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# BLOCK II SOLAR CELL MODULE ENVIRONMENTAL TEST PROGRAM

Kevin L. Holloway
Naval Weapons Support Center

October 1978

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract C-1892-D



for
**U.S. DEPARTMENT OF ENERGY**
**Office of Energy Technology**
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Division of Distributed Solar Technology
Washington, D. C. 20545
Under Interagency Agreement E(49-26)-1022

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REPORT SUMMARY

BLOCK II SOLAR CELL MODULE ENVIRONMENTAL TEST PROGRAM

The Naval Weapons Support Center was tasked to perform environmental tests on 76 solar cell modules produced by four different manufacturers. The following tests were performed:

1. 28-day Temperature and Humidity
2. Rain and Icing
3. Salt Fog
4. Sand and Dust
5. Vacuum/Steam/Pressure
6. Fungus
7. Temperature/Altitude
8. Thermal Shock

The environmental testing produced cracked cells, cracked encapsulant and encapsulant delaminations on various modules. There was also some minor cell and frame corrosion. Vacuum/steam/pressure (VSP) testing resulted in cracked cells on Solar Power, Solarex and Sensor Technology modules. There were no cracked cells on Spectrolab modules during any test. Sensor Technology modules were the only type to have cracked cells during the temperature and humidity, rain and icing, temperature/altitude and thermal shock tests. The VSP tests caused the most severe damage to the modules. The three Solarex modules undergoing VSP testing had a total of 18 cracked cells, one module with no post-test current output and another with 27 percent of its original current output. Salt fog and sand and dust were the only other tests to significantly affect the module electrical outputs during the functional checkouts performed at NAVWPNSUPPCEN Crane. Two Solar Power modules had only 50 percent of their original output current following salt fog due to a salt film on the module surface. Solarex and Sensor Technology modules had current decreases up to 77 percent following sand and dust due to a film of sand and dust on the module surface. The VSP test resulted in one crack in the Spectrolab encapsulant while the other three types of modules had a total of approximately 168 cracks. Solar Power modules also had cracked encapsulant following temperature and humidity, salt fog and temperature/altitude testing. Encapsulant delaminations occurred during temperature and humidity tests on Spectrolab and Solar Power modules and during VSP tests on Solar Power and Solarex modules. Sensor Technology was the only module to support fungus growth during the standard fungus test.

The test results indicate that Spectrolab modules were the most resistant to the effects of the applied environmental tests.

## INTRODUCTION

The NASA Lewis Research Center, Cleveland, Ohio provided the Naval Weapons Support Center, Crane, Indiana with 16 solar cell modules from four different manufacturers for environmental testing. These modules were subjected to various environmental tests as shown in Figure 1. Table I gives the serial numbers of the modules tested according to Figure 1.

These environmental tests were performed to establish failure modes of the modules and determine the relative resistance of various manufacturer's modules to different environments. No attempt was made to predict a life expectancy of the modules since these tests were not an accelerated real-life environment.

## FUNCTIONAL CHECKOUT

A functional checkout was conducted on the modules before and after environmental testing with the exception of those undergoing temperature and humidity testing and fungus testing. Each module was placed in a fixed location under five 150-watt floodlamps. The open-circuit voltage and the voltage drop across a one-ohm resistor in series with the module were measured with a digital voltmeter. The test setup is shown in Figure 2. The checkout was not meant to accurately document small changes in performance but only to show that the modules were working properly and to show gross changes in performance. The actual electrical performance tests were conducted by NASA Lewis Research Center before and after the environmental tests and will be reported separately.

## ENVIRONMENTAL TESTING

The results of the environmental tests are summarized in Table II. The individual test parameters and test results are reported below in detail.

28-day Temperature and Humidity. - A temperature and humidity test was performed on 12 solar cell modules, three from each manufacturer. All 12 modules were tested at the same time in the same temperature chamber, as shown in Figure 3. The test consisted of two complete 14-day temperature and humidity cycles, as shown in Figure 4, for a total test time of 28 days.

The following solar cell modules were tested:

| Manufacturer | Serial Numbers |
|---|---|
| Spectrolab | 0132, 0152, 0158 |
| Solar Power | 1565, 1566, 1567 |
| Solarex | 228134, 228153, 229023 |
| Sensor Technology | 0089, 0135, 0143 |

A visual examination following testing showed the following:

Spectrolab - all modules showed some delamination of the encapsulant where it is fastened to the glass as shown in Figure 5. The cells showed no visible defects.

Solar Power - The encapsulant on all modules was cracked, some in the upper layer and some through both layers as shown in Figure 6. Some cells were corroded.

Solarex - all modules showed no visible defects.

Sensor Technology - cells in all modules showed fading and corrosion. S/N 0143 had several cracked cells as shown in Figure 7.

No functional tests were performed by NAVWPNSUPPCEN Crane on these twelve modules.

Rain and icing. - Twelve modules were subjected to rain and icing tests. The rain test consisted of 2 $\pm$ .5 inches/hour applied to the modules in two orientations for four hours in each orientation. The modules were tilted 45° for one orientation then turned 180° for the second orientation. Figure 8 shows the modules in the rain chamber. Four modules, one from each manufacturer, were tested during each run. To perform the icing test, the frame shown in Figure 8 was placed in a temperature chamber. The modules, with the cells facing up as in Figure 8, were cooled to 0°F and sprayed with water until the ice was approximately 1 inch thick. The modules were left in the temperature chamber for 48 hours. Only one orientation was used. Four modules were tested during each run.

The following modules were tested:

Spectrolab S/N's 0208, 0206, 0169
Solar Power S/N's 1316, 1342, 1315
Solarex S/N's 220117, 229018, 230038
Sensor Technology S/N's 2694, 2683, 2673

A visual check of the modules following rain and icing showed that Sensor Technology S/N 2683 had one cracked cell, shown in Figure 9. Figure 9 is typical of cracked cells occurring throughout the test program. All other modules showed no visible defects. A visual check was not made between the rain test and the icing test.

A functional check was done before the rain test and after the icing test. The results were as follows:

| | | Before Rain Test | | After Icing Test | |
|---|---|---|---|---|---|
| Manufacturer | S/N | Open Circuit Voltage | Voltage-1 Ohm Resistor (mv) | Open Circuit Voltage | Voltage-1 Ohm Resistor (mv) |
| Spectrolab | 0208 | 22.2 | 580 | 22.3 | 563 |
| " | 0206 | 22.0 | 554 | 22.5 | 538 |
| " | 0169 | 22.0 | 520 | 22.3 | 515 |
| Solar Power | 1315 | 21.3 | 239 | 21.5 | 226 |
| " | 1316 | 21.7 | 275 | 22.0 | 255 |
| " | 1342 | 22.3 | 250 | 22.4 | 240 |
| Solarex | 220117 | 19.8 | 330 | 20.1 | 324 |
| " | 229018 | 21.7 | 220 | 22.3 | 226 |
| " | 230038 | 22.0 | 222 | 21.9 | 221 |
| Sensor Tech | 2694 | 23.1 | 146 | 23.5 | 140 |
| " | 2683 | 23.7 | 163 | 24.1 | 147 |
| " | 2673 | 24.1 | 160 | 24.0 | 158 |

As seen above, all readings were similar before and after testing.

Following the testing, the modules were returned to NASA Lewis Research Center for post-test analysis. All modules, except Sensor Technology S/N 2683, were later returned to NAVWPNSUPPCEN Crane for use in salt fog testing.

Salt fog. - Salt fog testing was performed on 11 modules. These modules had previously undergone rain and icing testing. The salt fog test was Method 509.1 of MIL-STD-810C (reference (1)). The test consisted of an exposure to a salt fog in a salt fog chamber at a temperature of 35°C (95°F) for a period of 48 hours. The modules were tested in groups of four, four and three per 48-hour test.

The following modules were tested:

Spectrolab S/N's 0208, 0206, 0169
Solar Power S/N's 1315, 1316, 1342
Solarex S/N's 220117, 229018, 230038
Sensor Technology S/N's 2694, 2673

A visual check following the salt fog test showed one crack in the encapsulant on Solar Power S/N 1315. The other 10 modules showed no visible defects. All modules had a film of salt deposited on their outer surfaces.

A functional checkout was performed before and after the salt fog tests. The results are shown below:

| | | Before Salt Fog Test | | After Salt Fog Test | |
|---|---|---|---|---|---|
| Manufacturer | S/N | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor |
| Spectrolab | 0208 | 22.9 | 594 | 21.8 | 460 |
| | 0206 | 22.7 | 580 | 22.0 | 477 |
| | 0169 | 22.6 | 546 | 21.6 | 411 |
| Solar Power | 1315 | 22.2 | 242 | 21.3 | 128 |
| | 1316 | 22.5 | 268 | 21.7 | 210 |
| | 1342 | 23.0 | 276 | 22.4 | 146 |
| Solarex | 220117 | 20.3 | 323 | 19.6 | 306 |
| | 229018 | 22.7 | 222 | 21.8 | 201 |
| | 230038 | 22.9 | 218 | 21.9 | 200 |
| c | 2694 | 23.7 | 145 | 23.2 | 135 |
| ogy | 2673 | 24.5 | 163 | 24.1 | 143 |

Solar Power S/N's 1315 and 1342 had nearly a 50 percent decrease in output current following salt fog. The other modules also had lower output currents. These decreases were caused by a salt film on the surface of the modules.

<u>Sand and dust</u>. - Sand and dust testing was performed on eight modules. The testing was performed in the sand and dust chamber shown in Figure 10. The modules were tested in two orientations; standing vertically with the sand and dust impacting the front and the back of the modules. A wind velocity of 45.7 km/hr (2500 feet per minute) was used. Each module was tested 3 hours in each orientation at a temperature of 25°C (77°F) and 3 hours in each orientation at a temperature of 71°C (160°F) for a total test time of 12 hours. The sand and dust mixture was in accordance with the requirements of Test 116, MIL-STD-331 (reference (2)). Four modules were tested during each run.

The following modules were tested:

Spectrolab S/N's 0216, 0221
Solar Power S/N's 1269, 1550
Solarex S/N's 228088, 227059
Sensor Technology S/N's 2524, 2546

A visual examination following the sand and dust test showed that the Solarex and Sensor Technology modules were extremely dusty making it impossible to see the cells or encapsulant to check for material damage. Figure 11 shows one Solarex module and one Sensor Technology module following sand and dust. The Spectrolab and Solar Power modules were also dusty but the dust film was light enough that the cells and encapsulant could be seen. There was no visible damage to the Spectrolab and Solar Power modules. The modules were returned to NASA Lewis Research Center for post-test analysis without being cleaned so it is not known if the dust was embedded in the encapsulant or just lying on the surface.

The results of the functional tests are shown below:

| | | Before Sand and Dust | | After Sand and Dust | |
|---|---|---|---|---|---|
| Manufacturer | S/N | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor |
| Spectrolab | 0216 | 22.5 | 537 | 22.4 | 438 |
| | 0221 | 22.4 | 483 | 21.5 | 417 |
| Solar Power | 1269 | 21.5 | 252 | 20.7 | 202 |
| | 1550 | 21.9 | 219 | 20.7 | 149 |
| Sensor Technology | 2524 | 24.1 | 137 | 20.6 | 48 |
| | 2546 | 24.2 | 108 | 21.5 | 25 |
| Solarex | 228088 | 22.0 | 226 | 19.7 | 122 |
| | 227059 | 21.8 | 248 | 16.0 | 70 |

All modules had lower voltage and current outputs following the sand and dust tests. Sensor Technology and Solarex modules had decreases in output current ranging from 46 to 77 percent. The lower outputs were caused by the dust film on the surface of the modules.

Vacuum/steam/pressure. - VSP tests were performed on 12 modules according to the requirements of Test 106 of MIL-STD-331 (reference (2)). The VSP chamber is shown in Figure 12. The test consisted of 15-minute cycles following the pressure and temperature curves of Figure 13. The test item was subjected to 1000 cycles for a total test time of about 10 days. Four modules were tested during each run.

This 10-day test of 1000 cycles has been found to be the equivalent of at least 6 months Pacific Fleet life for World War II VT (variable time) Fuzes. The test was designed to give, on an accelerated basis, the same failure modes as had been experienced by the fuze components at the end of 6-8 months of fuze storage (in unsealed packages) or ready use (assembled to weapons). The test was applied to the solar cell modules as an accelerated tropical environment. However, the test would not necessarily be equivalent to 6-8 months of fleet life as it was for VT fuzes.

The following modules were tested:

Spectrolab S/N's 0173, 0195, 0187
Solar Power S/N's 1287, 1307, 1323
Solarex S/N's 229163, 229156, 228138
Sensor Technology S/N's 2714, 2671, 1786

The results of the visual examination were as follows:

Spectrolab - Two screws in each of the outer frames were rusted. There was some other corrosion on the frames. S/N 0187 had a crack in one spot in the encapsulant backing the panel.

Solar Power - There were numerous cracks in the encapsulant (approximately 15 places on S/N 1287, 21 places on S/N 1307 and 15 places on S/N 1323). The encapsulant had delaminated from the backing in several spots on all modules. Figure 14 shows the delaminated and cracked encapsulant on S/N 1323. Figure 14 is typical of cracked and delaminated encapsulant occurring during VSP and other environmental tests for all types of modules. S/N 1287 had one cracked cell (row 3, cell 1). S/N 1307 showed signs of corrosion on two cells (row 4, cells 5 and 6) as shown in Figure 15.

NOTE: The cell location designation is obtained by placing the module in its upright position so the printing on the name tag is in the normal reading orientation and then numbering the rows from left to right and the cells from top to bottom. This location designation will be used throughout the remainder of this report.

Sensor Technology - There were numerous cracks in the encapsulant (approximately 25 places on S/N 1786, 17 places on S/N 2671 and 24 places on S/N 2714). Some cells were discolored near the cracks. S/N's 1786 and 2714 had corrosion around the upper mounting holes as shown in Figure 16.

Solarex - There were numerous cracks in the encapsulant (approximately 14 places on S/N 229156, 18 places on S/N 228138 and 17 places on S/N 229163). The encapsulant was delaminated in numerous places. Figure 17 shows some of the delaminations on S/N 229163. There was some pitting of the frame of S/N 229163. The plugs in the terminal boxes were corroded on S/N's 229156 and 228138 as shown in Figure 18. The following cells were cracked:

| S/N 229156 | | | | | | | S/N 228138 | | | | | | | | S/N 229163 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| row | 2 | 3 | 3 | 3 | 4 | 6 | row | 3 | 3 | 4 | 5 | 5 | 6 | 6 | row | 1 | 2 | 6 | 6 | 6 |
| cell | 1 | 3 | 5 | 6 | 2 | 5 | cell | 1 | 7 | 1 | 1 | 7 | 1 | 3 | cell | 7 | 1 | 1 | 5 | 7 |

All of the cracked cells on S/N 228138 had pieces which had fallen down behind the rest of the cell as shown in Figure 19 and 20. This was possible because of the delamination of the encapsulant.

The results of the functional tests are shown below:

| Manufacturer | S/N | Before VSP Test: Open Circuit Voltage | Before VSP Test: Voltage (mv) 1-Ohm Resistor | After VSP Test: Open Circuit Voltage | After VSP Test: Voltage (mv) 1-Ohm Resistor |
|---|---|---|---|---|---|
| Spectrolab | 0173 | 21.9 | 518 | 22.7 | 508 |
| | 0195 | 22.3 | 583 | 22.9 | 615 |
| | 0187 | 22.0 | 600 | 22.5 | 577 |
| Solar Power | 1287 | 22.2 | 242 | 23.2 | 268 |
| | 1307 | 21.6 | 216 | 22.4 | 188 |
| | 1323 | 22.3 | 219 | 22.5 | 198 |
| Solarex | 229156 | 21.9 | 209 | 0 | 0 |
| | 228138 | 21.8 | 238 | 22.4 | 65 |
| | 229163 | 21.9 | 217 | 21.4 | 205 |
| Sensor Technology | 2671 | 23.9 | 152 | 24.9 | 124 |
| | 1786 | 23.4 | 156 | 24.3 | 136 |
| | 2714 | 23.4 | 158 | 23.8 | 144 |

All modules had similar outputs, though in most cases somewhat lower, before and after VSP testing with the exception of Solarex S/N's 229156 and 228138. S/N 228138 had a normal open-circuit voltage but only 27 percent of its pretest current through the 1-ohm resistor. S/N 229156 had no current and no voltage following VSP. During the visual inspection, S/N 228138 appeared to be in worse shape than S/N 229156 since the seven cracked cells all had pieces missing from them.

Fungus. - Fungus testing was performed on the following eight modules:

| | GROUP A | GROUP B |
|---|---|---|
| Spectrolab S/N's | 0167 | 0191 |
| Solar Power S/N's | 1357 | 1536 |
| Solarex S/N's | 229158 | 227037 |
| Sensor Technology S/N's | 1839 | 2437 |

Group A modules were tested in an "as received" condition according to Procedure 1, MIL-STD-810B (reference (3)). After 28 days, Sensor Technology module S/N 1839 supported moderate amounts of fungal growth. The test was contined for an additional 32 days. No growth had occurred on the other three modules after 60 days. Group B modules were "soiled" by application of a nutrient. This resulted in heavy fungal growth on all four modules. Nutrient was applied to the Group B modules to ensure fungal growth so the effects of the growth on the materials in the modules could be investigated by NASA Lewis Research Center. Appendix A is a detailed report of the fungus testing. Following the tests, the eight modules, with the fungal growth still intact, were returned to the NASA Lewis Research Center for post-test analysis. No functional or visual check was performed at NAVWPNSUPPCEN Crane following the fungus tests.

Temperature/Altitude. - Twelve modules were subjected to a temperature/altitude test. The modules were placed in a test chamber and subjected to four 24-hour temperature and altitude cycles as shown in Figure 21. The twelve modules were all tested at one time.

The following modules were tested:

Spectrolab S/N's 0220, 0211, 0218
Solar Power S/N's 1525, 1172, 1231
Solarex S/N's 229039, 228089, 229036
Sensor Technology S/N's 2551, 2523, 2517

A visual check was made of the modules following the tests. Sensor Technology S/N 2523 had one cracked cell (row 5, cell 8). The encapsulant was cracked in two places on Solar Power S/N 1231. The other 10 panels showed no visible defects.

The results of the functional tests were as follows:

| | | Before Temperature/Altitude Test | | After Temperature/Altitude Test | |
|---|---|---|---|---|---|
| Manufacturer | S/N | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor |
| Spectrolab | 0220 | 22.4 | 541 | 22.6 | 554 |
| | 0211 | 22.5 | 519 | 22.7 | 549 |
| | 0218 | 22.5 | 566 | 22.7 | 600 |
| Solar Power | 1525 | 22.3 | 189 | 22.8 | 201 |
| | 1172 | 22.5 | 209 | 23.1 | 230 |
| | 1231 | 22.0 | 224 | 22.4 | 246 |
| Solarex | 229039 | 21.0 | 236 | 21.0 | 214 |
| | 228089 | 22.4 | 237 | 22.7 | 231 |
| | 229036 | 22.2 | 205 | 22.6 | 200 |
| Sensor Technology | 2551 | 23.7 | 132 | 24.1 | 157 |
| | 2523 | 24.1 | 109 | 24.4 | 112 |
| | 2517 | 23.8 | 111 | 24.2 | 126 |

All modules showed similar outputs before and after testing.

Thermal shock. - Twelve modules were subjected to thermal shock. The test was performed by preconditioning the modules in a temperature chamber at -54°C (-65°F) for at least 4 hours. After the preconditioning, each module was quickly (within 20 seconds) transferred to a second temperature chamber at 71°C (160°F) and 20 percent relative humidity and maintained for at least 4 hours. This process was repeated until the modules had been exposed to both temperatures three times. The 12 modules were all tested at one time.

The following modules were tested:

Spectrolab S/N's 0223, 0219, 0210
Solar Power S/N's 1166, 1561, 1527
Solarex S/N's 229169, 228035, 229029
Sensor Technology S/N's 2559, 2555, 2526

A visual check following the test showed that Sensor Technology S/N 2526 had one cracked cell (row 3, cell 6) and Sensor Technology S/N 2555 had two cracked cells (row 4, cells 4 and 7). All other modules showed no visible defects.

The results of the functional tests are shown below:

| | | Before Thermal Shock Test | | After Thermal Shock Test | |
|---|---|---|---|---|---|
| Manufacturer | S/N | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor | Open Circuit Voltage | Voltage (mv) 1 Ohm Resistor |
| Spectrolab | 0223 | 22.6 | 535 | 22.6 | 589 |
| | 0219 | 22.5 | 585 | 22.5 | 608 |
| | 0210 | 22.7 | 551 | 22.7 | 607 |
| Solar Power | 1166 | 22.9 | 214 | 22.9 | 251 |
| | 1561 | 22.5 | 247 | 22.5 | 273 |
| | 1527 | 22.5 | 233 | 22.4 | 308 |
| Solarex | 229169 | 21.8 | 236 | 22.1 | 227 |
| | 228035 | 22.5 | 201 | 22.6 | 200 |
| | 229029 | 22.3 | 197 | 22.6 | 191 |
| Sensor Technology | 2559 | 24.4 | 111 | 24.9 | 160 |
| | 2555 | 23.4 | 198 | 24.0 | 191 |
| | 2526 | 22.6 | 119 | 23.1 | 138 |

All modules had similar outputs before and after testing.

## SUMMARY OF RESULTS

Environmental testing of the solar cell modules produced cracked cells, cracked encapsulant and encapsulant delaminations on various modules. In addition, there was some minor cell and frame corrosion. Vacuum/steam/pressure testing caused the most severe damage to the modules. One Solarex module had no electrical output following vacuum/steam/pressure. The sand and dust test and salt fog test caused lower current outputs from the modules due to dust and salt films on the module surface. A Sensor Technology module supported fungus growth during fungus testing. Results show that Spectrolab modules were more resistant to the applied environmental tests than Solar Power, Solarex and Sensor Technology modules.

APPENDIX A

# FUNGAL GROWTH ON NORMAL AND "SOILED" SOLAR PANELS

REPORT NUMBERS
MATD - 20B/21B

PREPARED BY:
NAVAL WEAPONS SUPPORT CENTER
WEAPONS QUALITY ENGINEERING CENTER
MATERIALS ANALYSIS AND TECHNOLOGY DIVISION
CODE 3032

## SUMMARY

Four sets of solar panels were tested to determine their abilities to support fungus growth. One panel of each set was tested in an "as received" condition, being inoculated with a mixture of fungus spores and incubated at a temperature and humidity conducive to fungus growth. The other panel of each set was "soiled" by applying nutrient prior to inoculation and incubation. One of the test panels supported fungus growth when tested "as received". All "soiled" panels supported growth after 3 days incubation. Extremely heavy growth covered the entire "soiled" surfaces of the panels for the remainder of the test.

## BACKGROUND

Microorganisms, particularly fungi, are known to grow on a variety of materials when environmental conditions favorable for their growth are present. Some electronic materials will support growth of these microbiota. Their growth has been known to cause problems with electronic equipment, including short circuits, changes in insulation characteristics, etc. Further, any significant fungal fouling could adversely affect the transmission of light through transparent specimens.

Most polymeric materials in current construction use will - at best - support only slight growth. However, any material exposed to an outdoor environment - especially in regions near dense vegetation - will develop a coating of materials consisting of condensed organic chemicals from the air, plant juices and parts, insect parts, pollen, dust, animal, bird and insect excreta, and similar materials. This coating will frequently support the growth of microorganisms. The effect of biological growth, either on clean or soiled materials, can be deleterious to the material, either by overgrowth, release of enzymes or corrosive waste products, holding moisture, serving as electrical path, destroying the integrity of the material, or in many other ways.

## OBJECTIVE

The purpose of these studies was to determine whether the supplied solar panels would support growth as manufactured, as well as after they had been artificially soiled as could happen after prolonged exposure in areas supporting heavy plant growth.

## TEST ITEMS

Two solar panels from each of four manufacturers were divided into groups A and B, one panel from each manufacturer in each group, as listed below:

| Manufacturer | Panel Serial Number Group A | Group B |
|---|---|---|
| Spectrolab - Solectric Power Systems | 0167 | 0191 |
| Solar Power Corp | 1357 | 1536 |
| Solar Energizer - Solarex Corp. | 229158 | 227037 |
| Sensor Technology, Inc. | 1839 | 2437 |

## "SOILING"

24g Bacto Difro Potato Dextrose Broth (a dehydrated concoction prepared from the solubles extracted from potatoes with hot water, supplemented with the sugar glucose) and 15g gelatin are dissolved in 1000 ml hot water. The solution is allowed to cool below 50°C and then is applied to the upper surface of the panels in Group B to a depth of 1 to 3 mm (the depth varied with surface irregularities) and allowed to dry overnight.

## TEST METHOD

The test specimens, along with appropriate controls, are inoculated with fungi according to Procedure 1, Method 508 of MIL-STD-810B by spraying a composite fungal spore suspension over the surface of the specimens of either group. The composite spore suspension contains equal portions of suspensions of washed spores of five separate cultures (*Aspergillus niger* ATCC* 9642; *Aspergillus flavis* ATCC 9643; *Aspergillus versicolor* ATCC 11730; *Penicillium funiculosum* ATCC 9644; *Chaetomium globosum* ATCC 6205). The individual spore suspensions contain 1,000,000 $\pm$ 200,000 spores of the appropriate organism per ml. The spores are suspended in a mineral salts solution consisting of the following:

Potassium dihydrogen phosphate ($KH_2PO_4$), 0.7 g; potassium monohydrogen phosphate ($K_2HPO_4$), 0.7g; magnesium sulfate ($mgSO_4.7H_2O$), 0.7g; ammonium nitrate ($NH_4NO_3$), 1.0g; sodium chloride (NaCl), 0.005g; ferrous sulfate ($FeSO_4.7H_2O$), 0.002g; zinc sulfate ($ZnSO_4.7H_2O$), 0.002g; maganous sulfate ($MnSO_4.H_2O$), 0.001g; distilled water, 1 liter.

The spore suspension was utilized immediately after preparation. The surfaces of the specimens were sprayed with the composite suspension until the surfaces were thoroughly moistened.

After inoculation, the samples were incubated at 29°C and a minimum relative humidity of 95 percent. The panels in Group B were

*American Type Culture Collection Assession Number incubated for a total of 60 days. The panels in Group A were to be incubated for at least 28 days. If no growth was evident after 28 days, incubation was to continue to a maximum of 60 days. (In practice, growth was noted on one panel after 28 days; after consultation it was agreed to continue incubation of all Group A panels for 60 days). The samples were to be observed for growth at intervals during the incubation period.

## RESULTS

Controls to assure the viability of the individual spore suspensions, as well as samples of materials known to support fungus growth (cork, leather and paper) which were inoculated and incubated with the test panels, supported copious fungus growth.

All soiled panels in Group B had heavy fungal growth after 3 days of incubation. This growth persisted throughout the incubation period. Typical growth is demonstrated in Figures 22 through 26. Figures 22 and 23 depict the panels in the humidity chamber. An idea of the overall growth can best be seen on the top panel in Figure 22 and the top right panel in Figure 23. The growth can be seen more clearly in Figures 24 and 25. Figure 25 is magnified approximately two times natural size. Further magnification is provided in Figure 26 (approximately 4X) and 27 (approximately 7X).

The only panel in Group A to support growth was the panel from Sensor Technology, Inc., which supported moderate amounts of growth after 28 days. There was no significant change in the amount of growth when incubation was continued for an additional 32 days. The growth on this panel is shown in Figure 28 and Figure 29 (approximately normal size). An overall view of the growth of the soiled unit from Sensor Technology, Inc., is provided (Figure 30) for comparision with Figure 28.

The effects of the fungus growth are not known. The panels are to be returned to the National Aeronautics and Space Administration, Lewis Research Center, for functional testing in an "as is" condition. Any material changes could only be observed after cleansing.

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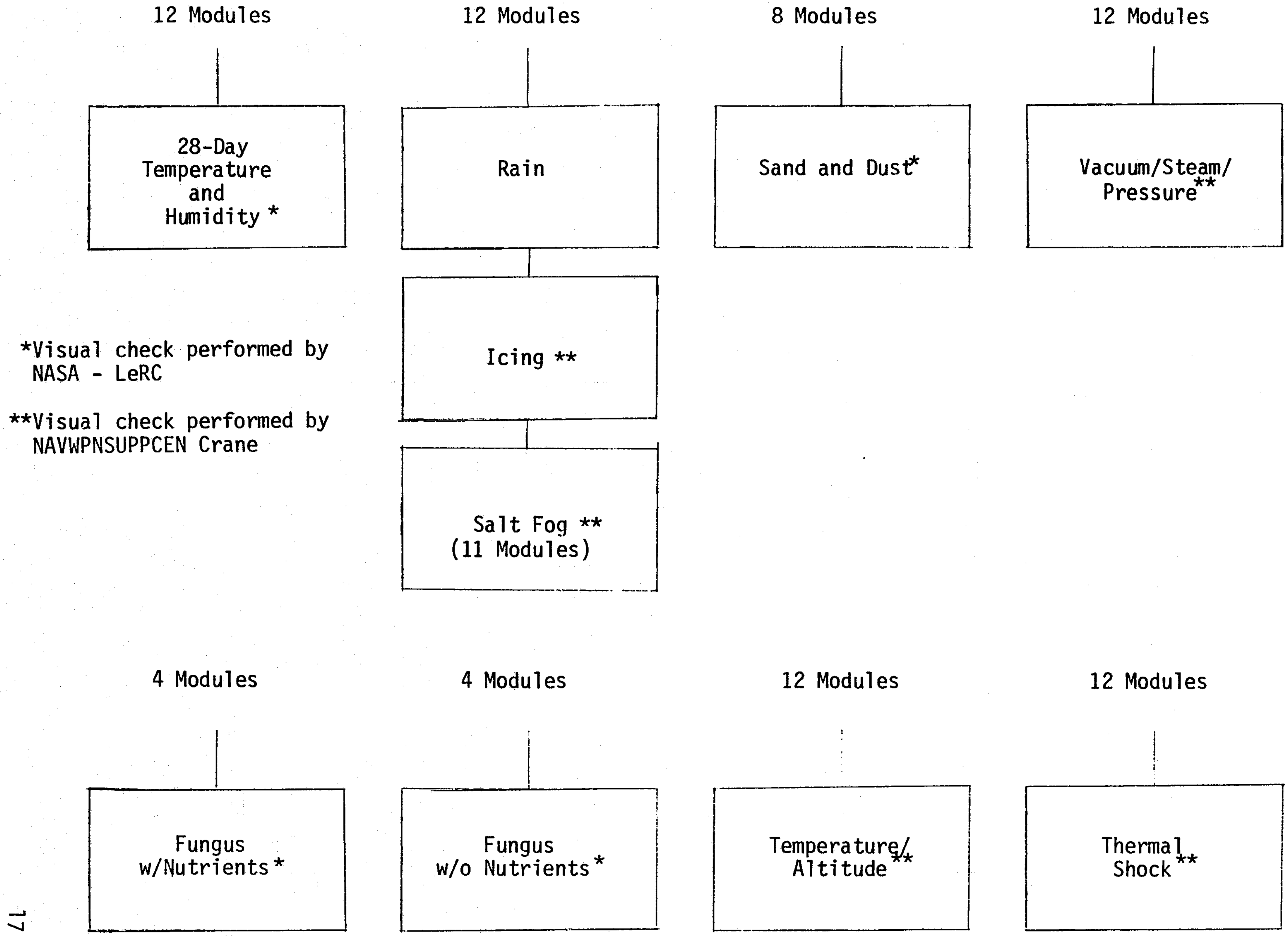



FIGURE 1

Test Flow Chart

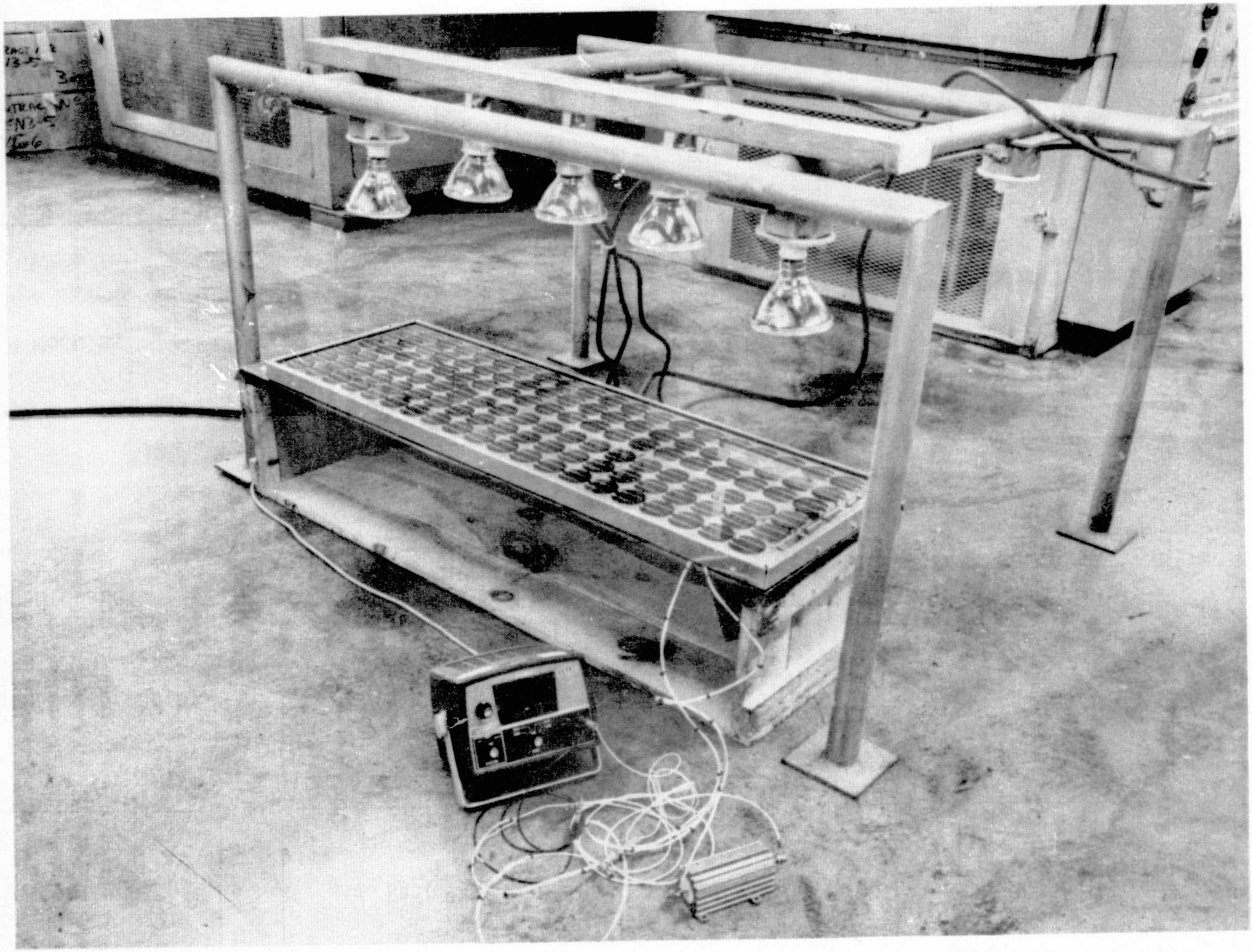


FIGURE 2
Setup for Functional Checkout

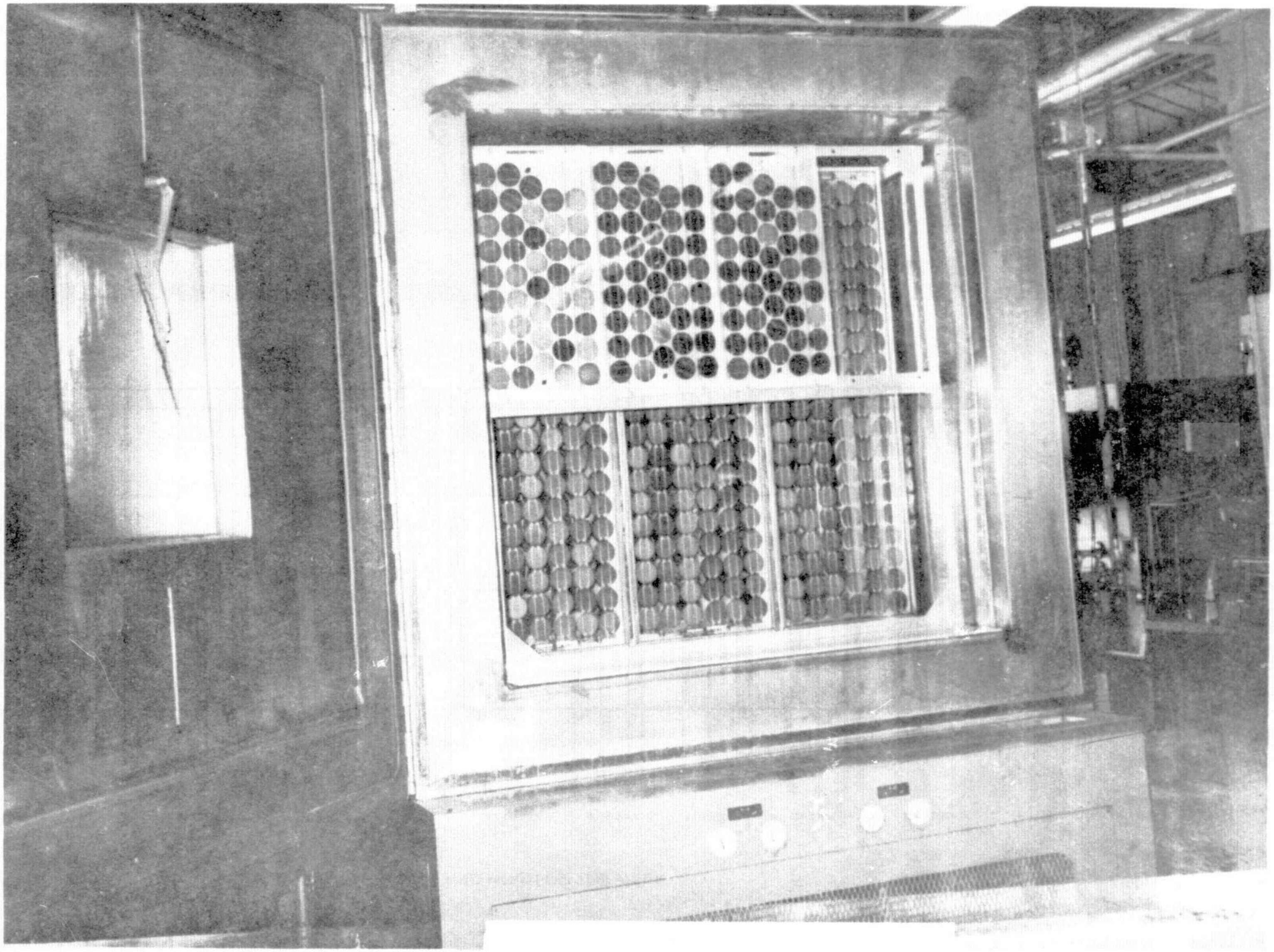
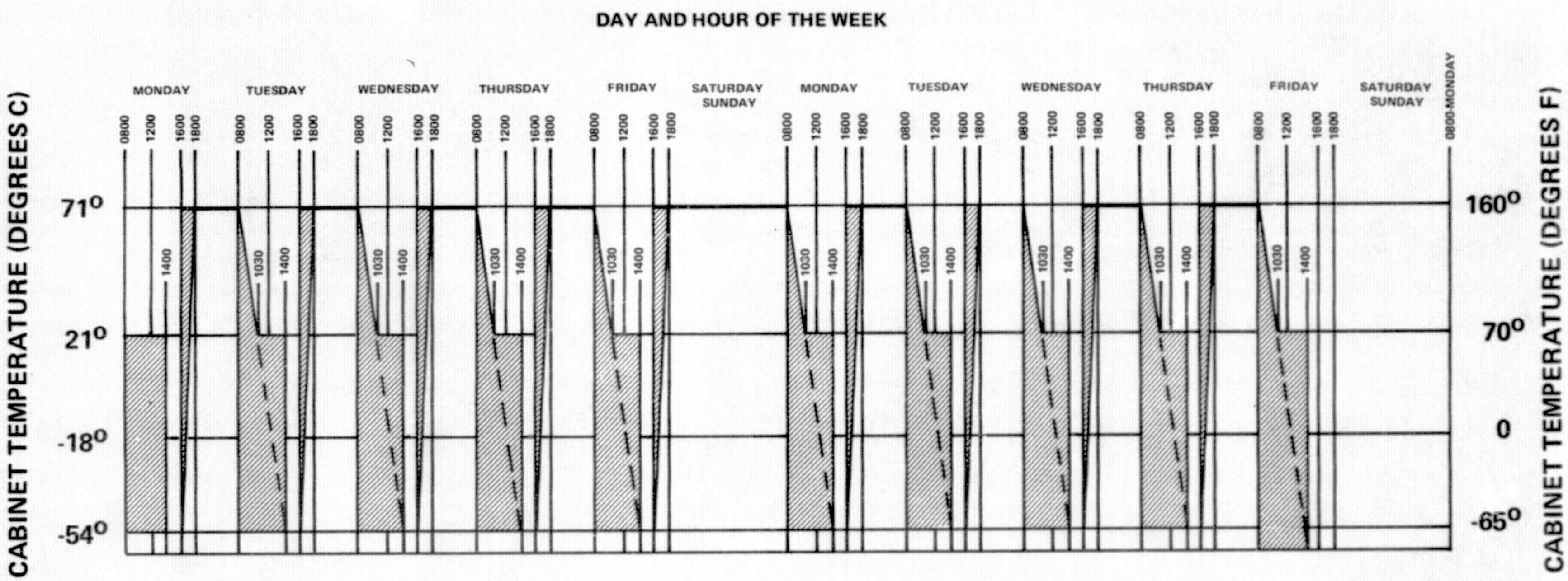


FIGURE 3

28-Day Temperature and Humidity
Test Facility

## JAN TEMPERATURE AND HUMIDITY CYCLE




MAINTAIN CABINET HUMIDITY AT 95% RELATIVE HUMIDITY WHEN TEMPERATURE AT 71°C.

FIGURE 4
28-DAY TEMPERATURE AND HUMIDITY CYCLE

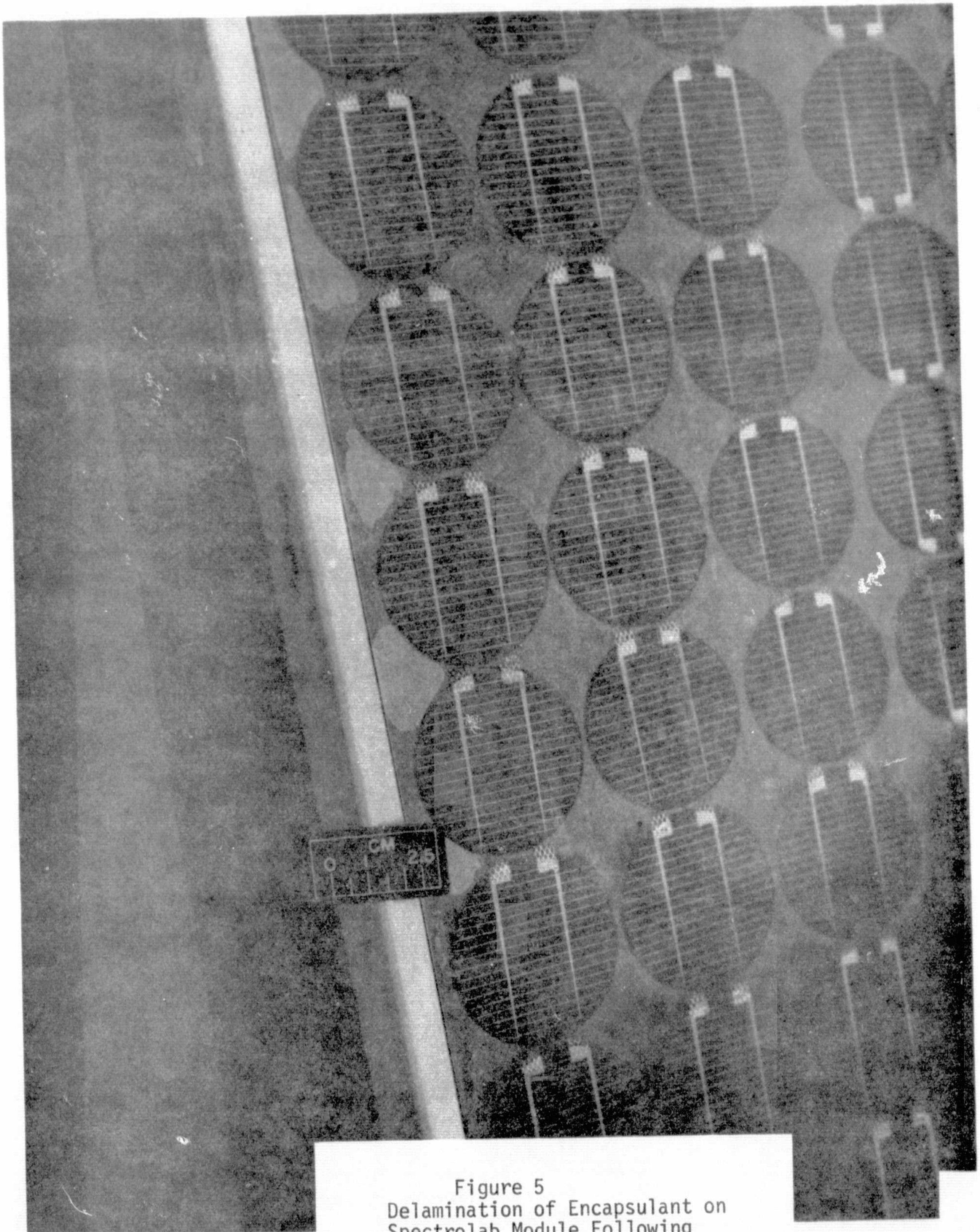



Figure 5
Delamination of Encapsulant on Spectrolab Module Following 28-Day Temperature and Humidity

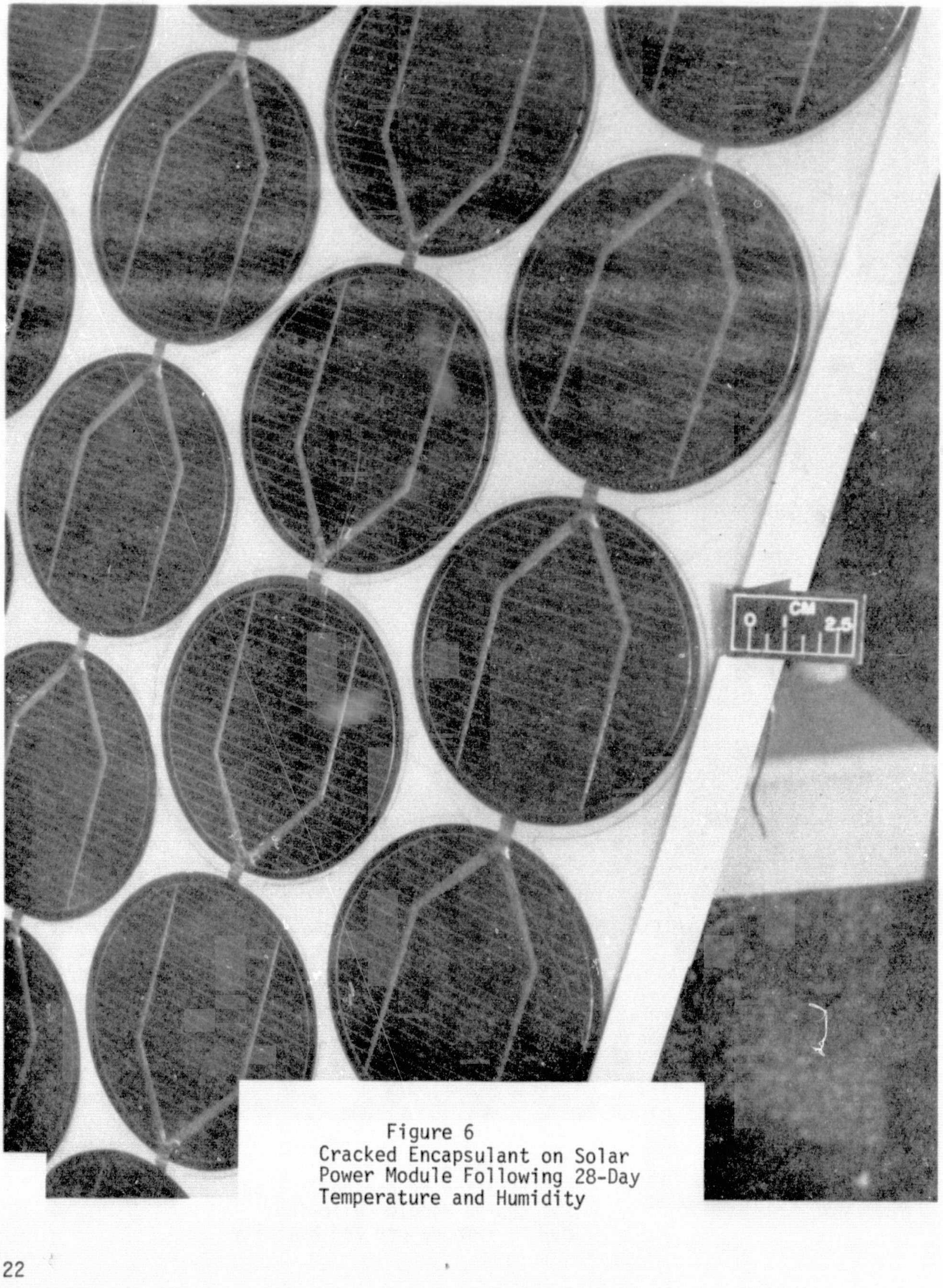



Figure 6
Cracked Encapsulant on Solar Power Module Following 28-Day Temperature and Humidity

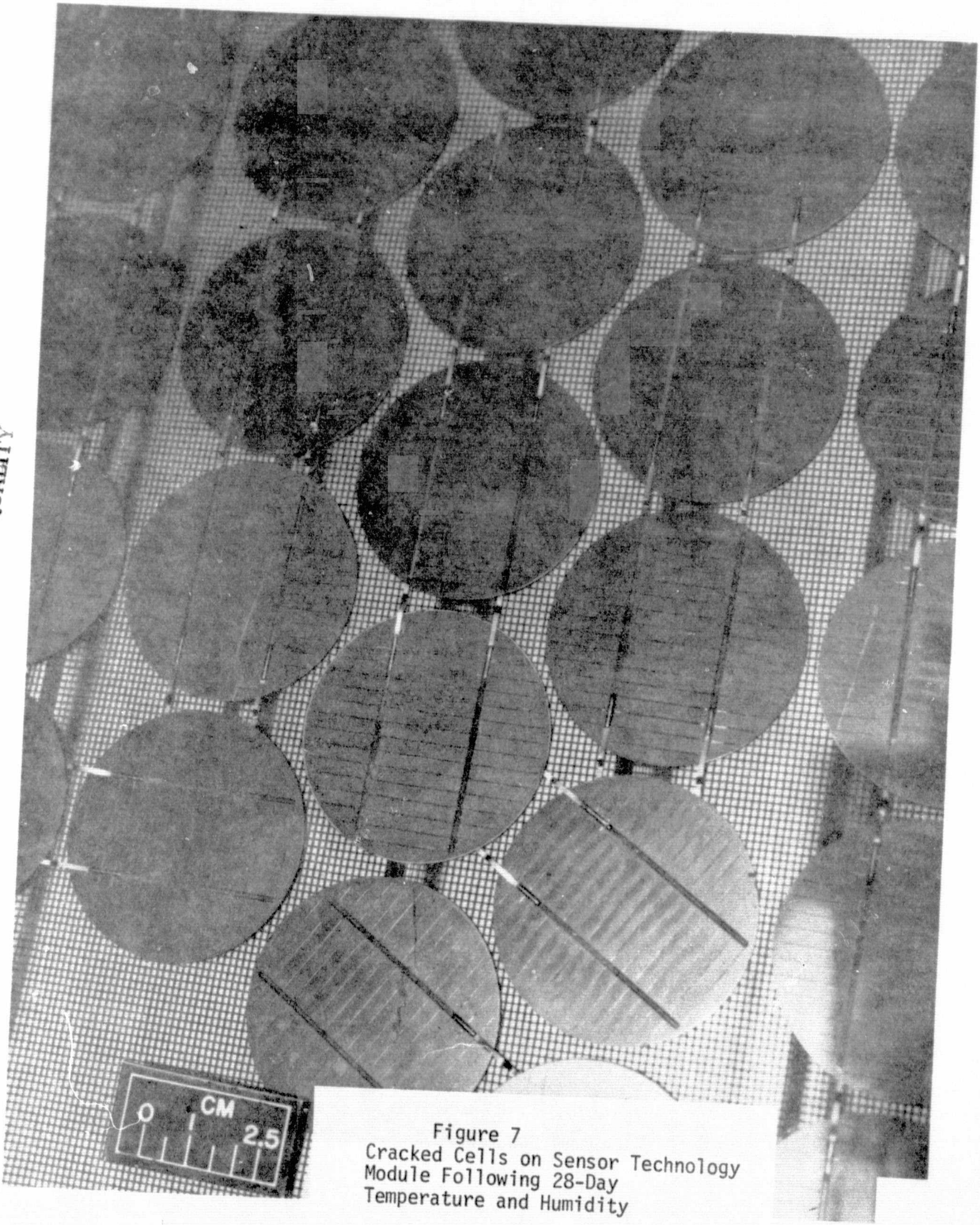



Figure 7
Cracked Cells on Sensor Technology
Module Following 28-Day
Temperature and Humidity

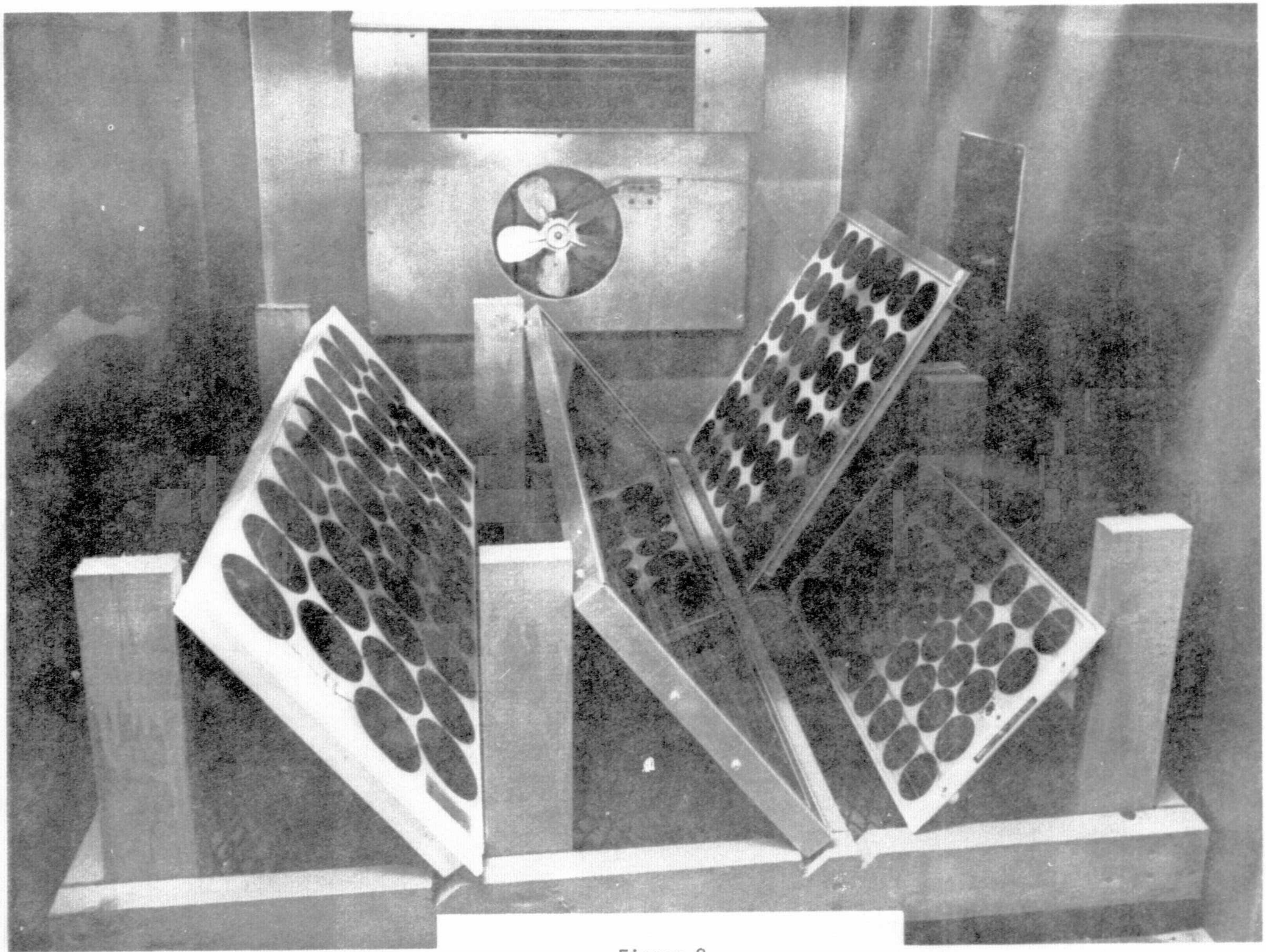


Figure 8

Rain Test Facility

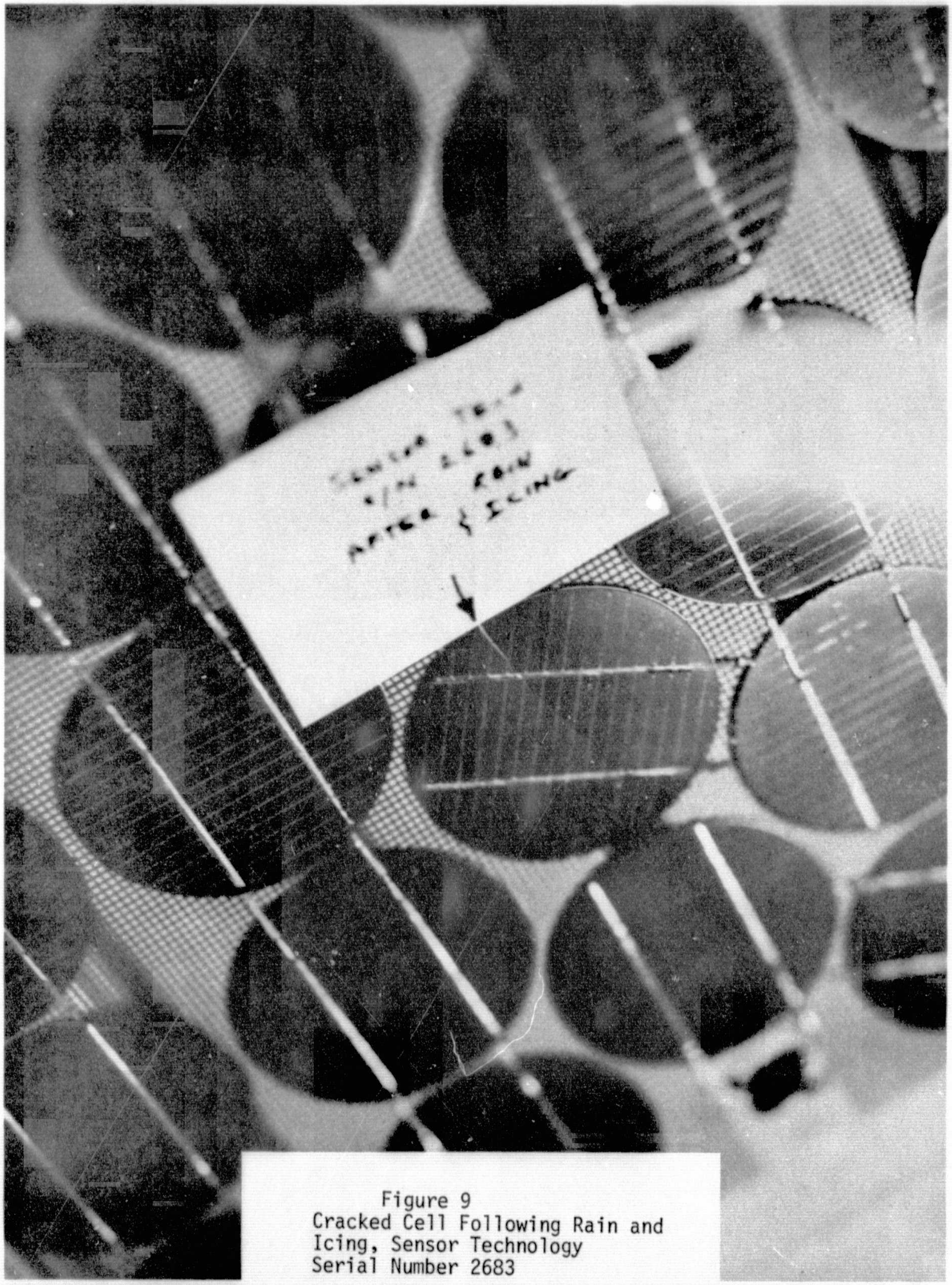


Figure 9
Cracked Cell Following Rain and
Icing, Sensor Technology
Serial Number 2683

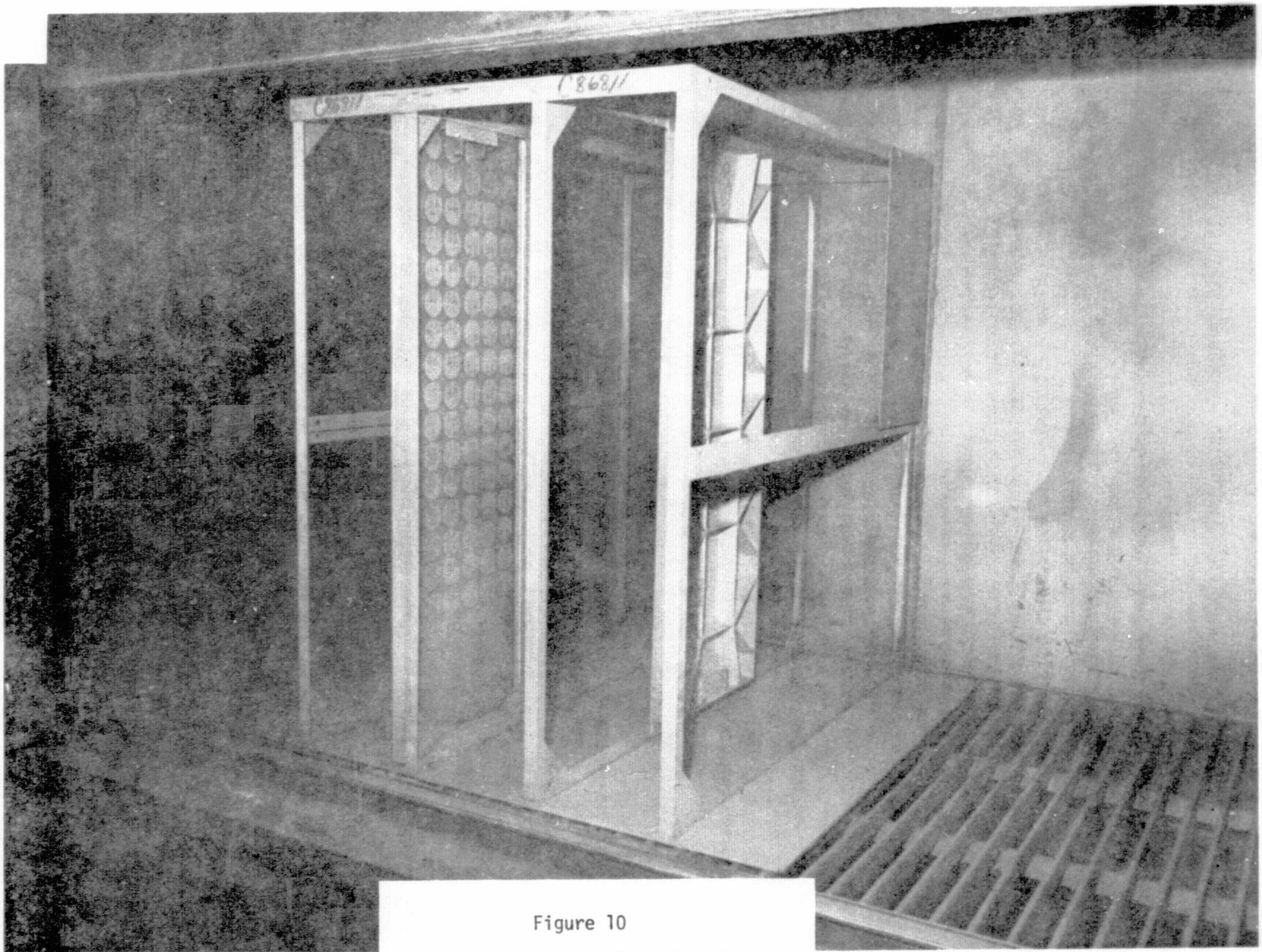


Figure 10

Sand and Dust Test Facility

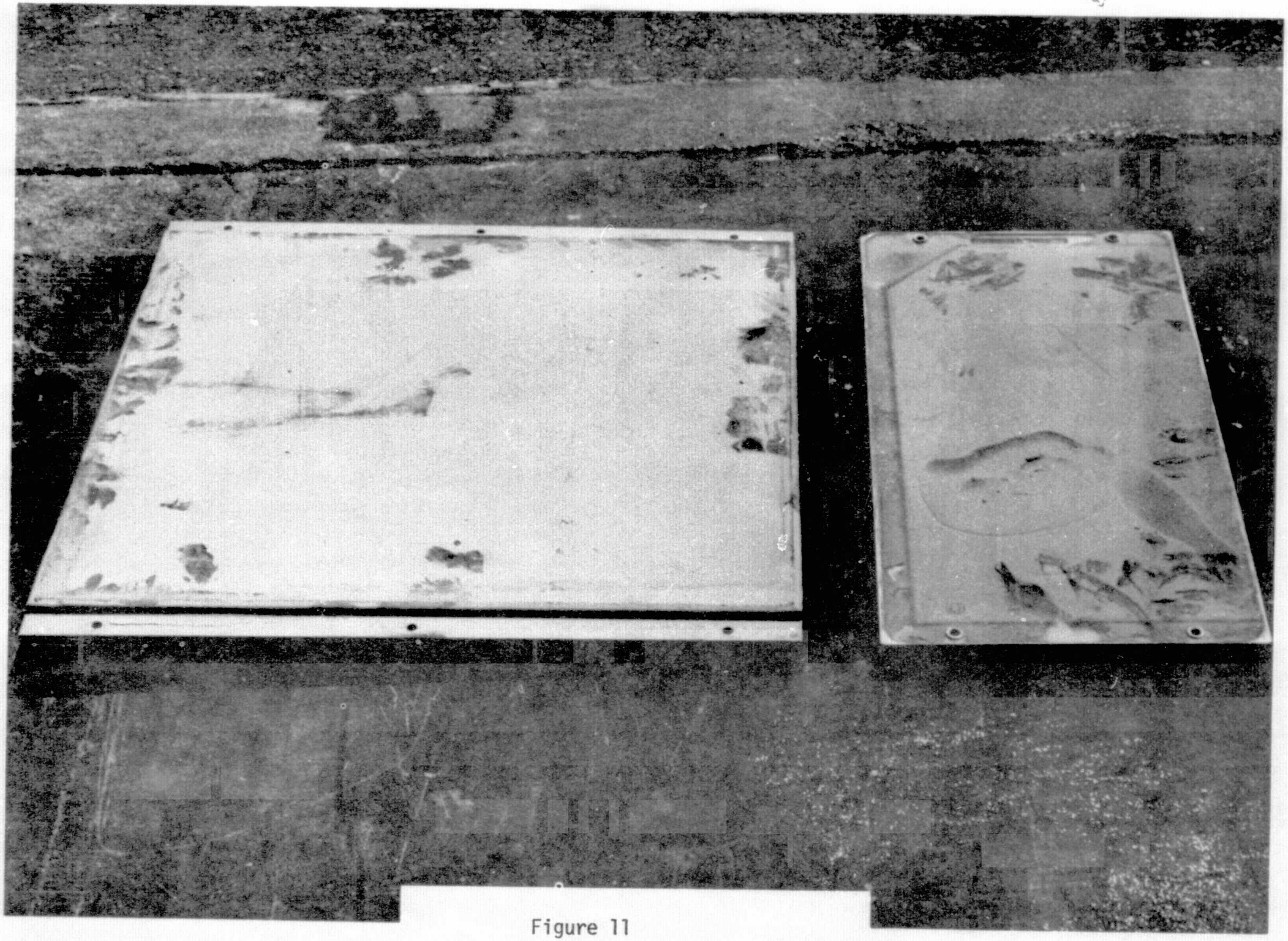


Figure 11

Solarex and Sensor Technology
Modules Following Sand and Dust

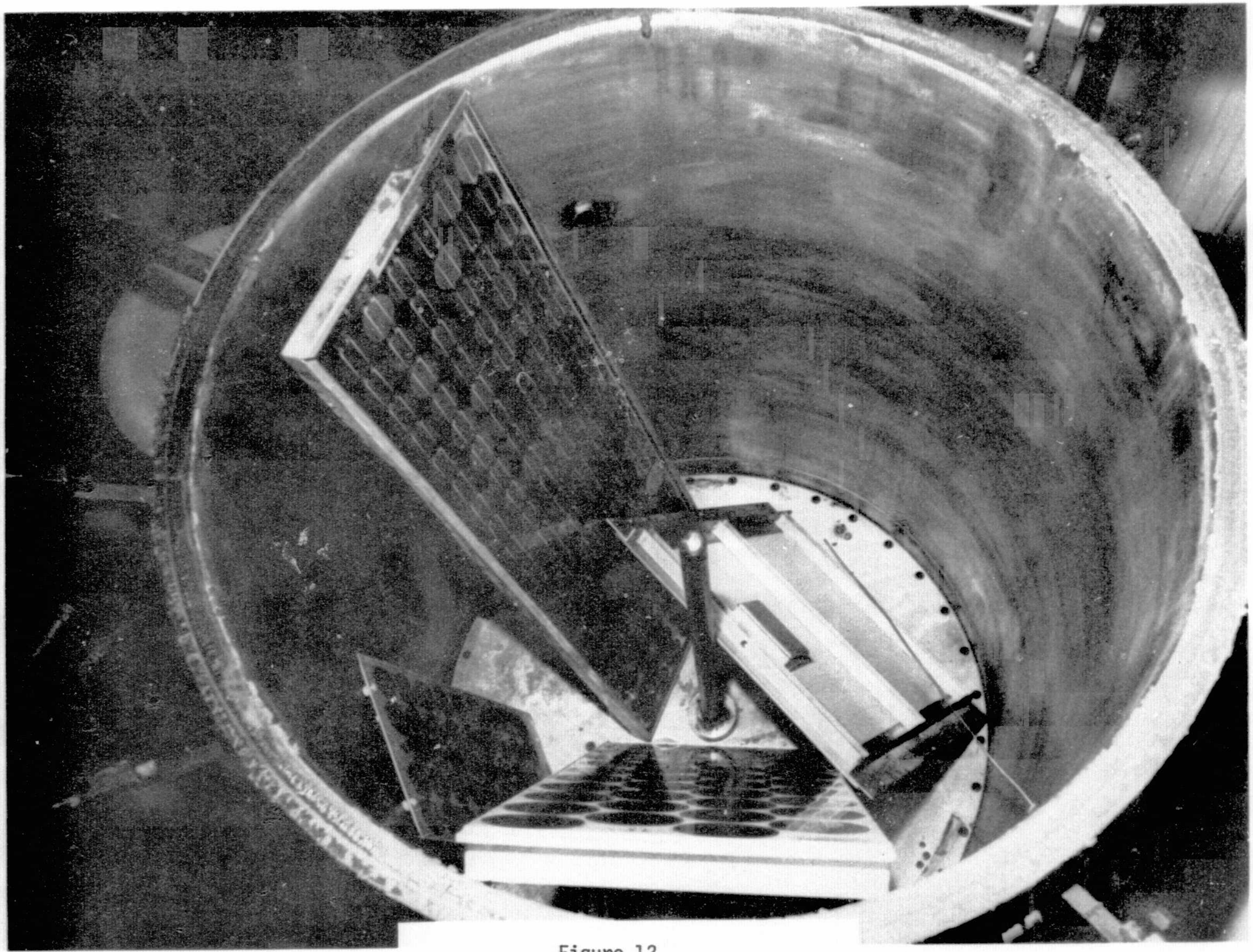
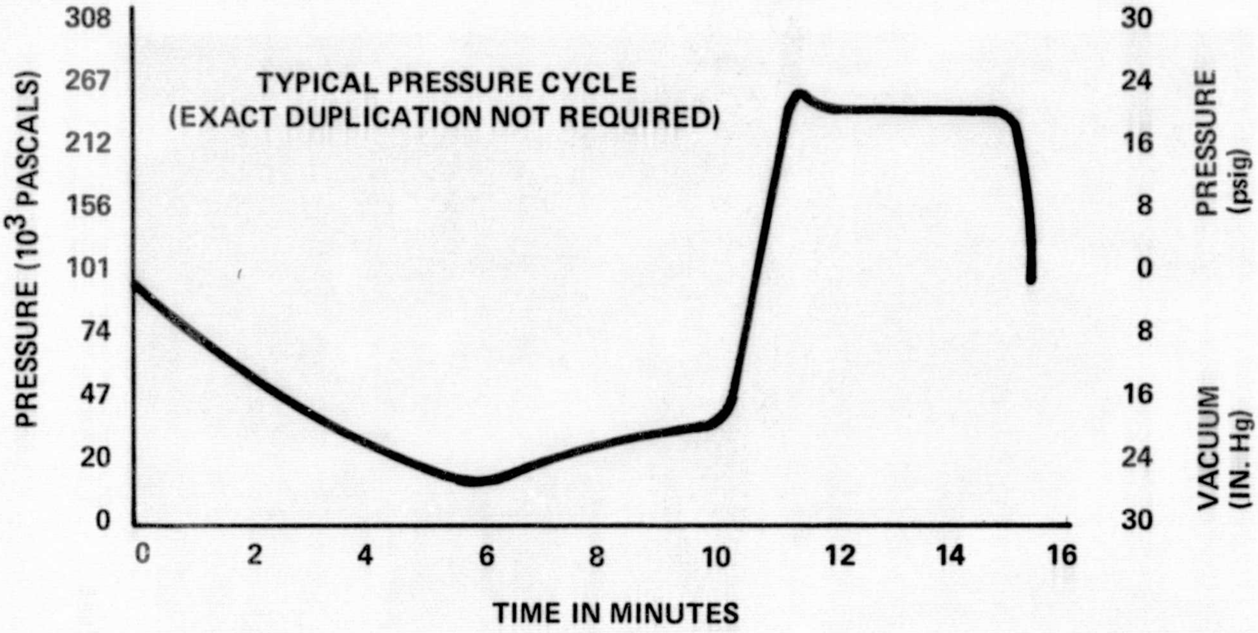


Figure 12

Vacuum/Steam/Pressure Test Facility



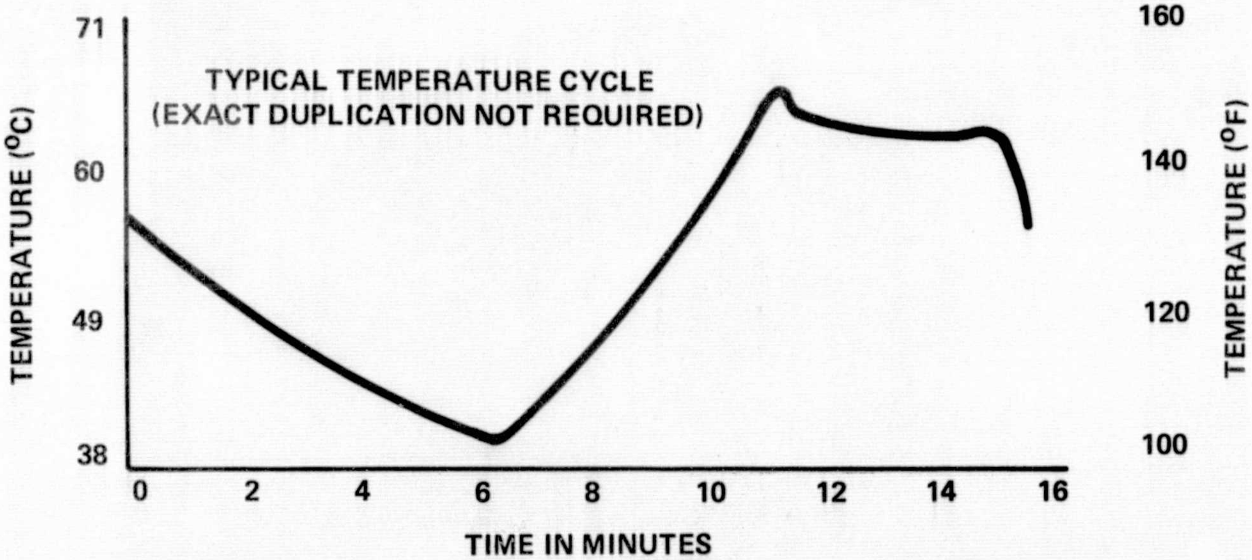




FIGURE 13
VACUUM/STEAM/PRESSURE CYCLE

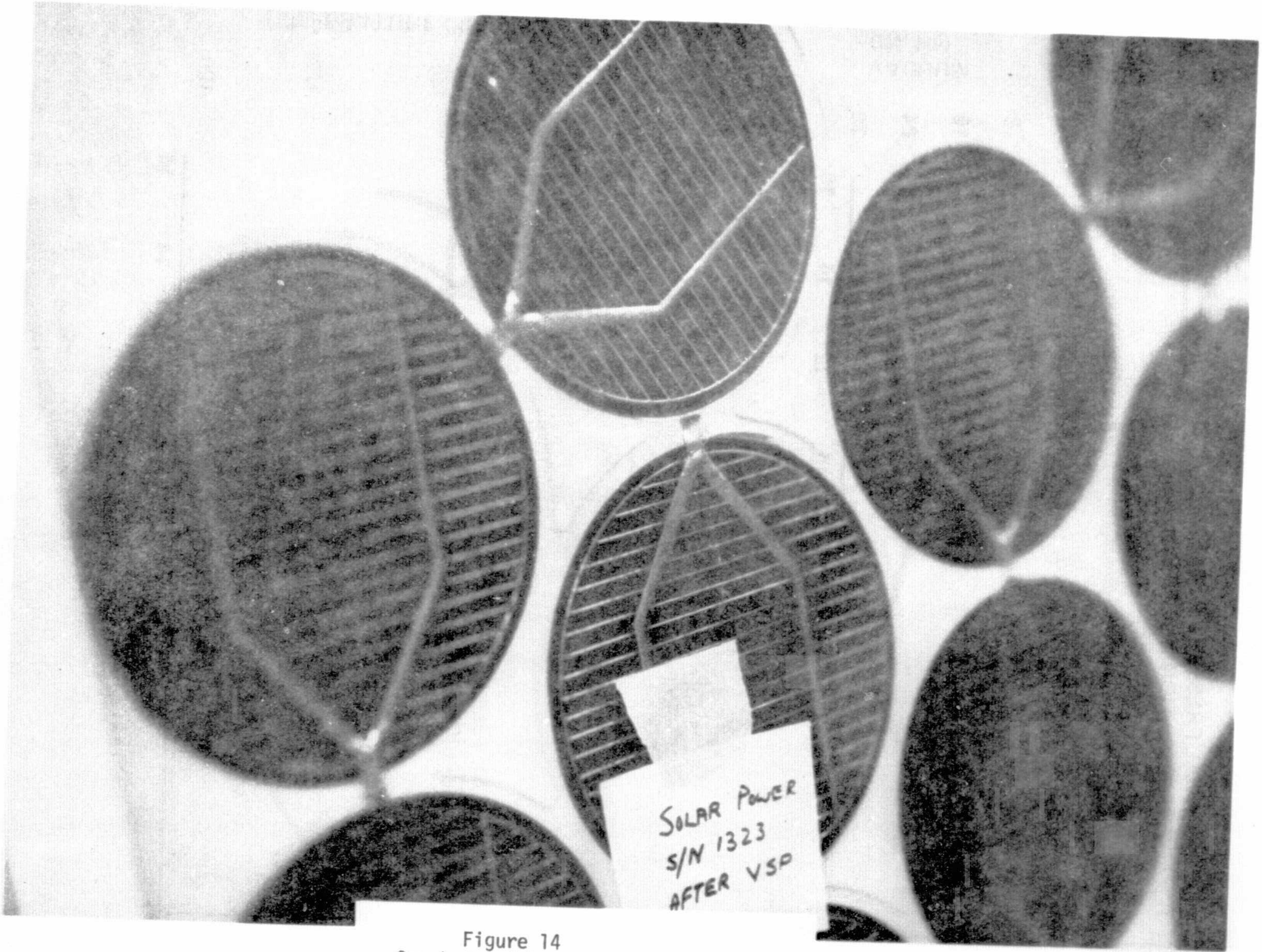



Figure 14
Cracked and Delaminated Encapsulant
Following Vacuum/Steam/Pressure,
Solar Power Serial Number 1323


Figure 15
Corroded Cell Following
Vacuum/Steam/Pressure, Solar
Power Serial Number 1323

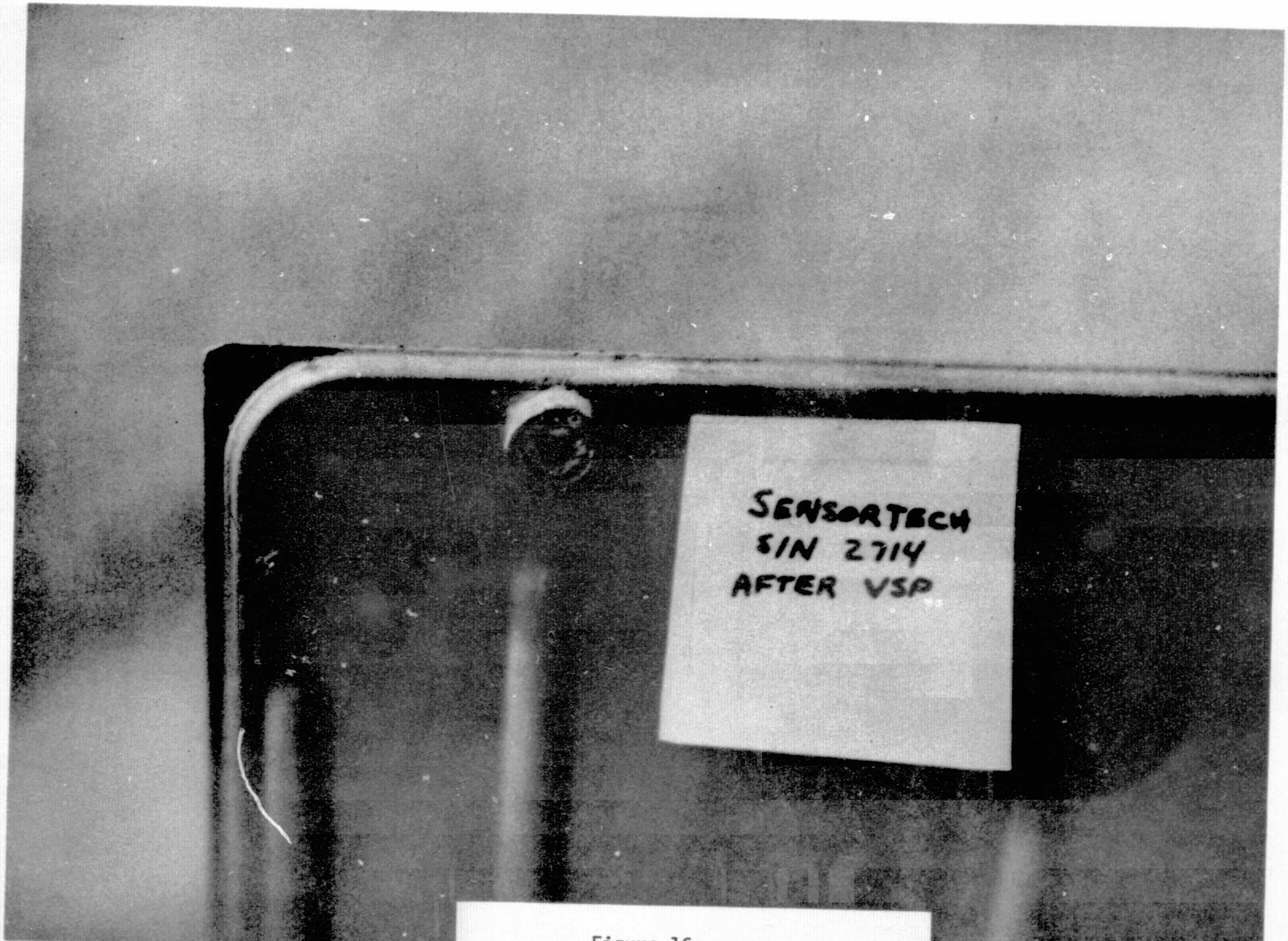



Figure 16
Corrosion Around Upper Mounting Hole of Sensor Technology Module Following Vacuum/Steam/Pressure

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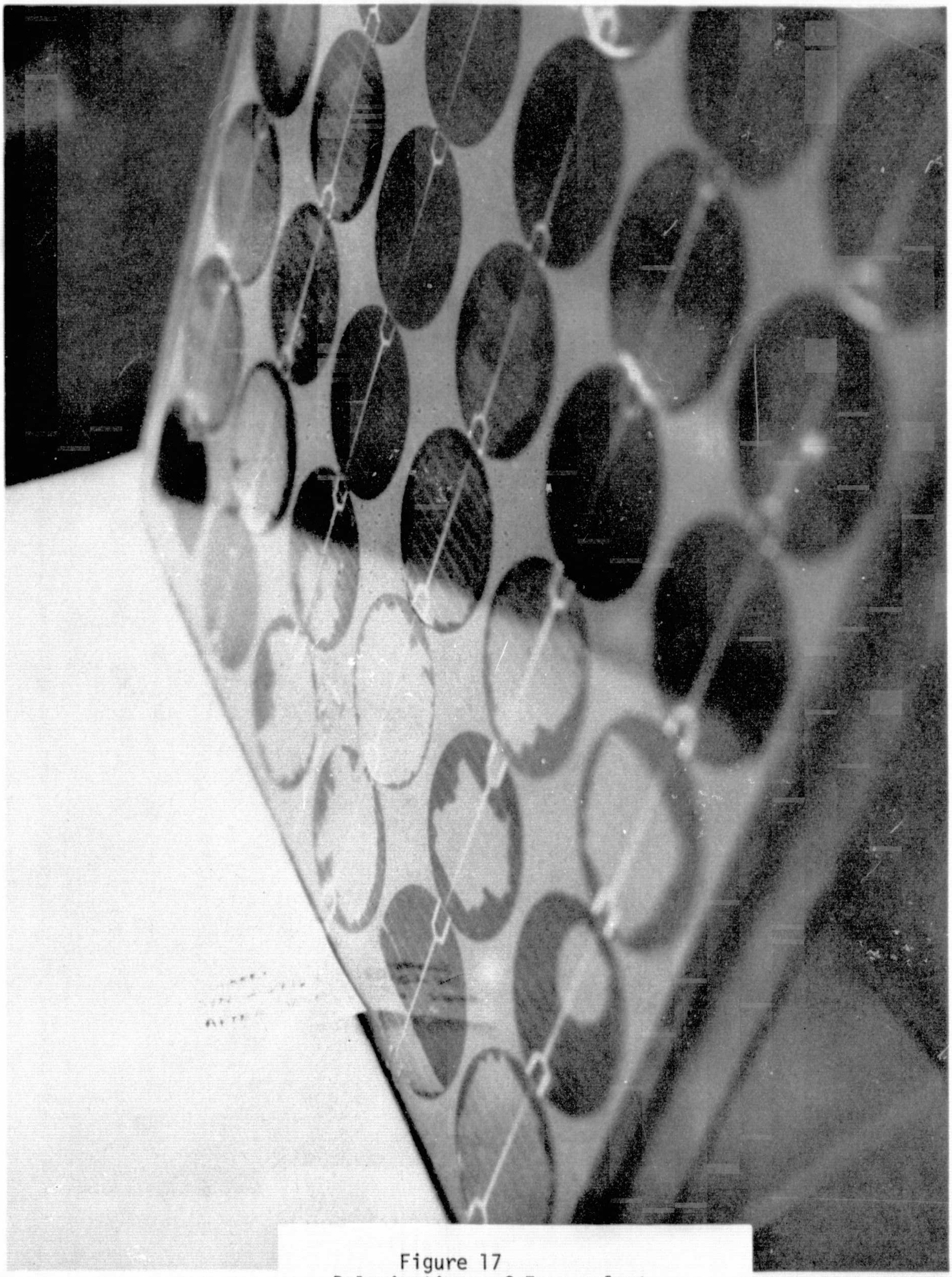

Figure 17
Delaminations of Encapsulant
Following Vacuum/Steam/Pressure,
Solarex Serial Number 229163

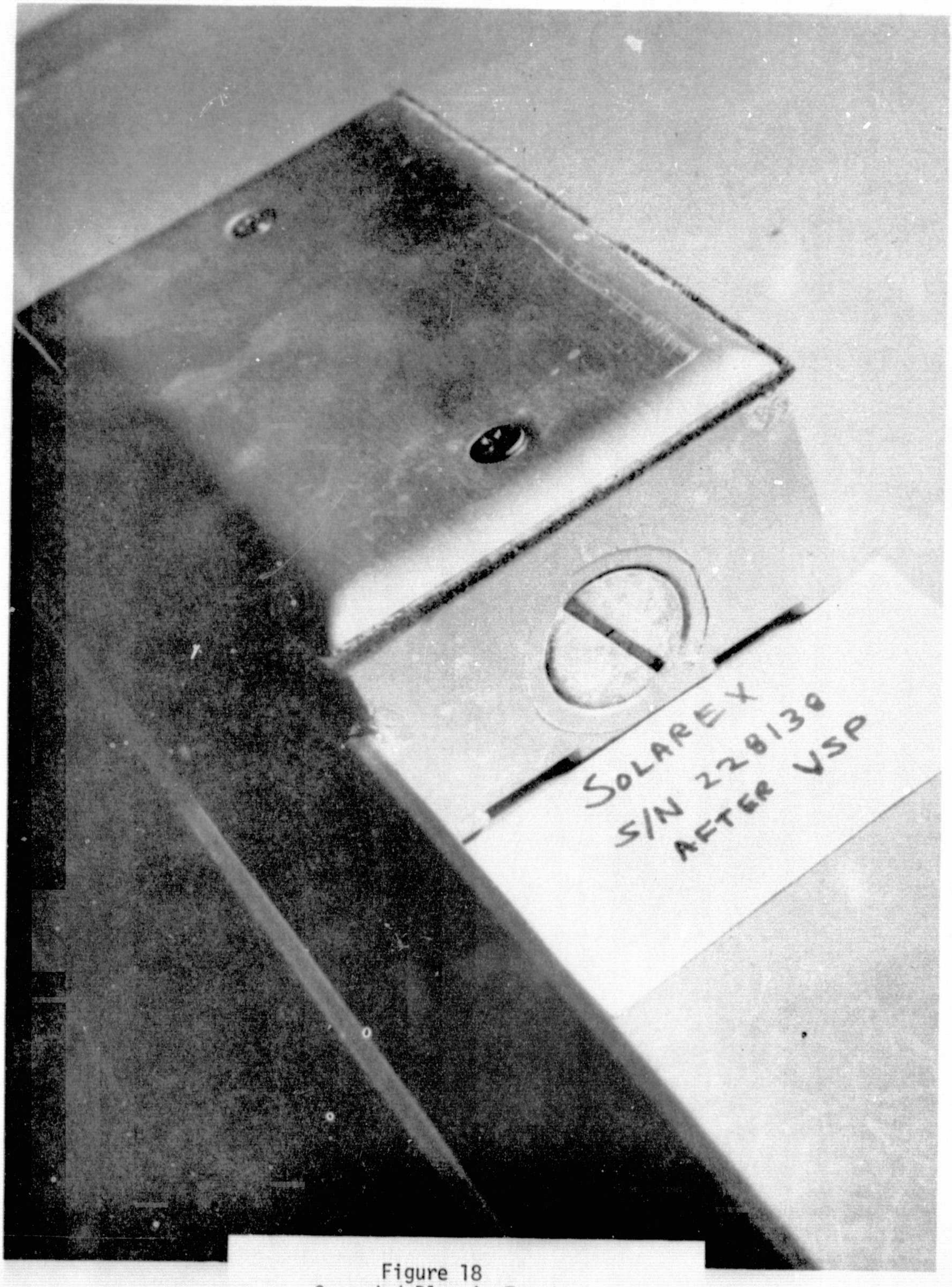


Figure 18
Corroded Plug in Terminal Box
of Solarex Module Following
Vacuum/Steam/Pressure

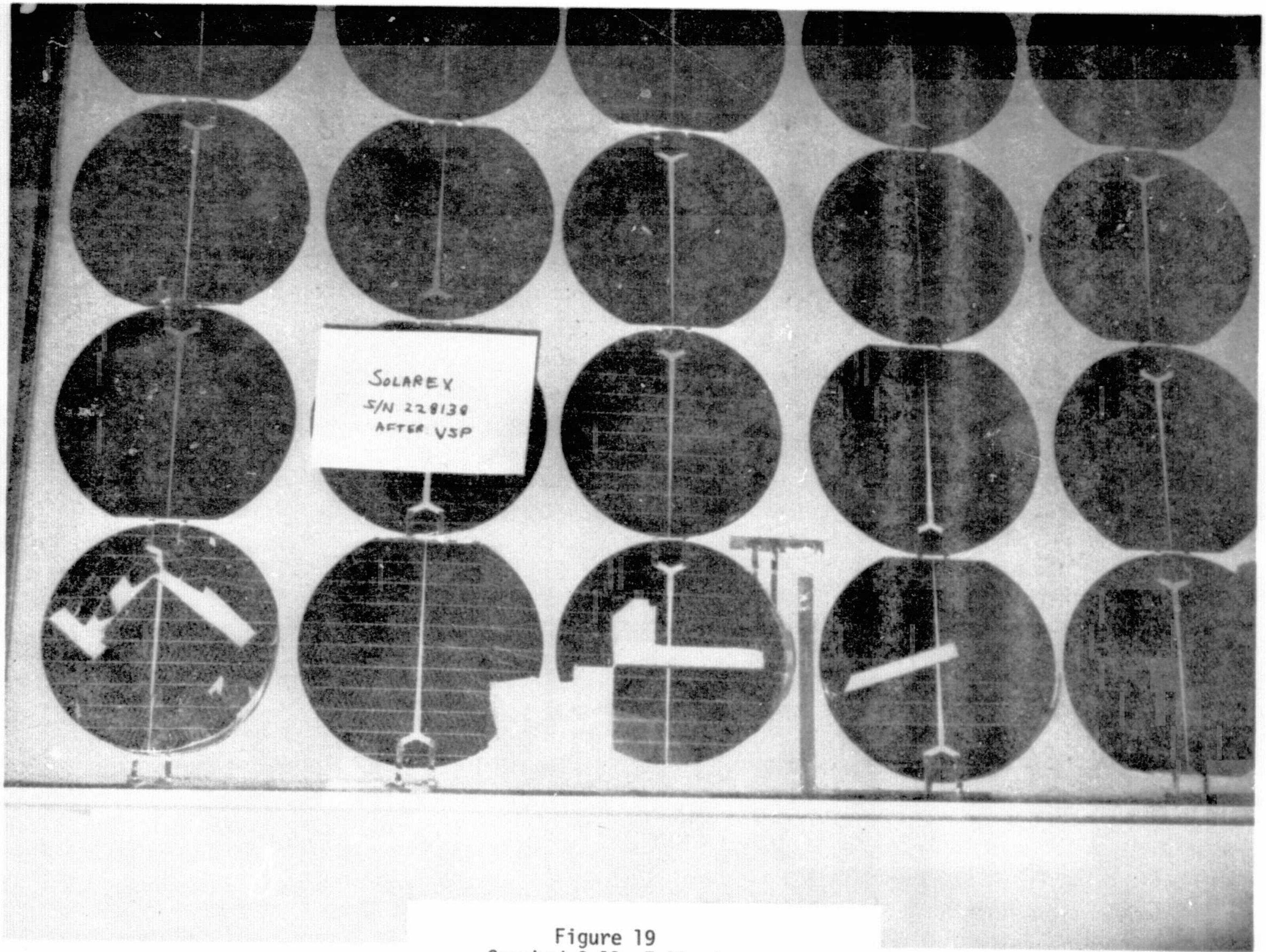


Figure 19
Cracked Cells Following
Vacuum/Steam/Pressure, Solarex
Serial Number 228138

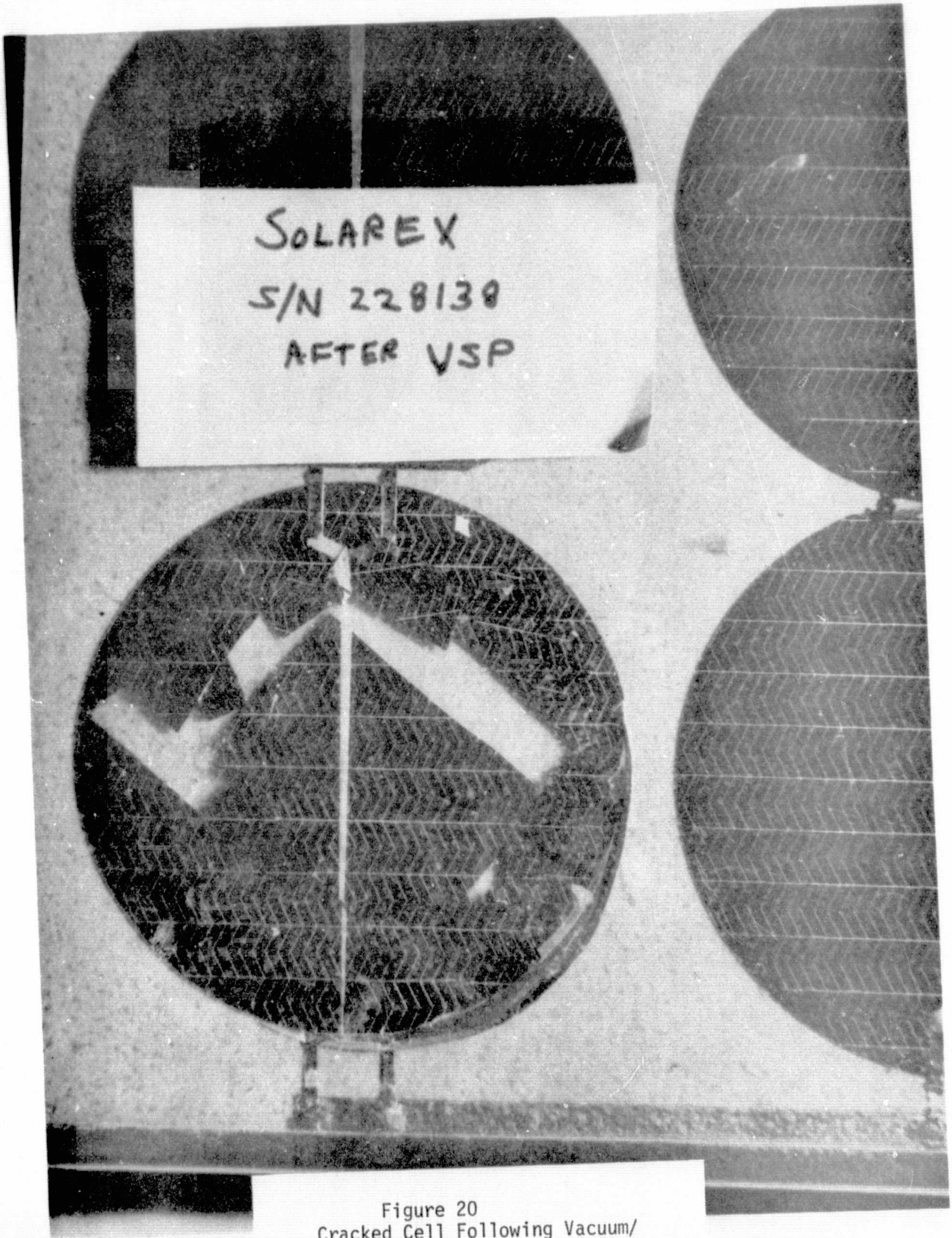


Figure 20
Cracked Cell Following Vacuum/Steam/Pressure, Solarex Serial Number 228138

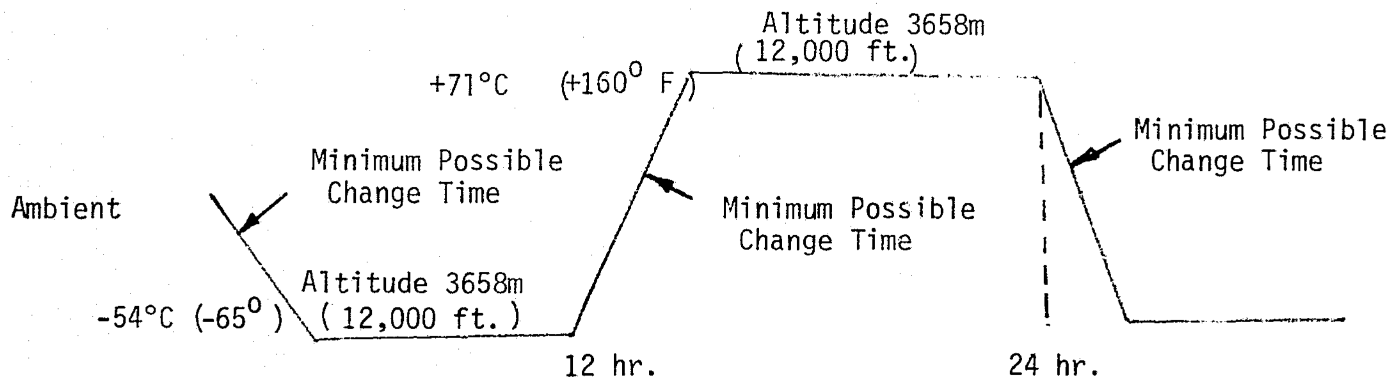


Figure 21

Temperature/Altitude Test Cycle

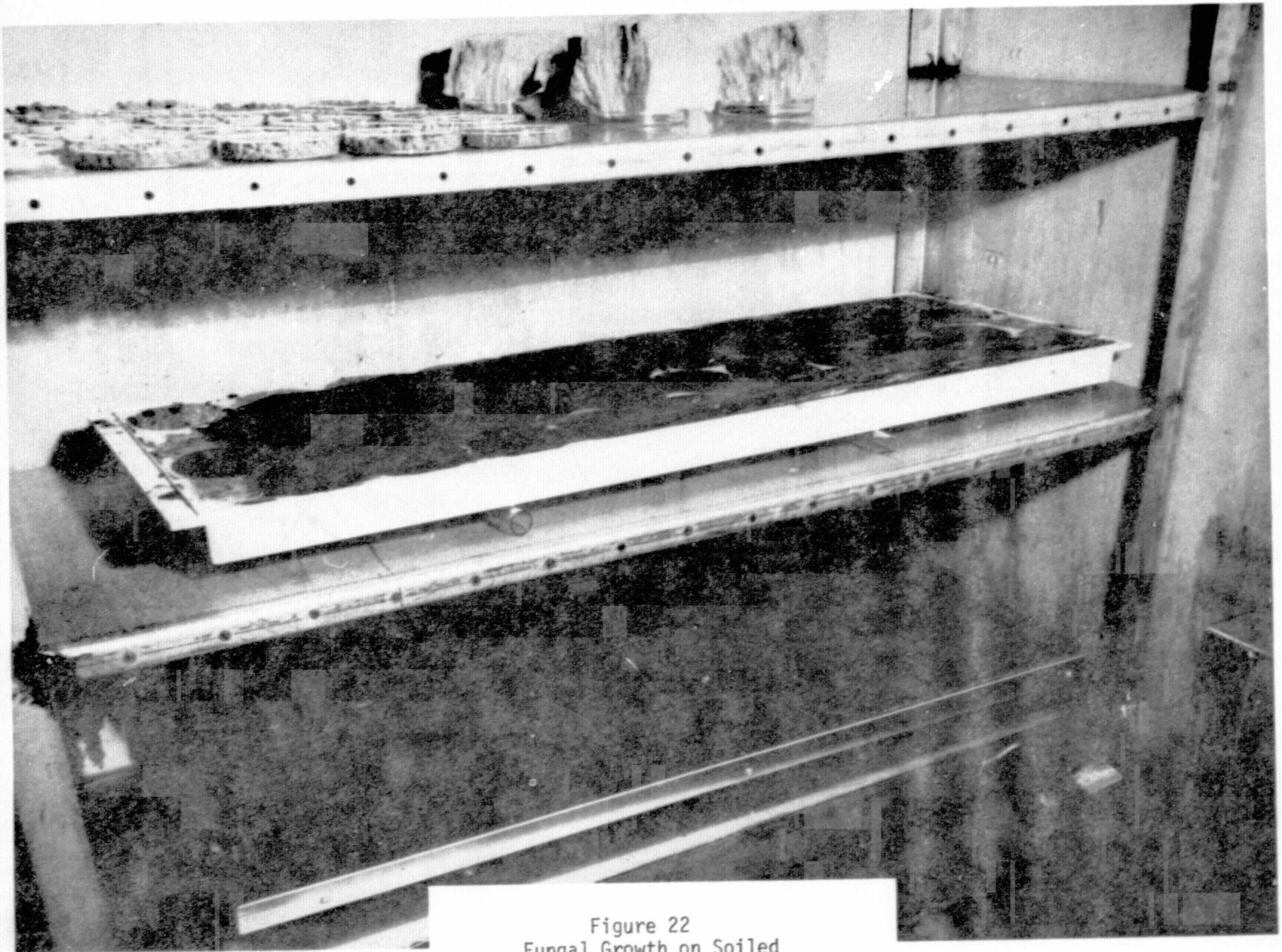

Figure 22
Fungal Growth on Soiled
Spectrolab and Solar Power
Modules

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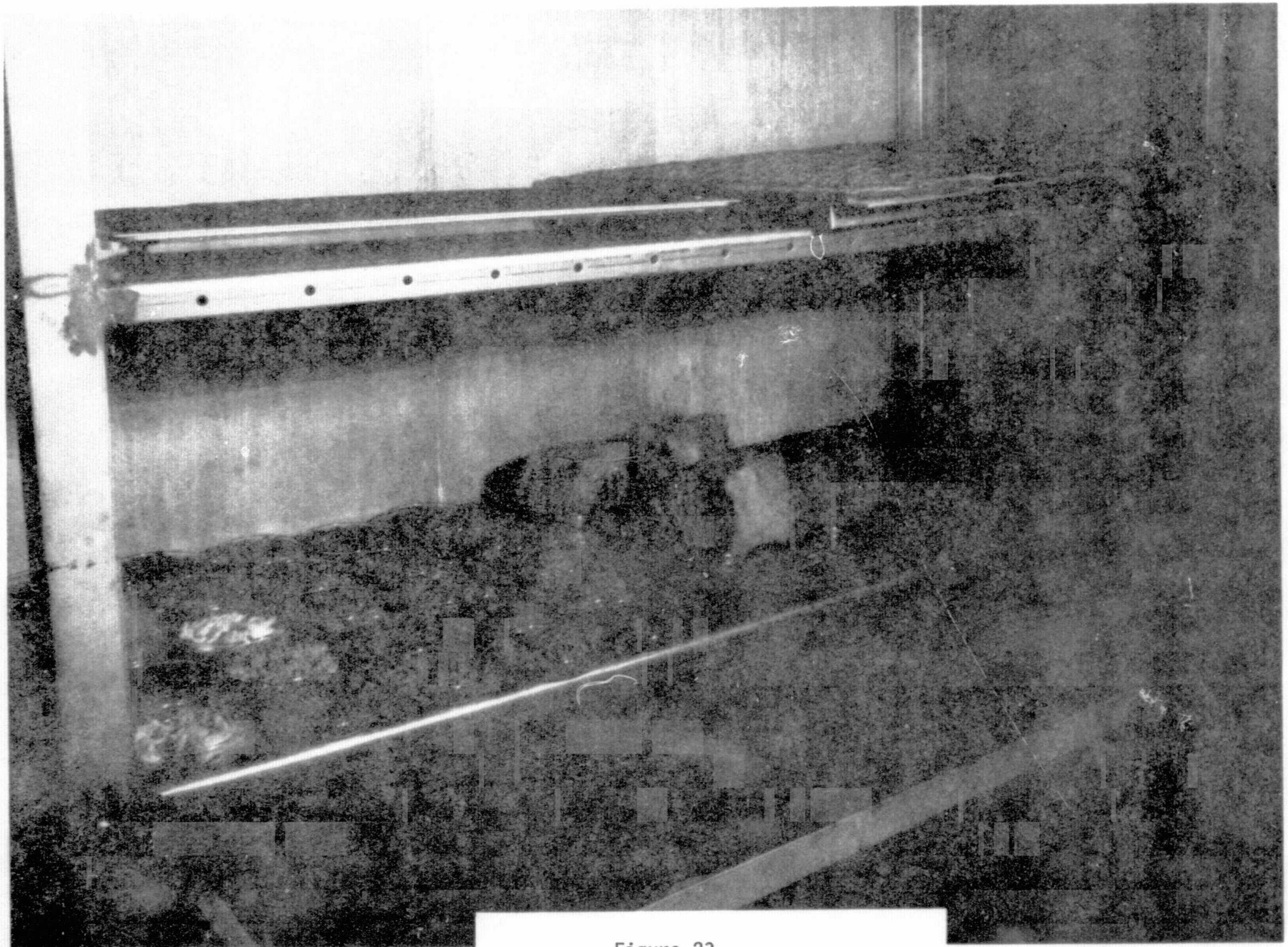

Figure 23
Fungal Growth on Soiled Solar Power, Solarex and Sensor Technology Modules

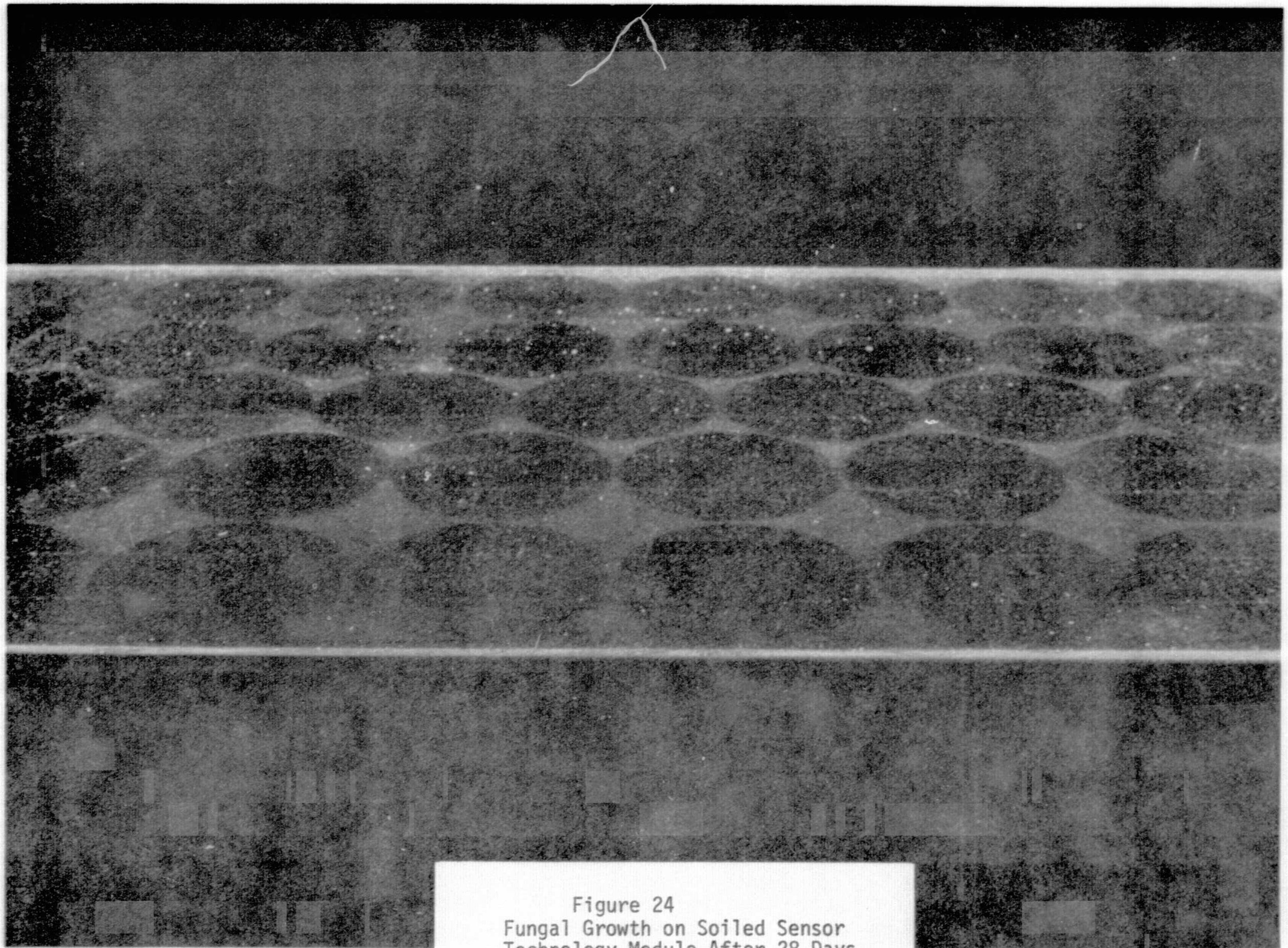

Figure 24
Fungal Growth on Soiled Sensor
Technology Module After 28 Days

Figure 25
Fungal Growth on Soiled Solar
Power Module at 2X Magnification

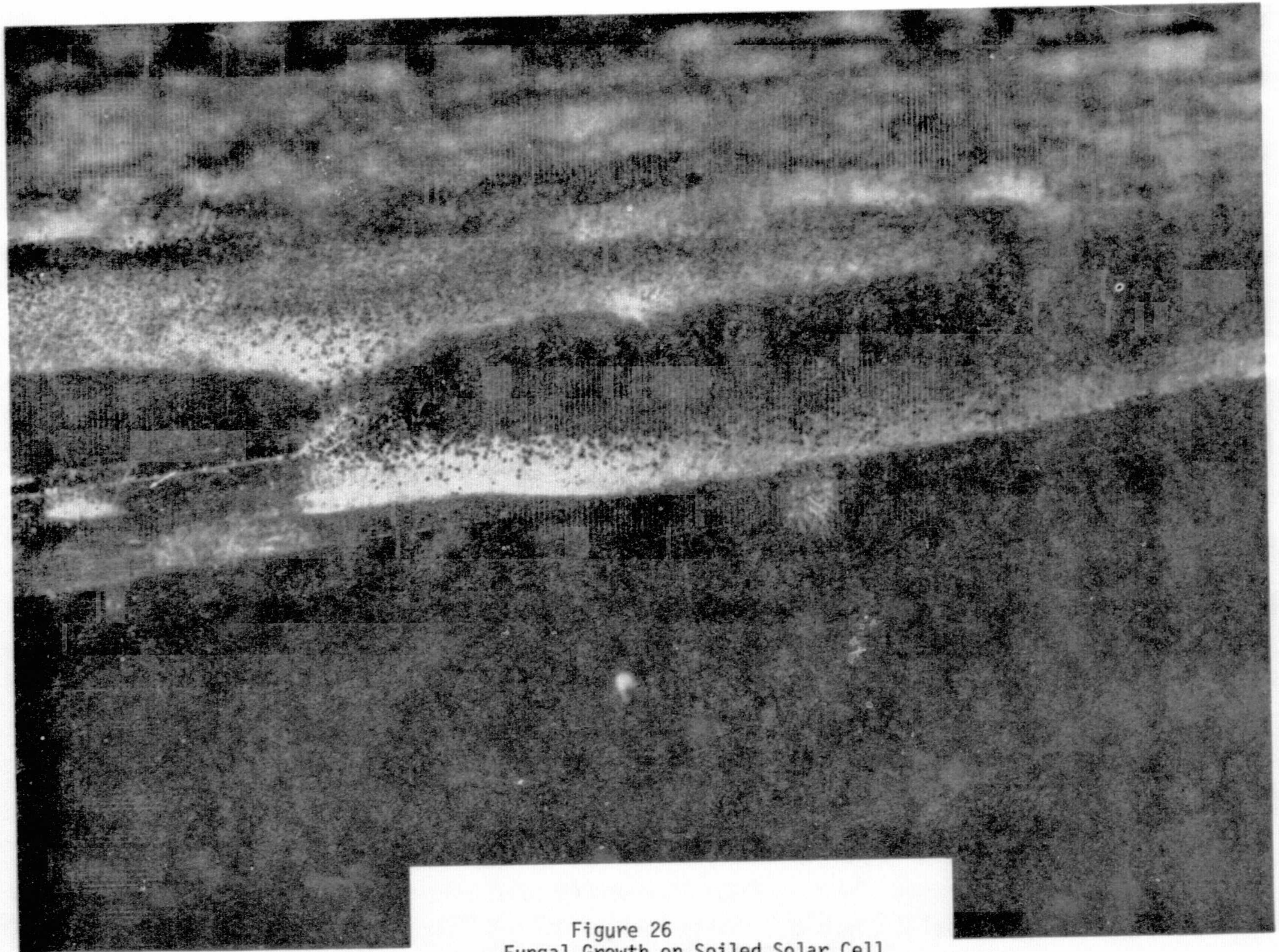

Figure 26
Fungal Growth on Soiled Solar Cell
Module at 4X Magnification

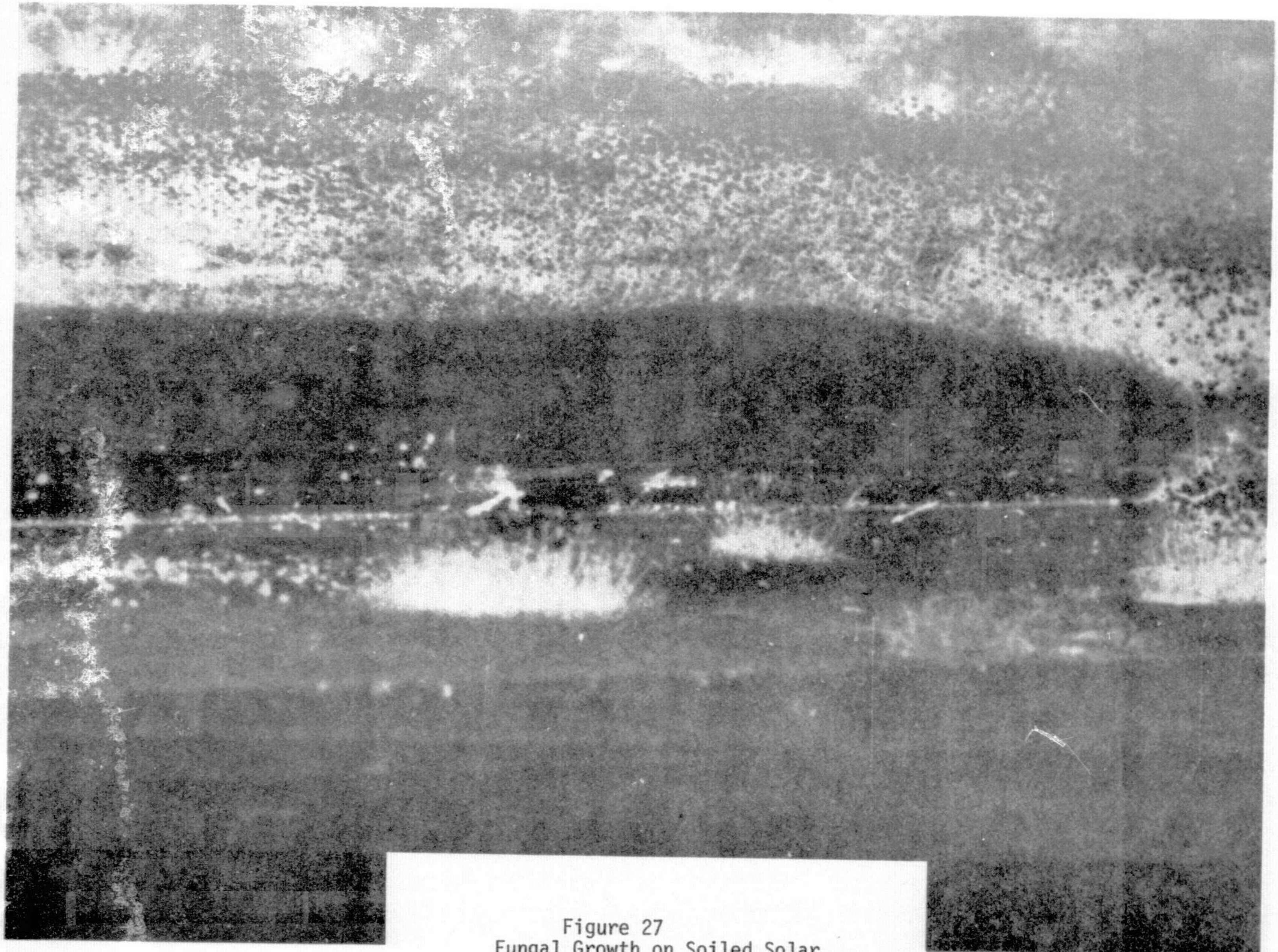

Figure 27
Fungal Growth on Soiled Solar
Cell Module at 7X Magnification

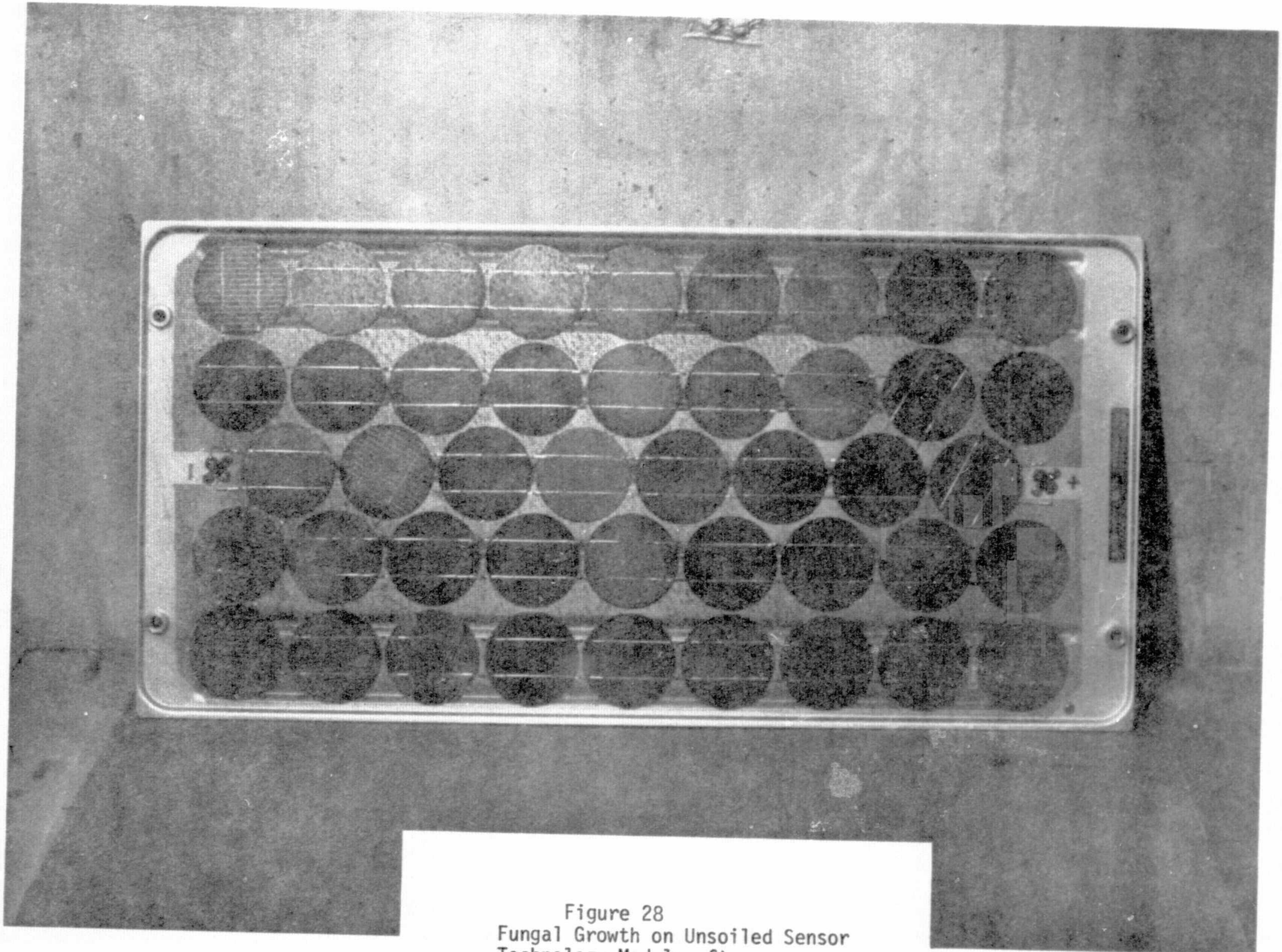

Figure 28
Fungal Growth on Unsoiled Sensor
Technology Module after
MIL-STD-810B Fungus Test

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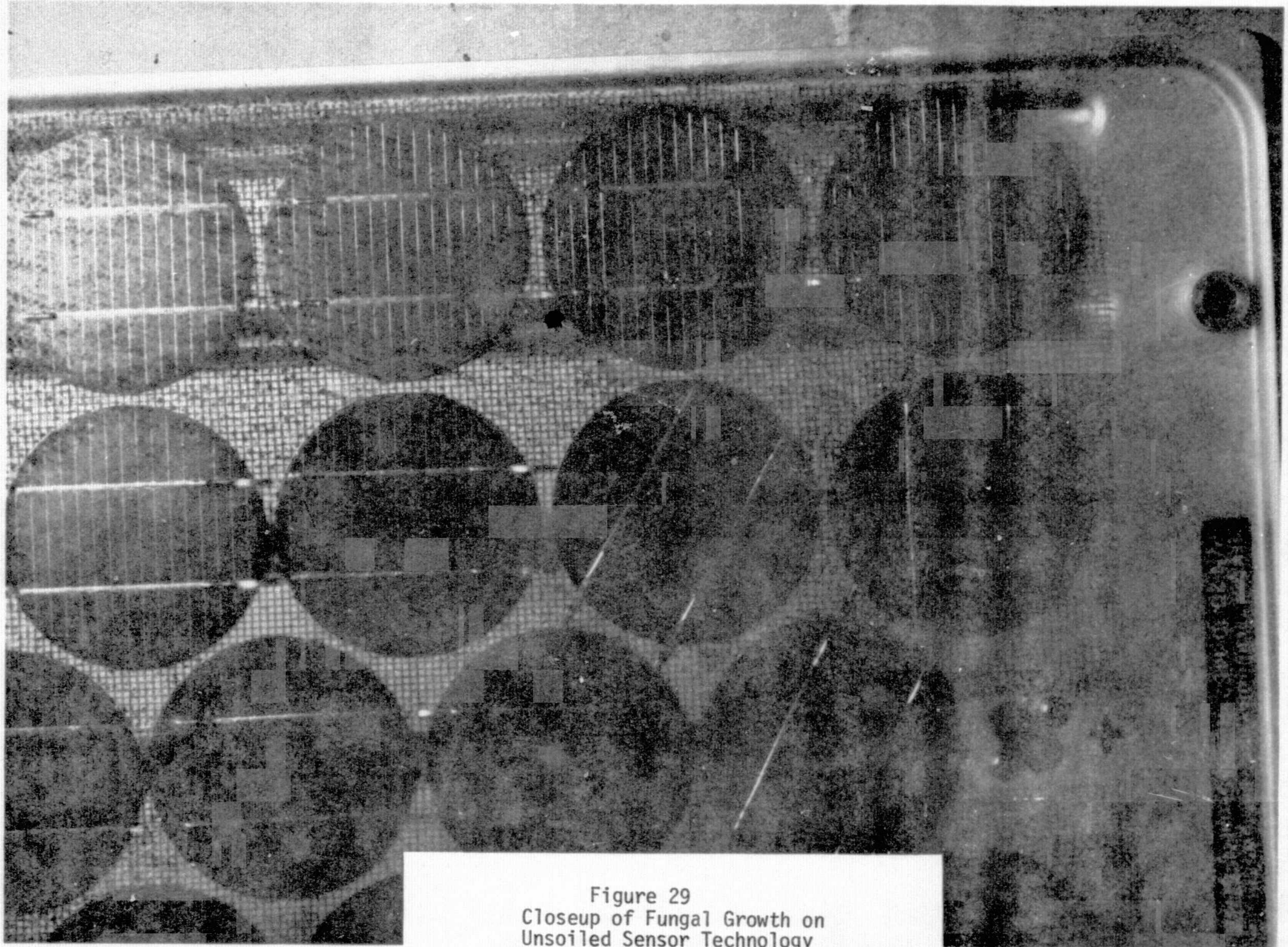

Figure 29
Closeup of Fungal Growth on
Unsoiled Sensor Technology
Module after MIL-STD-810B
Fungus Test

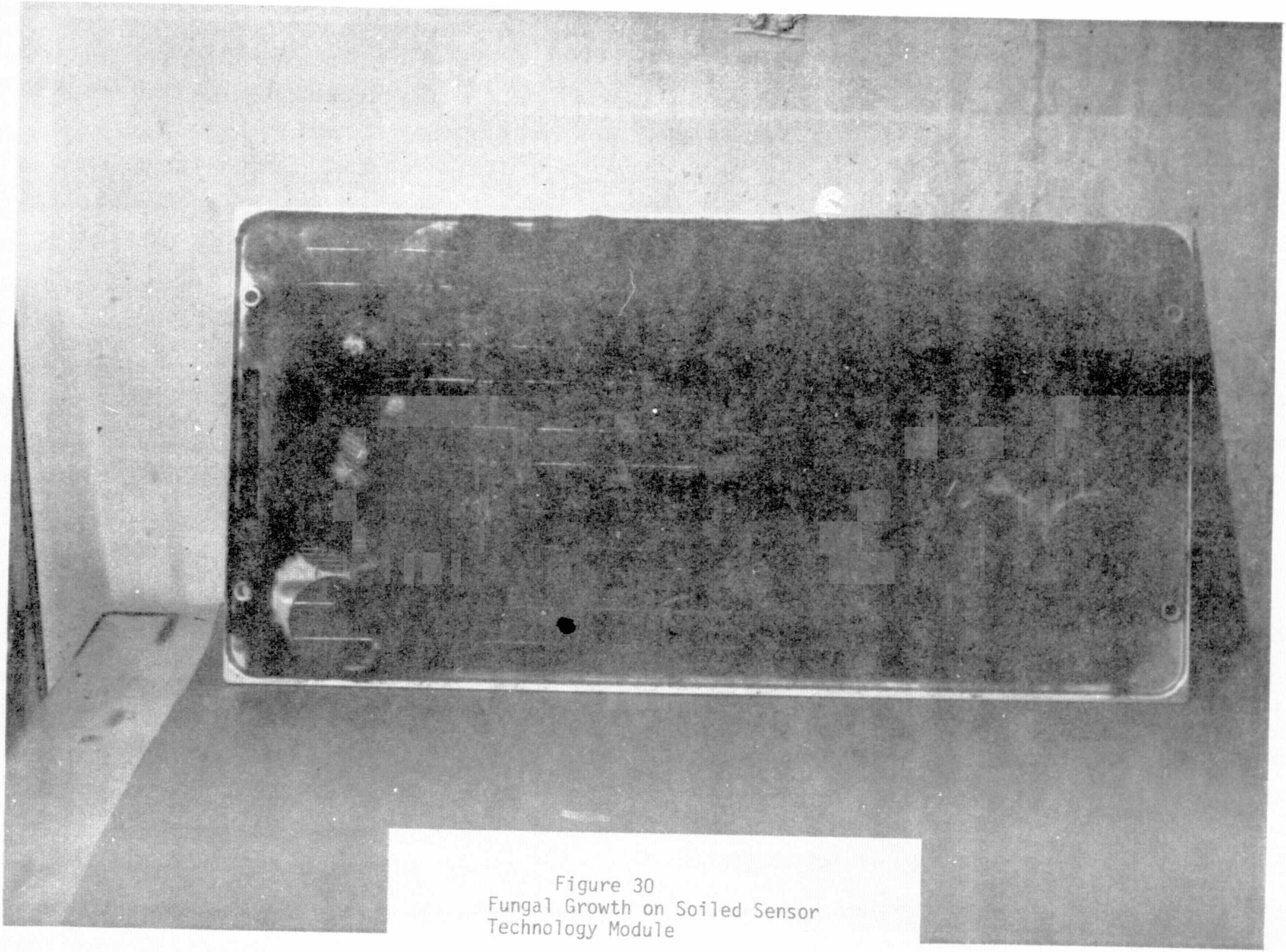

Figure 30
Fungal Growth on Soiled Sensor
Technology Module

TABLE I

SOLAR CELL MODULES IN ENVIRONMENTAL TEST PROGRAM

| Test | Serial Numbers | | | |
|---|---|---|---|---|
| | Spectrolab | Solar Power | Solarex | Sensor Technology |
| 28 Day Temperature and Humidity | 0132 | 1565 | 228134 | 0089 |
| | 0152 | 1566 | 228153 | 0135 |
| | 0158 | 1567 | 229023 | 0143 |
| Rain and Icing | 0208 | 1315 | 220117 | 2694 |
| | 0206 | 1316 | 229018 | 2683 |
| | 0169 | 1342 | 230038 | 2673 |
| Salt Fog | 0208 | 1315 | 220117 | 2694 |
| | 0206 | 1316 | 229018 | 2673 |
| | 0169 | 1342 | 230038 | |
| Sand and Dust | 0216 | 1269 | 228088 | 2524 |
| | 0221 | 1550 | 227059 | 2546 |
| Vacuum/Steam/Pressure | 0173 | 1287 | 229163 | 2714 |
| | 0195 | 1307 | 229156 | 2671 |
| | 0187 | 1323 | 228138 | 1786 |
| Temperature/Altitude | 0220 | 1525 | 229039 | 2551 |
| | 0211 | 1172 | 228089 | 2523 |
| | 0218 | 1231 | 229036 | 2517 |
| Thermal Shock | 0223 | 1166 | 229169 | 2559 |
| | 0219 | 1561 | 228035 | 2555 |
| | 0210 | 1527 | 229029 | 2526 |
| Fungus (with nutrient) | 0191 | 1536 | 227037 | 2437 |
| Fungus (w/o nutrient) | 0167 | 1357 | 229158 | 1839 |

TABLE II

SUMMARY OF TEST RESULTS

| Test | Manufacturer | Encapsulant Delaminations | Cracked Encapsulant | Cracked Cells | Corrosion | Functional Check |
|---|---|---|---|---|---|---|
| Temperature and Humidity | Spectrolab | yes | - | - | - | None Made |
| | Solar Power | yes | yes* | - | yes | " |
| | Solarex | - | - | - | - | " |
| | Sensor Technology | - | - | yes* | yes | " |
| Rain and Icing | Spectrolab | - | - | - | - | - |
| | Solar Power | - | - | - | - | - |
| | Solarex | - | - | - | - | - |
| | Sensor Technology | - | - | 1 | - | - |
| Salt Fog | Spectrolab | - | - | - | - | - |
| | Solar Power | - | 1 | - | - | Two with 50 percent of original output |
| | Solarex | - | - | - | - | - |
| | Sensor Technology | - | - | - | - | - |
| Sand and Dust | Spectrolab | - | - | - | - | Up to 18% current decrease |
| | Solar Power | - | - | - | - | Up to 32% current decrease |
| | Solarex | - | - | - | - | Up to 77% current decrease |
| | Sensor Technology | - | - | - | - | Up to 72% current decrease |
| Vacuum/Steam/Pressure | Spectrolab | - | 1 | - | yes | - |
| | Solar Power | yes | 51 | 1 | yes | - |
| | Solarex | yes | 49 | 18 | yes | One with zero output, one with 27% of original |
| | Sensor Technology | - | 66 | 2 | yes | - |
| Temperature/Altitude | Spectrolab | - | - | - | - | - |
| | Solar Power | - | 2 | - | - | - |
| | Solarex | - | - | - | - | - |
| | Sensor Technology | - | - | 1 | - | - |

*Visual checkout performed by NASA-LeRC. Number of defects not known.

TABLE II (continued)

| Test | Manufacturer | Encapsulant Delaminations | Cracked Encapsulant | Cracked Cells | Corrosion | Functional Check |
|---|---|---|---|---|---|---|
| Thermal Shock | Spectrolab | - | - | - | - | - |
| | Solar Power | - | - | - | - | - |
| | Solarex | - | - | - | - | - |
| | Sensor Technology | - | - | 3 | - | - |
| Fungus | All modules which had nutrient applied supported fungus growth. The Sensor Technology module which did not have nutrients applied also supported fungus growth. The visual and functional check was performed by NASA LeRC. | | | | | |

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NASA CR-159393 | | |
| 4. Title and Subtitle<br>BLOCK II SOLAR CELL MODULE ENVIRONMENTAL TEST PROGRAM | | 5. Report Date<br>October 1978 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Kevin L. Holloway | | 8. Performing Organization Report No.<br>WQEC/C 78-224 |
| | | 10. Work Unit No. |
| 9. Performing Organization Name and Address<br>Naval Weapons Support Center<br>Crane, Indiana 47522 | | 11. Contract or Grant No.<br>C-1892-D |
| | | 13. Type of Report and Period Covered<br>Contractor Report |
| 12. Sponsoring Agency Name and Address<br>U.S. Department of Energy<br>Division of Distributed Solar Technology<br>Washington, D.C. 20545 | | 14. Sponsoring Agency ~~Code~~ Report No.<br>DOE/NASA/1892-78/1 |

15. Supplementary Notes

Final report. Prepared under Interagency Agreement E(49-26)-1022. Project Manager, S. J. Marsik, Solar and Electrochemistry Division, NASA Lewis Research Center, Cleveland, Ohio 44135

16. Abstract

Environmental tests were conducted on solar cell modules produced by four different manufacturers. The tests were performed to establish failure modes of the modules and determine the relative resistance of various manufacturers' modules to different environments. Functional and visual checks were made to determine the effects of the environments. The tests caused cracked cells, cracked encapsulant and encapsulant delaminations on various modules. Results show that Spectrolab modules were more resistant to the applied environmental tests than Solar Power, Solarex and Sensor Technology modules.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| Solar cell modules<br>Environmental testing | Unclassified - unlimited<br>STAR Category 44<br>DOE Category UC-63 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
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