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THERMAL CYCLING TEST OF A FLEXIBLE SOLAR CELL MODULE

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SUMMARY

A thermal cycling test was performed on a representative module of a flexible rolled-up solar array. The experiment was designed to expose the module to temperature cycles between 87° C in simulated sunlight and -108° C in darkness at a pressure of 10^{-7} torr. Conditions were chosen to simulate the temperature profile the array would experience while in orbit. The test module was exposed to over 2000 such cycles. The results showed that changes in open-circuit voltage and short-circuit current were within measurement error. The cover glasses did not crack or delaminate and the soldered silver mesh interconnect did not fail. Stains were visible on the module and there was a very slight darkening of the fiberglass reinforcing in the Kapton substrate. This did not appear to affect performance.

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INTRODUCTION

The Air Force Aero Propulsion Laboratory with a contract to Hughes Aircraft Company (ref. 1) is developing a flexible rolled-up solar array. This program is designed to demonstrate the capability of large retractable solar arrays to supply electrical power to advanced aerospace vehicle systems. The effort includes the design, fabrication, qualification for flight and orbital flight test of an actively sunoriented 1.5 kW array.

The NASA Lewis Research Center, because of availability of facilities, was requested by the Air Force to perform thermal cycling tests on a representative module of the flexible rolled-up solar array. The experiment was designed by Lewis to expose the module to temperature cycles between 87^{o} C in simulated sunlight and -108^{o} C in darkness at a pressure of 10^{-7} torr. Sunlight was simulated by a filtered short arc xenon lamp. The module was exposed to over 2000 such cycles. Current-voltage characteristics of the module were obtained periodically to measure performance.

APPARATUS AND TESTS

The Air Force supplied NASA Lewis with two representative modules of the flexible rolled-up solar array. One module was prepared for testing while the other was used as a control. These modules were manufactured by Hughes for this test. Briefly, the modules are made up of nine N/P 8-mil thick silicon solar cells with 6-mil cover glasses, series-parallel connected and bonded to a flexible substrate of fiberglass reinforced Kapton. A complete description of the fabrication process can be found in reference 1.

Initial performance measurements (pre-test data) of the modules were made on the temperature controlled plate shown in figure 1. For these measurements the simulator was rotated through 90 degress so that the light beam was incident on the temperature controlled plate. With the simulator in this position, measurements of the beam intensity, uniformity and spectrum were also obtained using standard solar cells, the control module and calibrated radiometers. These intensity and uniformity measurements were used to correct the in-situ data.

Calculations by Hughes indicated that portions of the flexible rolled-up solar array near the spacecraft would reach temperatures near 90^{o} C due to earth albedo, reflections from the spacecraft and incident sunlight. During the eclipse portion of the orbit, temperatures were expected to drop to about -100^{o} C. The thermal cycling facility used for this test figure 2 (ref. 2) was capable of temperature cycles of about 50^{o} C in sunlight and -100^{o} C in darkness. Since it was necessary to increase the sunlight temperature to near 90^{o} C, an auxiliary heating system made up of sping-loaded tantalum wires (fig. 3) was designed and installed. The heater wires were placed directly behind the module between the test plane and the LN_2 cooled back wall. Current was applied to these heaters during the sunlight portion of the cyle to raise the temperature to the required value as measured by thermocouples attached to the back of the module. The temperature profile of the module during one complete cycle is shown in figure 4.

Front and back views of the instrumented test module are shown in figures 5 and 6. The module was one of a number of different samples that were thermal cycled during this evaluation. All samples were mounted to a fiberglass epoxy frame by means of thermosetting adhesive Kapton tape. This method was found to give very low thermal conducting paths to the frame and produced very low mechanical stresses on the samples. Calibrated solar cells were also mounted to the frame to measure light intensity during the test.

Prior to the test, some stains were visible on the test module. These appeared to be on top of the cover glass, but their exact location was difficult to determine without damaging the sample. Current-voltage characteristics of the module were taken during testing to measure module performance. The module was connected to an electronic load by a four wire system to take the measurements.

RESULTS AND DISCUSSION

After initial performance measurements were made, thermal cycling of the module was begun. After 65 cyles a facility breakdown occured which necessitated shutdown and opening of the vacuum chamber. The test was restarted and was periodically interrupted for facility maintenance and repair. Most of these interruptions were for periods of two to eight hours. Some interruptions were for longer periods of time. However, with only one other exception, vacuum was maintained throughout the test. In this case, at cycle 328, the relay controlling the auxiliary heaters failed closed causing the module temperature to rise to approximately 100° C and also caused heater wire failure. Following repairs, cycling was continued to 2092^{+7}_{-0} cycles. The uncertainty in final cycle number is due to a complete shutdown of the system over a weekend when the facility was unattended. The last in-situ performance measurements were taken at cyle 1868. In-situ measurements were planned for the end of the test, but were precluded by the shutdown. Final performance measurements (post-test data) were then made on the temperature controlled block outside the vacuum chamber.

Table I shows pre-test and post-test data for the test module and the control module. The precision error for these measurements was estimated to have a standard deviation of 0.75 percent for the short-circuit current and 0.35 percent for the open-circuit voltage. All data in the table is corrected to 24° C, AMO.

The short-circuit current and open-circuit voltage of the test module as a function of the cycles is shown in figures 7 and 8. These are in-situ data and are corrected for intensity, uniformity and temperature. The temperature for these data is 84° C, which was the temperature at cycle 1. The standard deviation of these data are 1.9 percent for the short-circuit current and 0.8 percent for the open-circuit voltage. The precision of the measuring system has been determined to have a standard deviation of 2 percent for the short-circuit current and 1 percent for the open-circuit voltage. Also shown on the curves for comparison are pre-test and post-test data of the test module corrected to 84° C.

Figure 9 is a close-up photograph of the test module taken immediately after removal from the vacuum chamber. More stains were visible after the test than prior to the test. The new stains appear to be under the cover glass, but again, their exact location could not be determined. No cracking or delamination of cover glasses or failure of the soldered silver mesh interconnects could be observed. Except for the stains the module appeared to be unchanged as a result of the test. There was, however, a slight darkening of the fiberglass reinforcing in the substrate.

SUMMARY OF RESULTS

The following results were observed for a representative module of a flexible rolled-up solar array exposed to approximately 2100 temperature cycles between 87° C in simulated sunlight and -108° C in darkness at a pressure of 10^{-7} torr:

1. Changes in open-circuit voltage and short-circuit current were within measurement error.

2. Cover glasses did not crack or delaminate.

3. Soldered silver mesh interconnects did not fail.

4. Stains on the module were visible but did not appear to affect performance.

5. Fiberglass reinforcing in the substrate darkened slightly.

REFERENCES

1) Felkel, Edward O.; Wolff, George; Olson, M. C.; Turner, W.N.; and Daniel, R.E.: Flexible Rolled-Up Solar Array. Rep. SCG-10013R, Hughes Aircraft Co., Jan. 1971.

2) Klucher, Thomas M.; and Ratajczak, Anthony F.: Test of Cadmium Sulfide Solar Cells in a Series String. NASA TN D-2231, 1971.

TABLE I. - PRE-TEST AND POST-TEST DATA - AMO, 24° C

		Test Module (TC-1)	Control Module (TC-2)
Pre-test data	SCC	0.362 amp	0.363 amp
	VOC	1.696 volts	1.695 volts
Post-test data	SCC	0.364 amp	0.367 amp
	VOC	1.688 volts	1.698 volts

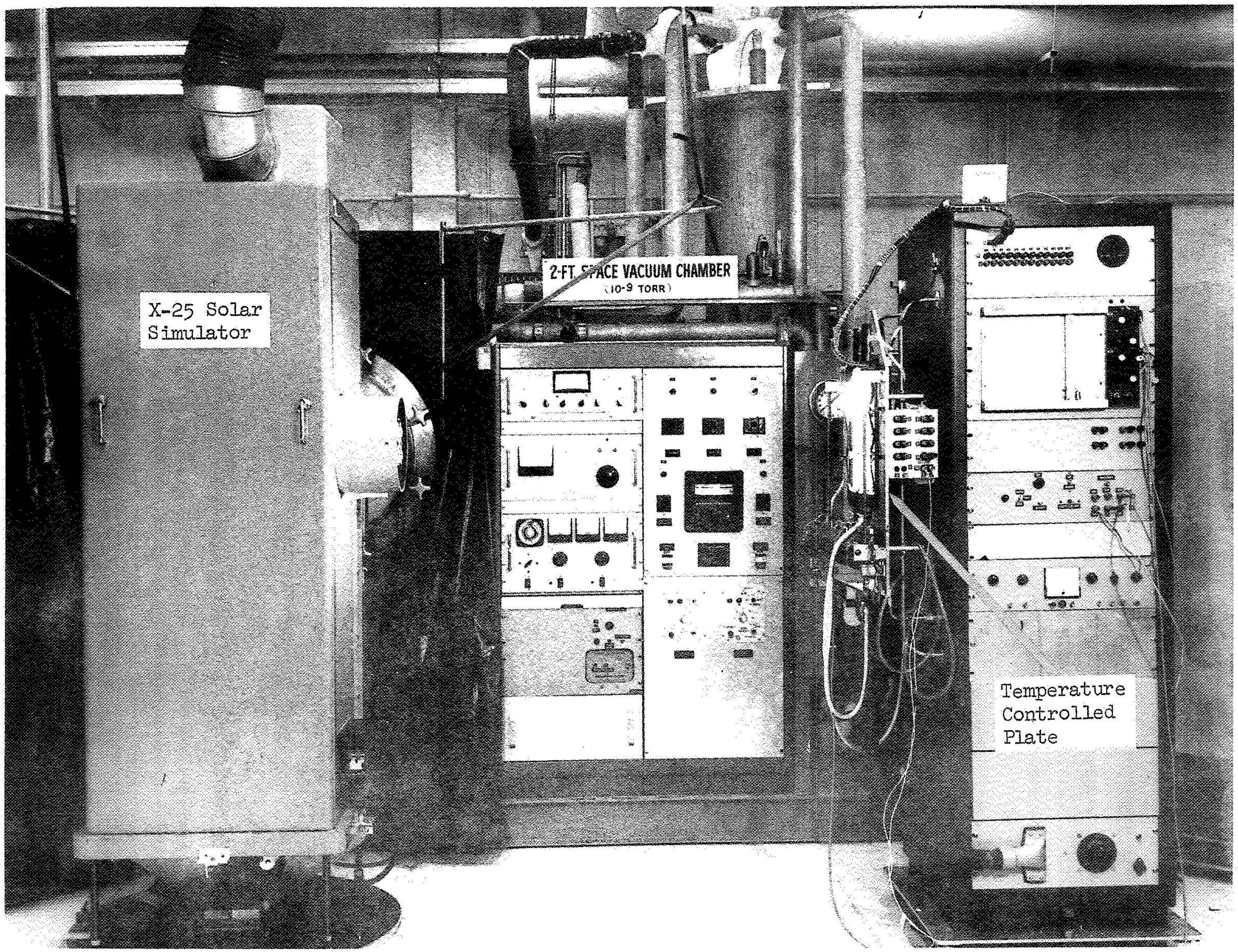

Figure 1. - Simulator rotated 90 degrees with light beam incident on temperature controlled plate.

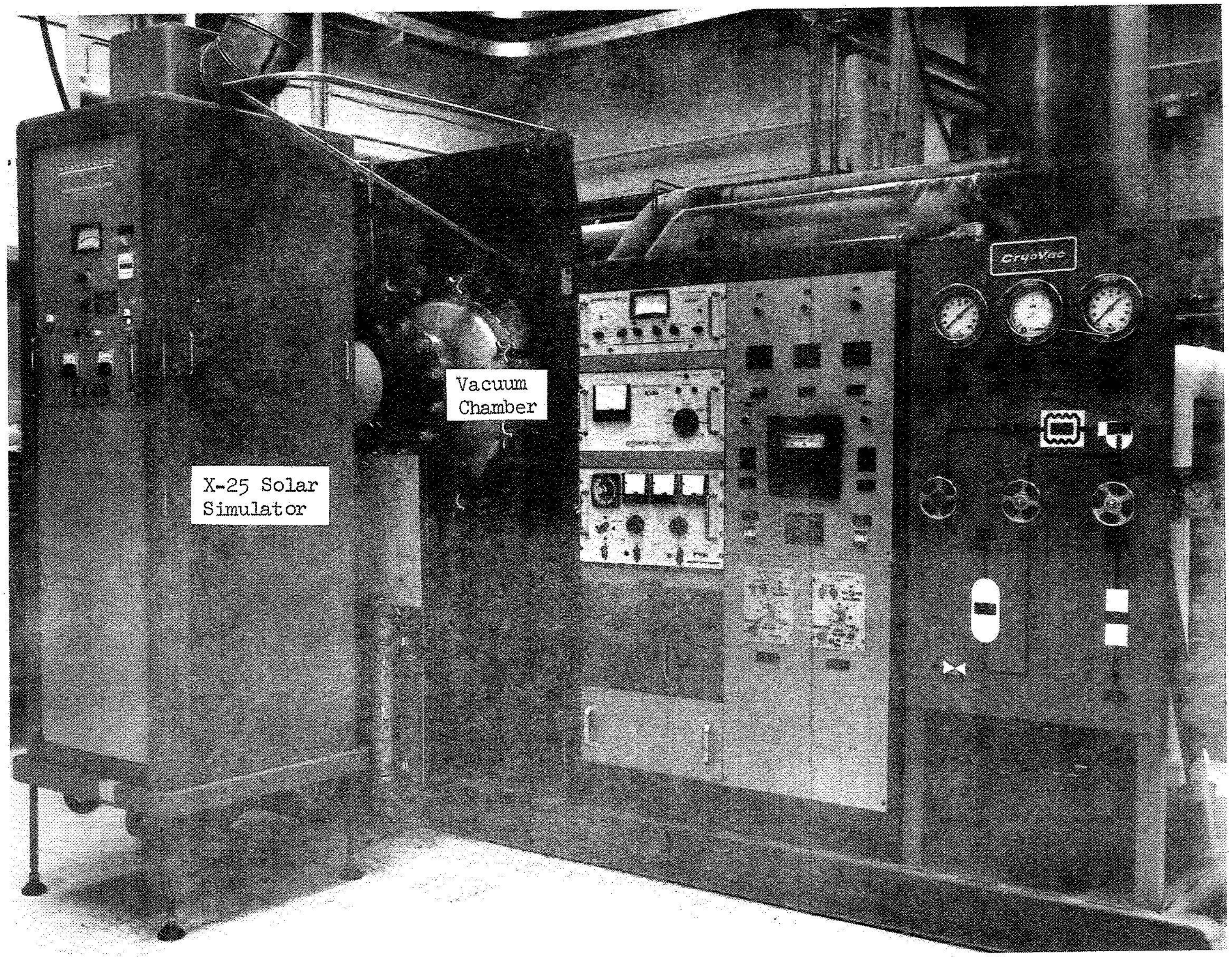

Figure 2. - Thermal cycling facility.

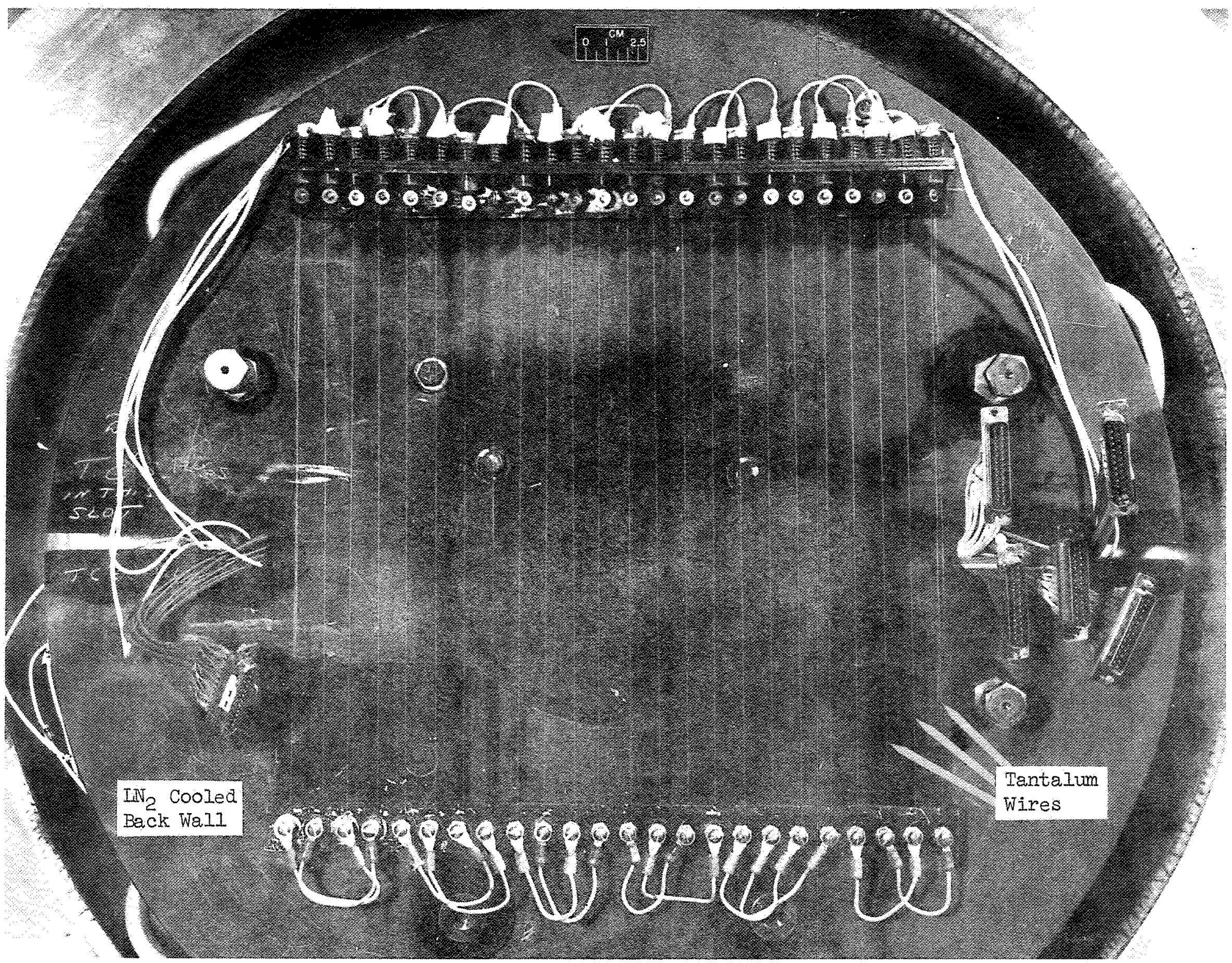

Figure 3. - Auxiliary heating system.

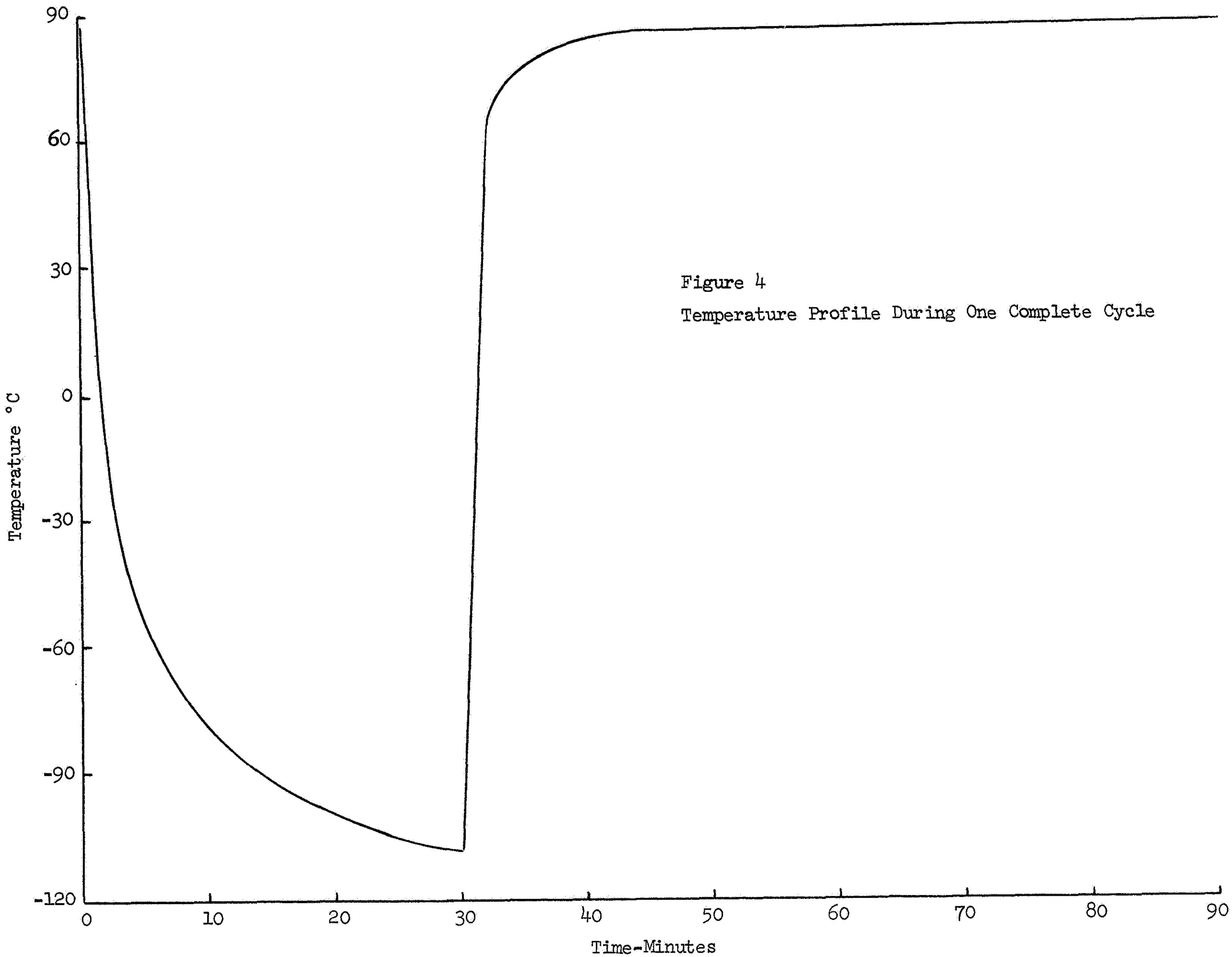

Figure 4
Temperature Profile During One Complete Cycle

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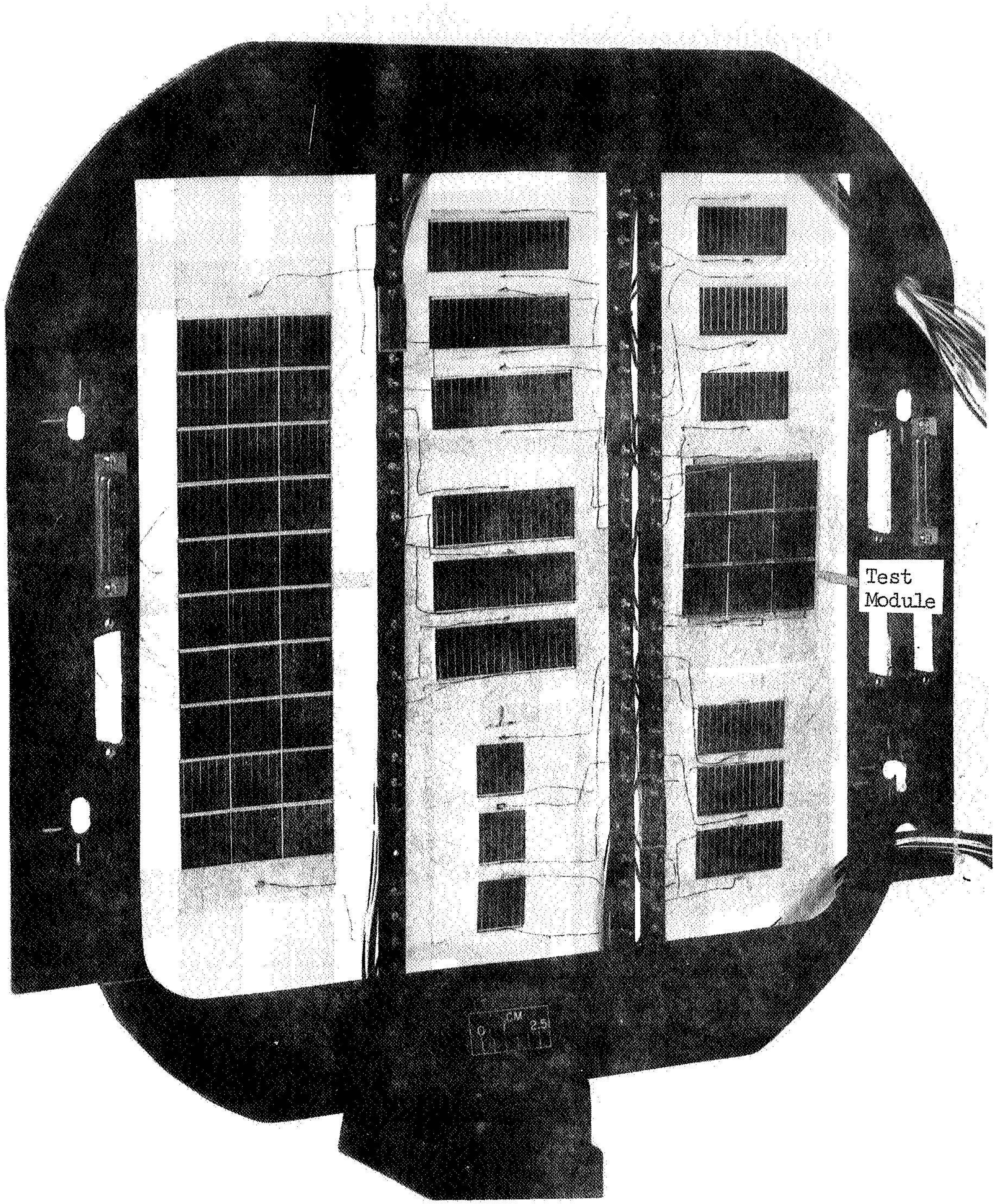

Figure 5. - Front view of instrumented samples on mounting frame.

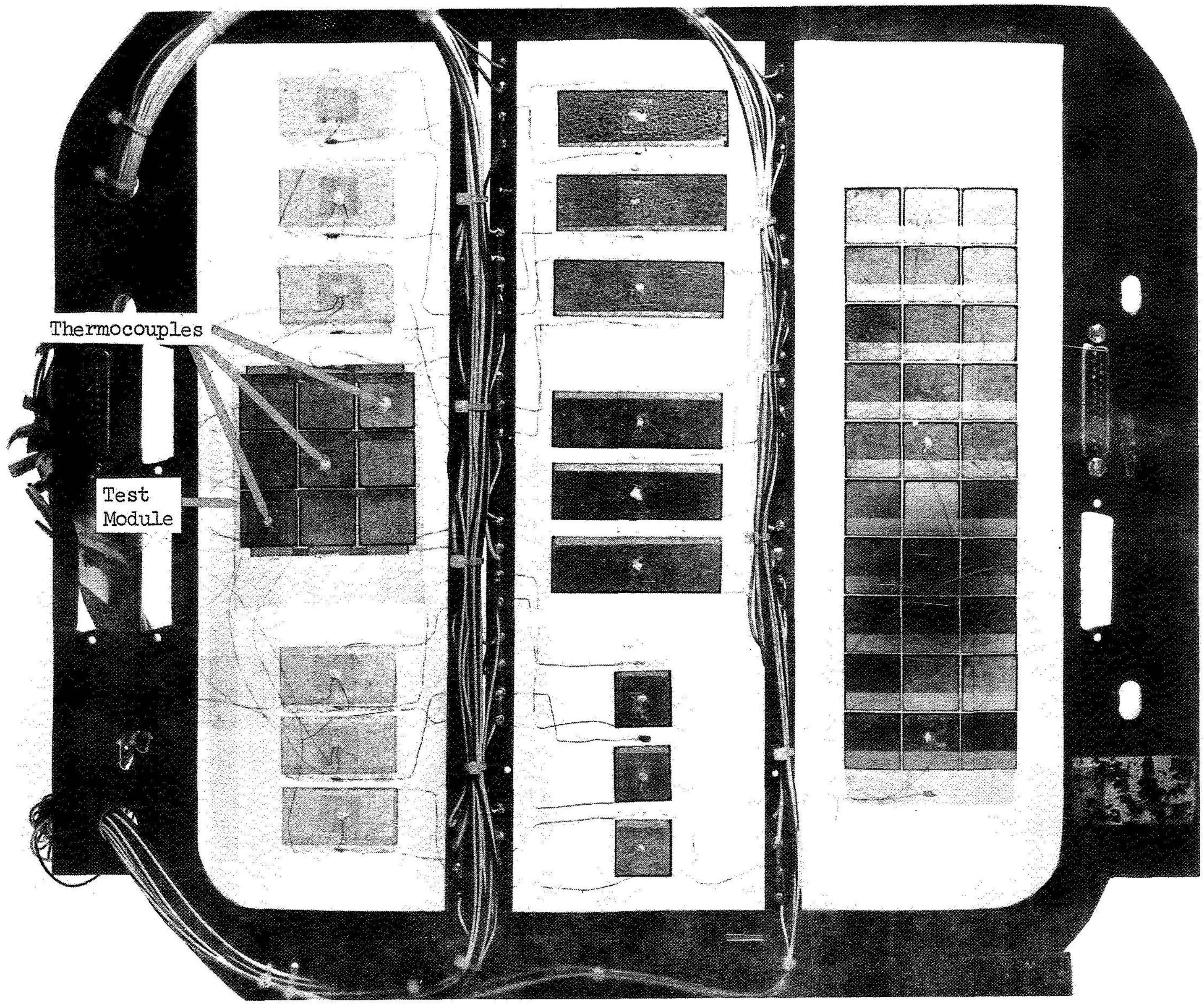

Figure 6. - Rear view of instrumented samples on mounting frame.

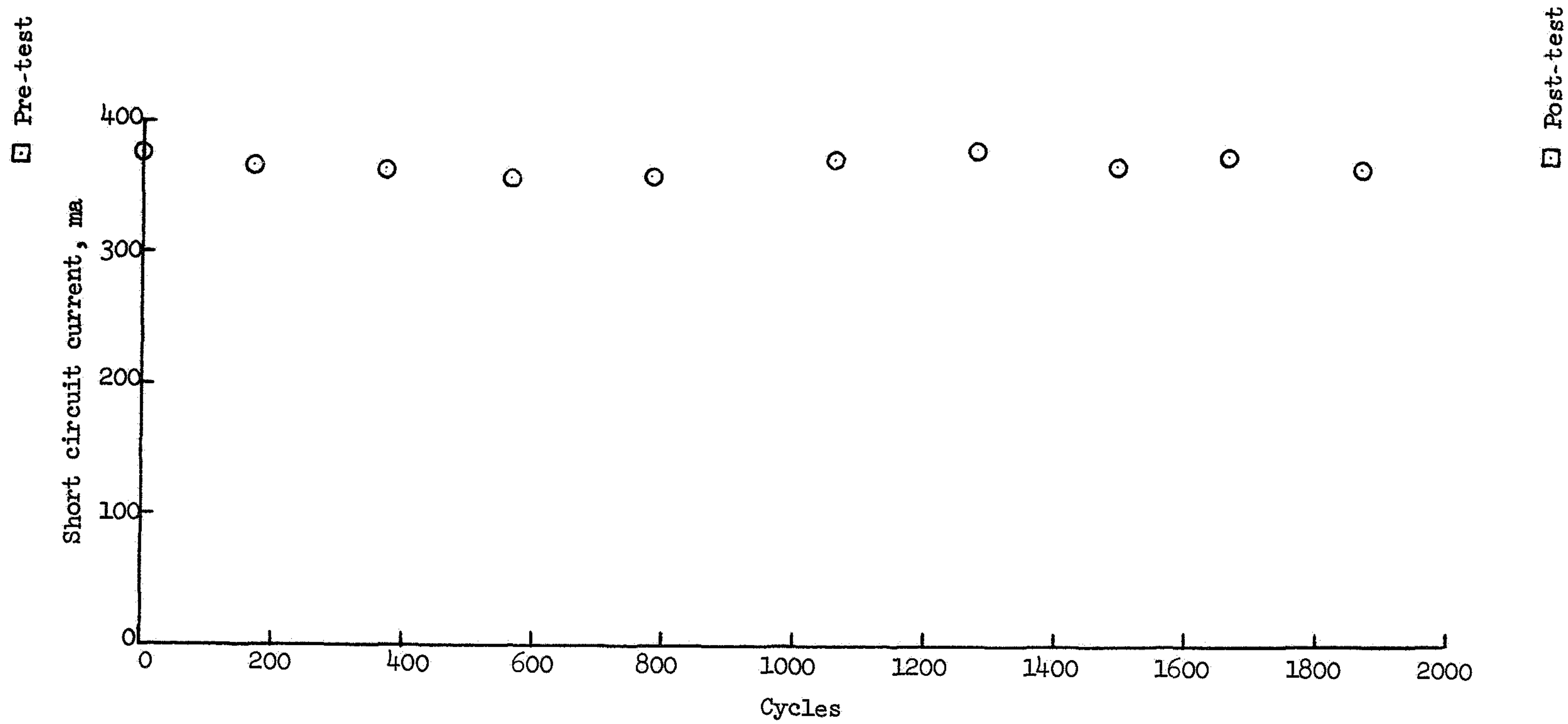

Figure 7. - In-situ short circuit current, AMO, 84° C

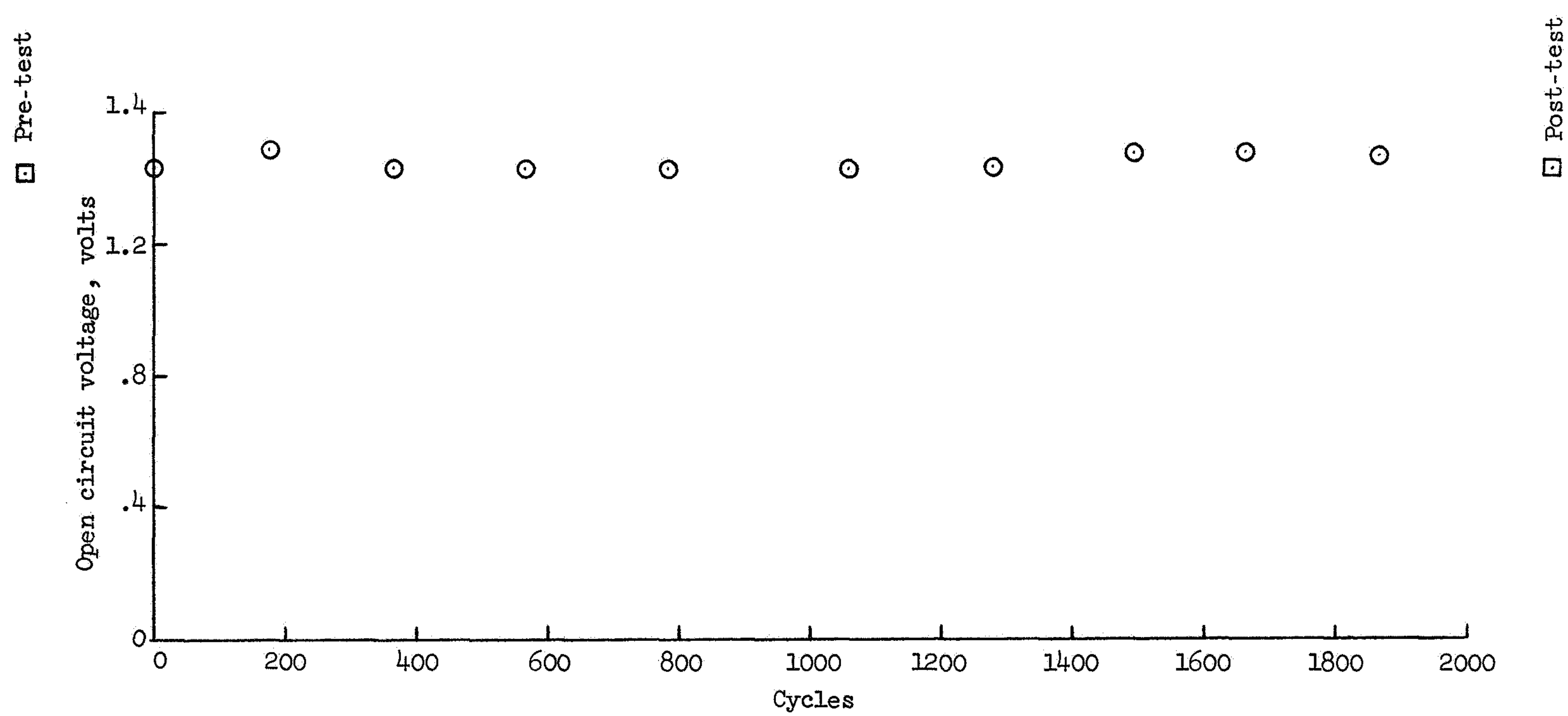

Figure 8. - In-situ open circuit voltage, AMO, 84° C

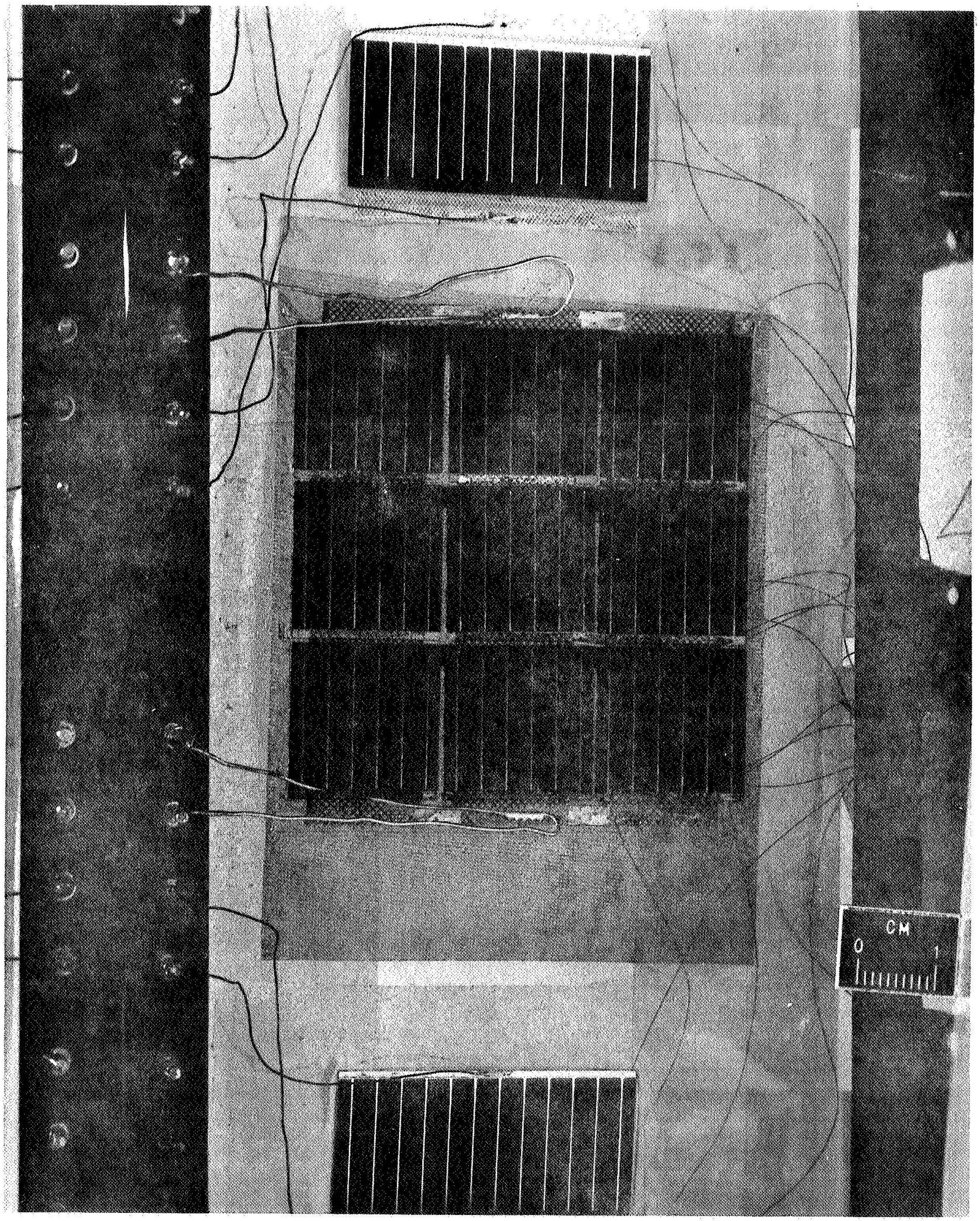

Figure 9. - Close up of test module after test.