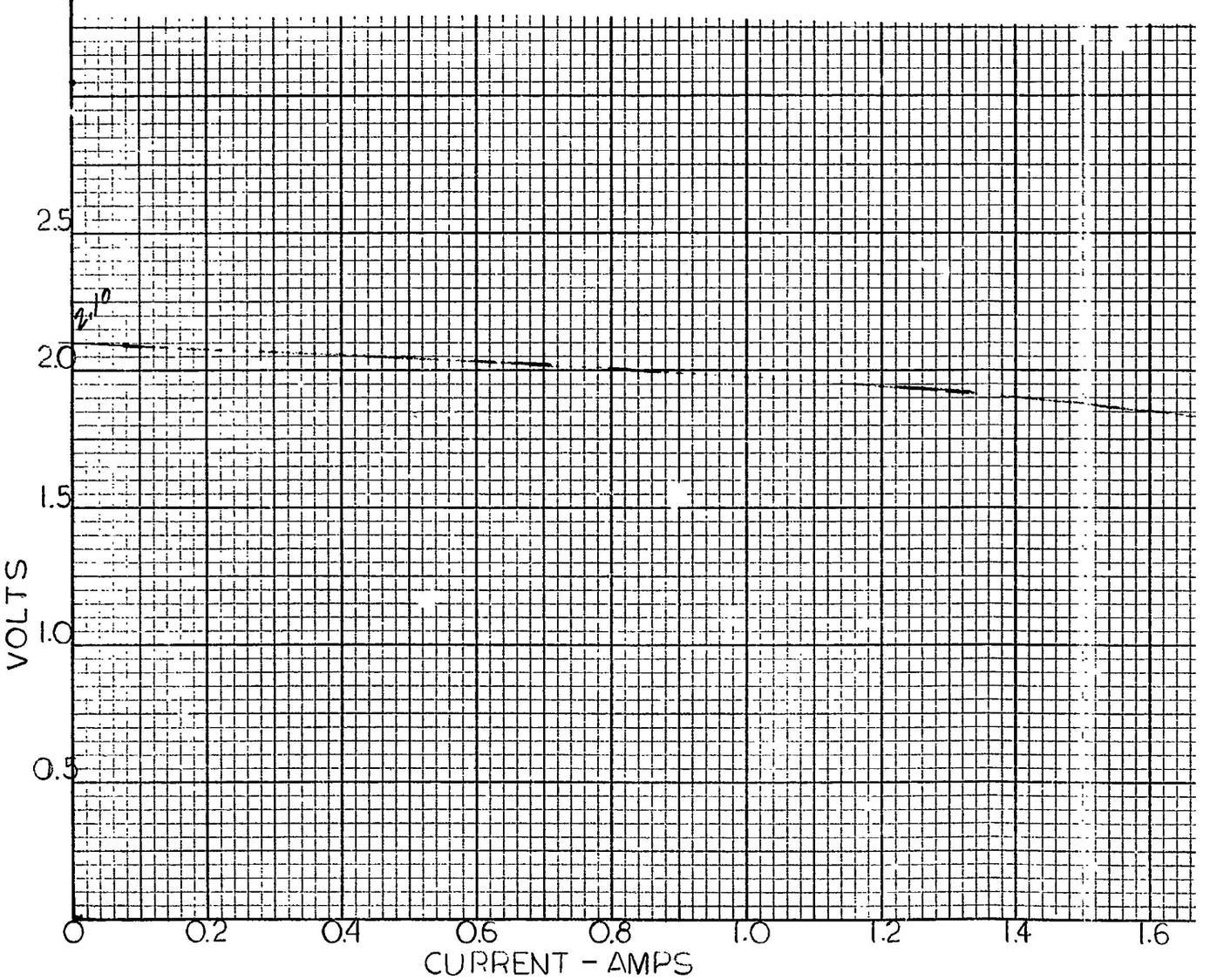
MOD TEMP DEG CENT
53.0556

Silicon Intensity Standard .208 a.
.209 a.

Silicon Open Circuit Standard .4849 v.
.4853 v.

Thermocouple Voltages 2.26 mv. = 131.4 °F
2.20 mv. = 128.9 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

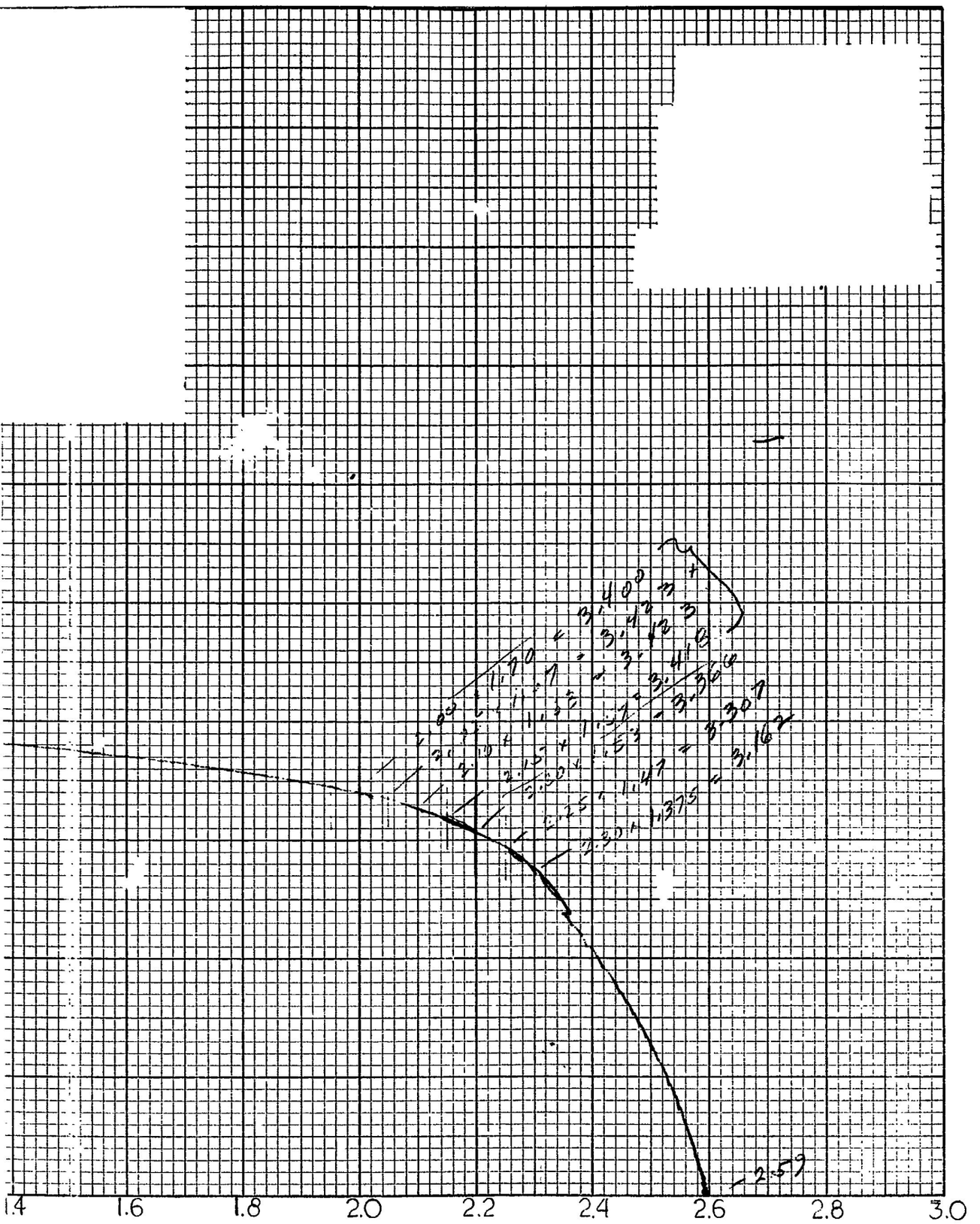


Figure B-23. Solar Test V-I Curve - Module 20 Test A - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=20,	.2085,	.4851,	133.1

2.0850000E-01	2.0602420E-01
2.0602420E-01	2.0608801E-01
2.0608801E-01	2.0608638E-01
2.0608638E-01	2.0608642E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2061	0.5206	83.3903	114.1363

POWER POINT CURRENT-VOLTAGE

=2.00,	1.70
=2.05,	1.67
=2.10,	1.63
=2.15,	1.59

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.0000	1.7000	3.4000	2.9789
2.0500	1.6700	3.4235	2.9995
2.1000	1.6300	3.4230	2.9990
2.1500	1.5900	3.4185	2.9951

MOD ISC	MOD VOC
=2.59,	2.10

FILL FACTORS

0.6251

0.6294

0.6293

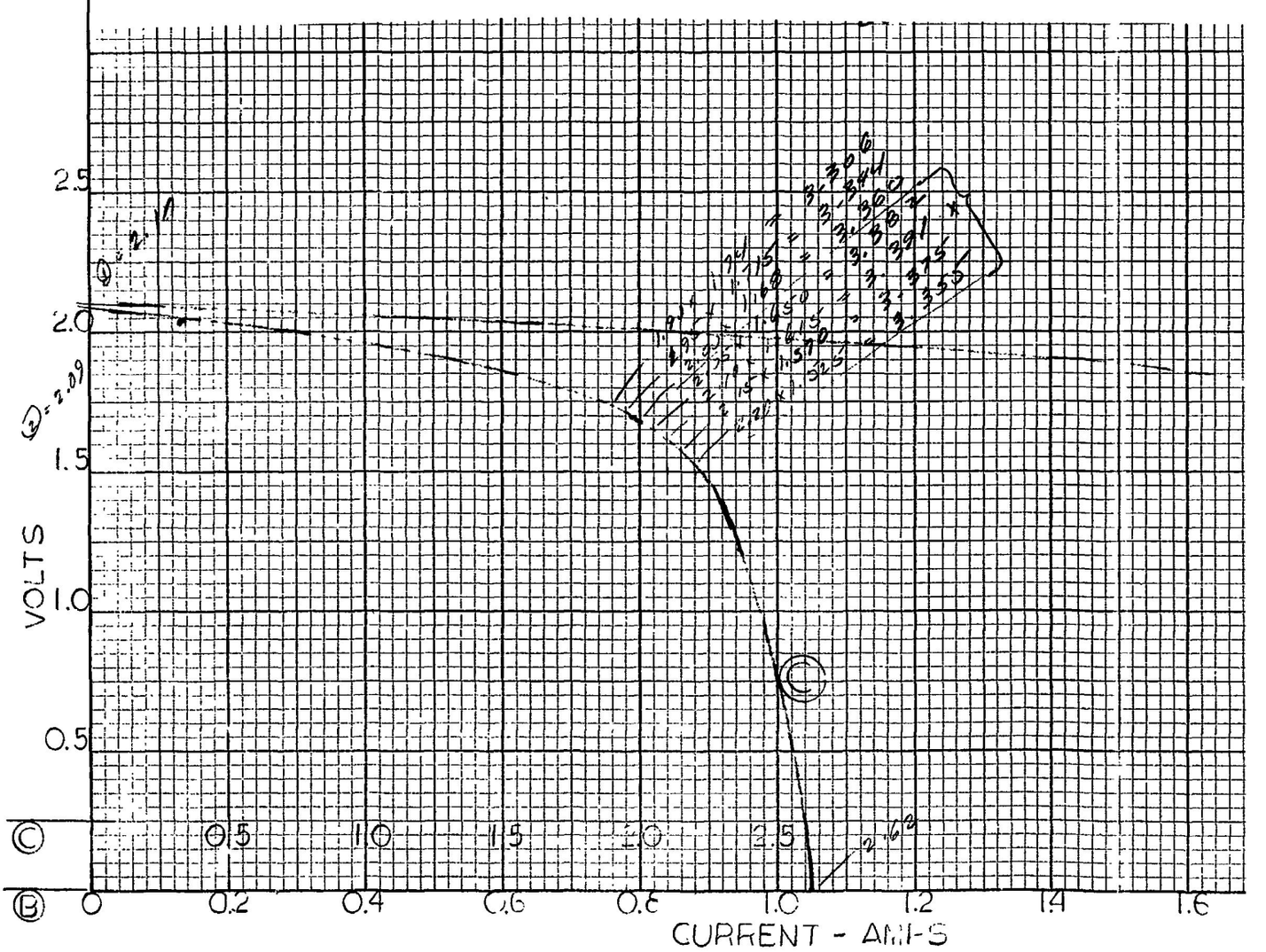
0.6285

MOD TEMP DEG CENT
56.1667

Test B

Silicon Intensity Standard	.209 a. .209 a.
Silicon Open Circuit Standard	.4850 v. .4853 v.
Thermocouple Voltages	2.21 mv. = 129.3 °F 2.20 mv. = 128.9 °F

Scale = 0.2 Amps/inch
0.5 Volts/inch



FOLDOUT FRAME 1

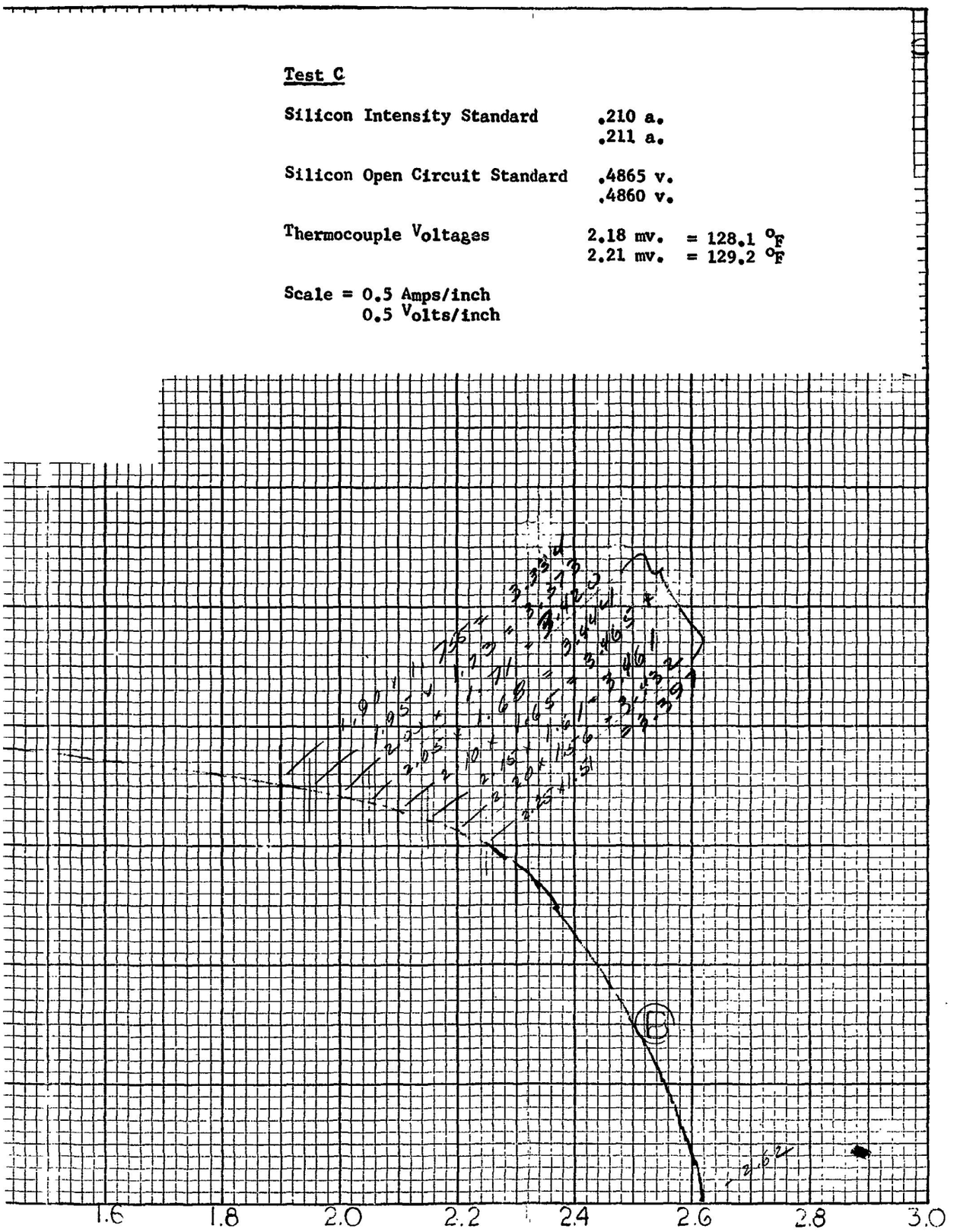


Figure B-24. Solar Test V-I Curve - Module 20 Tests B & C - 7/17/68

FOLDOUT FRAME 2

S/N	ISC STD	VOC STD	TEMP F
=20,B	.209,	.4851,	129.1

2.0900000E-01	2.0651121E-01
2.0651121E-01	2.0657553E-01
2.0657553E-01	2.0657387E-01
2.0657387E-01	2.0657392E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2066	0.5207	83.5876	114.4063

POWER POINT CURRENT-VOLTAGE

=2.05, 1.68
=2.10, 1.65
=2.15, 1.61
=2.20, 1.56

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.0500	1.6800	3.4440	3.0103
2.1000	1.6500	3.4650	3.0287
2.1500	1.6100	3.4615	3.0256
2.2000	1.5600	3.4320	2.9998

MOD ISC MOD VOC
=2.62, 2.10

FILL FACTORS

0.6260

0.6298

0.6291

0.6238

MOD TEMP DEG CENT
53.9444

S/N	ISC STD	VOC STD	TEMP F
=20	.2105,	.4862,	128.7

2.1050000E-01	2.0804845E-01
2.0804845E-01	2.0811141E-01
2.0811141E-01	2.0810980E-01
2.0810980E-01	2.0810984E-01

I STD	V STD	MW/CM2	INPUT WATTS
0.2081	0.5210	84.2091	115.2570

POWER POINT CURRENT-VOLTAGE

=2.05,	1.65
=2.10,	1.615
=2.15,	1.57
=2.20,	1.525

P.P.CURRENT	P.P. VOLTS	POWER-WATTS	EFF-PERCENT
2.0500	1.6500	3.3825	2.9347
2.1000	1.6150	3.3915	2.9426
2.1500	1.5700	3.3755	2.9287
2.2000	1.5250	3.3550	2.9109

MOD ISC	MOD VOC
=2.62,	2.09

FILL FACTORS

0.6177

0.6194

0.6164

0.6127

MOD TEMP DEG CENT
53.7222

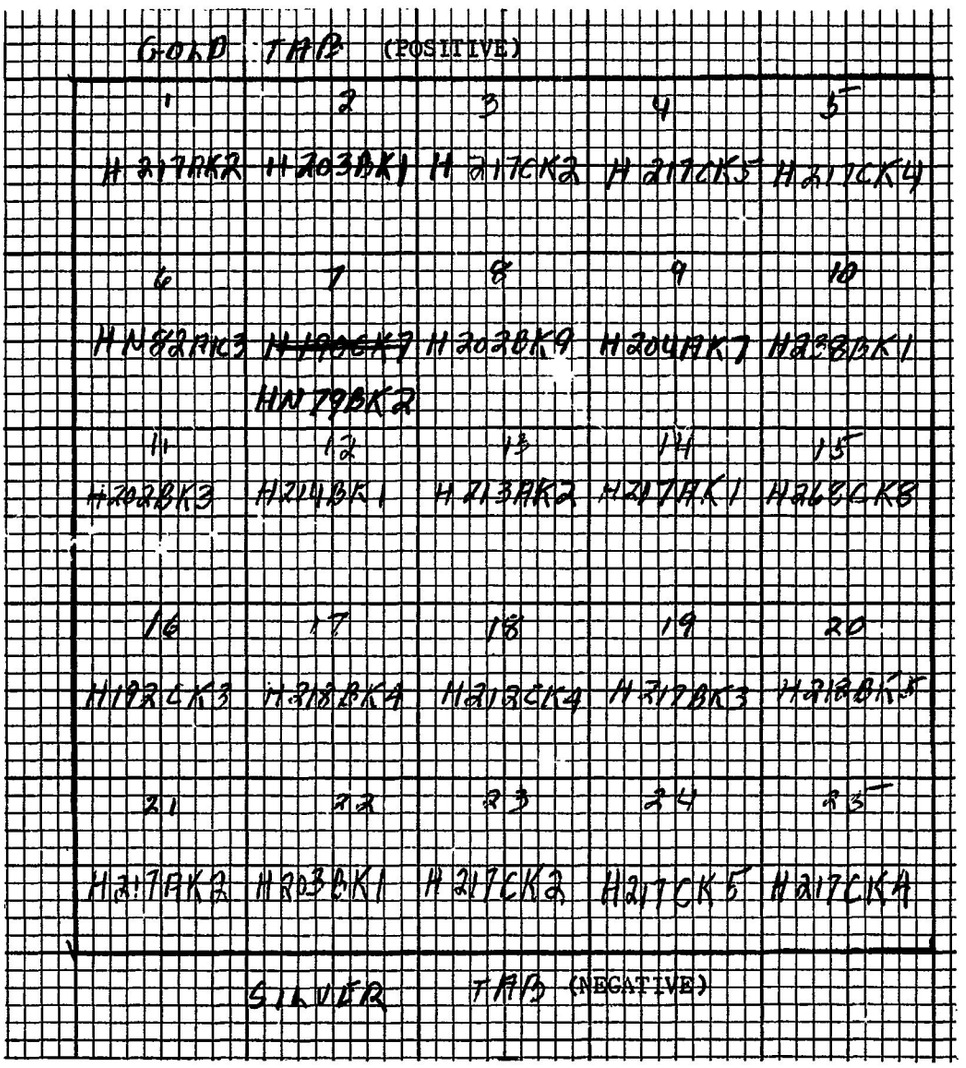


Figure C-1. Cell Positions Within CdS Solar Cell Module No. 9

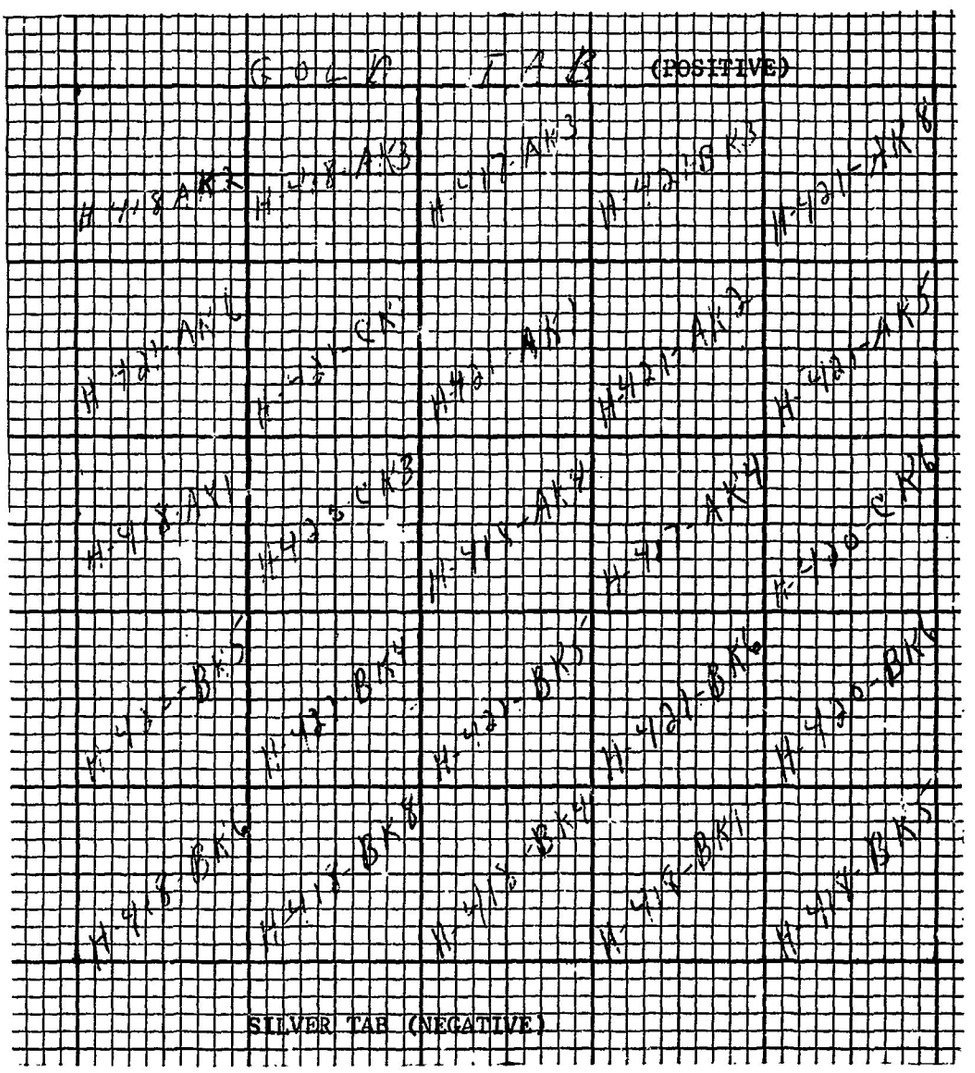


Figure C-2. Cell Positions Within CdS Solar Cell Module No. 10

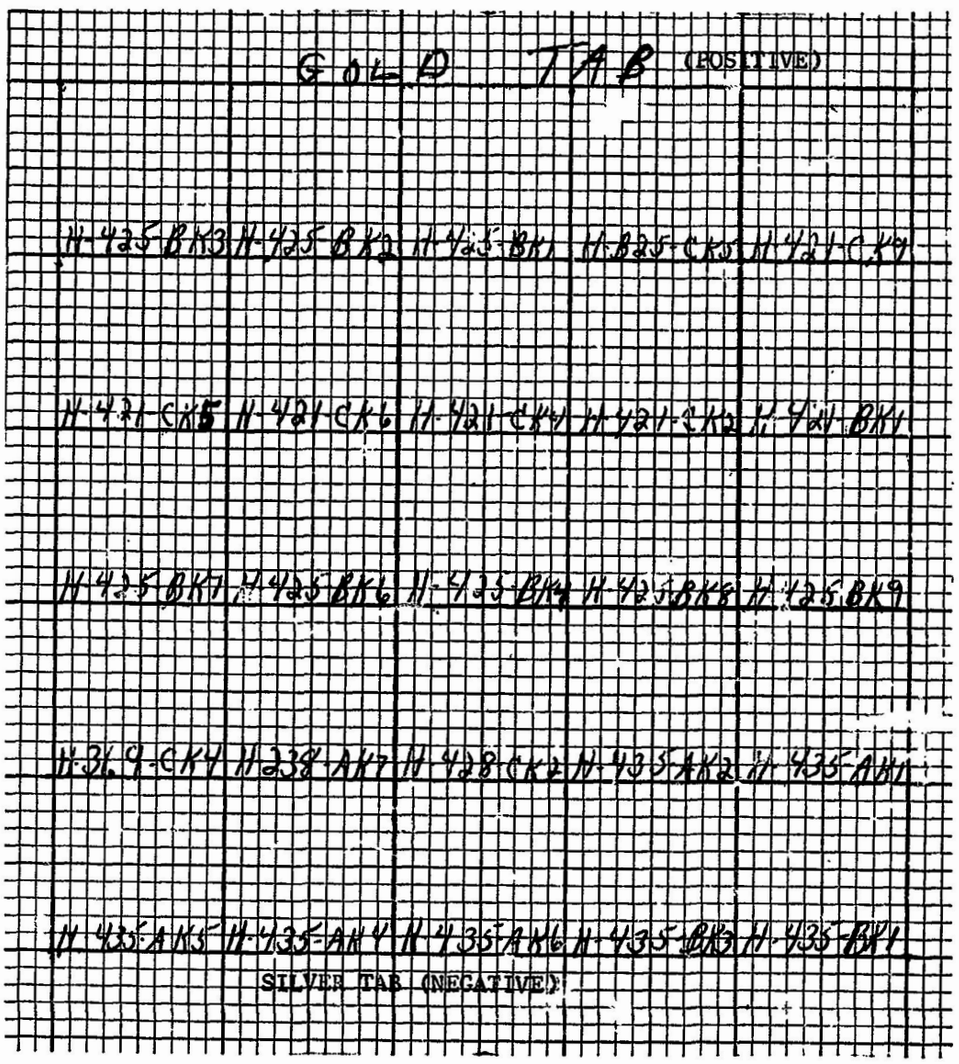


Figure C-3. Cell Positions Within CdS Solar Cell Module No. 11

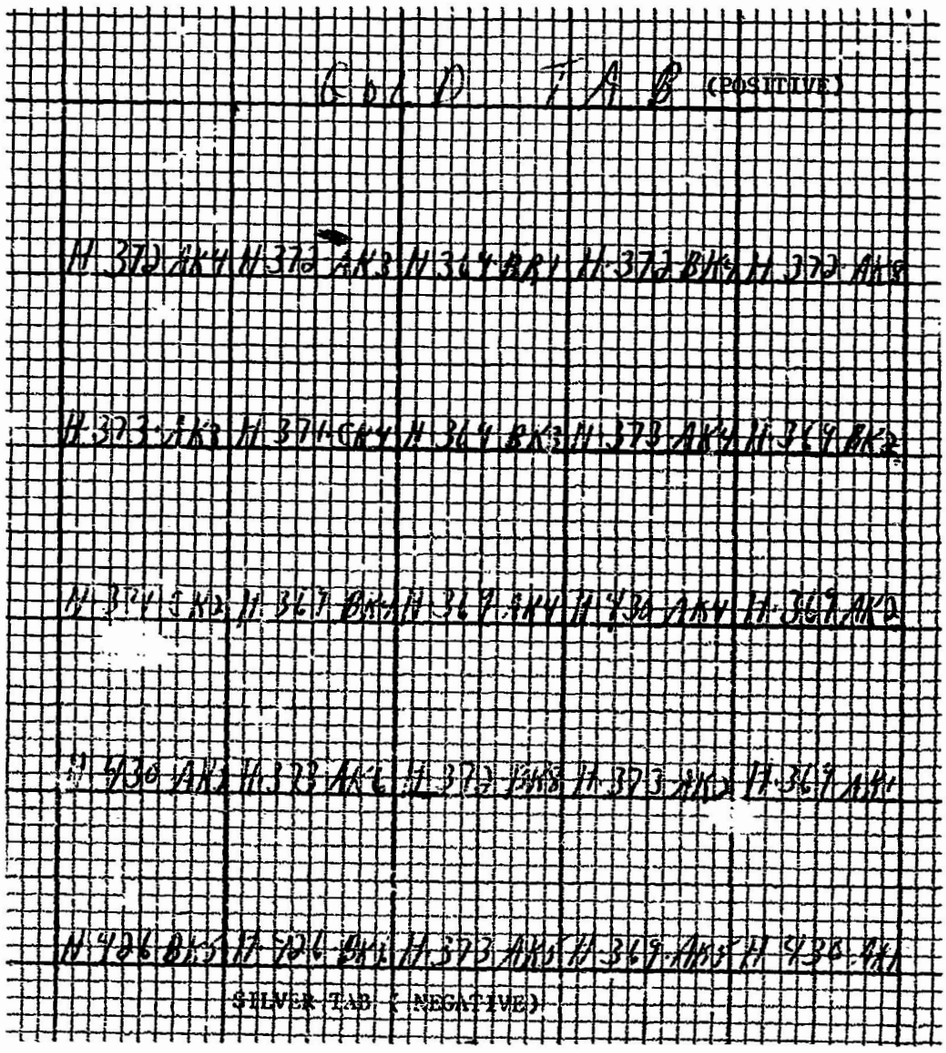


Figure C-4. Cell Positions Within CdS Solar Cell Module No. 12

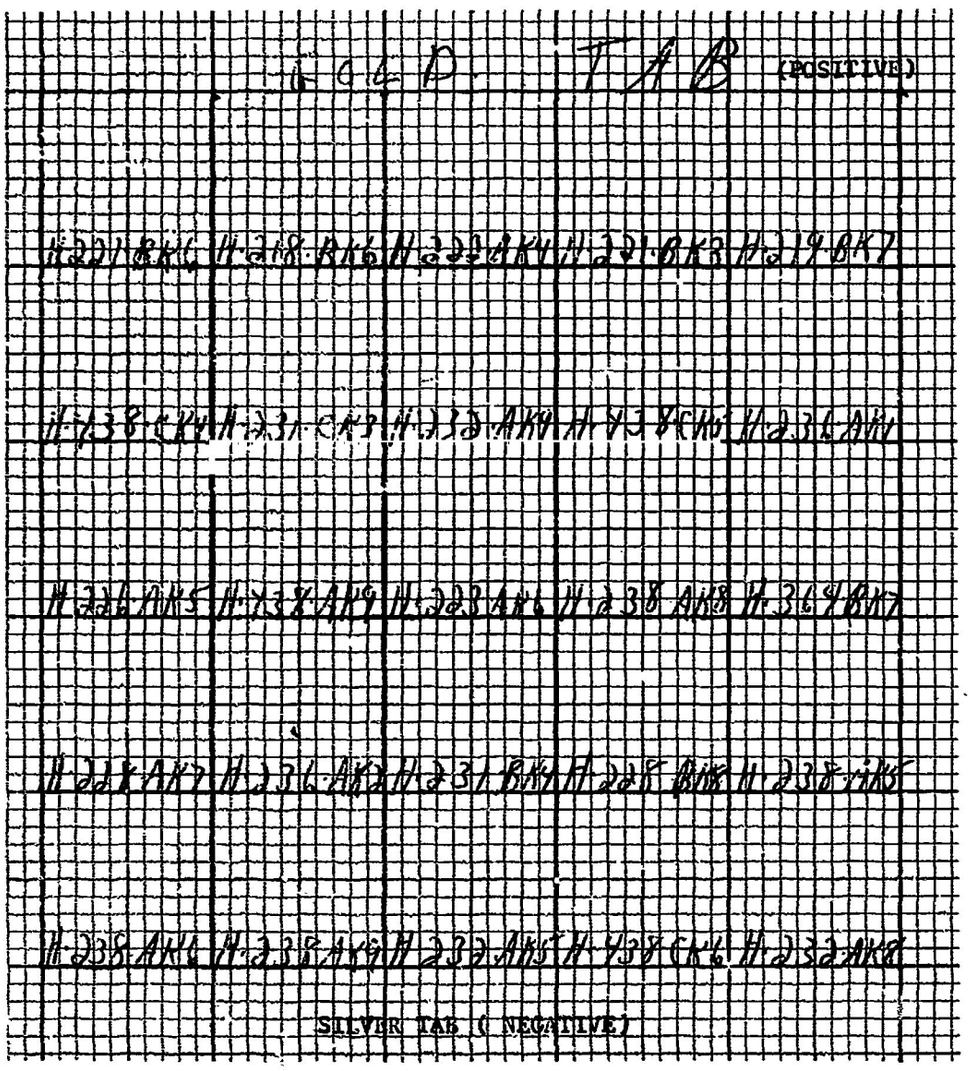


Figure C-5. Cell Positions Within CdS Solar Cell Module No. 13

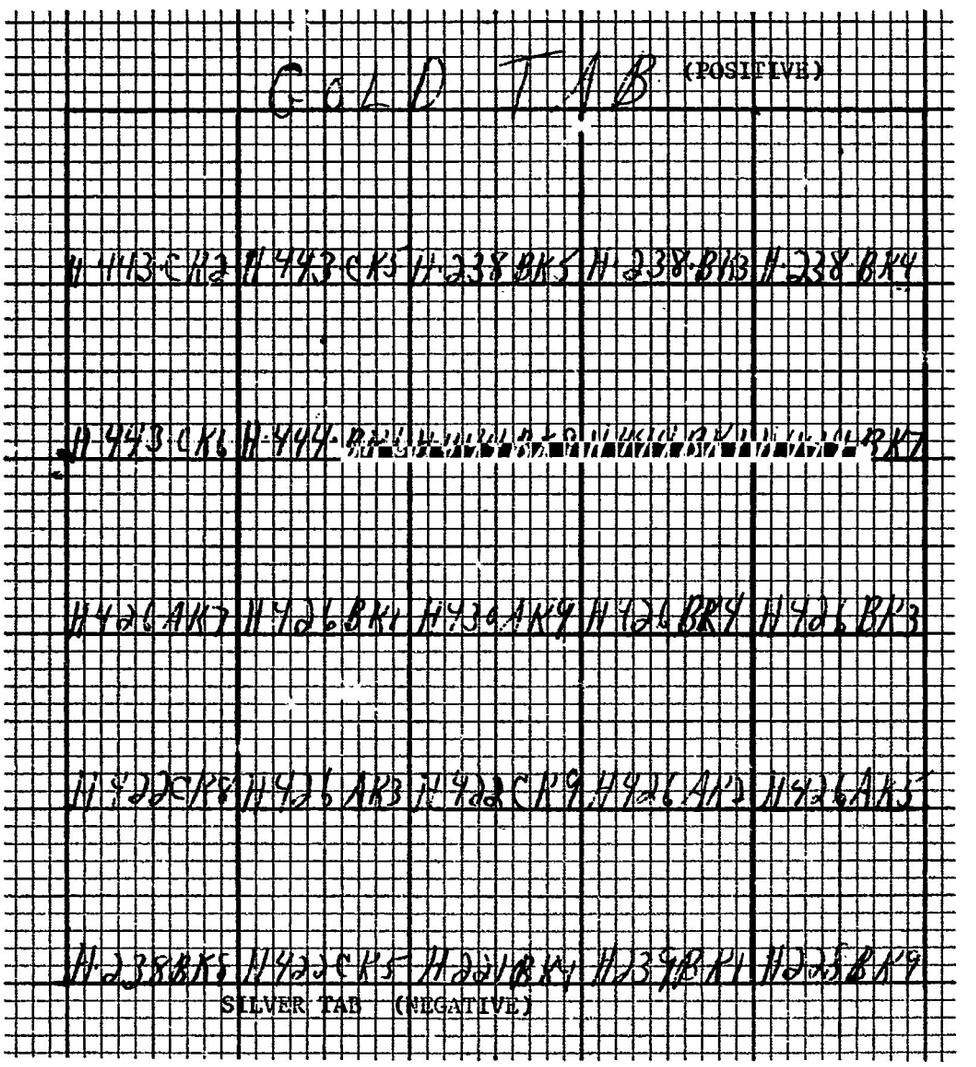


Figure C-6. Cell Positions Within CdS Solar Cell Module No. 14

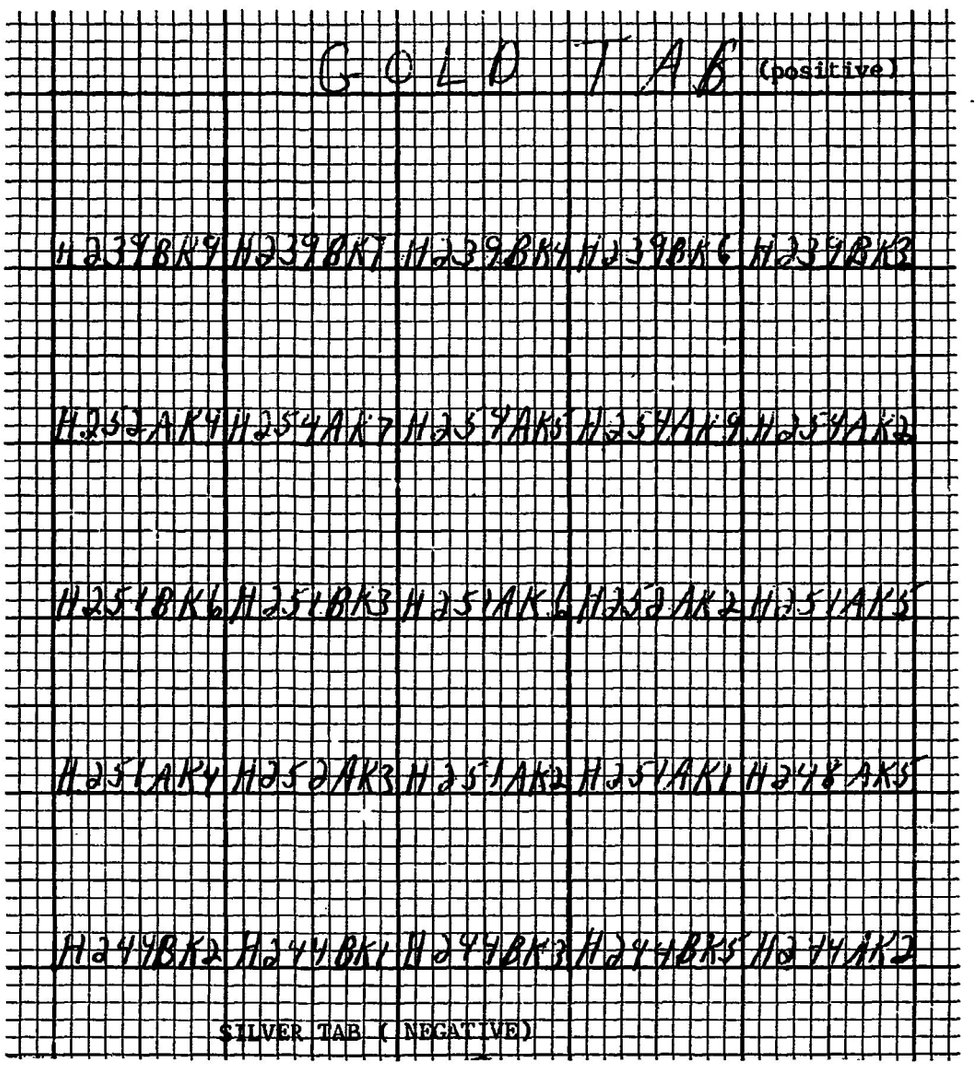


Figure C-7. Cell Positions Within CdS Solar Cell Module No. 15

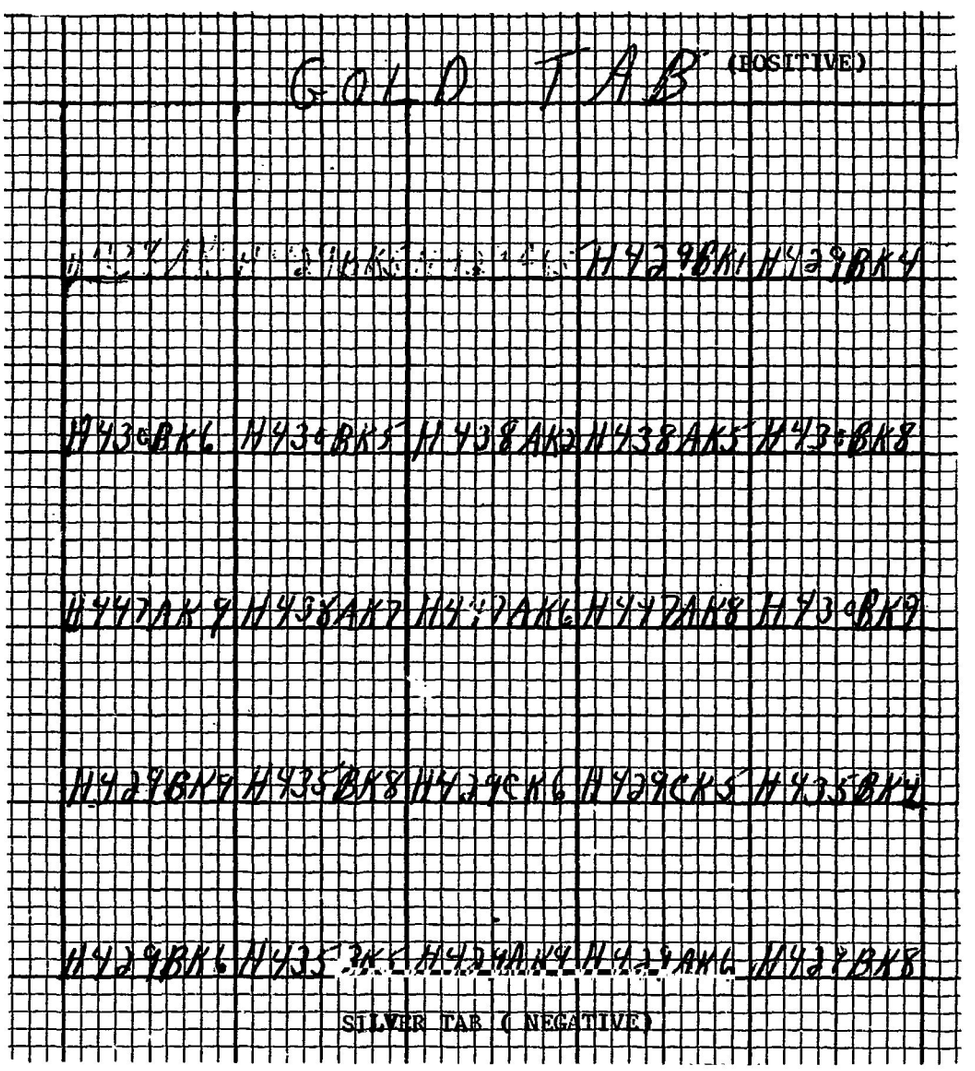


Figure C-8. Cell Positions Within CdS Solar Cell Module No. 16

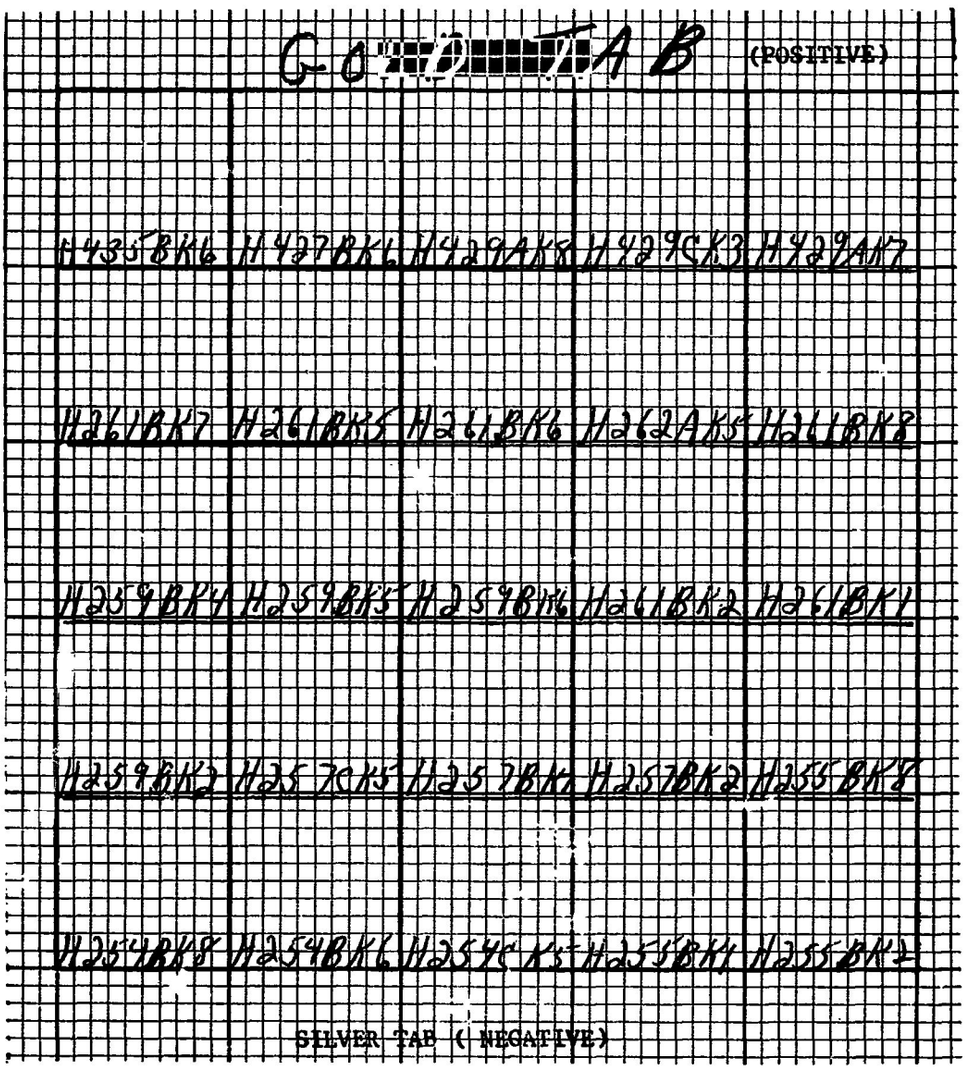


Figure C-9. Cell Positions Within CdS Solar Cell Module No. 17

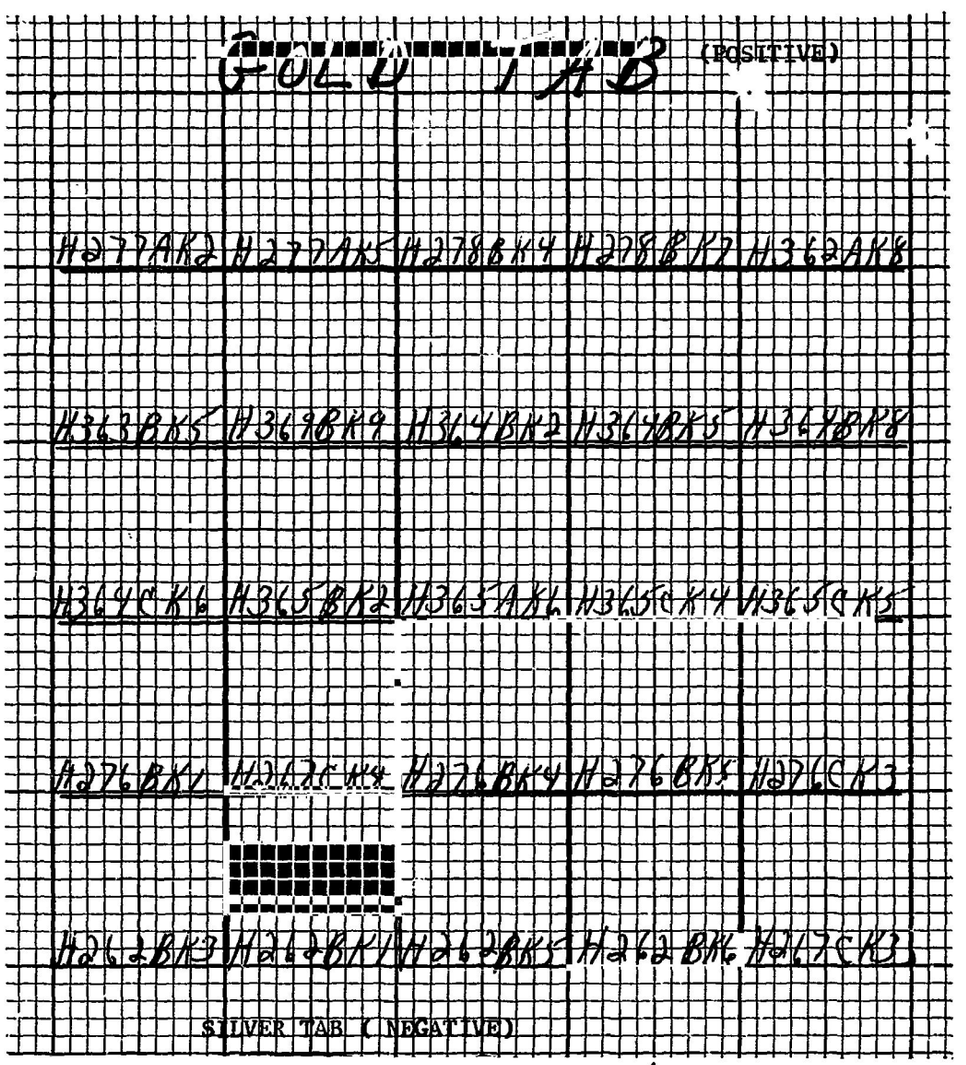


Figure C-10. Cell Positions Within CdS Solar Cell Module No. 18

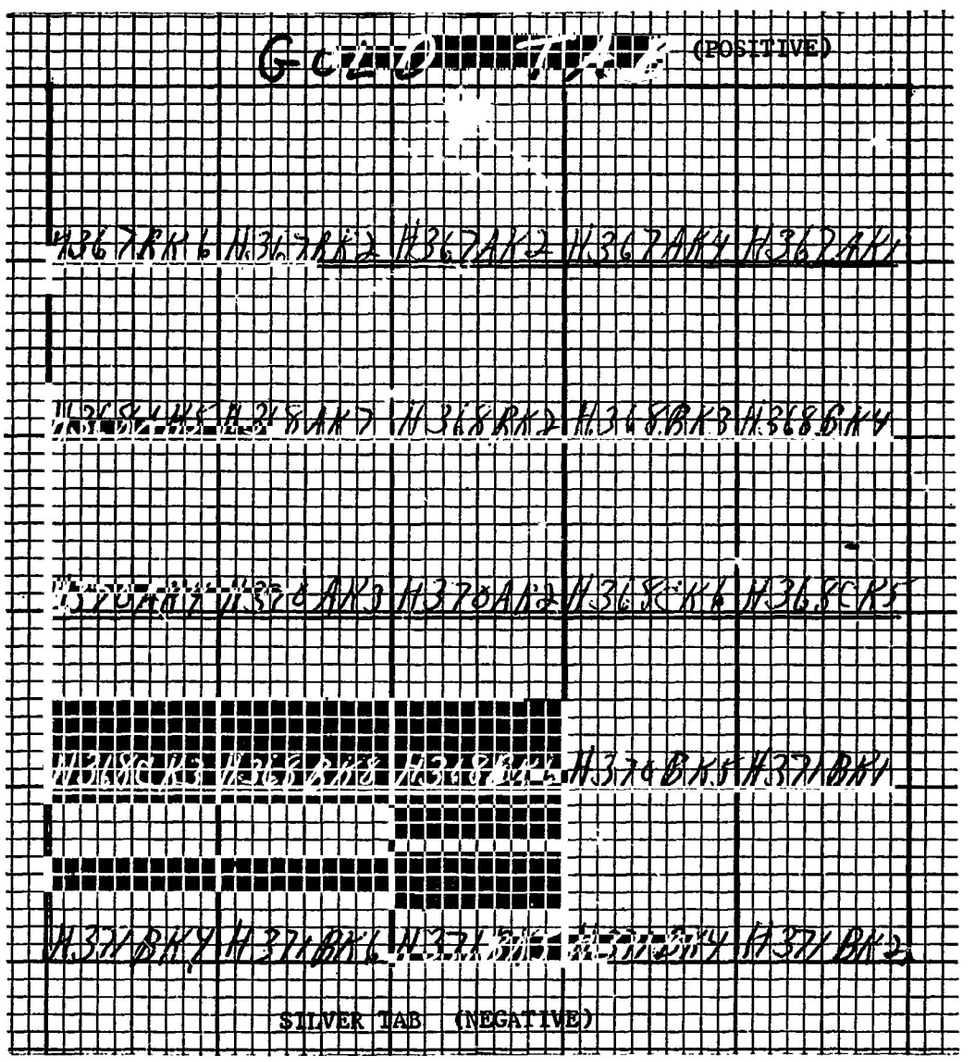


Figure C-11. Cell Positions Within CdS Solar Cell Module No. 19

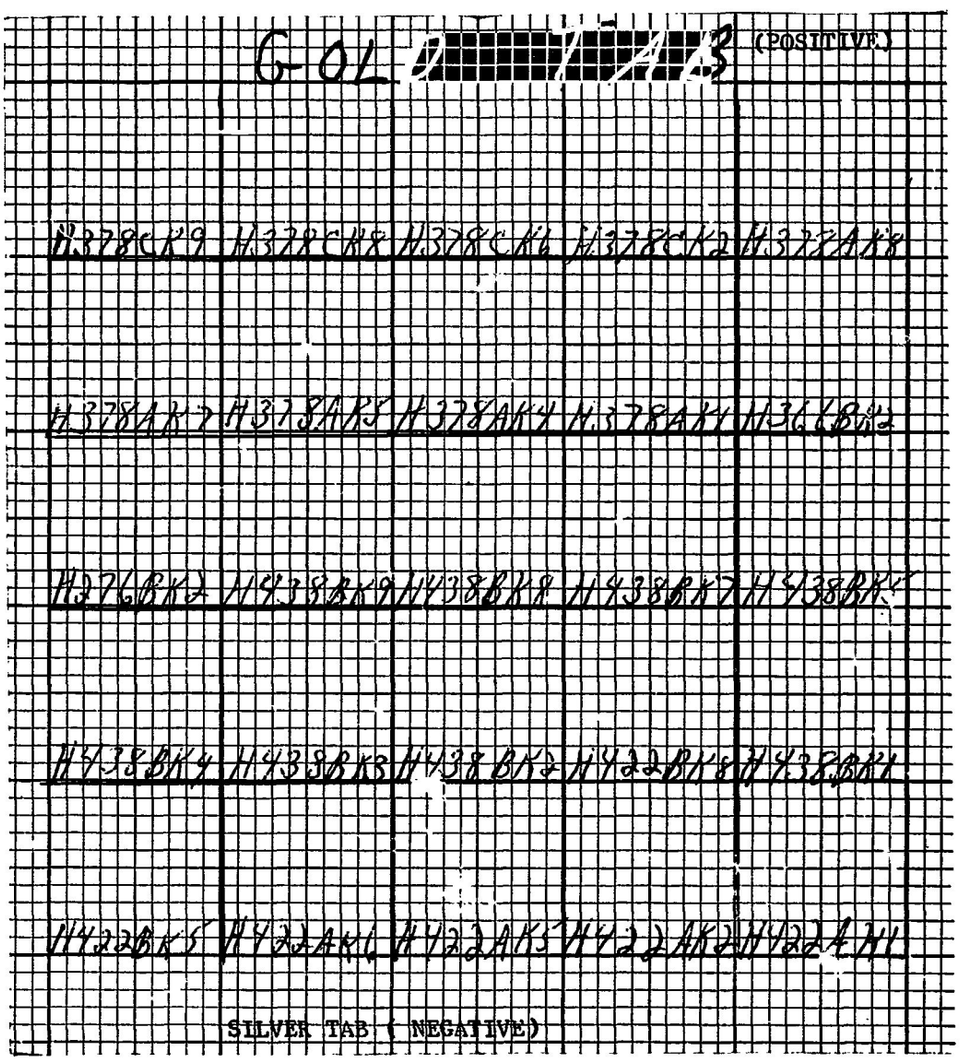


Figure C-12. Cell Positions Within CdS Solar Cell Module No. 20