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TESTING OF A CASCADED THERMOELECTRIC MODULE

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NORTH AMERICAN ROCKWELL CORPORATION
ATOMICS INTERNATIONAL DIVISION

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-13452
William J. Bifano, Project Manager

NOTICE

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FINAL REPORT

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ABSTRACT

The life-testing of a cascaded thermoelectric converter, which had been fabricated and tested to 3450 hours under Contract F33(615)-67-C-1822, was extended to about 3930 hours. At that time, the coolant pump of the heat rejection system failed, resulting in severe damage to the module. The test was subsequently terminated. During the first 450 hours of testing, the power output of the module remained essentially constant.

INTRODUCTION

This program was intended to resume and continue the life-testing of a cascaded thermoelectric module which had been fabricated under Contract F33(615)-67-C-1822 and tested to 3450 hours (see reference 1). When a total test time of 8000 hours would be reached, the module was to be destructively examined. In case of serious operational problems prior to 8000 hours, Lewis Research Center was to advise on discontinuance of testing.

I. SUMMARY

Restarting the life test involved extensive renovation of the test facility, which was accomplished.

The module testing was resumed and the first good data set was taken on December 14, 1969, at 3502 hours. On or about January 1, 1970, the coolant pump of the heat rejection system failed and on January 5, 1970, the test was terminated.

The module was found to be so severely damaged as to make a post-mortem analysis meaningless. It was decided, in conference with LeRC personnel, to terminate the program with this summary report.

II. DISCUSSION

A. Description of Module

The module consisted of 14 SiGe couples bonded to a Hastelloy interstage plate, and 28 PbTe couples attached to the other face of the interstage plate by a tension-stud and spring construction. The cold junctions of the PbTe stage were thermally connected by flexible copper straps to a flat tank, through which an organic liquid was to be circulated (see Fig. 1). A more detailed description of the module is presented in reference 1.

B. Description of Test Facility

The module was set up in a vacuum test station with the SiGe hot shoes facing an electrical radiant heater (sheet-metal box, right center of Fig. 2). The coolant tank was plumbed to stainless steel tubing which penetrated the vacuum station "collar" and joined the heat rejection system.

The heat rejection system, which had originally consisted of a single loop containing a flowmeter, valves, centrifugal pump and temperature-controlled sump, was extensively modified. The principal changes were: (1) A helical coil of stainless steel tubing was inserted into the constant temperature sump or "bath", this separated the primary coolant from the bath liquid and prevented oxidation; (2) Since this resulted in a closed loop, a gas-pressurized expansion tank was added at the highest point of the loop; (3) The original centrifugal pump, which had always leaked at a rotating seal, was replaced with a seal-less stainless steel centrifugal pump.

The original instrumentation, which used a digital voltmeter with tape print-out for all temperature, voltage and current readings, was retained.

The plant line-voltage instabilities, however, caused intolerable temperature fluctuations in the experiment, even within a 5-minute reading period. An available tube-type AC voltage regulator was therefore installed, but was not a complete solution, and repeatable readings continued to be difficult. (From this and similar other test experiences, it is felt that the very highly regulated power supplies, usually DC and ± 0.1% or better, should be used if possible.)

C. Test Data Recorded

It had been intended to "read" the test each week on a regular schedule. Two "good" initial readings (among several attempts) were taken on December 14 and 15; another on December 21; and the final one on December 31. The reduced data from these are given in Table I.

D. Analysis of Performance

The data from Table I are presented in graphic form in Fig. 3, where they have been added to the prior performance history.

Attention is called to the data points recorded at 2240, 2600, 2888 and 3177 hours. In all of these, the power output of the SiGe stage, and of the module, was substantially lower than normal. The original raw data have been closely inspected, and the only significant anomaly was found to be the voltage, both open-circuit and loaded. It is concluded that during this period there was a partial short circuit, of the order of 20 ohms, across Stage I. Shorting of this kind had been experienced very early in the testing (first 300 hours) and had been traced to the reflective insulation touching the current leads and/or the temperature-monitoring thermocouples. It is hypothesized,

TABLE I

REDUCED DATA FROM FOUR READINGS

Date:	12/14/69	12/15/69	12/21/69	12/31/69
Cumulative Hours:	3502	3516	3670	3902
Hot Junction Temp., °F	1840	1860	1838	1859
Cold Junction Temp., °F	400	393	395	399
Module Load Volts	3.53	3.59	3.54	3.59
Open-Circuit Volts	7.07	7.19	7.03	7.16
Current (amps)	4.66	4.77	4.72	4.74
Resistance (Ohms)	0.759	0.756	0.740	0.753
Power (watts)	16.5	17.1	16.7	17.0
Normalized Power (watts)	16.7	16.7	16.9	16.8
Stage I Load Volts	1.93	1.92	1.92	1.92
Open-Circuit Volts	4.10	4.13	4.04	4.12
Current (amps)	4.66	4.77	4.72	4.74
Resistance (Ohms)	0.466	0.463	0.449	0.464
Power (watts)	8.99	9.16	9.08	9.10
Normalized Power (watts)	9.11	8.95	9.17	8.97
Stage II Load Volts	1.72	1.79	1.73	1.78
Open-Circuit Volts	2.95	3.05	2.92	3.04
Current (amps)	4.67	4.77	4.72	4.74
Resistance (Ohms)	0.263	0.264	0.252	0.266
Power (watts)	8.03	8.54	8.17	8.44
Normalized Power (watts)	8.14	8.34	8.25	8.32
Stages Added				
Power (watts)	17.0	17.7	17.3	17.5
Normalized Power (watts)	17.3	17.3	17.4	17.3
Resistance (Ohms)	0.729	0.727	0.701	0.730

therefore, that this shorting occurred again at the time of a shutdown for repair of vacuum leaks, at 2200 hours. Also, the condition must have corrected itself at the 3450-hour shutdown for revision of the cooling system.

The last three plotted points are taken from the data of Table 1, the 3502 and 3516-hour readings being averaged to make a single reading. Since the junction temperatures could not be stabilized at 1850°F-400°F, the power outputs were normalized by a $(\Delta T)^{-2}$ correction for graphing. The actual correction factor used was $(\text{Total } \Delta T / 1450^{\circ}F)^{-2}$, the denominator of which corresponds with the nominal operating range of 1850°F - 400°F.

The slope of the module power line, following the 1600-hour point, gives a degradation rate of 1.6% per 1000 hours. The individual graphs of the stages for both power output and internal resistance show that the degradation is assignable almost equally to the two stages, with perhaps a slightly greater rate in the PbTe (Stage II).

E. Catastrophic Damage

Successful operation of the test required continuous cooling of the cold junctions whenever the module was heated. The coolant pump incorporated a series-wound, brush-type motor, rated for life in excess of 10,000 hours. The ambiguity overlooked at time of purchase was that attainment of that life might require replacement of brushes. This was realized when the component was received. However, the carbon brushes were unusually long (3/4") and backed up by a generously long spring. It was estimated, therefore, that the brushes would last at least 1000 hours, especially since the motor was being run at about 60% of nominal voltage and the speed was thereby greatly reduced.

The concern over this problem was serious. One consideration was to remove the brushes periodically and measure them for wear; this would involve a shut-down each time, however, and the thermal cycling would not be consistent with the programmed operation, which was to simulate isotopic heating as in a space mission. Therefore, brush inspection was not instituted.

Instead, it was decided that a temperature controller and switching relay would be installed which would shut off the main heater power in the event of a failure of the coolant pump. However, pump failure occurred before this safety feature was incorporated. The loss of coolant flow resulted in cold junction temperatures of about 1100°F. Prior to shut down of the main heater, an electrical output of about 25% of normal was observed.

The Stage II atmosphere had been discharged into the vacuum system, and most of the temperature-monitoring thermocouples were reading very incorrectly or not at all. The test was shut down for internal examination.

Subsequently, the vacuum chamber was opened and various insulations and a portion of the Stage II "can" were removed. As seen in Figs. 4 and 5, large portions of the SiGe hot shoes had evaporated or melted, the SiGe cold junctions had diffused with the "stack" and strap materials, and the PbTe elements had evaporated to a large extent. Lesser problems were the loss of thermocouples and melting of the soldered connections of the Stage II "thermal connectors" to the coolant tank. The reflective foils of the heater were largely disintegrated, and only the coiled heater wire appeared to have survived serious damage. It has been calculationally estimated that the SiGe hot shoes reached a temperature of at least 2400°F.

In consultation with NASA-Lewis personnel, it was agreed that the damage was so catastrophic that no useful information concerning module behavior could be obtained by destructive examination. Therefore, the program effort was terminated.

References

1. S. R. Rocklin, W. D. Leonard, and R. C. Saunders, "Development of a High-Efficiency Cascaded Thermoelectric Module," AFAPL-TR-68-144, January, 1969.

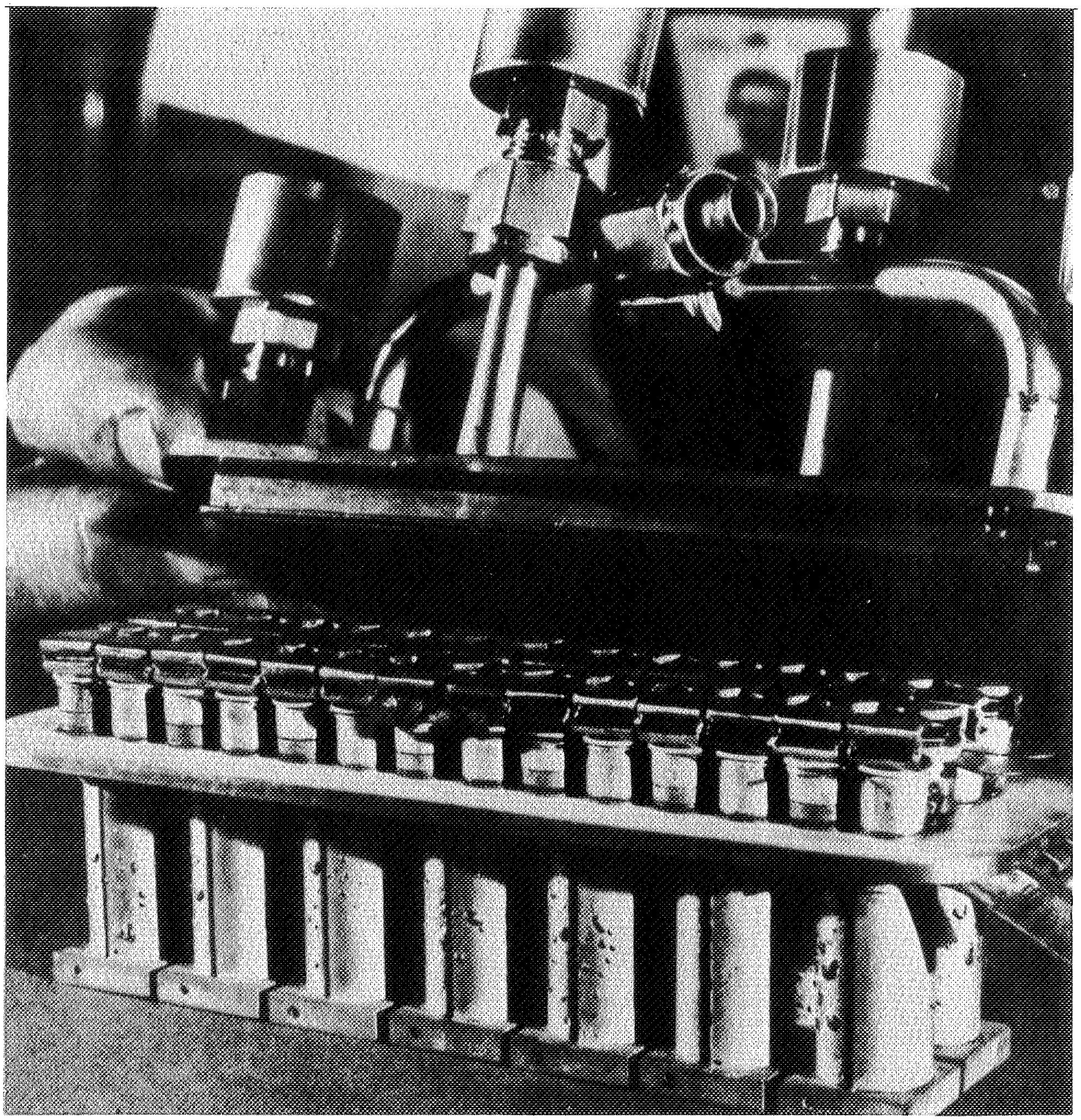

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Figure 1. Cascaded Module Assembly

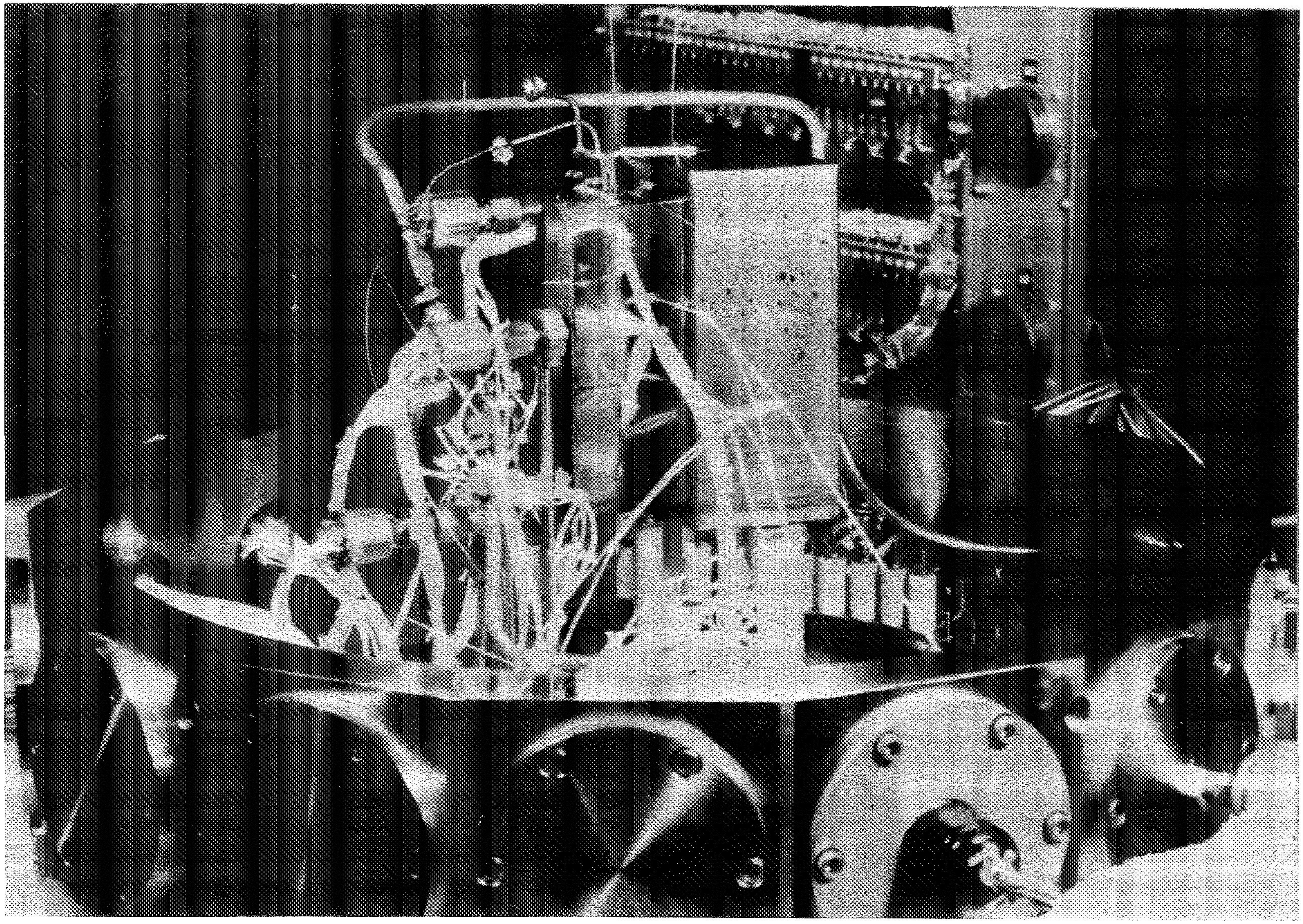

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Figure 2. Cascaded Module Installed in Test Chamber

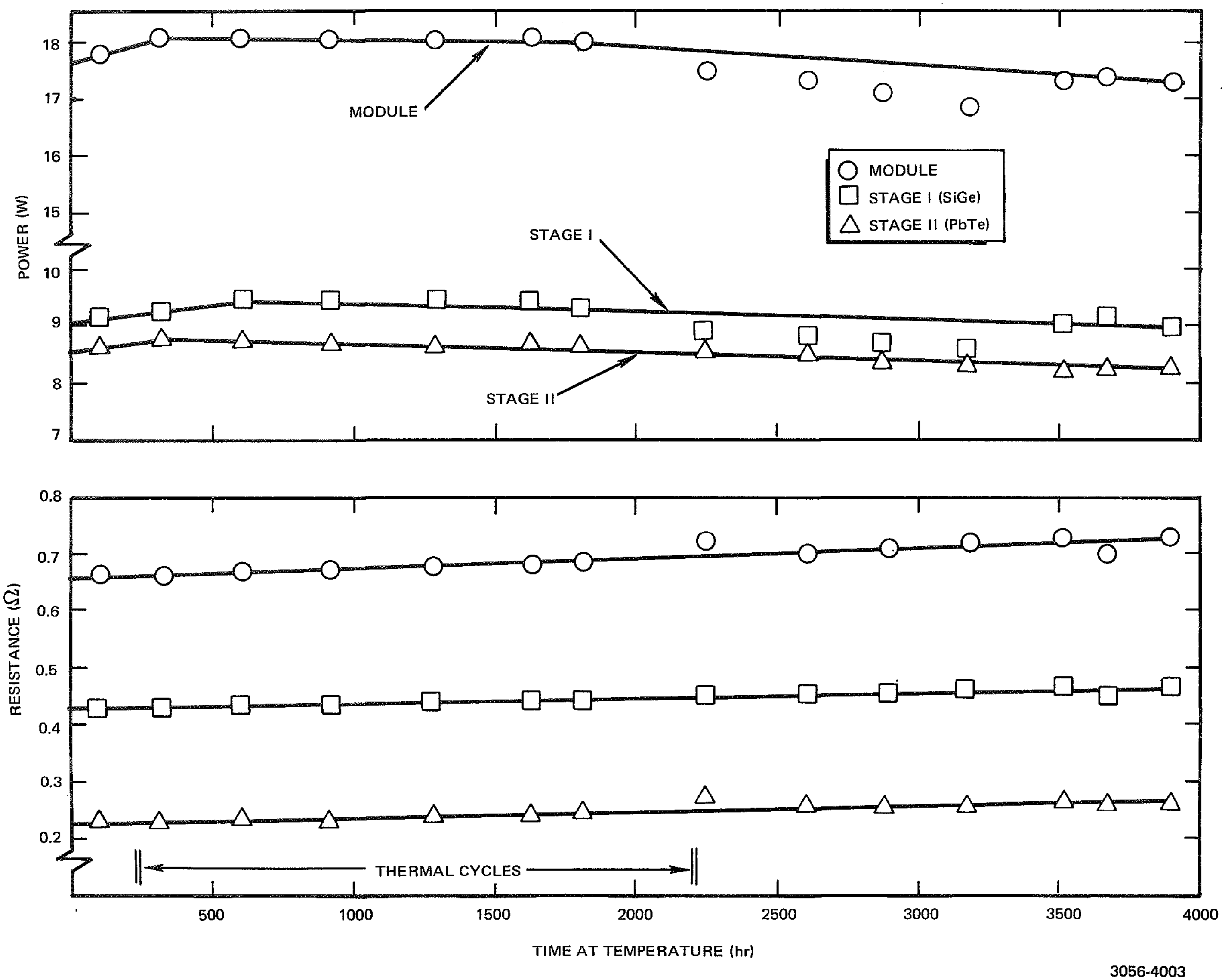

Figure 3. Life Test Performance Graph
(Stage I – $T_{HJ} \simeq 1850°F$, Stage II – $T_{CJ} \simeq 400°F$)

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Figure 4. Damaged SiGe Stage

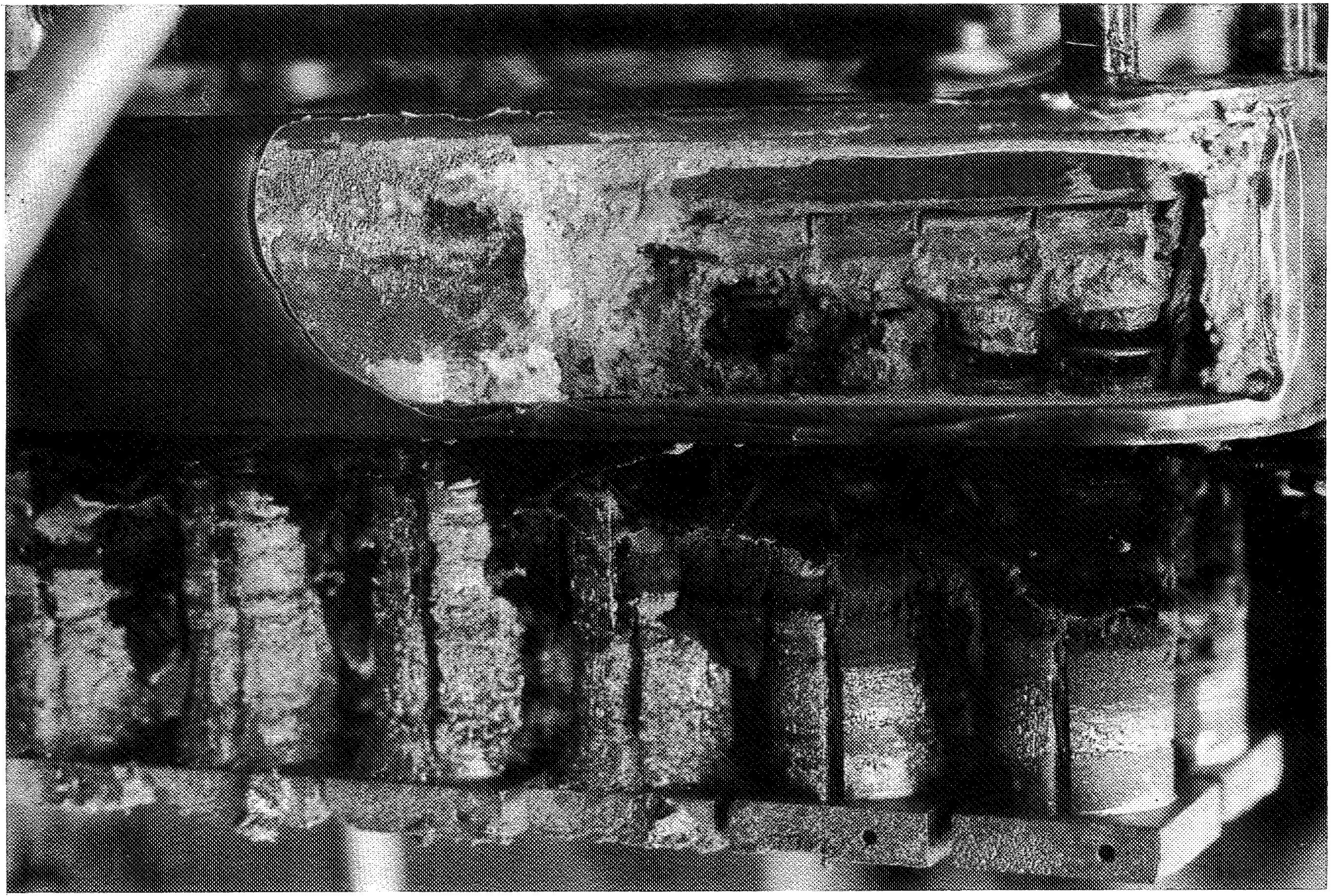

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Figure 5. PbTe Stage Cut Open to Show Damage