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NASA Technical Memorandum

NASA TM - 108373

HUBBLE SPACE TELESCOPE THERMAL CYCLE TEST REPORT FOR LARGE SOLAR ARRAY SAMPLES WITH BSFR CELLS (Sample Numbers 703 and 704)

By D.W. Alexander

Information and Electronics Systems Laboratory
Science and Engineering Directorate

April 1992

(NASA-TM-108373) HUBBLE SPACE TELESCOPE THERMAL CYCLE TEST REPORT FOR LARGE SOLAR ARRAY SAMPLES WITH BSFR CELLS (SAMPLE NUMBERS 703 AND 704) (NASA) ~~21 p~~

N93-10809

Unclas

G3/44 0123612

28p

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

MSFC - Form 3190 (Rev. May 1983)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Hubble Space Telescope Thermal Cycle Test Report for Large Solar Array Samples With BSFR Cells (Sample Numbers 703 and 704)

5. FUNDING NUMBERS

6. AUTHOR(S)
D. W. Alexander

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM - 108373

11. SUPPLEMENTARY NOTES
Prepared by the Information and Electronic Systems Laboratory, Science and Engineering Directorate.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified—Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Hubble space telescope (HST) solar array was designed to meet specific output power requirements after 2 years in low-Earth orbit, and to remain operational for 5 years. The array, therefore, had to withstand 30,000 thermal cycles between approximately +100 and -100 °C. The ability of the array to meet this requirement was evaluated by thermal cycle testing, in vacuum, two 128-cell solar cell modules that exactly duplicated the flight HST solar array design. Also, the ability of the flight array to survive an emergency deployment during the dark (cold) portion of an orbit was evaluated by performing a cold-roll test using one module.

14. SUBJECT TERMS
Hubble Space Telescope, Solar Arrays, Solar Cells, Thermal Cycle Testing

15. NUMBER OF PAGES
21

16. PRICE CODE
NTIS

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

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TECHNICAL MEMORANDUM

HUBBLE SPACE TELESCOPE THERMAL CYCLE TEST REPORT FOR LARGE SOLAR ARRAY SAMPLES WITH BSFR CELLS

(Samples No. 703 and 704)

I. INTRODUCTION

The Hubble space telescope (HST) solar array consists of two flexible rollup wings designed after the Hughes flexible rollup solar array (FRUSA) and developed for the HST by the European Space Agency (ESA). The array was designed for a functional lifetime of 5 years, which required all array components to survive 30,000 orbital hot-cold thermal cycles. The ability of the array to function reliably during this period was evaluated at Marshall Space Flight Center (MSFC) by thermal cycle testing, in vacuum, two 128-cell solar cell modules which represented the HST flight solar array design. Also, in order to evaluate the ability of the array to survive an emergency deployment during the dark (cold) portion of an orbit, a "cold-roll" test was performed on one of the modules.

II. OBJECTIVE

The objective of the HST solar cell module thermal cycle test was to verify the performance of the HST solar array design for 30,000 thermal cycles, in vacuum, under simulated orbital conditions. Previous testing included only a few cycles in vacuum.

III. TEST ARTICLES

Two solar cell modules provided by ESA were used for this test (fig. 1). These modules duplicated the design, materials, and fabrication and manufacturing techniques used to manufacture the flight solar array, and were supplied with hinge pins and loops as on the flight modules. Each module measured 38.1 by 40.6 cm and contained 128 2- by 4-cm back surface field-reflector (BSFR) solar cells. The cells were arranged 16 cells in series by 8 cells in parallel with a shunt diode connected across the 16-cell series string as in the flight configuration. For identification, the modules were numbered 703 and 704.

IV. FACILITY DESCRIPTION

The thermal cycle test facility (fig. 2) in building 4619 is capable of testing solar cell modules over a wide range of orbital conditions. Test chamber V-3, which was used for this test, is capable of operation at pressures below 5×10^{-7} torr. Pressure during testing typically runs 2×10^{-6} torr.

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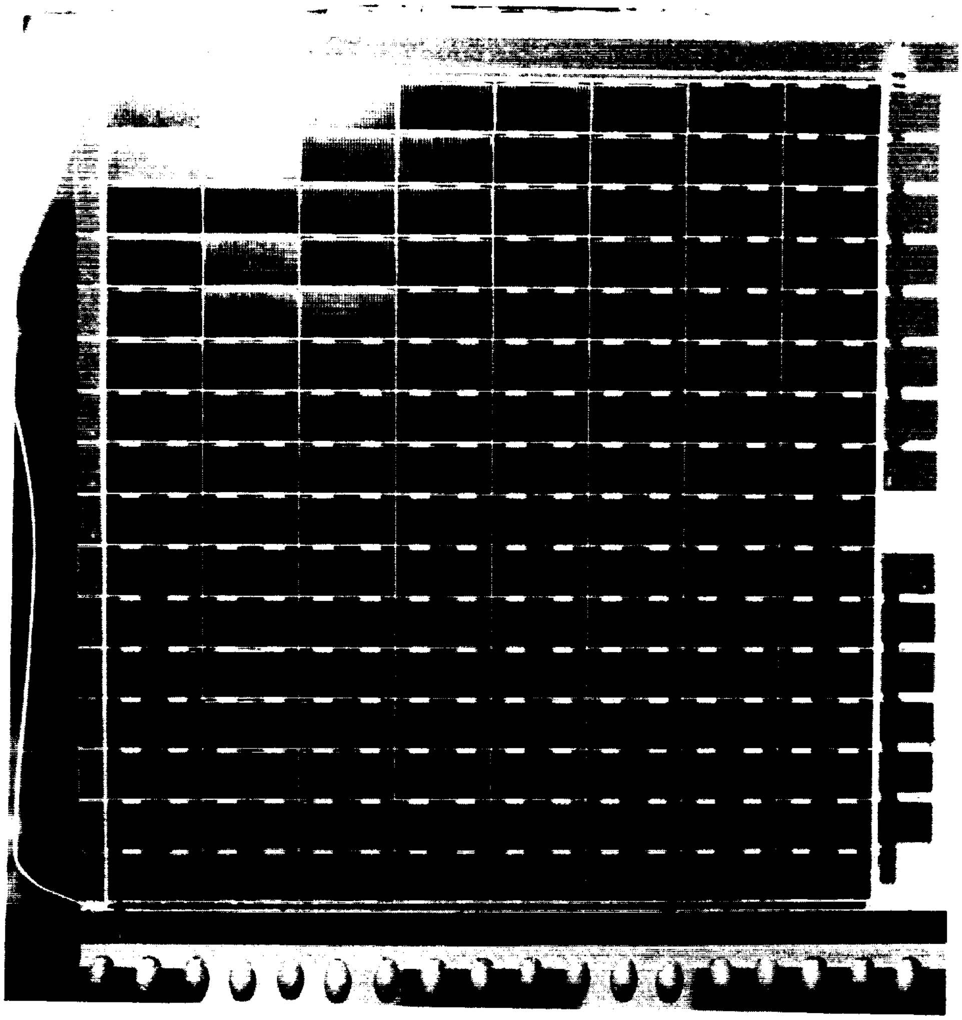

Figure 1. HST thermal cycle test module (1 of 2).

The test fixture inside the test chamber (fig. 3) consists of a 1.83-m long "T" bar, which is suspended by steel cables over a pulley system, a cold box, and a quartz heat lamp array. All functions pertaining to thermal cycle testing (temperature monitoring, raising and lowering of the test article, safety cutoffs, etc.) are performed under computer control by an automatic data acquisition and control system.

The cooling cycle is accomplished by raising the "T" bar, from which the test article is suspended, up into the cold box by the motor-driven pulley system. Liquid nitrogen flowing through the walls of the cold box absorbs heat from the test article. The cooling rate of the test article is controlled only by the rate at which heat is radiated to the walls of the cold box.

The heating cycle is accomplished by lowering the "T" bar out of the cold box, down in front of a quartz heat lamp array. The rate of module heating is controlled by controlling the amount of electrical power supplied to the lamp array. Heat is applied to the front surface of the test article only.

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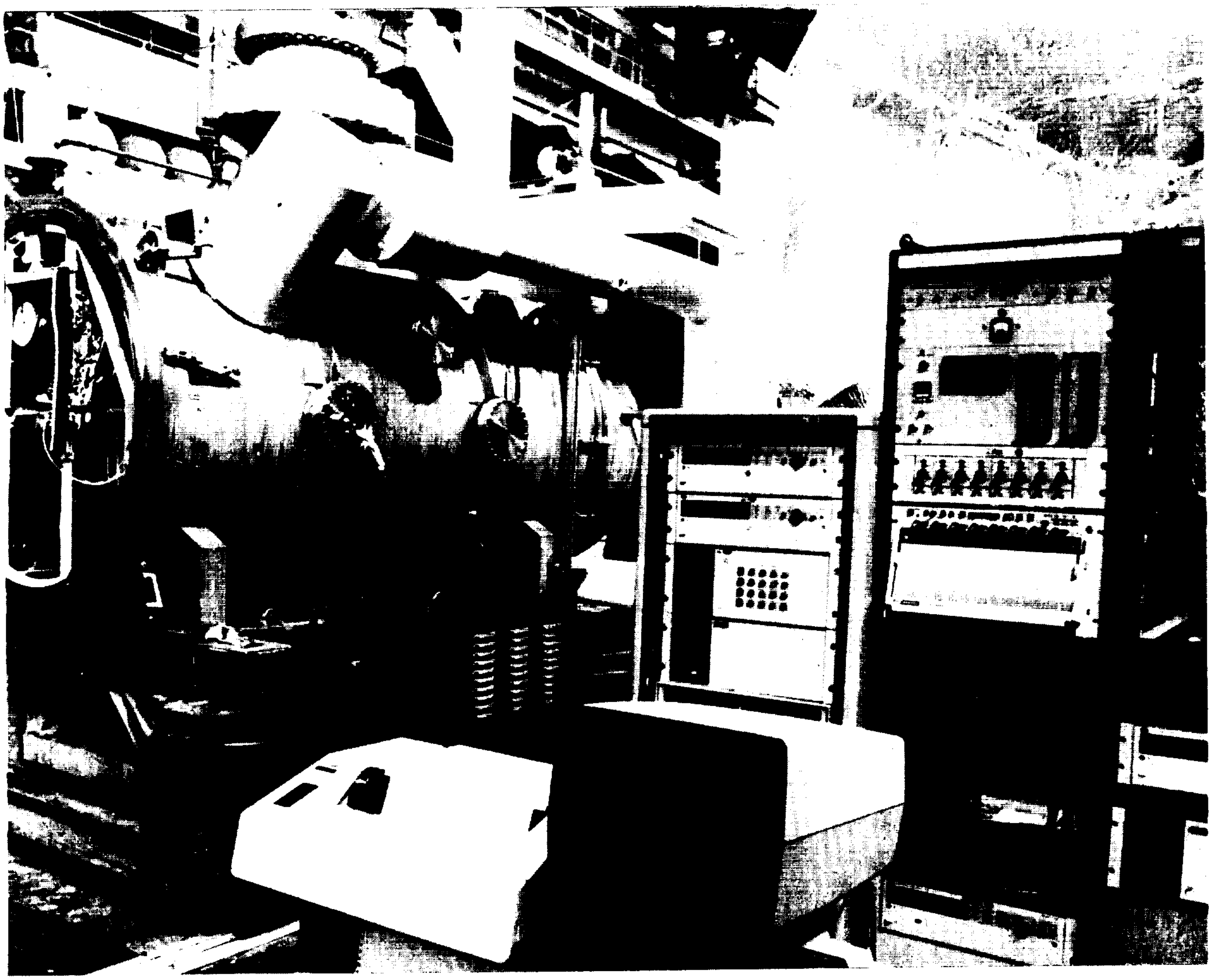

Figure 2. Thermal cycle test facility.

The Solar Array Laboratory in building 4475 houses a Spectrolab, Inc., large area pulsed solar simulator (LAPSS) system (fig. 4) capable of testing large solar array components under air mass zero (AM0) spectral conditions. Although the test article temperature cannot be controlled, data corrected to the desired temperature can be obtained by entering the solar cell temperature coefficients into the LAPSS.

V. TEST PREPARATION

The two solar cell modules were securely suspended from the metal "T" bar by attaching the top hinge pin of each module to the bar, between the hinge loops, centered along the length of the "T" bar (fig. 5). Metal weights were attached along the length of the bottom hinge pin of each module in order to keep the modules under homogeneous tension of 12.5 N/m ±10 percent as specified for the flight array blanket.

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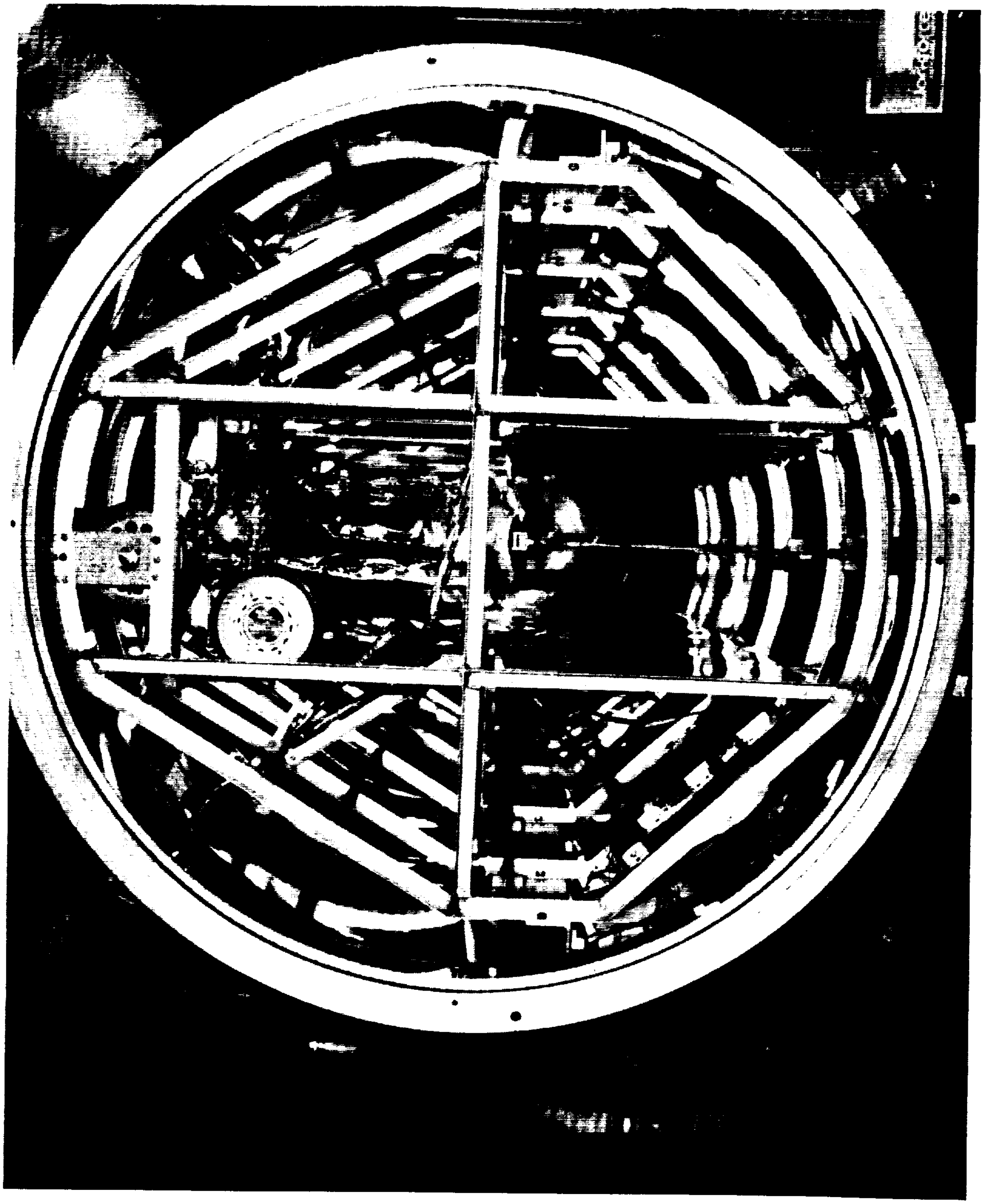

Figure 3. Thermal cycle test fixture.

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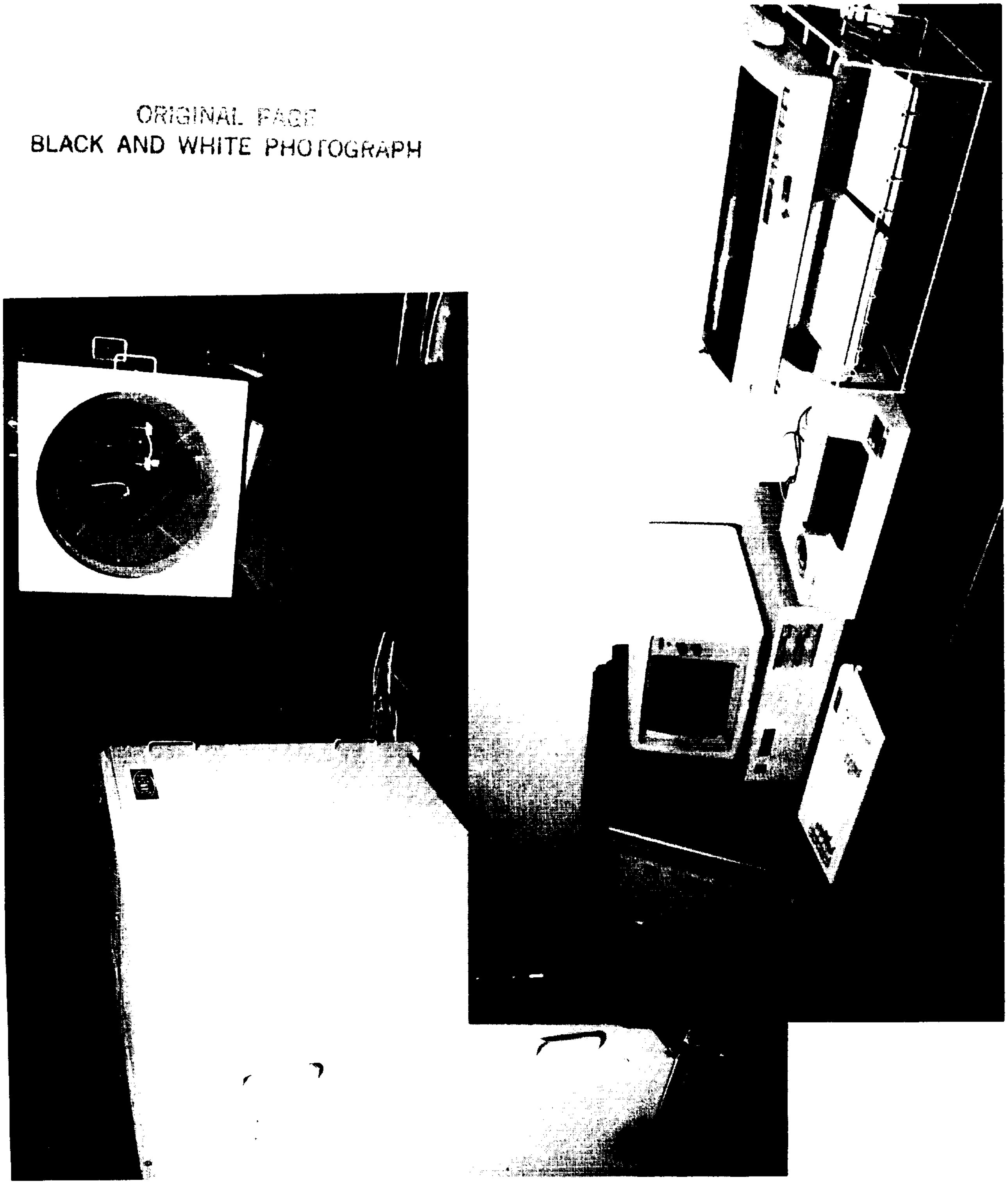

Figure 4. LAPSS system.

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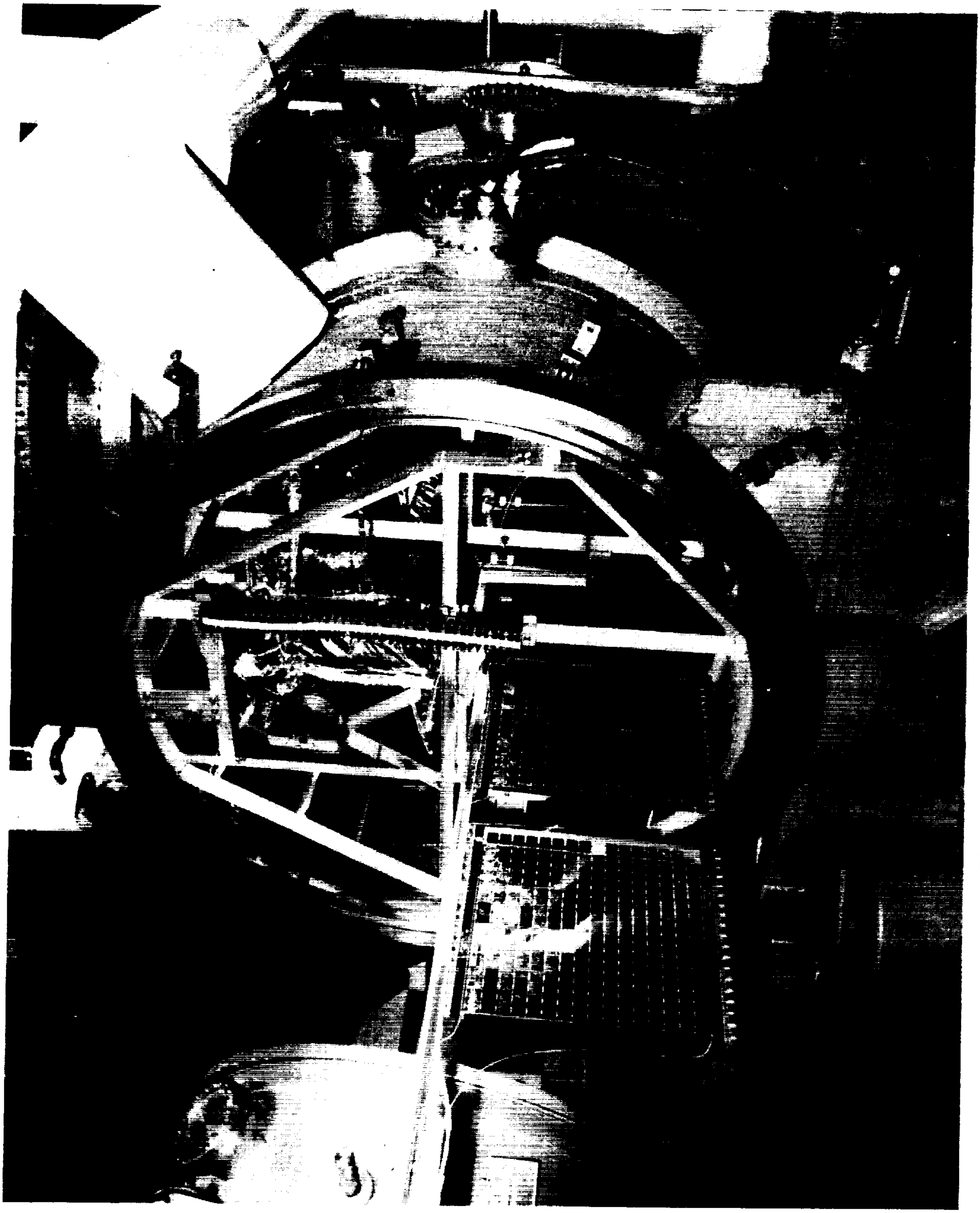

Figure 5. HST test modules ready for testing.

Five type T thermocouples were attached to the backside of each module using Emerson & Cuming, Inc., 2850MT thermally conductive epoxy in order to monitor the average temperature of each module during testing (fig. 6). The thermocouples were arranged with one thermocouple in the center and one thermocouple in each of the four corners of each module. An extra thermocouple was attached to the center backside of each module in order to provide over/under temperature protection by the test facility.

In order to monitor electrical continuity through the solar cell strings of each module during testing, Teflon coated wiring (AWG 20 stranded) was attached to the (+) and (–) bus bar connections on each module. This wiring was also used for electrical performance testing.

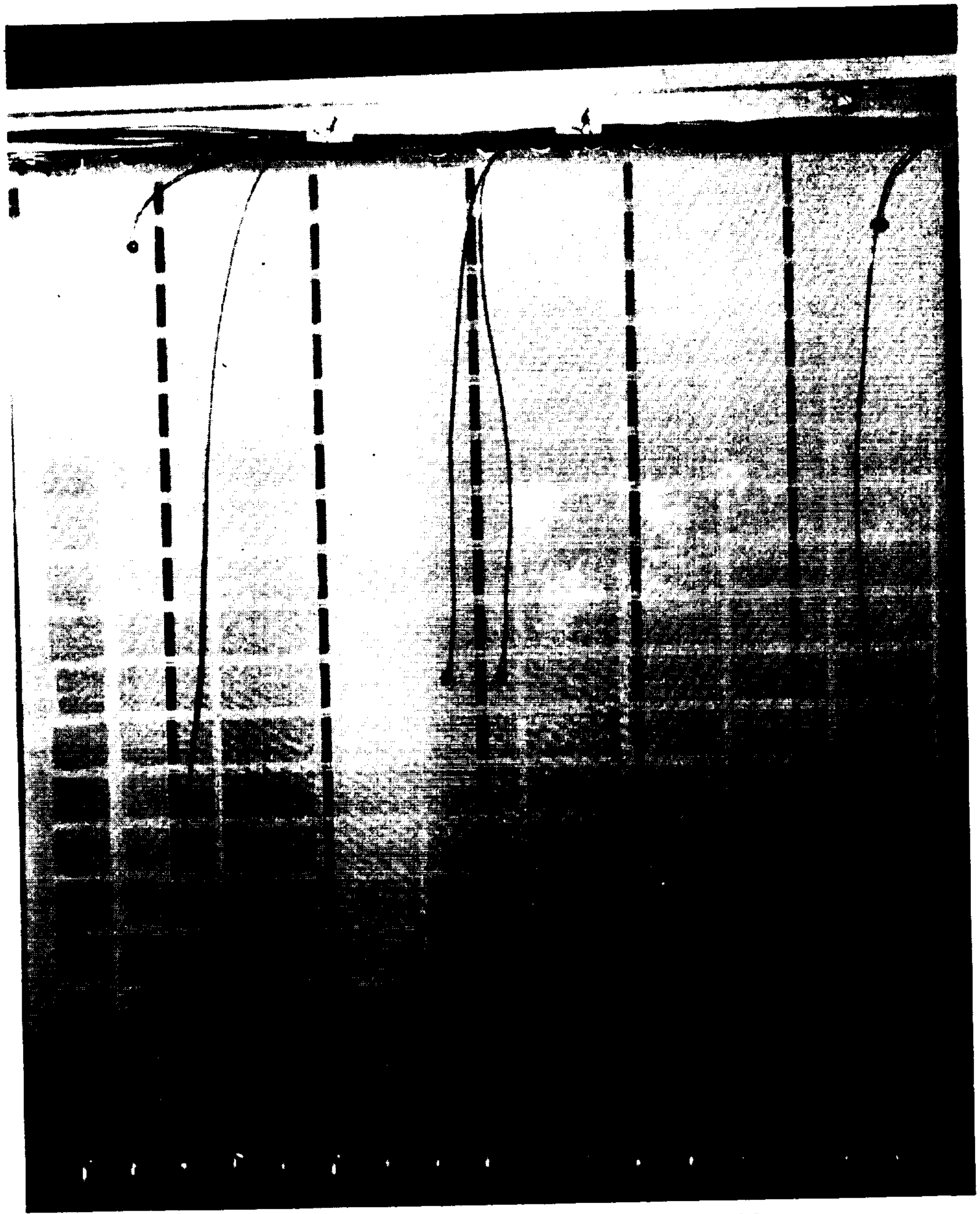

Figure 6. Back side of HST test module 703.

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VI. TEST DESCRIPTION

A. Pretest Visual Inspection

After being attached to the "T" bar, the two modules were visually inspected by MSFC and ESA personnel for solar cell/coverslide cracks, interconnect breakage, and any other abnormalities. The initial inspection confirmed a hairline crack in one coverglass on module 703 as previously documented by AEG, manufacturer of the two modules. It was also noted that the (+) and (–) bus bars on each module were deformed and unbonded from the Kapton substrate apparently due to stresses introduced by attaching the electrical wiring (fig. 7). Consequently, the first interconnect fingers of the cells closest to the bus bar attachments were found to be deformed but not broken. The bus bars on each module were reattached to their respective substrates using an epoxy adhesive prior to thermal cycle testing.

B. Pretest Electrical Performance Test

The electrical performance of each module was measured prior to thermal cycle testing by the LAPSS in the Solar Array Laboratory. The initial electrical performance data for test modules 703 and 704 are shown in figure 8. All data was corrected to 28 °C by the LAPSS.

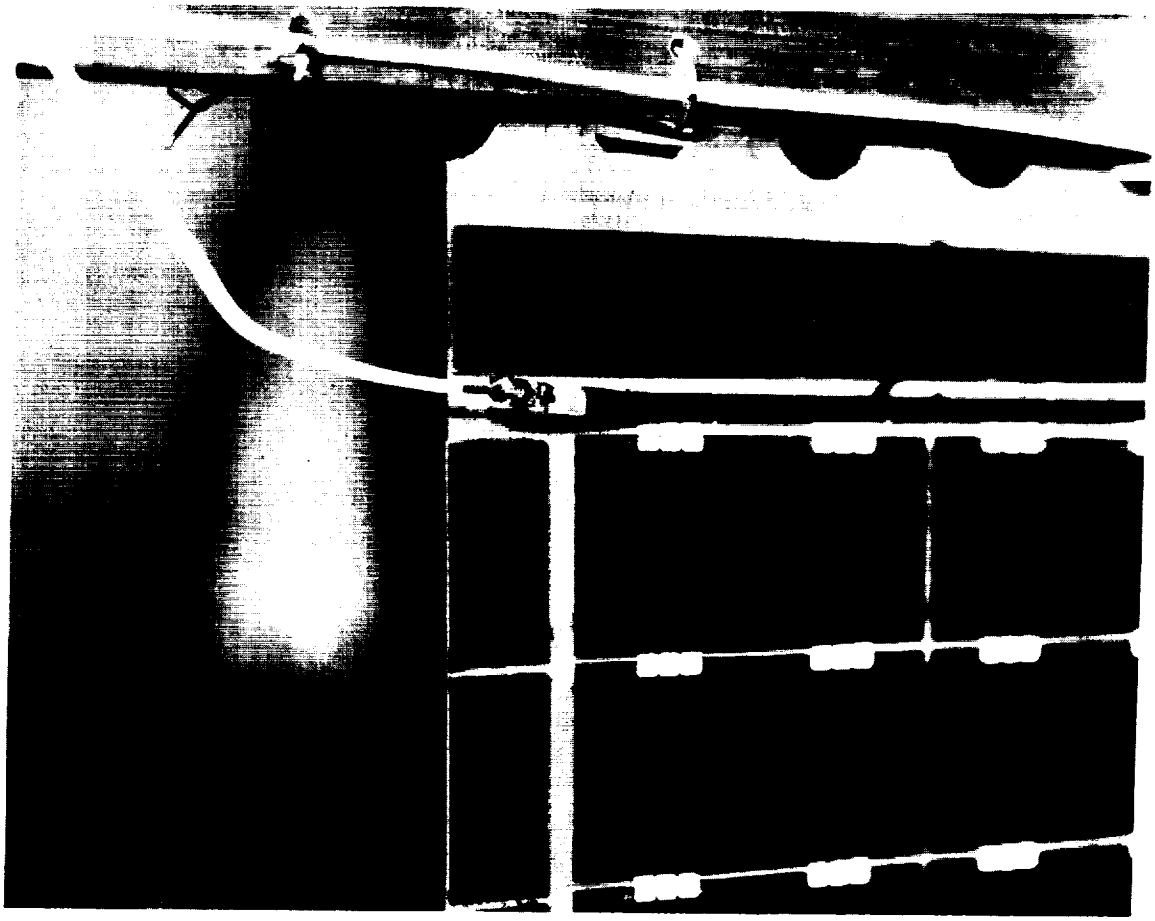

Figure 7. Deformed bus bar tab on HST test module.

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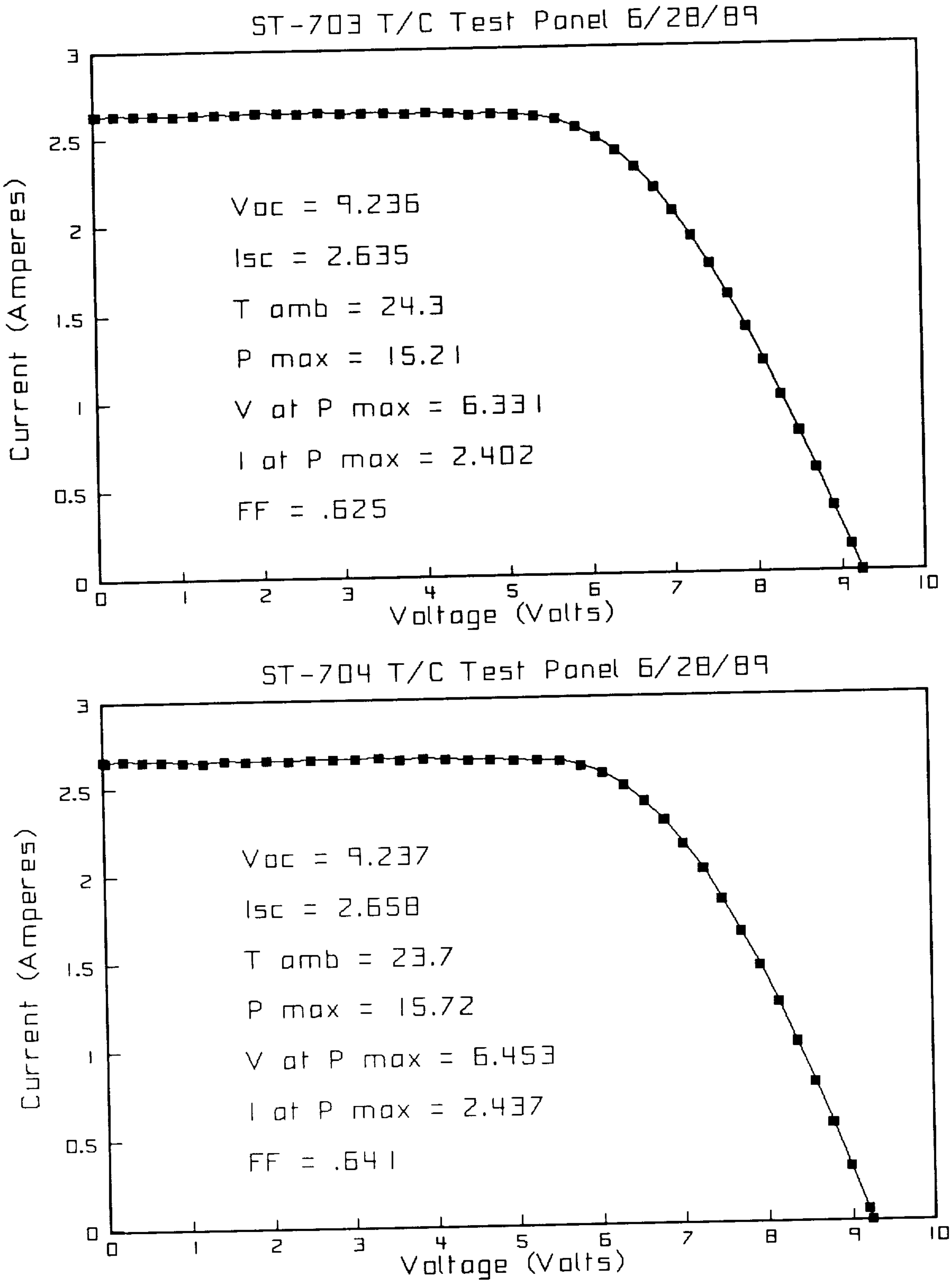

Figure 8. Initial electrical performance of modules 703 and 704.

C. Thermal Cycle Test

The "T" bar/modules assembly was placed into the support channel of the thermal cycle test fixture inside test chamber V-3 (fig. 5) and secured with a set screw. Thermocouple wiring and electrical continuity wiring were then connected to their respective feed-through interfaces inside the test chamber and verified for correctness. Upon completion of wiring checkout inside the test chamber and verification of proper operation of the data acquisition and control system, the chamber door was attached and evacuation of the test chamber was begun.

When the pressure inside the test chamber reached 2×10^{-6} torr, thermal-cycle testing began. Upon completion of the first thermal cycle, the test was halted in order to verify proper operation of all monitoring and control equipment and to define the over/under emergency temperature cutoff limits. It was found that there was an in-plane temperature gradient across each module of approximately 15 °C for the hot case and approximately 20 °C for the cold case. A front-to-back temperature gradient of approximately 10 °C was measured during previous testing of a similarly constructed module. In consideration of the thermal gradients across and through the modules and the requirement by ESA to not allow the module temperatures to exceed ±100 °C, the cycle limit temperatures for this test were set at +75 °C and –90 °C as measured using the five rear-side thermocouples averaged together. Emergency over-temperature and under-temperature test cutoff limits were set to +102 °C and –105 °C, respectively. Total cycle time was 15.5 min, including a 2-min dwell at +75 °C.

Electrical continuity through each module was monitored during each hot cycle by monitoring the current through a 1-ohm resistor connected across the output of each module external to the test chamber. Continuity was monitored at the rate of once each second by the data acquisition system and continuously monitored by a continuous-trace strip chart recorder. Had continuity been lost at any time during testing, the data acquisition system would have automatically stopped the test.

Since each module had 8 strings of 16 cells wired in parallel, each cell string contributed 12.5 percent of the total current measured through each resistor. By noting any drop in resistor current of approximately 12.5 percent or more, loss of continuity through a cell string would have been detected. No reduction of that magnitude was detected for either module throughout the duration of the test.

D. Visual Inspection After 80 Thermal Cycles

The test was stopped after 80 thermal cycles, and both modules were inspected visually, under magnification, by MSFC and ESA personnel. No damage to either module was detected other than deformation of the bus tabs as described in section A. No electrical performance test was performed at that time in order to minimize handling of the modules.

E. Cold-Roll Test

In order to simulate and evaluate an emergency cold-case deployment of the HST flight solar array wings, a cold-roll test of module 704 was proposed and implemented. Module 704 was chosen for this test because it was closest to the front of the test chamber and more easily removed. The thermal cycle test was halted after 2,577 thermal cycles, and both modules were inspected by MSFC and ESA personnel. No new damage or anomalies were noted. Module 704 was then removed from the test chamber and mounted on the cold-roll test fixture (fig. 9).

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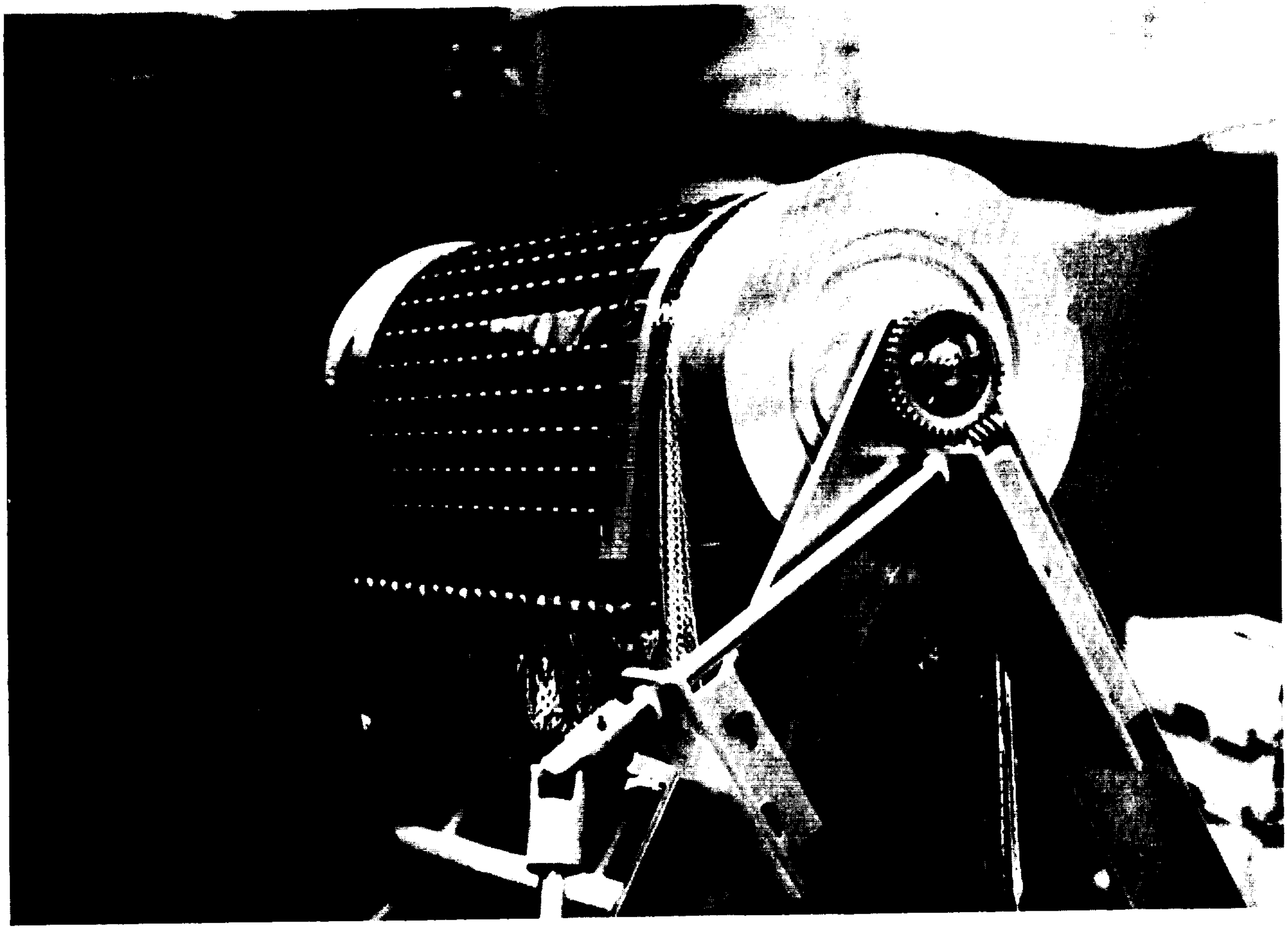

Figure 9. HST module 704 mounted on cold-roll test fixture.

The cold-roll test fixture was constructed of aluminum and consisted of a drum, 8 inches in diameter, mounted in a suitable frame assembly on a free-rotating shaft. Grooves were machined into one end of the drum so that when the module was hanging vertically from the bottom of the drum, the drum could rotate up to 270° in either direction. The shaft on the opposite end of the drum was connected to a gear-drive mechanism and a shaft which passed through the test chamber wall so that the drum could be rotated by a hand crank from outside the chamber. In order to duplicate the flight array configuration prior to deployment, the module was rolled onto the drum with the cells facing outward prior to the test (fig. 9). In order to protect the module from mechanical damage, a thin thermal blanket was installed on the drum so that it hung down in front and back of the module, cushioning and protecting it from direct contact with the drum. The five thermocouples attached to the backside of the module for the thermal cycle test were also used to monitor module temperature during the cold-roll test. Another thermocouple was attached to the drum in order to monitor its temperature. The electrical continuity leads were disconnected from the module prior to removal from the "T" bar in order to eliminate stresses on the module's (+) and (–) bus bars.

When preparations were complete, the test fixture/module assembly was placed into the test chamber (chamber V-6, a smaller chamber which was particularly suited for this test), and all internal wiring and mechanical linkages connected and verified for proper operation. The chamber door was then attached and evacuation of the chamber begun. When chamber pressure stabilized at 2.7×10^{-5} torr, the cooling shroud which surrounded the test fixture/module assembly was filled with LN_2, and cool down of the module was begun. It was decided to perform this test with the module at approximately –95 °C in order to closely duplicate a cold deployment case for the flight arrays.

After approximately 27 h, the module temperature read –94.0 °C (average of the five rear-side thermocouples) and the cold-roll test was begun. With one person rotating the crank outside the chamber and another person visually verifying proper operation of the test fixture, the module was first unrolled to the vertical position then rolled with the cell side in. The cell-side-in roll did not quite reach 270° because the thermal blanket had stiffened due to the low temperature, and damage to the module was a concern. The module was unrolled back to vertical position and the test was terminated. The average module temperature at the end of the test was –97 °C. All rolling was accomplished at or less than the on-orbit flight solar array blanket deployment rate of 10°/s. The chamber was warmed back up to ambient and allowed to pressurize to atmospheric pressure prior to removal of the fixture/module assembly from the test chamber.

A post-test visual inspection of module 704 revealed no additional damage or anomalies. No electrical performance test was performed.

The module was removed from the cold-roll test fixture and reattached to the thermal cycle fixture "T" bar for further thermal cycle testing.

After module 704 was reattached to the "T" bar and all wiring was reconnected, both modules were again visually inspected. At this time, a second cracked cover-slide was discovered on module 703. Since this second crack was not noted during the pre-cold-roll test inspection, it was attributed to activities associated with removing and reattaching module 704 to the "T" bar. After verifying that both modules were correctly installed and all wiring was correct, the thermal cycle test chamber door was attached and the chamber evacuated in order to resume thermal cycle testing as before.

F. Visual Inspection After 5,777 Cycles

The thermal cycle test was halted after the modules had completed 5,777 thermal cycles (3,200 cycles since the cold-roll test) for visual inspection by MSFC and ESA personnel. No additional damage or abnormalities were found.

G. Visual Inspection After 16,761 Cycles

The thermal cycle test was halted after the modules had completed 16,761 thermal cycles for visual inspection by MSFC and ESA personnel. Other than the deformed bus bars on both modules as noted earlier in the test, no additional damage or anomalies were discovered. However, an interesting and potentially disastrous situation was noted upon opening the test chamber. Due to thermal stresses and slight movements of the module hinge rods and loops, the upper hinge rods had moved out of several hinge loops; five loops on module 703 and one on module 704. Also, the lower hinge rods had moved out of several loops on both modules, allowing several of the tensioning weights to fall off. All hinge rods were subsequently placed back into their respective hinge loops and secured so that this situation could not occur again.

H. Electrical Performance Test After 16,761 Cycles

Electrical performance data taken with the LAPSS after 16,761 thermal cycles revealed no performance degradation for either of the test modules (fig. 10). In fact, data for both modules showed maximum power performance to be 0.4 percent (module 704) to 0.5 percent (module 703) higher than initial data taken prior to test start. Although this increase is well within the accuracy of the LAPSS system, it could, at least in part, probably be attributed to an LAPSS software update and recalibration after the initial check and prior to this performance check.

I. Visual Inspection After 22,469 Cycles

The thermal cycle test was again halted after the modules had completed 22,469 thermal cycles and visually inspected by MSFC and ESA personnel. No additional damage or abnormality was detected on either module.

J. Electrical Performance After 22,469 Cycles

Electrical performance data taken after 22,469 cycles showed no degradation of either module. There was a slight increase in the maximum power performance of module 704 since the last check at 16,761 cycles (0.4 percent), but there was no change for module 703 (fig. 11).

K. Visual Inspection After 30,000 Cycles (Final Inspection)

The test was halted and the modules inspected for damage after 30,000 cycles. No additional damage or abnormalities were found.

L. Electrical Performance Test After 30,000 Cycles (Final Test)

Electrical performance data taken from the modules after 30,000 cycles revealed no degradation in the maximum power of either module since the last check at 22,469 thermal cycles. However, both modules showed slight increases in maximum power performance; 0.5 percent for module 703 and 0.3 percent for module 704 (fig. 12).

VII. CONCLUSION

The inspection data and electrical performance data taken from the two test modules during this test revealed no damage or abnormality for either module which could be directly attributed to the effects of this test. Even the cold-roll test performed on module 704 apparently did not degrade its mechanical or electrical performance.

Electrical performance tests performed on both modules periodically during the test showed no degradation of the electrical power output of either module. Overall, from the initial test at 0 cycles to the final test after 30,000 cycles, there was an increase of output power of 1.0 percent for module 703 and 1.1 percent for module 704. At least part of this increase can be attributed to a software update and recalibration of the LAPSS between the initial test and the second test at 16,761 cycles. The remainder of the output power increases are within the calibration tolerance of the LAPSS.

Based on this data, especially the final inspection data and electrical performance data, and on the fact that these two modules were fabricated using the same materials and techniques as the HST flight arrays, the HST flight arrays should function reliably and fulfill all requirements for the duration of its 5-year design lifetime.

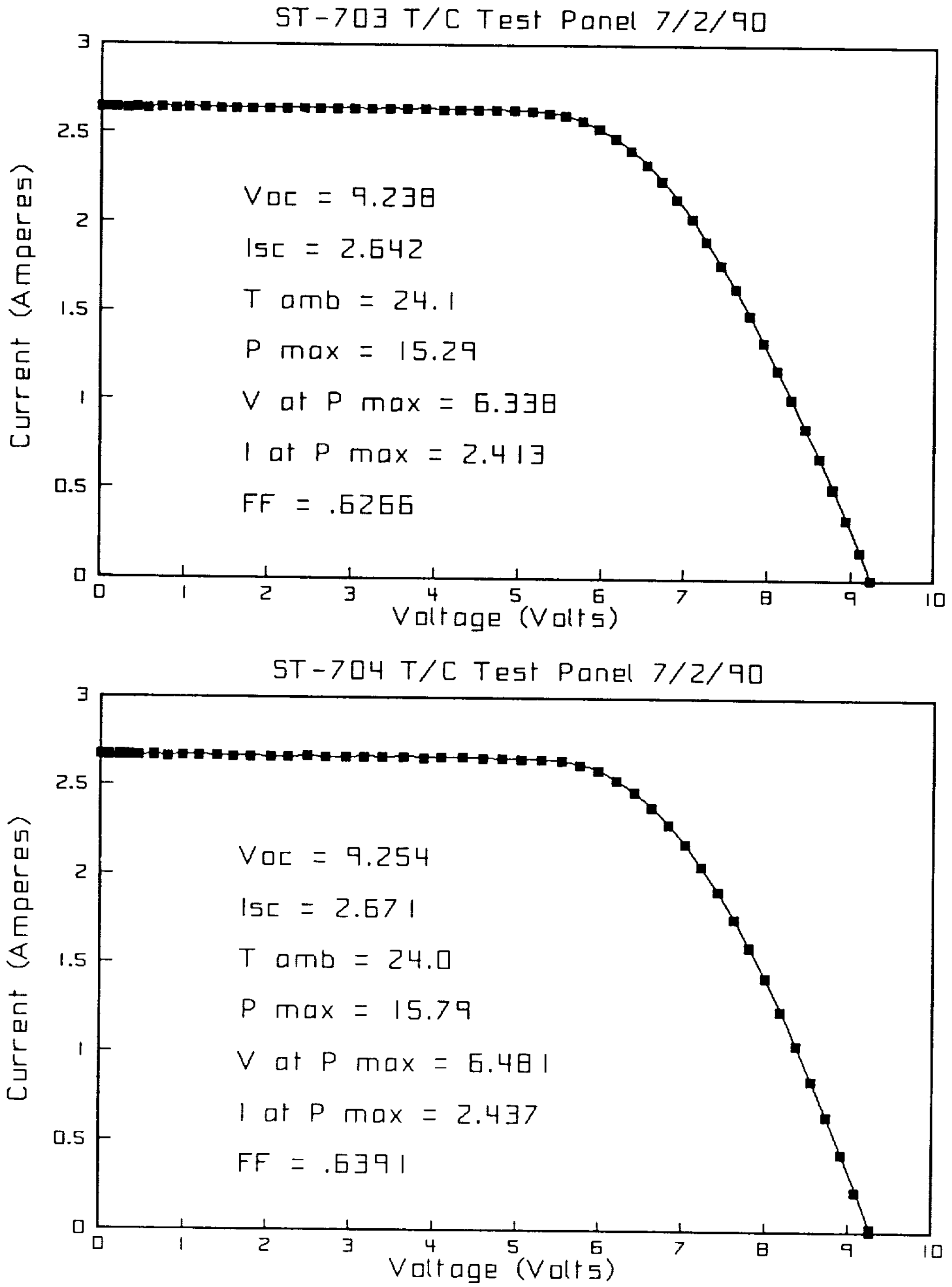

Figure 10. Electrical performance of modules 703 and 704 after 16,761 cycles.

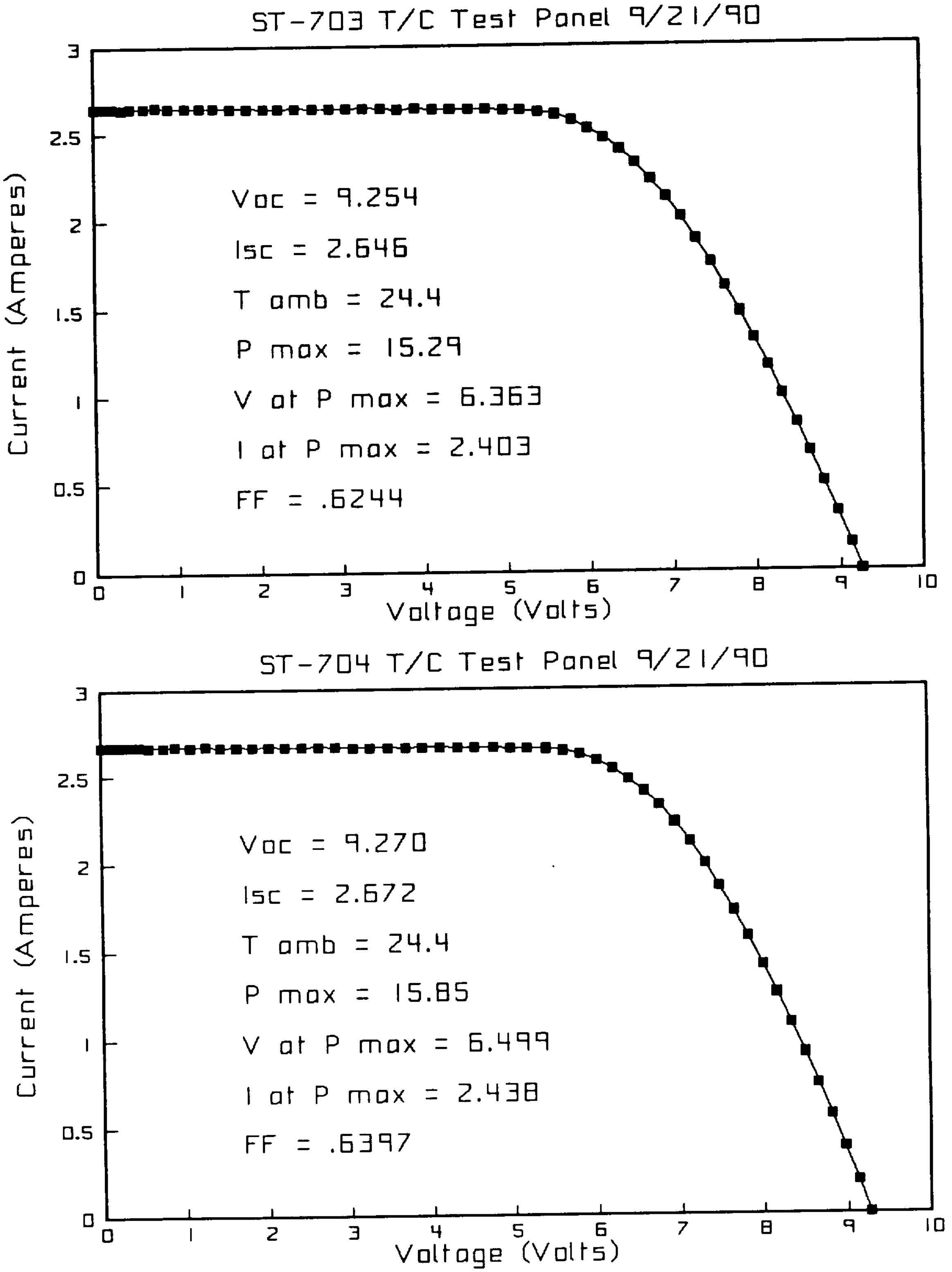

Figure 11. Electrical performance of modules 703 and 704 after 22,469 cycles.

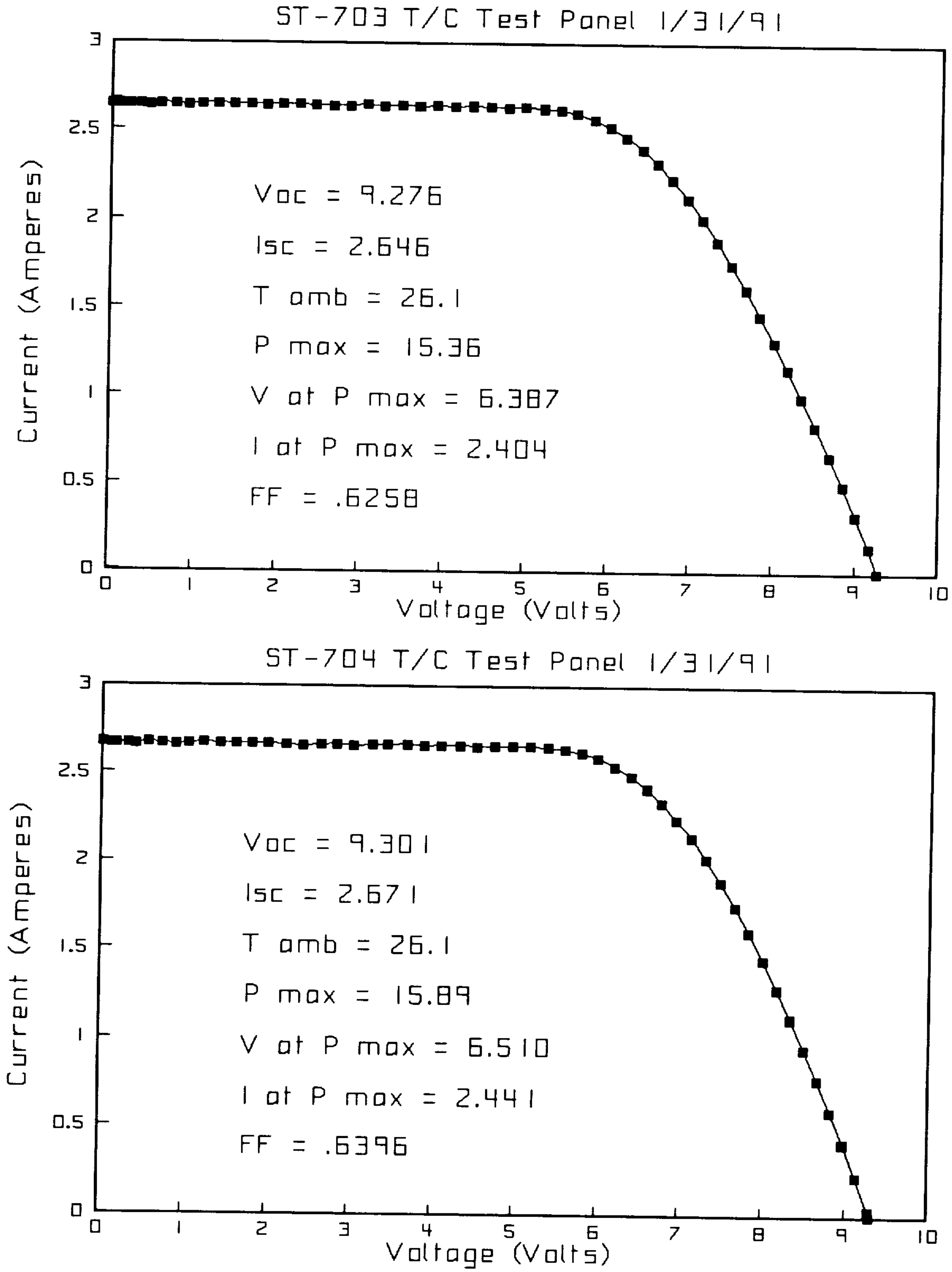

Figure 12. Electrical performance of modules 703 and 704 after 30,000 cycles.

APPROVAL

HUBBLE SPACE TELESCOPE THERMAL CYCLE TEST REPORT FOR LARGE SOLAR ARRAY SAMPLES WITH BSFR CELLS

(Sample Numbers 703 and 704)

By D.W. Alexander

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

J.L. RANDALL
Director, Information and Electronic Systems Laboratory

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