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MATERIALS, PROCESSES AND TESTING LABORATORY TECHNICAL PROGRESS REPORT: MARCH, APRIL, MAY, JUNE 1980

30 October 1980

S.E. Forman
M.P. Themelis

Massachusetts Institute of Technology
Lincoln Laboratory
Lexington, Massachusetts 02173

Prepared for the
U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT NO. DE-AC02-76ET20279

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ABSTRACT

The U. S. Department of Energy has set a 20-year lifetime goal for terrestrial photovoltaic modules. In its capacity as a Photovoltaic Field Test and Application Center, Massachusetts Institute of Technology Lincoln Laboratory has established various experimental test sites, ranging in size from 0.1 to 100 kW of peak power, throughout the United States. The sites contain modules from several manufacturers and serve as test beds for photovoltaic system components. This report, the eighth in a series of similar reports (1-7), summarizes the activities of the Materials, Processes and Testing Laboratory of the Solar Photovoltaic Field Tests and Applications Project during the four-month period 1 March 1980 through 30 June 1980. During this period, site evaluations at test facilities in Chicago, Illinois; Bryan, Ohio; Mead, Nebraska; and Natural Bridges National Monument (NBNM), Utah, were conducted. Current-voltage (I-V) curves were generated for all branch circuits at the University of Texas at Arlington (UTA) and at NBNM. Module failures at the UTA and NBNM were analyzed. Two versions of a new type of photovoltaic/thermal air collector were visually analyzed. Two liquid PV/T collectors from the same manufacturer were subjected to degradation analyses. The Lincoln Laboratory Large-Area Pulsed Solar Simulator (LAPSS) was relocated and recalibrated.

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1.0 INTRODUCTION

In previous reports (1-7), 33 months of test experience (5/77-2/80) with photovoltaic (PV) modules at various Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) experimental PV test facilities were detailed. In this report, further data are presented for the next four-month period (3/80-6/80). Specific details are given for site evaluations at Chicago, Illinois; Bryan, Ohio; Mead, Nebraska; and Natural Bridges National Monument (NBNM), Utah. Current-voltage (I-V) curve generation at NBNM and the University of Texas at Arlington (UTA) is described and analyzed. Module failure analyses on modules removed from UTA and NBNM are also described. Visual and degradation analyses on Model G photovoltaic/thermal (PV/T) air collectors are provided as are details of the relocation and recalibration of the LL Large-Area Pulsed Solar Simulator (LAPSS).

MIT LL serves as a Field Tests and Applications Center for the U. S. Department of Energy (DOE) to evaluate the energy potential of PV components in various test applications. As part of the DOE Jet Propulsion Laboratory's (JPL) Large-Scale Procurement Program, MIT LL receives PV modules from various manufacturers for use at its experimental test sites. (The names of the module manufacturers are not relevant to this report, and the module types discussed are referred to as Models A, B, C, D, E, F, and G.) Each module is inspected visually at the factory of origin and a "road map" outlining its physical appearance and workmanship-related anomalies is completed in the manner discussed previously by one of the authors (8).

Modules are field tested at two types of experimental test facilities. Modules and many components of a PV system are evaluated at a Systems Test Facility. Four such sites are discussed in this report: a 7.5-kWp array field at (UTA), a 25-kWp array field at the Mead Field Station of the University of Nebraska, a 15-kWp AM radio station at Bryan, Ohio, and a 100-kWp array field at NBNM. Modules undergo weathering and soiling in special climates at Environmental Test Sites (urban rooftops in New York City; Cambridge, Massachusetts; Chicago, and a Mount Washington, New Hampshire, weather station). Data from the Chicago site are discussed in this report.

2.0 SITE EVALUATION - CHICAGO MUSEUM OF SCIENCE AND INDUSTRY

During this reporting period, the authors visited the experimental PV system at the Chicago Museum of Science and Industry. Measurements were made to locate the presence of electrically defective modules.

The array field at the Museum consists of 288 Block I Model A modules wired three in series by 96 in parallel. It has been operational since August 16, 1977. Because of cloudy weather, only the open-circuit voltage of each branch circuit could be measured. Since there are no protective diodes on each module, an open-circuited module would cause the open circuit voltage of a branch circuit to be zero. A summary of these readings is presented in Table I.

TABLE I

CHICAGO MUSEUM DATA

May 21, 1980 Insolation: 27 mw/cm^2
Ambient temperature: 15.5°C Weather: Cloudy

BC	V_{oc}	BC	V_{oc}	BC	V_{oc}	BC	V_{oc}	BC	V_{oc}
1-1	34.1	2-1	33.7	3-1	33.9	4-1	33.5	5-1	33.8
2	34.1	2	33.8	2	33.9	2	34.0	2	33.8
3	33.9	3	33.8	3	34.3	3	33.8	3	34.0
4	34.0	4	34.1	4	33.9	4	33.4	4	33.6
5	34.2	5	33.7	5	34.0	5	33.7	5	33.4
6	34.0	6	34.2	6	33.7	6	33.7	6	33.8
7	34.2	7	34.1	7	33.8	7	33.3	7	33.8
8	33.9	8	34.3	8	34.2	8	34.0	8	33.8
9	33.9	9	34.0	9	33.7	9	33.6	9	33.6
10	34.0	10	34.1	10	34.0	10	33.2	10	33.6
11	34.3	11	34.2	11	34.0	11	33.8	11	33.5
12	33.8	12	34.1	12	34.1	12	33.7	12	33.9
6-1	33.6			7-1	33.7			8-1	33.5
2	33.5			2	33.7			2	33.4
3	33.5			3	33.4			3	33.2
4	33.8			4	33.4			4	33.2
5	33.8			5	33.6			5	33.7
6	33.9			6	33.6			6	33.2
7	33.6			7	33.3			7	33.6
8	33.7			8	33.3			8	33.6
9	33.9			9	33.5			9	33.5
10	33.7	BC:	branch	10	33.4	V_{oc}:	open-	10	33.1
11	33.7		circuit	11	33.7		circuit	11	33.2
12	33.8			12	33.7		voltage	12	33.3

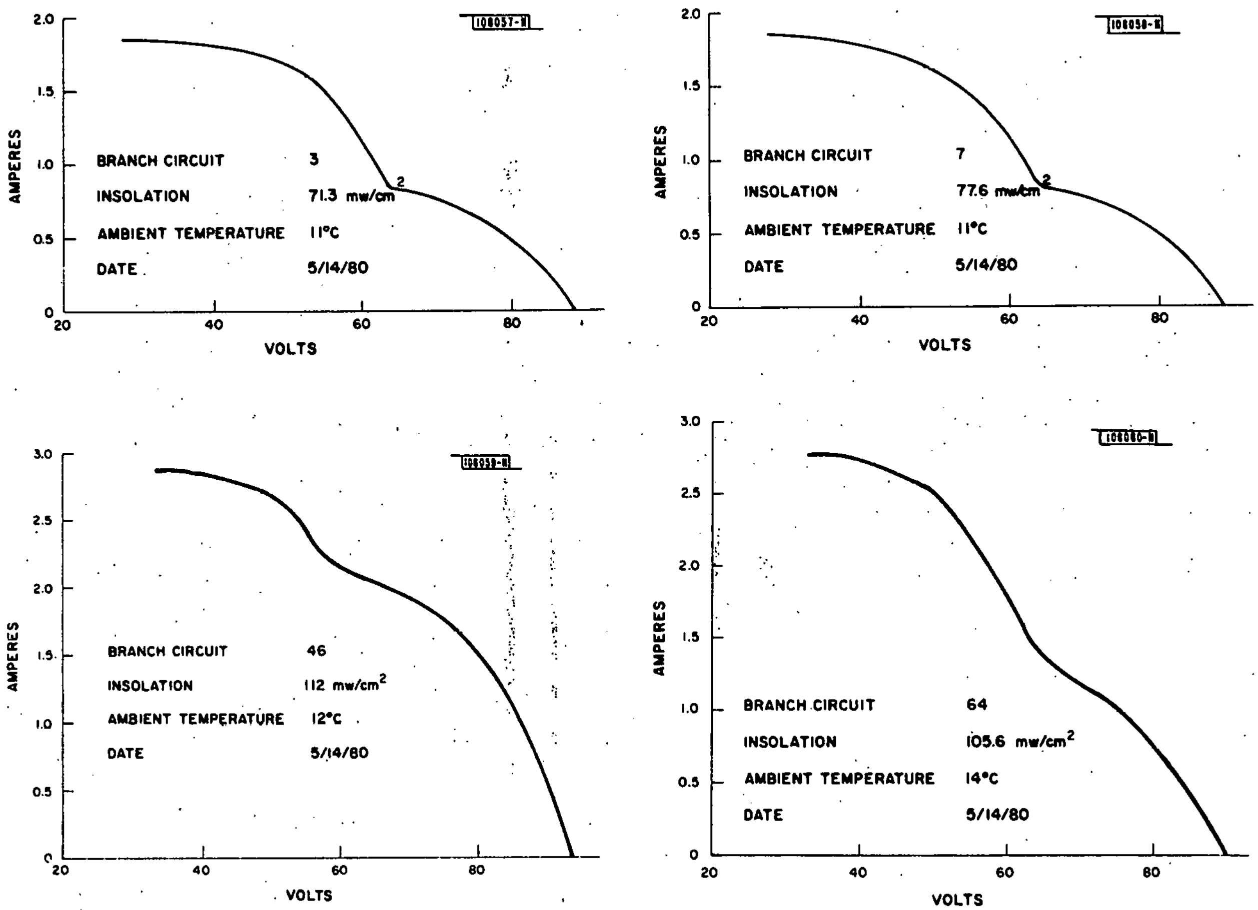
The table shows that all branch circuits were operational. This is quite remarkable, in that it indicates that no apparent electrical failures have occurred. (It may be that if the measurements were repeated in bright sunlight on a warm day, that some cracked cells might expand and subsequently cause modules to open circuit.) These modules have been known to have problems at voltages over 100 volts, however, at the low system voltage used, no problems were apparent.

The array is cared for by a member of the Museum shop staff and is washed every summer. The next measurement visit is scheduled for May 1981.

3.0 SITE EVALUATION - BRYAN, OHIO

During this reporting period, the authors visited the PV array field at radio station WBNO in Bryan, Ohio. The array field consists of 800 Block III Model D modules. Each of 100 arrays consists of four modules in series, paralleled with four more in series. An I-V curve was made for each array with portable curve-tracing equipment.

The array was first turned on in August 1978, and on this visit four failed modules were found. The I-V curves for the branch circuits containing these failures (strings 3, 7, 46, and 64) are displayed in Figs. 1–4 along with the normal curve



Figs. 1–4. I-V curves for branch circuits 3, 7, 46, and 64.

(Fig. 5) for Array Number 3 after the failed module was replaced. A collection of all the curves is available from the authors.

These curves were made subsequent to the array being washed by a local cleaning establishment for $395.00.

The measurements will be repeated in approximately one year.

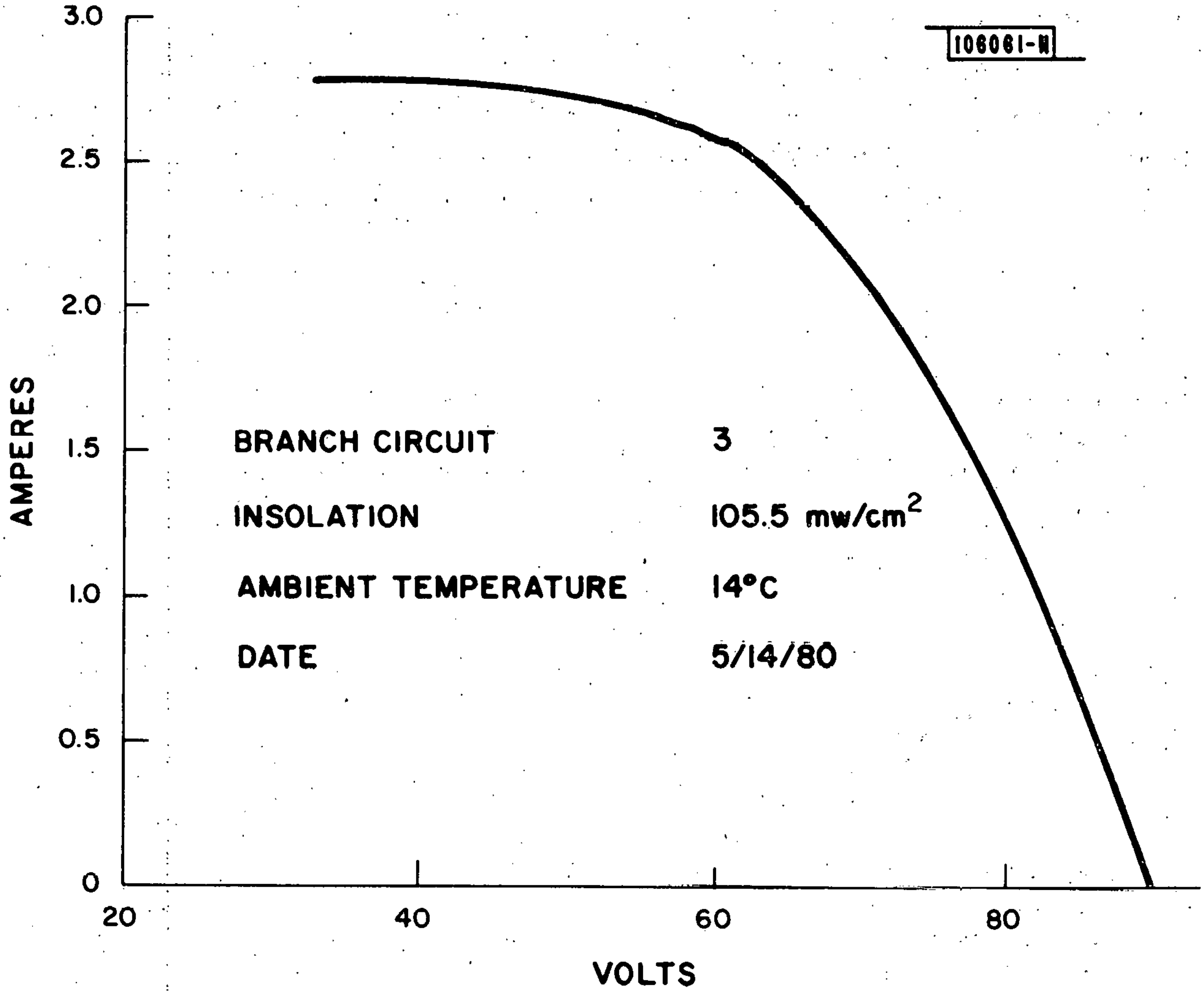


Fig. 5. I-V curve. Failed module replaced in branch circuit 3.

4.0 SITE EVALUATION - MEAD, NEBRASKA

During the week of June 9, 1980, members of the Materials, Processes and Testing Laboratory (MP&TL) visited the Mead, Nebraska, test site to search for electrically defective modules and to characterize each branch circuit with an I-V curve. The weather was sunny for a day and a half and then cloudy and overcast for a day and a half.

The array at Mead was turned on in July 1977 and has been operating successfully since. The array field consists of 28 frames containing 2240 Block II modules. In the front row there are 728 Model D modules and in the back row there are 1512 Model C modules. The branch-circuit arrangements for each type of module are:

Model D - two in parallel by 10 in series

Model C - four in parallel by nine in series.

Previously, electrically failed modules were found by measuring the short-circuit current of every quad and pair in the array field with a multimeter. On this visit, an I-V curve was made for each branch circuit and only those with defects were searched for bad modules. The results of this process are discussed next.

4.1 Model D Modules

There are 35 Model D branch circuits; electrically failed modules were found in 11 of these. A typical curve with a failure is shown in Fig. 6 and the same curve is shown after replacing the failed module in Fig. 7. It is interesting to note that the first curve was made on a day with blue skies, while the second was made as the sun passed between two clouds. The extra reflections or bounce from the clouds enhanced the output of the cells, but not necessarily the pyranometer which was used as an insolation reference. Reference cells are not presently used at the Nebraska site.

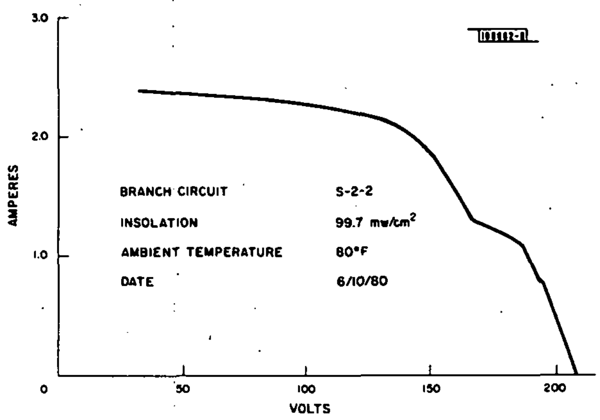


Fig. 6. Mead branch circuit S-2-2 with failure.

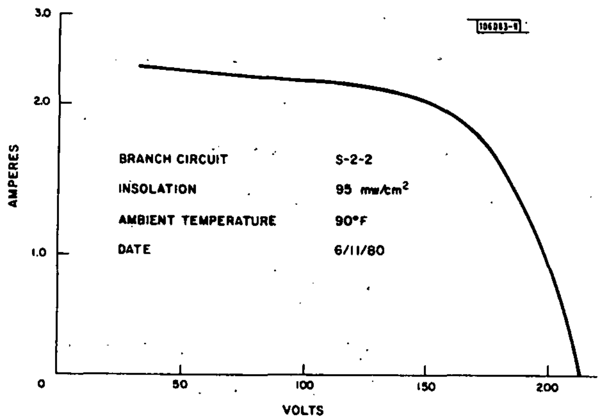
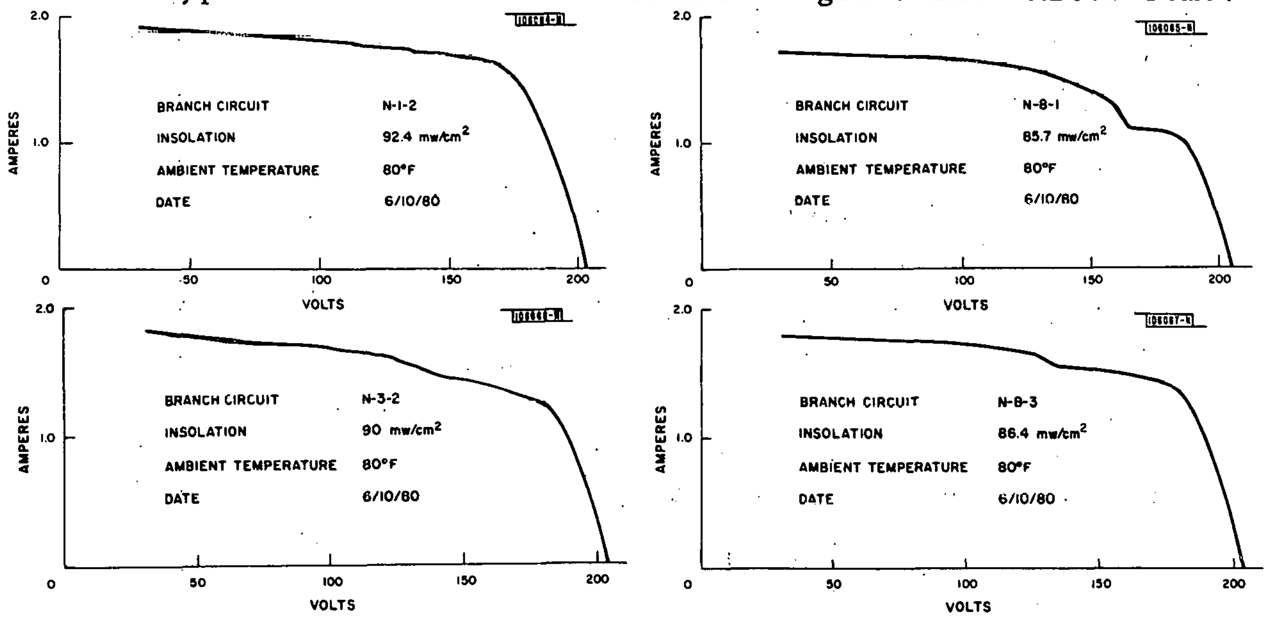


Fig. 7. Mead branch circuit S-2-2 after failure replacement.

In 35 months, 31 of 728 Model D modules have failed (4.26%) and each failure has been a complete open circuit.

4.2 Model C Modules

In the 42 Model C branch circuits at least seven failed modules were found. There were irregularities on almost every Model C I-V curve, and only the worst were isolated and removed from the system. A normal I-V curve is shown in Fig. 8. Curves with various types of anomalies are shown in Figs. 9–11. After remov-



Figs. 8–11. Mead branch circuits: (8) circuit N-1-2, normal; (9) circuit N-8-1 with failure; (10) circuit N-3-2, irregular; (11) circuit N-8-3, irregular.

ing failures from these branch circuits, new curves could not be made because of excessive cloudiness. These same clouds prevented searching for what appears to be 20 other locations with electrical problems. These modules will be fully characterized again in October 1980.

In 35 months of operation there have been 35 failures of 1512 modules, or 2.31%. In each failure the module output was reduced by at least 25% from normal.

4.3 Module Failure Analysis

The total number of module failures found at the Mead test site in 35 months is 66 of 2240 modules or 2.95%. A plot of the cumulative percentage of failed modules as a function of time is displayed in Fig. 12. Each data point represents a separate search for electrical failures, starting in July of 1977. Because of a considerable number of hail-cracked cells in the system, it is expected that this curve will continue to rise. Copies of all curves and data are available from the authors.

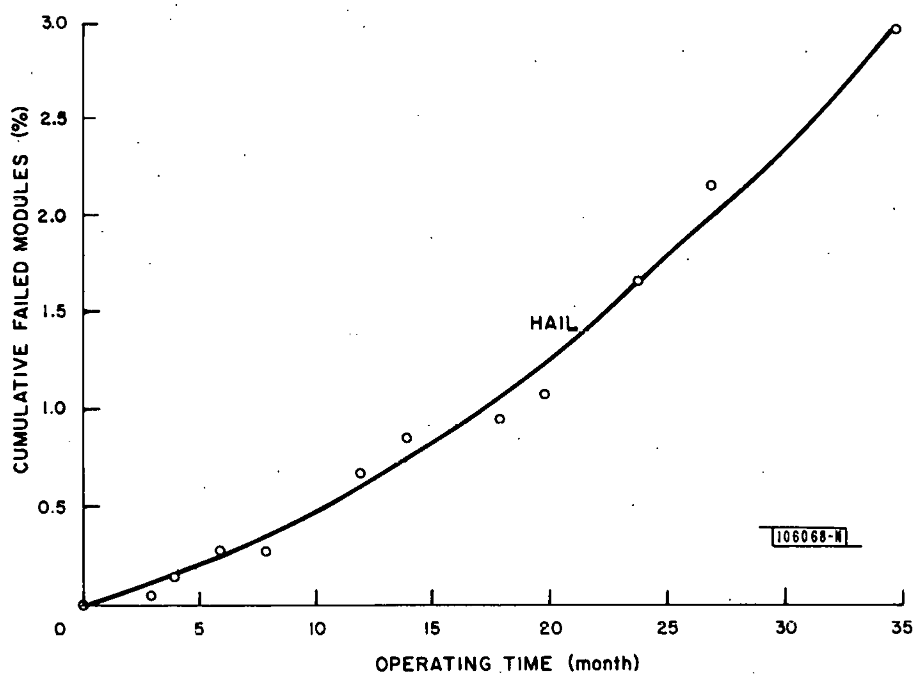


Fig. 12. In-service performance record for 2240 Nebraska PV modules.

4.4 Other Observations and Tasks

While making I-V curves on frame N-11, it was noticed that the branch circuit's negative leads for circuits 2 and 3 had been exchanged. This had no effect on total output when the three circuits were paralleled since the negative terminals are all common. This was fixed by the resident site manager.

The solid-state relay for array S-6 chatters when the array is switched on-line. This appears to be an intermittent problem that should be corrected.

Forty-six modules filled with cracked cells were removed from the two designated degradation analysis frames. These modules were returned to the MP&TL for analysis with the infrared microscope prior to use of this device at the Mead test site. In addition, one hail pad was removed as there was evidence of a number of small hailstone (1/4 to 1/2-inch-diameter) impacts.

The Mead test site continues to operate reliably with now-considered obsolete modules. The site speaks well of the initial efforts and thoughts behind its creation.

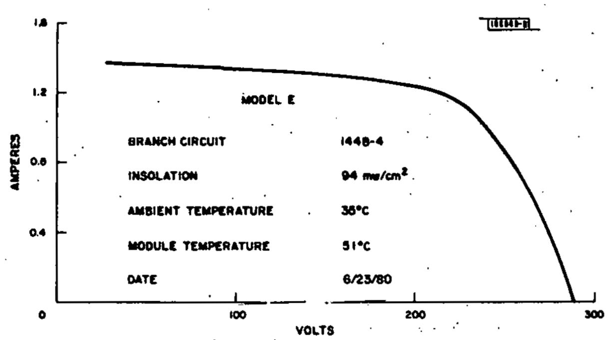
5.0 SITE EVALUATION - NATURAL BRIDGES NATIONAL MONUMENT

During the week of June 22, 1980, members of the MP&TL visited the NBNM PV test site to inventory modules and measure their performance. The weather for the week was ideal—3-1/2 days of clear blue skies with temperatures ranging from 26.6 to 40.5°C.

5.1 Branch Circuit I-V Curves

An I-V curve was made for every branch circuit in the array field. This amounts to 116, 43, and 10 I-V curves for the Model E, F, and A branch circuits, respectively.

For Model E modules, two circuits appeared to have problems. These were 114B-4, where there was one open-circuited module and branch circuit 139A-3, where there was an inoperative quintet (five modules in series). The I-V curves for these branch circuits are shown in Figs. 13 and 14 along with a curve in Fig. 15 for string 139A-3 after a replacement quintet was installed. The inoperative quintet appeared to operate normally when left in the sunlight for three or four hours after it was removed. It is



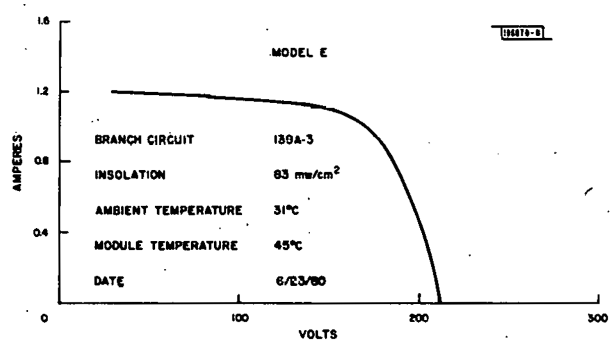
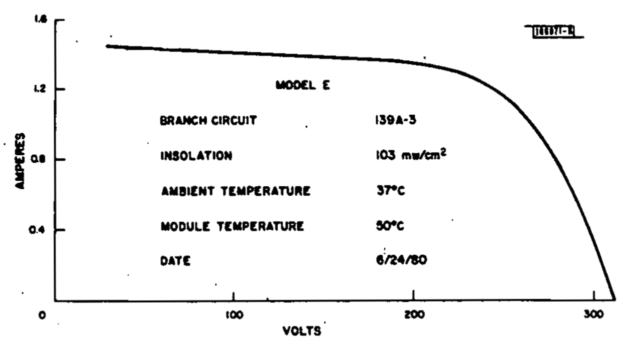


Fig. 13. Branch circuit 144B-4 with inoperative module.

Fig. 14. (Upper right) Branch circuit 139A-3 with inoperative quintet.

Fig. 15. (Right) Branch circuit 139A-3 after repair.



probable that the quintet was not properly joined electrically to its neighbors and it has been left in storage as a spare.

For Model A modules there was one branch circuit which had an irregular I-V curve (string 102, Fig. 16). Examination of each quintet (five modules in parallel) in the circuit revealed that one contained a module wired backwards. To find the module, the quintet with low output was first located and then the short-circuit current of this quintet was monitored while each module was shadowed. Shadowing a normally operating module causes a decrease in current, shadowing an open-circuited module causes no change in current, and shadowing a module wired backwards causes current to increase. The module was wired properly by partially removing the protective screen on the back of the frame and reversing the wires attached to the terminals. Unfortunately, this was one of the modules with five lugs attached to one terminal. The normal curve for this circuit is shown in Fig. 17. Troubleshooting in the Model A arrays is further complicated unless a wiring diagram is available to determine where the pieces of each quintet are located. It is recommended in future array wiring that electrically grouped modules be reasonably grouped mechanically to facilitate fault location and removal.

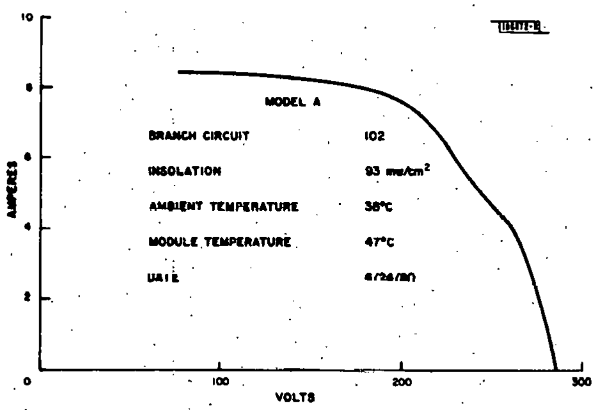


Fig. 16. Branch circuit 102 with module installed backwards.

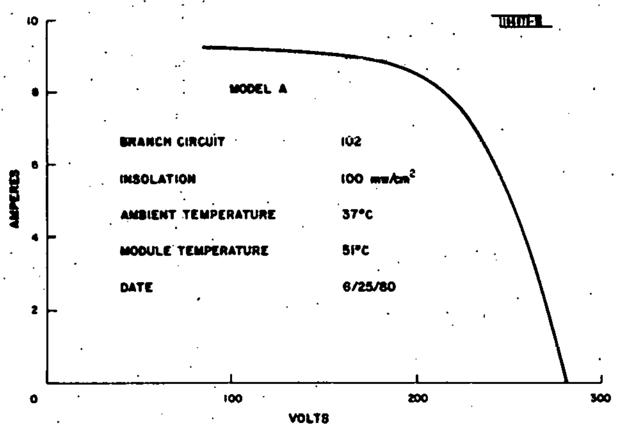


Fig. 17. Branch circuit 102 after repair.

For Model F modules, no curves could be obtained for branch circuits 110A, 120B, and 135A. On string 135A, a normal open-circuit voltage and short-circuit current were measured at the array frame but not at the control console. The exact problem could not be determined. For string 120B the branch-circuit diode in the subarray junction box (SAJB) was found to be inoperative; electrical output could not be passed to the I-V curve-making equipment. On string 110A there were breaks in the power wiring near the SAJB as well as one module (which was replaced) shorted to ground. (Thus far, 28 modules have been found shorted to ground.)

5.2 Cracked Cover Sheets in Model A Modules

The first field inspections in January 1980 revealed 24 Model A modules with cracked glass covers. It was thought initially that these cracks were caused during shipping, handling, and installation. Such was not the case, however. Not only have the cracks grown, but 28 more modules were found with cracks in their glass covers. The cracks were apparently caused by differential thermal expansion of the glass covering the cells and the glass at the module edges. The problem is being analyzed further at JPL.

A complete listing of the locations of each module with a cracked cover sheet is given in Table II for January and June observations.

5.3 Other Tasks

Members of the MP&TL labeled every module at National Bridges (except those in the trailer) with an MIT/DOE property number. These numbers will be used in conjunction with vendor serial numbers to develop a complete computer inventory and map of the modules at NBNM.

TABLE II

LOCATIONS OF MODULES WITH CRACKED COVER SHEETS

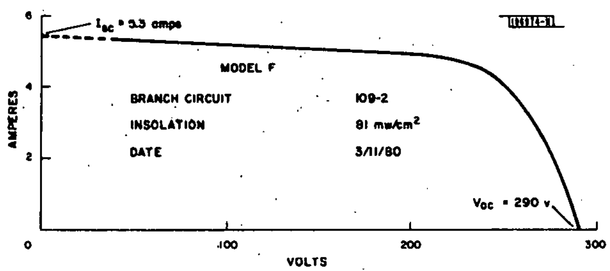
Frame No.	January	June
101A	10C	-
101B	-	12A, 10B
102A	12C	5B, 8A, 7B
102B	12B, 11A, 11C	12B, 3B, 9C
103A	4A	-
103B	9A, 8A, 8C, 7A, 7B	-
104A	10B	11A
104B	-	5A
105A	11B, 10B	8C, 6B
105B	10C	-
106A	7A	12A, 9A
106B	10C	2A, 9A
107A	11B	-
107B	8A, 7B	8A, 4B, 10C
108A	3A	10C
108B	-	7A
111A	10B	3A, 8B
111B	7B	-
112A	-	3A, 4A, 9A, 9B
112B	12A	5B
Totals	24 modules	28 modules

Troubleshooting in the Model A and E arrays appears straightforward, but the Model F arrays still pose problems. Documented techniques are required before the park rangers can be instructed in their use.

6.0 SITE EVALUATION - NBNM (FIRST LOOK)

During March 3–11, 1980, staff members of the MP&TL attempted to generate I-V curves for each branch circuit in the NBNM array field. In spite of the weather (which was extremely uncooperative) 169 curves were obtained. These curves provide first-look diagnostics of the condition of the modules in the array field. The only data to be presented here is that which is different than that described in the June visit (previous Section).

There are 43 Model F branch circuits, each containing 48 modules in series. A normal I-V curve is shown in Fig. 18 for string 109-2 where V_{oc} = 290 volts and I_{sc} = 5.3 amperes at an insolation of 101 mw/cm^2. There were four branch circuits with markedly reduced open-circuit voltages, namely, strings 116-1 at 142 volts, 116-2 at 160 volts, 124-1 at 55 volts, and 124-2 at 25 volts. One string (112-2) had a suspicious value of 278 volts; it has had previous problems. The I-V curves for the first two of these branch circuits are shown in Figs. 19 and 20. Each branch circuit was found to contain at least one module shorted to ground.



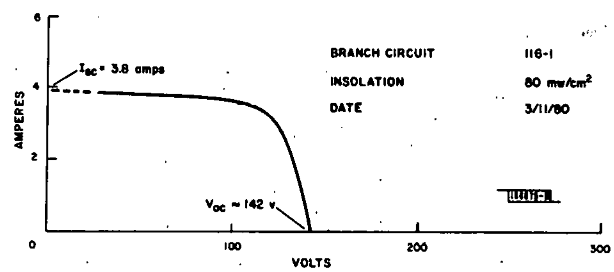
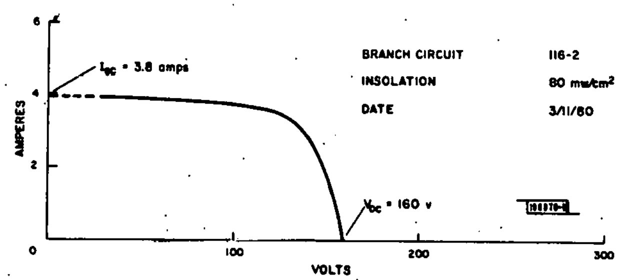


Fig. 18. Branch circuit 109-2, normal condition.

Fig. 19. (Upper right) Branch circuit 116-1, irregular condition.

Fig. 20. (right) Branch circuit 116-2, irregular condition.



In view of the weather problems, no attempt was made to trace the problems in each branch circuit. Troubleshooting was performed between March and the June visit as described in the previous Section.

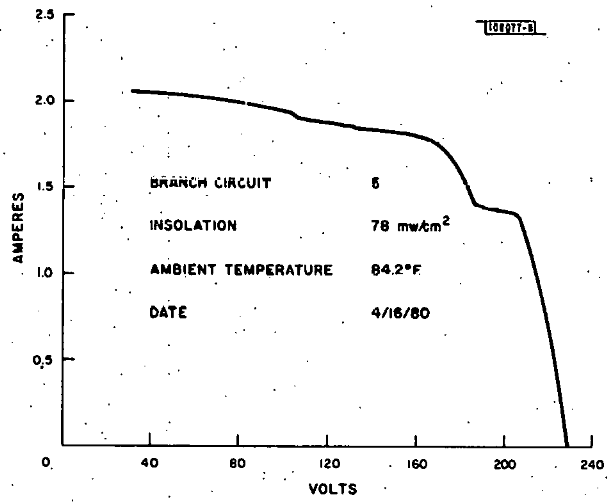


Fig. 21. UTA branch circuit 5.

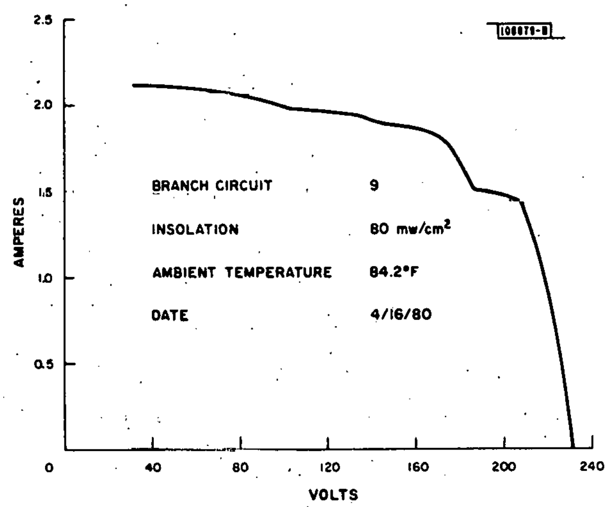


Fig. 22. UTA branch circuit 9

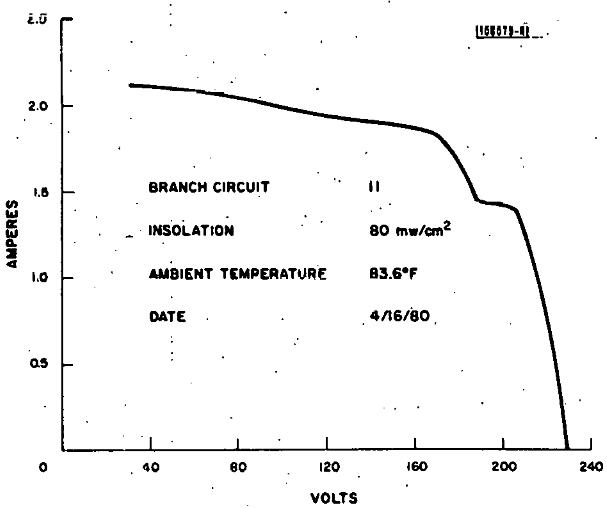


Fig. 23. UTA branch circuit 11.

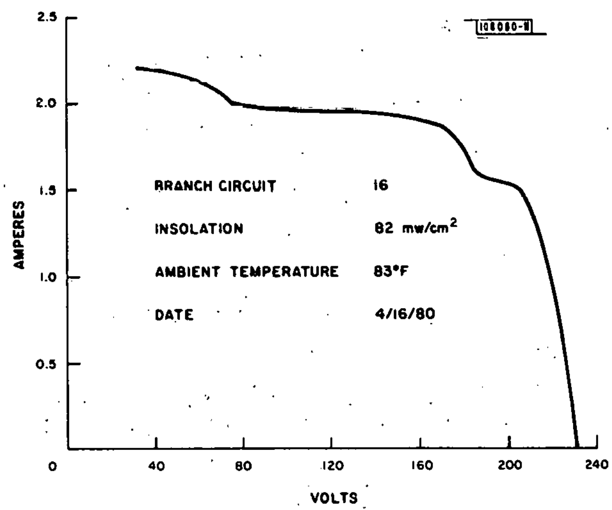


Fig. 24. UTA branch circuit 16.

7.0 I-V CURVE MEASUREMENTS AT UNIVERSITY OF TEXAS AT ARLINGTON

On April 16, 1980, the authors visited the UTA array field to make I-V curves of the newly installed branch circuits of Block III Model C modules. The sky was clear blue and temperatures ranged from 26.6 to 37.7°C during the entire operation.

When the UTA system was installed in August 1978, 240 Block II Model B modules were utilized. Between then and March 1980, 65 modules were found with reduced short-circuit currents (less than 75 percent of their nominal value). By mutual agreement with JPL, this condition consitutes a module failure. Each failure contained one or more cracked cells, most of which were caused by hot-spot heating under reverse-bias conditions.

In March 1980 the Model B modules were all replaced with 640 Block III Model C modules which are smaller in size and power. While the Model B array field had a nominal output power of about 6.9 kW, the new array field has an output of about 6 kW. Half of the Model C modules installed were new, while the other half had been removed from the LL Residential System Test Facility (RSTF) after one year of service. Each module was checked electrically prior to installation, and the array field was washed after installation.

An I-V curve was made during the morning for each branch circuit, each of which consists of 40 modules—four in parallel by 10 in series. There were four branch circuits that had obvious failures—strings 5, 9, 11, and 16 (Figs. 21–24). After replacing the failures, the branch-circuit I-V curves no longer showed a step near the peak power point. However, steps were evident at voltages away from the peak power point for several branch circuits (Fig. 25) after the failure replacement in the curve for string 16. The array field was washed with alconox and hot water to determine whether cleaning the array would smooth out the I-V curves.

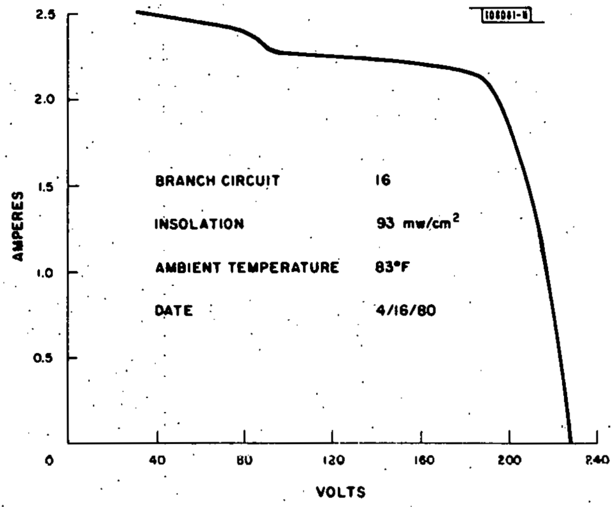


Fig. 25. UTA branch circuit 16 after repair.

After washing, an I-V curve was again made for each branch circuit (Figs. 26–41). Very distinct steps remained in strings 1, 3, 5, 9, 13, 14, 15, and 16, while poor fill factors (compared to string 7 in Fig. 32) were evident for most strings. The short-circuit current of each quad in string 15 was then measured with the following results: 2.24, 1.99, 2.01, 2.00, 2.07, 2.21, 2.01, 1.93, 1.96, and 2.31 amperes. The short-circuit currents of each module in the last two quads was then measured with the following results: 1.96-ampere quad: 0.51, 0.51, 0.51, and 0.49 amperes, and 2.31-ampere quad: 0.6, 0.6, 0.59, 0.59 amperes.

The 1.96-ampere quad consisted of four modules from the MIT LL

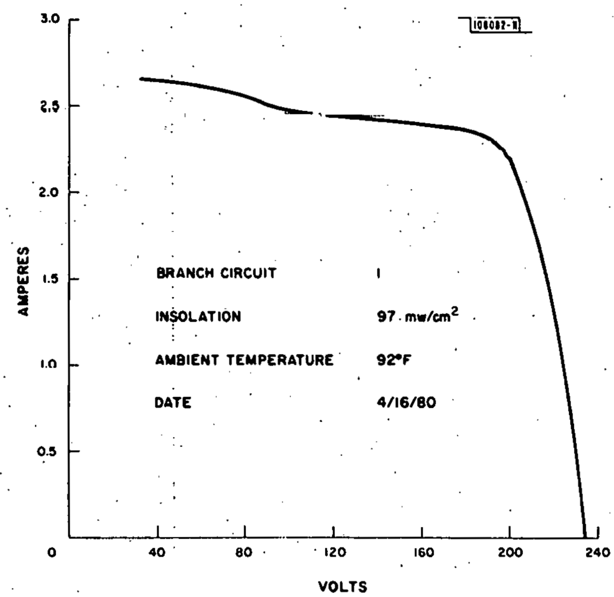


Fig. 26. UTA branch circuit 1 after washing.

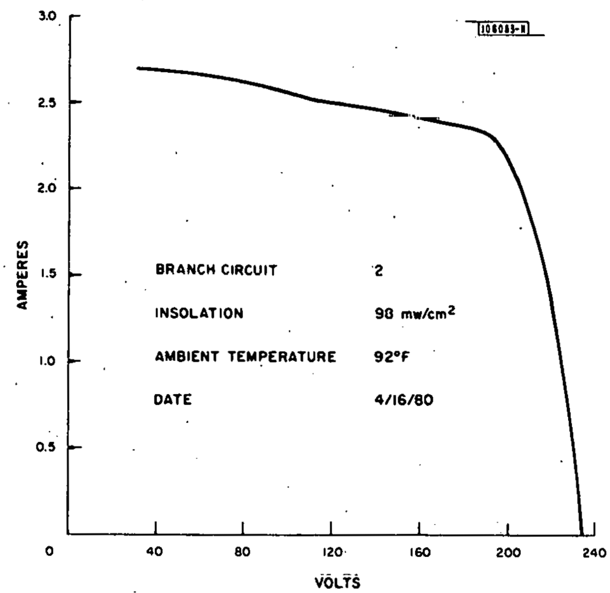


Fig. 27. UTA branch circuit 2 after washing.

RSTF and the 2.31-ampere quad consisted of new modules. It is clear that the surface dirt gained from one year of exposure had become embedded in the RTV encapsulant. Using alcohol for cleaning a 0.51-ampere module could be brought up to 0.54 ampere.

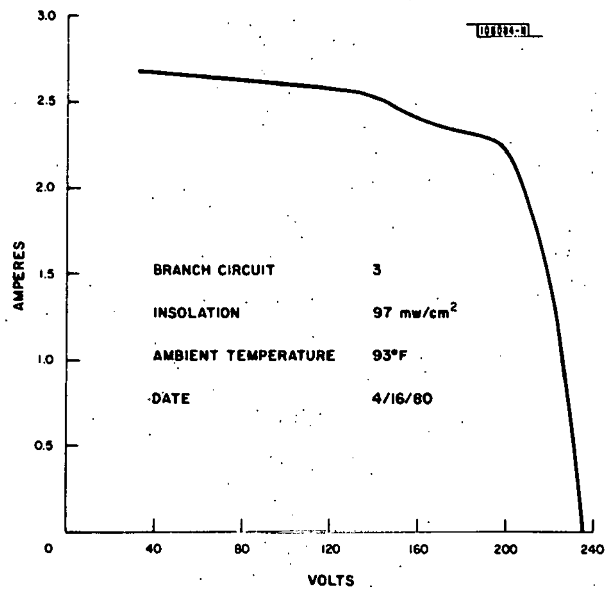


Fig. 28. UTA branch circuit 3 after washing.

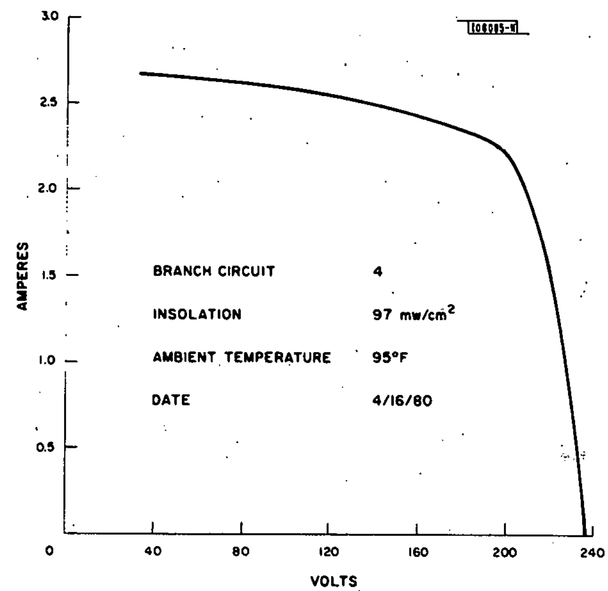


Fig. 29. UTA branch circuit 4 after washing.

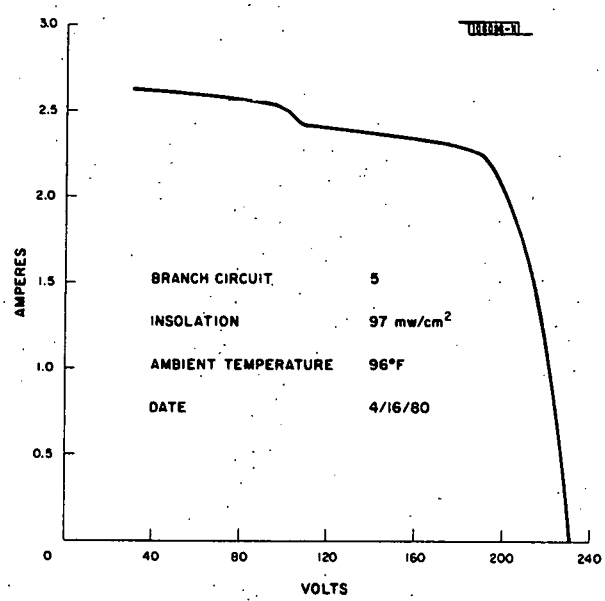


Fig. 30. UTA branch circuit 5 after washing.

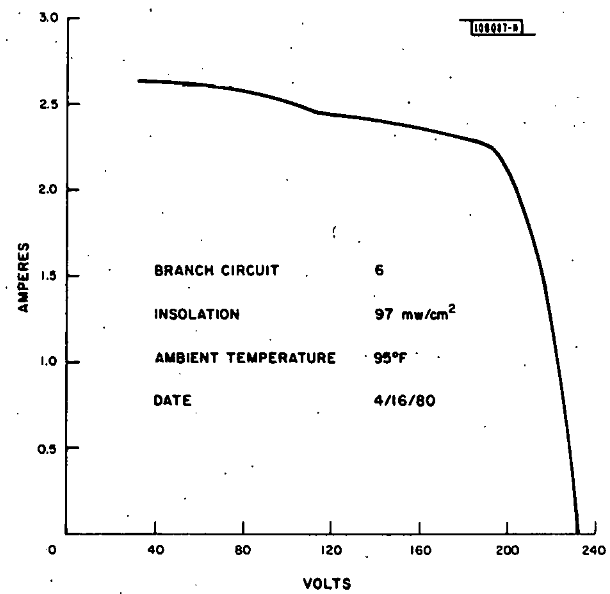


Fig. 31. UTA branch circuit 6 after washing.

Using pumice brought the increase in output to nearly 0.6 ampere. Mixing the two types of modules (new and those with one year of exposure) has caused mismatch problems throughout the array. A

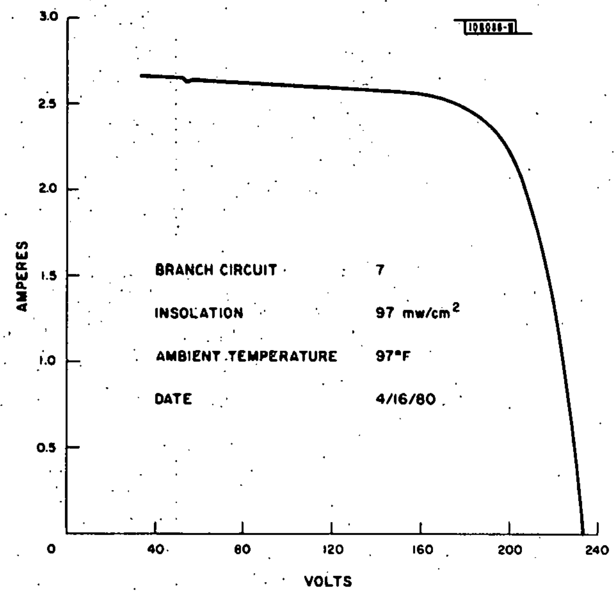


Fig. 32. UTA branch circuit 7 after washing.

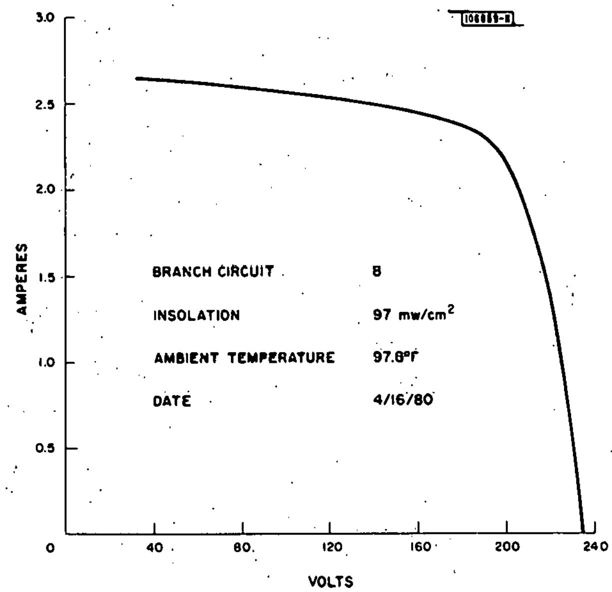


Fig. 33. UTA branch circuit 8 after washing.

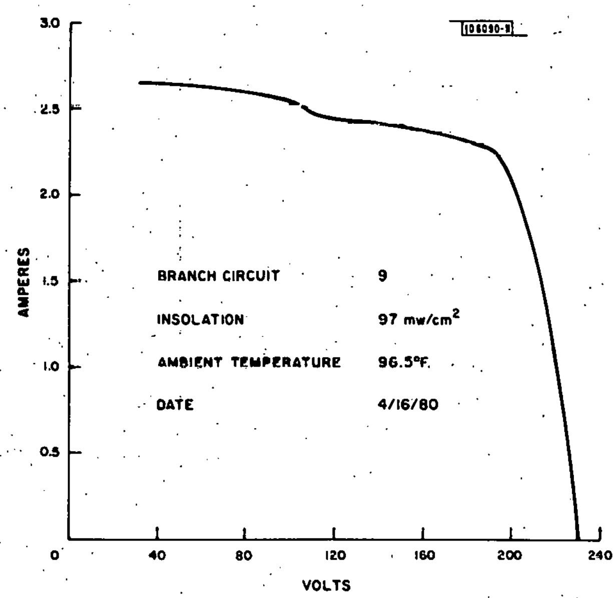


Fig. 34. UTA branch circuit 9 after washing.

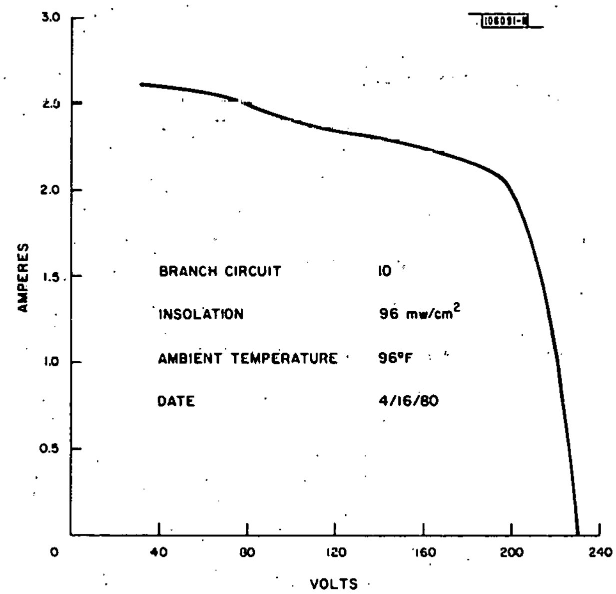


Fig. 35. UTA branch circuit 10 after washing.

supply of pumice was shipped to UTA to rewash the array with the expectation that its use will clean the older modules and reduce the mismatch losses.

Once again, branch circuit I-V curves have proven to be an

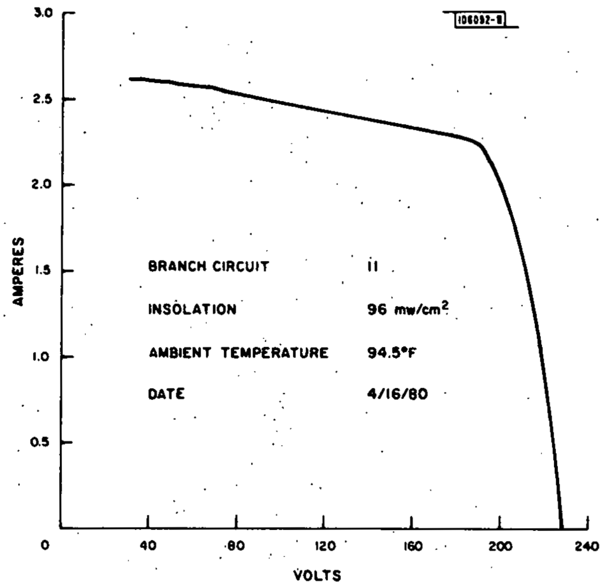


Fig. 36. UTA branch circuit 11 after washing.

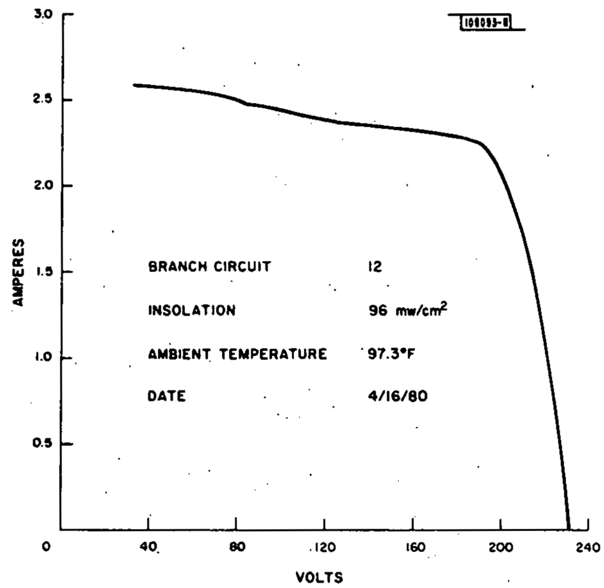


Fig. 37. UTA branch circuit 12 after washing.

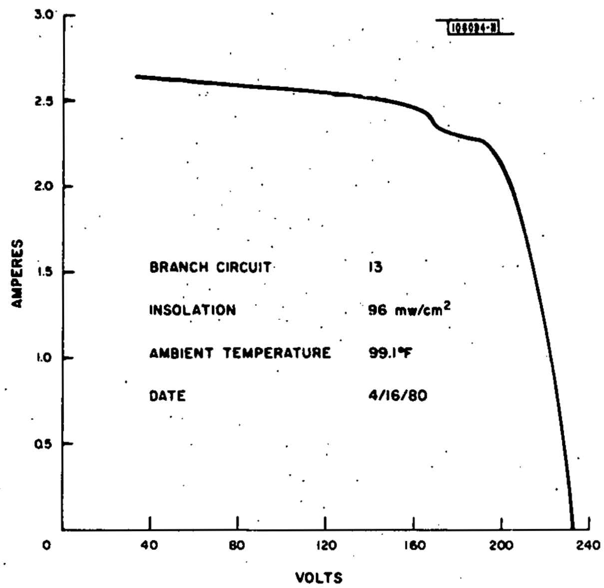


Fig. 38. UTA branch circuit 13 after washing.

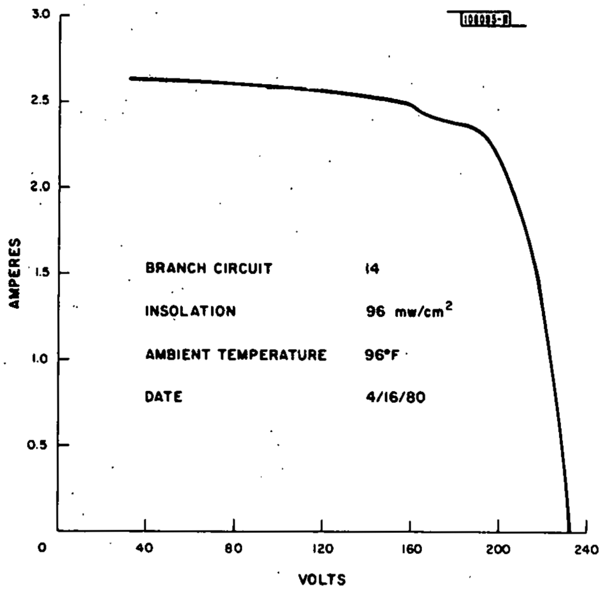


Fig. 39. UTA branch circuit 14 after washing.

invaluable tool in characterizing an array field and depicting problems within it.

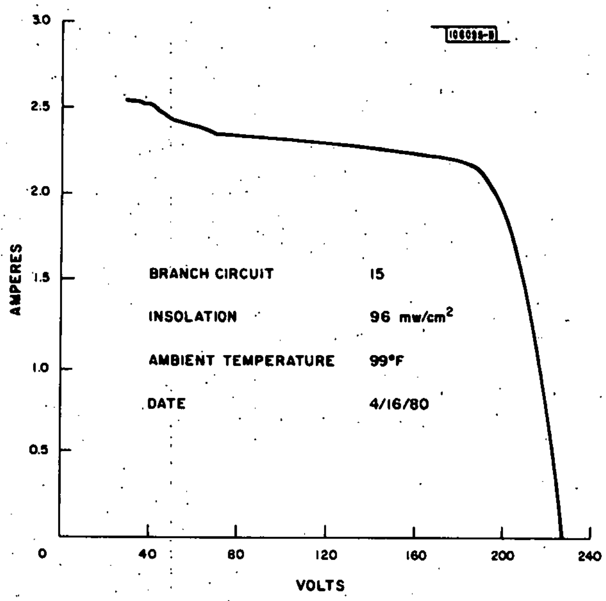


Fig. 40. UTA branch circuit 15 after washing.

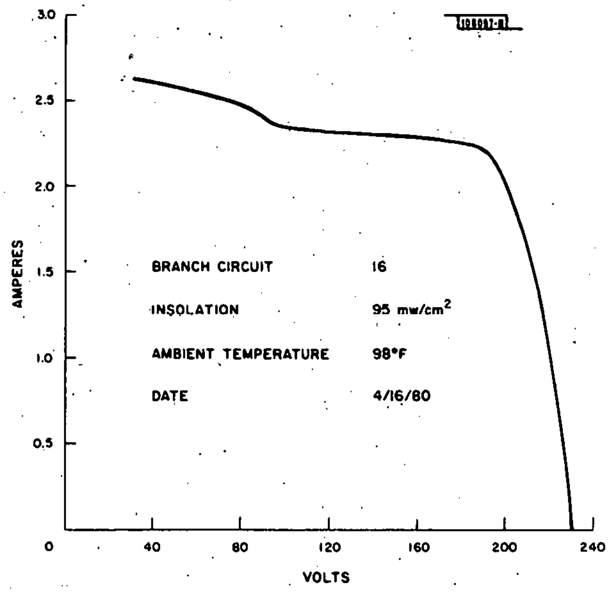


Fig. 41. UTA branch circuit 16 after washing.

8.0 MODULE FAILURE ANALYSIS

During this reporting period, electrical and visual failure analyses were completed on four Model C Block III and two Model F Block III modules. The Model C modules had been removed from the UTA residential test site on April 16, 1980, one month after their installation; they were found to have zero short-circuit current.

The two Model F modules were removed from the NBNM PV array field on April 14, 1980, three months after their installation; they were found to be shorted to ground.

8.1 UTA Failures

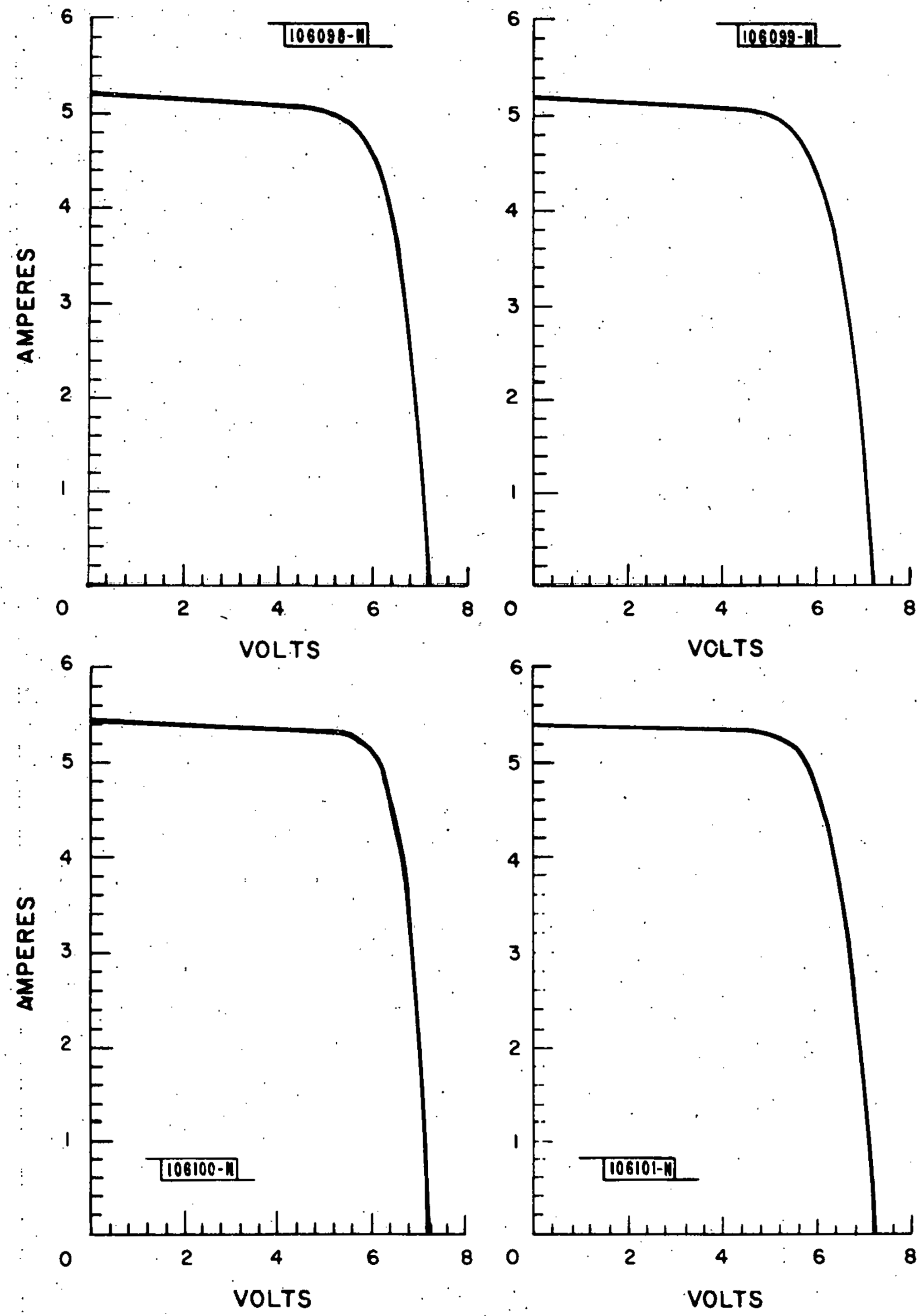
The four modules were flashed in the LL LAPSS and a flat response curve was obtained for each module.

A forward dark-curve measurement was made on each module. No forward dark-curve could be obtained on any of the four modules. By pressing on suspect cells, in the area of the rearside interconnects, a forward dark-curve was obtained on each module. However, when the pressure was released on the cell, the curve would be lost, immediately, in three cases, and, after a period of a few minutes, on the other module. Visually, no cracked cells were found. However, areas of suspected lack of solder on rearside interconnects were noted. When the modules were X rayed at LL it was confirmed that the rearside interconnects on the suspect cells were unsoldered.

8.2 NBNM Failures

The two Model F modules were flashed in the LL LAPSS in the usual method, and a normal I-V curve was obtained for each module.

On the first module, LL serial No. 20976, the negative lead was attached to the case, with the positive lead still attached to the positive terminal, and the module was again flashed in the LAPSS. A normal I-V curve was obtained indicating that the module was shorted to ground at the negative terminal (Figs. 42 and 43).



Figs. 42–45. NBNM failures: (42) leads normal, (43) positive lead on case, (44) leads normal, (45) negative lead on case.

The second module, LL serial No. 14931, was flashed a second time in the LAPSS with the positive lead attached to the case, while the negative lead was attached to the negative terminal, and a normal I-V curve was obtained. This indicated that this module was shorted to ground at the positive terminal (Figs. 44 and 45).

When the modules were examined visually, no obvious cause for failure could be found.

As the vendor identification plate is placed on the front of the module over the positive and negative terminals, it would be impossible to note any discrepancies in this area during any initial or subsequent visual inspection.

The four Model C and two Model F modules, along with the MP&TL findings, were shipped to JPL for further analysis.

Note: An additional 22 Model F modules, which were found shorted to ground at the NBNM site, have been received from the field, and electrical failure analysis has been started. When the analysis is completed, a report will cite the cause of failure.

9.0 MODEL G PV/T AIR COLLECTOR ANALYSIS

9.1 Specimen No. 1

On April 28, 1980 a newly received Model G photovoltaic/thermal (PV/T) air module (Fig. 46) was examined visually. The front plexiglass protective dome was not disturbed for this receiving examination so that the weather seal would remain intact for forthcoming testing and evaluation.

The following conditions were found on this module:

a. Taped/Spliced Wires

The wires, connecting each row of cells to the adjoining row of cells, were twisted together, soldered, and then the spliced area was wrapped with black electrical tape for insulation. The weather resistance of this type of splice is notoriously poor and these connections may prove to be a potential problem area.

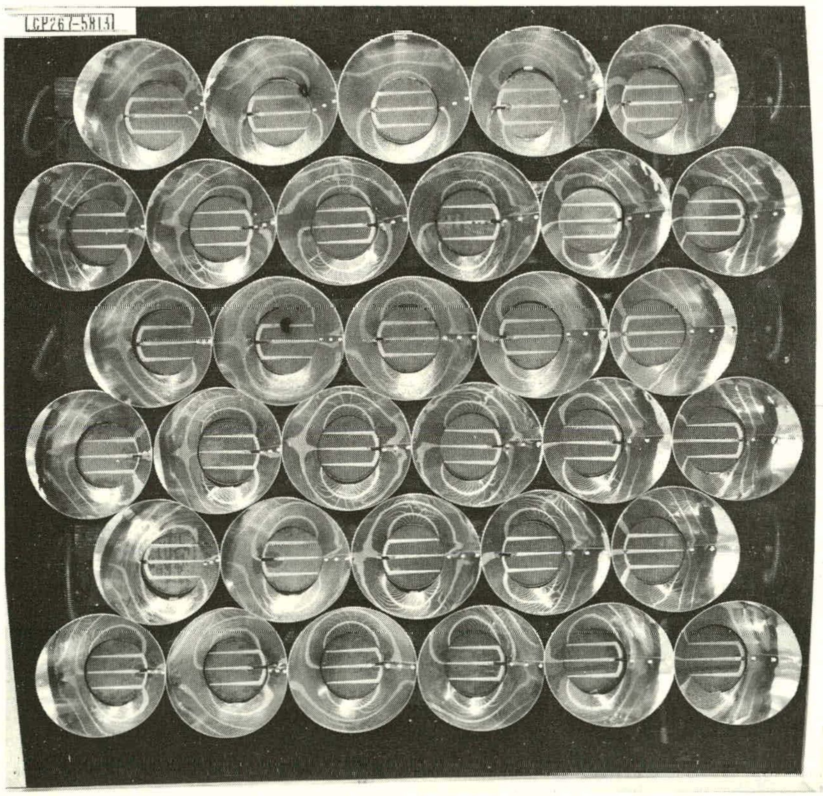


Fig. 46. Model G PV/T module.

b. Stress Relief

Most of the interconnecting wires between the cells were found to have little or no stress relief. Thermal expansion may cause cell cracking at the wire solder joints.

c. Wire Dressing

The interconnecting wires between the rows were epoxied into the channel on the heat-sink fin as a method of retention. This is a small improvement from having no retention at all, as was found on earlier versions of liquid PV/T modules built by this vendor.

d. Improperly Tinned Wire Connections

The copper stranded wires, used for cell-to-cell connections were tinned improperly prior to installation onto the cell. Numerous connections were found with the copper still showing.

e. Scratches

A few scratches were observed on the surface of four cells beneath a clear hardcoat layer on the cell front side.

f. Cracked Cell

One cell was found to have multiple cracks along one side, with one of the cracks running diagonally up the cell and terminating at the right of the interconnecting wire (Fig. 47). It is possible that this could cause a future open circuit when the cell goes through thermal cycling.

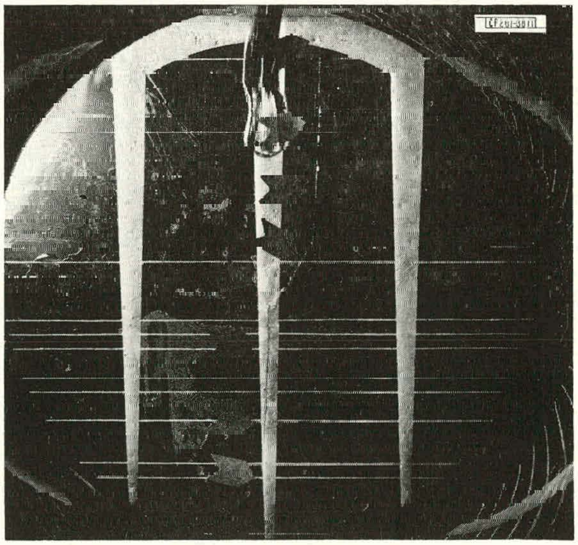


Fig. 47. Cracked cell in Model G PV/T module.

9.2 Specimen No. 2

On June 19, 1980 a second newly received Model G PV/T air module was examined visually. The protective plexiglass dome was again not disturbed for this examination so that the weather seal would remain intact for forthcoming testing and evaluation.

This module is the same as that shown in Fig. 46. The following conditions were found on this module:

a. Taped/Spliced Wires

The wires, connecting each row of cells to the adjoining row of cells, were twisted together, soldered, and then the spliced area was wrapped with black electrical tape for insulation. This technique is common for all Model G modules examined thus far and may lead to long-term degradation.

b. Stress Relief

Most of the interconnecting wires between the cells had very little or no stress relief. Thermal expansion may cause cell cracking at the wire solder joints.

c. Wire Dressing

The interconnecting wires between the rows were epoxied into the channel on the heat-sink fin as a method of retention.

d. Improperly Tinned Wire Connectors

The copper stranded wires, used for cell-to-cell interconnection were tinned improperly prior to installation onto the cell. Numerous connections were found with the copper still showing.

e. Scratches

A few minor scratches were found on the surface of several cells beneath the hardcoat.

f. Flux Residue

A residue of burnt flux was found on the majority of the solder connections on the cells. This condition is caused by the overheating of the solder during the soldering process, and poor cleaning of the soldering area afterwards.

g. Cold Solder Connection

One cold solder joint was found on a cell. This condition appears to have been caused by the movement of the wire being soldered before the solder had completely solidified.

The remaining 32 solder joints were a dull gray in appearance. This is due to overheating of the solder during the bonding process and improper cleaning of the surfaces to be soldered. A good joint will be shiny in appearance.

h. Cracked Cells

Two cracked cells were found. On the first cell, the crack started along the side of the cell and travelled diagonally along the cell, crossing one finger of the main connector and exiting to the left of the interconnecting wire connection (Fig. 48). This crack would not cause an open circuit in the cell string.

The second cell was found to have a crack travelling diagonally across the cell, running under the solder joint of the main collector. This crack has the potential to open circuit the cell string.

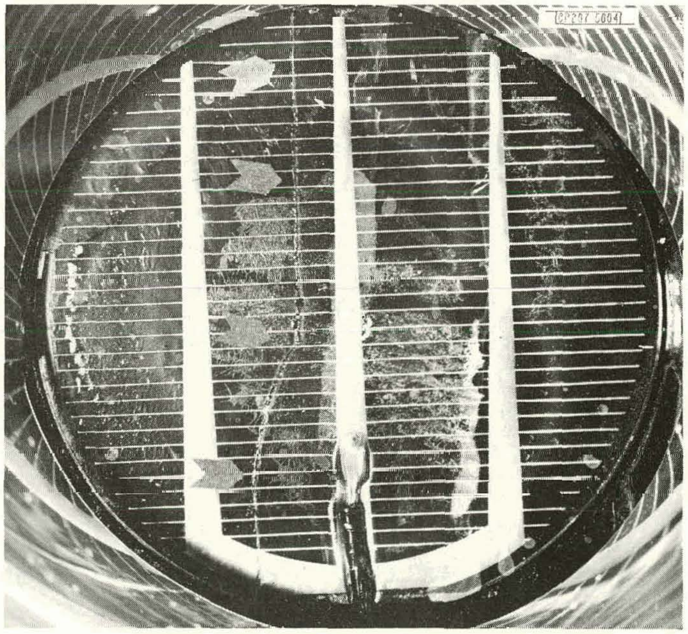


Fig. 48. Cracked cell in second Model G PV/T module inspected visually.

10.0 MODEL G PV/T LIQUID COLLECTOR DEGRADATION ANALYSIS

During this reporting period degradation analyses were performed on two Model G liquid PV/T modules. The modules were installed on the LL rooftop test bed in November 1979 where they were tested. The modules were removed in March 1980 after four months of exposure and brought to the MP&TL for degradation analysis.

A brief description of these modules follows for those unfamiliar with this type in order to better understand the results of this analysis. Physically, the module looks identical to the air collector shown in Fig. 46.

The four-foot-square module consists of six uneven rows of 33 cells. Each cell is surrounded by a conical concentrator. The cells are bonded to a black painted, metal fin that acts as a heat sink. Antifreeze (propylene glycol) is circulated through a tube running under the center of the fin to carry the heat away from the cells during residential heating and/or hot water applications. The heat sinks are pivoted by an actuator that tracks the sun under control of a sun sensor with three angular positions. The electricity generated by the PV cells is transmitted to storage batteries which supply supplemental electricity. The following conditions were found on these modules:

(The protective plexiglass front cover was removed to enable close inspection of all module components.)

a. Taped/Spliced Wires

Wires, connecting each row of cells to the adjoining row of cells, were twisted together, soldered and then the spliced area was wrapped with black electrical tape for insulation.

b. Stress Relief

Most of the interconnecting wires between the cells were found to have little or no stress relief. This condition was found throughout both modules.

c. Wire Dressing

Neither module constrained interconnecting wires between rows to prevent accidental entanglement during the tracking process

d. Paint Splitting

The black paint, sprayed on the metal fins to enhance heat absorption, was found to be splitting in several places around the cells, exposing the metal substrate. This condition was found on both modules.

e. Hardcoat

The surface of the cells had been sprayed with an unknown lacquer or hardcoat. This hardcoat was found to be blistered and/or split on 42 of the 66 cells on the two modules.

f. Delamination

What appeared to be spots of delamination of the hardcoat from the cell surface was found on three cells of one module.

g. Uncured Substrate Coating

The coating sprayed on the cells and substrate was found to be "sticky" to the touch. This condition was found in one place on one module, and in several places on the second module.

h. Conical Concentrator Mounting Bracket

The conical concentrator mounting brackets were found to be almost touching two cells on one module. The brackets were close to one cell on the second module and actually touching four other cells. It is believed that this condition could cause a short to ground of the cell string.

i. Improperly Tinned Wire Connections

The copper stranded wires, used for cell-to-cell connections were tinned improperly prior to installation onto the cell. Numerous connections were found with the copper still showing.

Although all of these areas have been coated with a hardcoat, when the hardcoat splits (as it already has), oxidation will begin on the copper wires due to the moisture in the air. Eventually, the oxidation will corrode the wires, possibly causing an open circuit in the cell string.

In addition, there were a couple of solder connections that had a single strand of wire sticking up out of the solder joint, as well as several connections where the wire had fanned out during the soldering process. These conditions are generally caused by improperly preparing the wires to be soldered.

The solder connections were a dull gray in appearance rather than shiny as a good solder joint should be. This condition could be due to overheating of the solder, underheating of the area to be soldered, or improper cleaning of the areas to be soldered.

j. Pivot Bushings

The nylon pivot bushings, located at the end of each of the liquid tubes, were found to be very loose in 21 of the 24 places on the two modules.

k. Corrosion Spots

Sporadic spots of corrosion were found on all 33 conical concentrators on one module.

A plastic hose carrying the liquid and clamped to the tube on the underside of the heat-sink fin had fallen off, spraying antifreeze throughout the interior of the module. The antifreeze evidently splashed on the metal of the concentrator cones and caused them to become corroded. This condition was due either to the failure of the retaining clamp on the plastic tube, or improper installation of the clamp during vendor assembly.

l. Cracked Cells

Each module was found to have one cracked cell. The first module had a cell that had cracked from top to bottom along one side of the cell. This would not cause an open circuit.

On the second module, the crack in the cell started to the right of the interconnecting wire, cut diagonally down through the center main collector and exited to the left of the rearside interconnecting wire leading to the next cell in the string. This condition could cause an open circuit in the future.

m. Scratches

Of the 66 cells on the two modules, 23 were found to have multiple scratches on the surface of the cell beneath the hard-coat.

n. Chipped Cell

One module was found to have a cell with a portion chipped out of the cell rim.

Note: The blistering and splitting of the hardcoat covering the cells made it difficult to tell if there were any additional cracked cells.

11. RELOCATION OF LAPSS

During this reporting period the LAPSS was relocated from the main location at Lincoln Laboratory to the RSTF. During installation, the LAPSS was realigned and recalibrated and is now fully operational at its new location.

Figure 49 represents the beam uniformity over a 6 x 6-foot area. Clearly, there is no more than a 4-percent deviation from one location to any other.

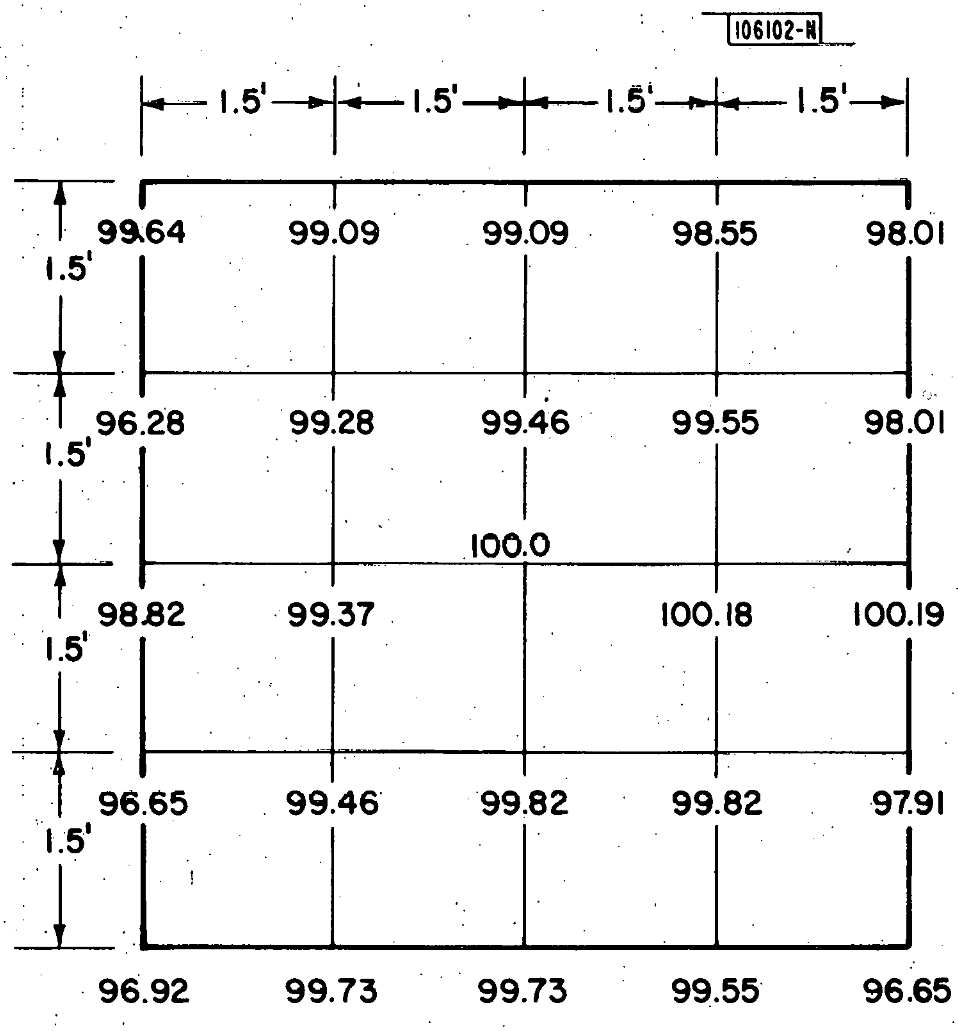


Fig. 49. LAPSS uniformity, June 4, 1980.

Table III represents flash data for new type C and D modules that have been repeated at various times over a two-year period to verify the LAPSS calibration. Agreement of short-circuit current (I_{sc}) is excellent and similarly for the open-circuit voltage (V_{oc}).

TABLE III

ELECTRICAL OUTPUT OF MODULES KEPT AS STANDARDS "FLASHED" BEFORE AND AFTER LAPSS RELOCATION

Module	Date	I_{sc} (amperes)	V_{oc} (volts)
C(II)10014	6-13-78	0.585	24.55
	4-24-80	0.590	25.15
	6-4-80	0.584	24.65
C(II)10077	6-13-78	0.570	24.92
	6-04-80	0.570	25.00
D(III)11926	7-25-78	1.407	23.30
	6-04-80	1.399	23.75
D(III)11927	7-25-78	1.376	23.78
	6-04-80	1.378	24.00

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