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MITG STATION 1 BUILD 1 AND BUILD 2 DISASSEMBLY

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MITG TEST ASSEMBLY

I. INTRODUCTION AND SUMMARY

The disassembly of an MITG Test Article is described in this document. The test article consisted of a complete slice through an MITG, an electric heater, eight standard silicon germanium multicouples, a foil insulation pack, and an aluminum housing. This constitutes a test article assembly. The details of this hardware have been described elsewhere. A similar test article containing eight GaP doped multicouples was also tested. The details of this disassembly are presented in a separate document. Only the Station 1 builds (standard SiGe) will be discussed in this document.

Two builds of Station 1 were performed. The first build reached a temperature of $\sim 500^{\circ}\text{C}$ and lasted ~ 100 hours. The second build reached full operating temperature (1000°C) and was at significant temperatures for ~ 800 hours. The testing of these builds was described in detail in FSEC-ESD-217/82/213. This document presents a commentary on the disassembly of both builds.

The general appearance of the components from both builds was identical. Some of the observations of deposits may be duplications of contamination which resulted from Build 1 since the tube and foils were reused for the second build without cleaning. The second build had a much stronger smell of hydrogen sulfide than did Build 1, although the rank smell of the first build outgassing tube was also noted.

The technical discussion concentrates on Build 2 since this is the more interesting and the hardware remained available. The message is that the modules failed at the cold end. Cracks traversed the zone from the edge of the cold stud assembly in a generally domed shape upward into the SiGe for as much as 30

mils. There was some failure in the bonds on some elements, but all elements observed with separated shoes (2, 4, 5) had at least some of the break in the SiGe.

The modules shown in Figures 1 and 2 are typical of six of those tested. Modules 1, 3, and 6 were clearly broken at the cold shoe. The assembly was held together by the power wire. Modules 2, 4, and 5 were completely separated. Module 7 appears to be intact but gentle pressure on the stud shows that the element is broken close to the cold stud assembly. Module 8 appears to be intact. This module is shown in Figure 3.

Some of the heat collectors showed extreme curling of their edges. Others showed no curling at all. This curling appears to be associated with the edge thickness. The thinner the edge the more curl the greater the curl. In any event the curling is not perceived as a problem. A more extreme example of curling is shown in Figure 4.

In general, the initial observations of the Station 1 modules confirm the predictions made in FSEC-ESD-217/82/213. The first impression is that the failures at the module cold ends are so gross that subtle problems will be masked. Also, some of the detailed observations of the modules may be influenced by the abnormal temperature gradient which developed when the cold stud assembly cleaved away. This is especially relevant to the power lead brazes and the general level of corrosion noted in the region of the power leads.

A summary of the module resistances before and after testing is presented in Table 1. The final after test values

Figure 1. Typical of Modules 1, 3, 6

Figure 2. Typical of Modules 2, 4, 5

Figure 3. Multicouple 8

Figure 4. Multicouple 3

Figure 4A. Close-up of Multicouple 3 .

Figure 4B. Close-up of MulticoUPLE 4

Figure 4C. Close-up of Multicouple 5

were made with all power and instrumentation wiring cut away. A summary narrative of the Station 1, Build 1 and Build 2 disassembly is given in Chapter II. A detailed narrative of the Station 1, Build 1 and Build 2 disassemblies is given in Appendix A. A detailed examination of each module was performed by Dr. Kling. The results of his observations are presented in Chapter III.

TABLE 1
Station 1 Module Resistances

Module	Build 1 as Installed	Build 1 after Test	Build 2 as Installed	Build 2 after Test	Build 2 All Leads Cut Away
	Ω	Ω	Ω	Ω	Ω
1	48	1405 ¹	108	∞	11600
2	30	1103 ¹	50	103.	742
3	303	1013 ¹	3.5	∞	(3)
4	34	72	185	2290	(3)
5	121	33	245 ²	∞	(3)
6	41	41	236 ²	59	5717
7	1776	997 ¹	90	272	556
8	124	36	43	61	76

- 1 Replaced for Build 2.
- 2 Note increase in resistance of same modules.
- 3 Module leads were brittle and disintegrated when cut. Appeared to have been attacked chemically.

II. MITG STATION 1 DISASSEMBLY NARRATIVE

The disassembly of the MITG assemblies in Vacuum Station 1 is discussed in this chapter. Only standard Silicon Germanium multicouples were tested in Station 1. GaP doped Silicon Germanium multicouples were tested in Vacuum Station 2. The disassembly of these multicouples is the subject of a separate report.

There were two Vacuum Station 1 builds. This document records those observations made during the disassembly of both of these builds. No attempt is made to establish firm causal relationships during the course of the disassembly. The observations were tape recorded as made and are presented in Appendix A in as nearly unedited form as possible so that the data will remain intact. Only expletives have been deleted.

A summary narrative based on these transcriptions as well as photographic documentation of the Build 2 disassembly is presented in the following sections. No photographic record was made of the Build 1 disassembly.

A. Build 1 Disassembly

This section is organized into four subsections. These are:

1. Power Wiring and Instrumentation Inspection
2. Insulation Removal and Inspection
3. Heater Removal and Inspection
4. Multicouple Removal and Inspection

The information presented here is in summary form. A full transcript of the disassembly tape is presented in Appendix A.

Build 1 was primarily a learning experience. There were a number of lessons learned which allowed improved instrumentation to be developed in the subsequent builds. The extremely small clearances between both the power and thermocouple wires as they exited from their ceramic insulators required greater care to install than was used on the first build.

Except for a black deposit in the module outgassing tube and the high resistance of four of the multicouples, there was nothing exceptional about this disassembly.

1. Power Wiring and Instrumentation Inspection

A complete resistance check of the instrumentation and power wiring was performed prior to disassembly. The details of this check are given in Appendix A. A number of thermocouples was open or shorted in locations other than their beads. Some thermocouples were shorted to power leads.

The general disarray of the instrumentation resulted from excessive ceramic tube length which left inadequate clearance between these tubes and the external MinK block insulation. After the MinK is installed the wiring is obscured. It is not possible to inspect for disturbances caused by installing this insulation. As a result of this difficulty, the instrumentation ceramics were shortened and the MinK was thinned to provide greater assembly clearance in subsequent builds.

The before and after test instrumentation status is given in Tables 2 and 3.

TABLE 2

Thermocouple Status at Test Initiation

<u>Module #</u>	<u>Continuity to Gnd</u>		<u>Continuity (+-)</u>	
	<u>H.J.</u>	<u>C.J.</u>	<u>H.J.</u>	<u>C.J.</u>
1	x	o	x .01	x .003
2	x	o	o	o
3	x	x	o	o
4	x	x	x .015	x .009
5*	o	o	o	o
6	x	o	o	o
7	o	x	o	x
8	x	o	o	x

x = Cont

o = Open

* NOTE:

- 1) C.J. T/C #5 Module was open, but I removed, squeezed bead and reinserted. This gave continuity to Gnd and +-.
- 2) #6 C.J. is OK up to ceramic, but bead appears open.
- 3) Room Temperature (25°C) = .018mv.

TABLE 3

Examination (Post Heating)

Module	HJ Res	HJ Res to Gnd	CJ Res	CJ Res to Gnd	Was Erratic at Temp?		Comment
					HJ	CJ	
1	2.1	1.4	1.2	30	N	N	CJ shorted at ceramic. Not tight in hole.
2	Open	1.7	1.27	35	Y	N	W CJ touching housing (α when moved)
3	1.14	7	1.14	α	N	N	
4	1.6	2	1.3	.5	N	N	Shorted HJ
5	1.75	α	1.5	α	Y	N	
6	2.2	1.5	1.18	.7	Y	Y	
7	1.67	α	1.47	.7	N	Y	
8	Open	1.8	1.2	α	Y	N	W HJ weld broken

Note:

Heater to Gnd > 20 Meg; Resistance = 2.98 Ω .

All power wire showed $\sim 0.2 \Omega$. Broke Module 3 wire while making measurements.

2. Insulation Removal and Inspection

The block insulation was removed without incident and, as far as could be determined, without disturbing any of the wiring. This build used scrap MinK pieces which had been obtained from 3M. It was very hard to handle but was quite effective thermally.

The foil insulation pack was intact when the chamber was opened. Seigo commented that there was excessive MinK powder between the first few foil layers. This probably occurred because of an excessively vigorous backfill. There was no indication that the foil pack had been dislodged by the pump-down sequence. This had been a concern of Mr. Beaudry; however, it does not seem to have been a problem even though several pump-down cycles were logged on this build.

The top half of the foil packet containing the module outgassing tube was removed without incident. The bore of this tube had a black deposit and a rank smell. The deposit was heaviest on the module end but it extended to the ionization gauge end. There was a whitish deposit on the heavy sheet to which the outgassing tube is welded.

There is a 3/4 inch hole in the center of the top foil pack below the heavy plate which is welded to the 3/4 inch OD outgassing tube. There are 60 layers of foil above and 60 layers below this heavy plate. The foil edges at the periphery of the hole below the outgassing tube are covered with a black deposit. This deposit has migrated into the foils about 1/16 of an inch. Samples of this deposit were taken for analysis.

The deposit in the outgassing hole stops 24 layers below the end of the outgassing tube. The general appearance of the foils is excellent. They are bright and shiny, there is no embrittlement, and they show no evidence of distress.

3. Heater Removal and Inspection

The heater cavity was exposed two hours after beginning the disassembly. There was a small amount of a black powder on top of the heater directly under the outgassing hole. This material probably fell out of the tube or off the upper foils during the disassembly. A sample was retained for analysis.

The heater block shows no change from installation. Hardy felt that it might be slightly lighter in color than when it was originally installed.

The heater wire is very ductile. This is an indication that the module atmosphere was acceptable throughout the test. A poor atmosphere would have embrittled the molybdenum.

4. Multicouple Removal and Inspection

A continuity check of the heat collectors to ground was performed. Most of the heat collectors were touching the foils. The details of this resistance check are presented in Appendix A.

All of the heat collectors were solidly attached to their respective multicouples. There was some evidence of discoloration where the heat collectors were in contact with the foil insulation. This was a shining, however, which looked benign.

The Module 1 stud nut was removed with a pair of long nose pliers. There was essentially zero torque required for its removal. Module 1 was removed from the housing with some difficulty. The heavy first foil corner brace locked the module and acted as a Chinese handcuff. The hole in this foil was enlarged in subsequent builds to alleviate this problem.

The multicouple was finally removed intact and cursorily inspected. There was a black deposit around the cold end plate. There was no evidence that the gold foil had been coined. This foil was reused in the rebuild.

The Module 2 stud nut was removed with essentially zero torque (fingers). The module was removed intact from the housing and showed no visible signs of distress.

The disassembly tape is silent on evidence of deposits on the cold end of Modules 2, 3, and 7. These modules were subsequently found to be fractured. They are now in the hands of TECO personnel. Further details as to their condition will await their documentation.

B. Build 2 Disassembly

This section is organized into five subsections. These are:

1. Module Preparation
2. Power and Instrumentation Wiring Inspection
3. Insulation Removal and Inspection
4. Heater Removal and Inspection
5. Multicouple Removal and Inspection

The information presented here is in summary form. A full transcript of the disassembly tape is presented in Appendix A.

Build 2 was operated for more than 800 hours. This included more than 200 hours at 1000°C hot junction temperature. The disassembly showed a very clean envelope. The general appearance was as it was after the much shorter Build 1 test. There were more deposits in the module outgassing tube and there was a strong smell of hydrogen sulfide when the bore was sniffed. Some of the deposits (for example, the whitish powder on the heavy central foil of the top foil pack) were unchanged from Build 1. There was no deposit in the module ionization gauge as had been in Build 1.

The significant feature of this disassembly was that all multicouples except Number 8 were fractured at the cold end. Each, including Number 8, had a black deposit on the wrap at approximately the location of the fracture. It is assumed that this deposit came from inside the multicouple. The multicouple had a strong hydrogen sulfide smell at the location of the black deposit.

The details of the disassembly and the tentative findings are discussed in the following paragraphs.

1. Module Preparation

The instrumentation wiring was tested prior to breaking vacuum. Each thermocouple was continuity checked both to itself and each leg to ground. This test was performed by passing a DC voltage through the wires with all feed through connectors removed. The voltage and the resulting current were measured and manually recorded. The resistances were then calculated. The results of these calculations are presented in Table 4.

The system was back-filled by equalizing the pressure across the isolation valve with the roughing and turbomolecular pumps. The foreline pressure was roughed to $4.E-5$ and the valve between the foreline and the chamber was opened. At this time, dry nitrogen gas was introduced into the system while the roughing pump was still running. The system was bled back to atmospheric pressure starting at 1012 on 12 October 1982. Atmospheric pressure was achieved in the chamber at 1024.

2. Power and Instrumentation Wiring Inspection

Inspection of the power wiring shows that the external power leads are open at the transition between the 10 mil nickel wire and the 16 gauge nickel plated copper wire. Also, the power leads are melted together as they exit from the cold stud ceramics. This must have been the result of the resistance measurement power supply since the multicouple lacks the power potential to do this kind of damage.

TABLE 4

Instrumentation Thermocouple Resistances
Prior to Breaking Vacuum

<u>Channel</u>	<u>Resistance + to -</u>	<u>Resistance + to Gnd</u>	<u>Resistance - to Gnd</u>
	Ω	Ω	Ω
1	13.1	2.4	6.7
2	8.6	α	α
3	α	7.1	α
4	α	2.6	α
5	34		1.9
6	α	α	α
7	α	α	α
8	8.9	2.2	5.9
9	10.3	1.9	5.0
10	4.1	1.1	3.8
11	7.8	2.1	5.0
12	7.4	α	α
13	α	α	α
14	8.4	α	α
15	10.0	3.3	7.9
16	α	α	α
17	10.7	4.1	9.0
18	9.3	3.7	8.2
19	13.7	4.5	10.8
20	9.1	3.9	8.2
21	12.2	4.8	10.7
22	12.3	α	α
23	α	α	α
24	α	α	α
25	12.1	5.3	10.7
26	α	α	α
27	13.5	3.8	10.7
28	12.0	3.5	10.8
29	12.1	2.3	10.8
30	4.8	1.5	5.3
31	6.7	2.3	5.1
32	7.1	α	α
33	α	α	α
34	6.9	α	α
35	5.7	2.5	4.2
36	α	α	α
37	10.9	3.1	6.2
38	6.1	3.6	5.6
39	14.5	3.4	11.6
40	14.5	5.0	12.4
41	α	α	α
42	α	α	α
43	9.2	2.9	7.8
44	9.7	3.2	8.7
45	α	6.9	α
46	α	4.2	α

A complete inspection of the remainder of the wiring showed no anomalies. A summary of the power wiring and module resistances is presented in Table 5.

A detailed inspection of the multicouple hot junction thermocouples was performed after their removal from the housing (see Section 5 for removal description). The results were as shown in Table 6.

TABLE 6

Multicouple Hot Junction Thermocouple
Status after Disassembly

<u>Multicouple HJ Thermocouple</u>	<u>Status</u>
1	Bead broken, not twisted, dark deposit at hot end of T/C ceramic.
2	Twisted at ceramic exit, barely touching, some deposit.
3	Twisted, touching 1/2 way up wrap, no deposit.
4	Looped and twisted at ceramic, no deposit.
5	Bead broken, twisted-touching at ceramic, light deposit.
6	No visible distress, light deposit.
7	Half twist, not touching, light deposit.
8	Bead broken, Nb eaten away, no twist, light deposit.

3. Insulation Removal and Inspection

This build used new MinK block insulation. The assembly and disassembly was much easier than it was in the previous build. A careful inspection of the MinK blocks showed no deposits

TABLE 5

Module Resistances at Disassembly

Module	Resist at Installation Module + to -	Resist after Test Module + to -	Resist after Wires Cut Module + to -	Module after Cut + to Gnd - to Gnd		Cut Module Wires + to Gnd - to Gnd	
	Ω	Ω	Ω	Ω	Ω	Ω	Ω
1	82	α	11600	6580	2.2 Meg	2724	0.3
2	24	103	742	19.K	1650	α	1852
3	41	α	(1)	4900	(1)	α	1805
4	10	2290	(2)	(2)	(2)	α	1500
5	9.7	α	(2)	(2)	(2)	α	1521
6	9.8	59	5717	α	α	α	1962
7	42	272	556	143K	α	α	1997
8	111	74	76	2.2 Meg	2.2 Meg	α	2128

(1) + to - wires melted together at module, + open, bead to ground.

(2) Nickel wires fatigued. Disintegrated when cut. May be chemically attacked.

(3) All measurements at room temperature.

or discolorations. Two oil stains, which were there when the unit was assembled, remained.

The foil insulation removal was begun at 1040. A strong odor of hydrogen sulfide was noted when the module outgassing tube was removed. Figure 5 shows a general view of the disassembly at this stage. Note the dark ring of deposit at the edge of the outgassing hole. Approximately 6 foils remain at this time.

There was an increasingly bluish tint to the foils' surface. Starting about 3 foils above the heavy foil and becoming progressively more pronounced toward the heater, this tint showed interference fringes. At layer 26-27 below the central plate, the foils became less ductile. There is nothing extraordinary about the appearance of these foils. They look essentially unaffected by their time at temperature.

4. Heater Removal and Inspection

The heater top surface was exposed at 1110. The external surface was as it was at installation. Removal of the cover showed a grayish-white deposit around the top edges of the box and on the inside of the top cover. Photographs of these deposits are shown in Figures 6 and 7.

A test of the heater wire showed good ductility. There is no evidence that the deposit has caused a problem in the heater. The deposit appears to be coming from the ceramic mandrel which holds the heater coils. The heater was set aside and the multicouple removal was begun.

Figure 5. Top View of Partially Disassembled Module

Figure 6. Heater Box

Figure 7. Heater Box Count

5. Multicouple Removal and Inspection

The first thing of note on observing the multicouple is the extreme distortion of some of the heat collectors. The thin edges of the moly portion of some of the heat collectors have wrinkled and draped around the heater box in quite lovely folds. Other heat collectors are unchanged and their surfaces are as planar as when they were installed.

All heat collectors are firmly attached to their multicouples. All are extremely shiny. The heat collectors had dull oxide finishes when installed. Their time at temperature has improved their appearance. It is to be hoped that their weight loss is confined to their extant oxide.

The inside of the foil box was also bright and shiny; everything looked scrubbed. There are no signs of sublimation. Since the exposed surfaces were at 1000°C , one would expect no deposits unless they came from the heater ceramic.

The first multicouple was removed at 1345. The following paragraphs describe the multicouples as they were removed and given their first inspection.

a. Multicouple 1. The cold stud nut required zero torque to remove. It was finger tight. There was no evidence of coining of the gold. There was evidence of a white deposit on the surface of the aluminum housing at the edge of the moly stud assembly. This deposit was left undisturbed. The multicouple was removed using the special tools to push the stud through the housings and to catch the body of the multicouple on the foil basket side. The extraction system worked well.

This multicouple was essentially intact; however, the cold end hardware was loose and hanging on the power leads. A black deposit was noted near the cold end of the wrap. There was a strong hydrogen sulfide smell coming from the cleaved end of the multicouple. A black deposit was noted on the foils opposite the deposit on the wrap. A white deposit was seen on the lower half of one corner of the multicouple after unwrapping.

The general appearance of the multicouple is shown photographically in Figures 8 and 9.

b. Multicouple 2. The cold stud nut was finger tight. Removal was routine except the cold end hardware fell off as the module entered the foil basket. There was no evidence of coining of the gold foil. The white deposit was observed on the housing and there was a black deposit on the foils opposite that on the wrap.

Examination of the separated cold end showed that a partial break had existed for some time. The area of this break was covered with a heavy black deposit. This deposit became lighter and blended into an area of SiGe which looked faceted. The entire break was in the SiGe legs rather than the bonds. The entire surface of the hot side of the break was faceted with no evidence of a deposit.

The general appearance of this multicouple is shown photographically in Figures 10 and 11.

c. Multicouple 3. The cold stud nut required 5 inch-pounds of torque to break away. This stud is unique. I had tightened it to 8 inch pounds at the instrumentation rebuild over Lois' objections. I wanted to see if additional torque would improve the conductance at the cold end. As it happens, this test shows

Figure 8. Multicouple 1

Figure 9. Multicouple 1

Figure 10. Multicouple 2

Figure 11. Multicouple 2

that the modulus of the aluminum housing may be a sufficient Belville spring to accommodate for thermal cycling of the multicouples. There was no evidence of coining or even the removal of surface wrinkles in the gold foil.

The white and black deposits observed in the previous multicouples were again observed. The cold end is clearly broken although it is held to the module by the power leads. The edges of the heat collector are extremely wrinkled. Multicouples 3 and 4 have the most severely distorted heat collectors.

The general appearance of this multicouple is shown photographically in Figures 12 and 13.

d. Multicouple 4. The stud nut of this multicouple was finger tight. Essentially no torque was required to loosen it. There was no indication of any deformation of the gold foil.

The power wires of this multicouple were fatigued. The cold end assembly fell off when the multicouple body exited the foil pack. The usual black and white deposits were noted on the foils and the housing. The break in this multicouple is partly through the thermoelectric material and partly through the bond. This break is quite old. There is considerable discoloration on the cold side of the break. The hot side is bright and faceted.

Multicouple 4 is shown photographically in Figures 14 and 15.

e. Multicouple 5. The stud nut of this multicouple was finger tight. The gold was not coined. The cold shoe break is entirely in the thermoelectric material. This is an old break. The entire cold side of the break is covered with a black deposit.

Figure 12. Multicouple 3

Figure 13. Multicouple 3

Figure 14. Multicouple 4

Figure 15. Multicouple 4

The hot side is faceted. The usual deposits are seen opposite the break in the foils and on the housing. This multicouple was examined under a microscope and is discussed in greater detail elsewhere.

Multicouple 5 is shown photographically in Figures 16 and 17.

f. Multicouple 6. The stud nut of this multicouple was finger tight. There was no coining of the gold. The foil surface was wrinkled. The module was removed intact, although it is obviously broken and held together by the power leads. The usual black and white deposits were found on the foils and the housing. There was an unusual black deposit on the face of the heat collector.

Multicouple 6 is shown photographically in Figures 18 and 19.

g. Multicouple 7. The stud nut of this multicouple was finger tight. There was no evidence of coining of the gold foil. This multicouple appears intact until slight pressure is placed on the stud. Then some small movement can be detected. The appearance of this multicouple was in keeping with its measured performance. It was showing good open circuit voltage until just before cool-down.

The usual black and white deposits were found on the wrap, foil, and housing.

Multicouple 7 is shown photographically in Figures 20 and 21.

h. Multicouple 8. The stud nut was finger tight. There was no evidence of coining of the gold foil. This multicouple appears to be intact. This is consistent with its performance

Figure 16. Multicouple 5

Figure 17. Multicouple 5

Figure 18. Multicouple 6

Figure 19. Multicouple 6

Figure 20. Multicoupler 7

Figure 21. Multicoupler 7

history. Some black deposits similar to those of Multicouple 7 were seen on the heat collector. The usual black and white deposits were observed on the wrap, foil and housing.

There is evidence of a longitudinal crack in one of the faces of this multicouple. The cold bond is quite good. There is indication of the flow in the glass. There is no indication of any cracking in the elements at the cold end. The general appearance of this module is that it is in the best shape of those that were removed.

Multicouple 8 is shown photographically in Figures 22 and 23.

1. Observations under the Microscope. Examination of Multicouple 2 shows a deposit on those elements which are not bright and shiny. The mating piece of the module is uniformly bright, although the fracture planes are quite diverse. This module appears to have had a matte finish plated from the hot side of the break to the cold side over perhaps ten of the legs. A resistance check showed that any part of the matte to any other part of the matte finish had about 50,000 ohms resistance.

Carefully examining the bond in the power leads showed a bad chemical reaction between the nickel wires and either the braze or the host material. This must be looked into carefully, since Dr. Kling pointed out some time ago that the aluminum brazes do form complex systems with nickel. This evidence of chemical reaction is quite severe, and there is evidence that the nickel wires were not completely brazed into their holes. Some of them were pulled out of the holes as the modules came apart on disassembly. The reader is reminded that black deposits were noted at the end of the power lead ceramics in the previous

Figure 22. Multicouple 8

Figure 23. Multicouple 8

disassemblies and builds of this module. The black color of the deposits on the cold shoe and around the end of those power leads ceramics appears identical. It seems to me relatively clear that whatever was coming across the crack was going down the ceramic tube and was producing a short on the output of the module.

Examination of Multicouple 5 shows that the cold shoe was completely severed from the remainder of the module during the disassembly. This cold shoe is completely black. There were small, almost pinpoint size, regions that are bright and may not have been broken. However, all of the legs show a black, matte finish on at least 90% of their area. A continuity check of the surface shows that any point to any other point on the surface has a resistance of 50,000 ohms or less. Again, the module power lead wire braze seems to have reacted with the power wire and caused a rather severe chemical attack. There is a substantial amount of erosion and there is possibly a reaction to such an extent that the wires were corroded through. There is no evidence of bright metal in these power leads. I find that especially disturbing since either the power lead braze evaporated and left no continuity or the nickel wire was corroded through. The entire cross-sectional area of the nickel wire has a black matte appearance.

Careful examination of the hot bonds does not show any significant irregularity. Multicouple 5 hot bond shows a number of blow holes around the periphery, although the bond, itself, seems quite sound. There appears to be a void in such a way that the hot shoes may not be completely covered. There is, however, no evidence of discoloration except on one side where it is possible that there is some vaporization coming out from under the glass. This is the side 90° clockwise from the location

of the thermocouple. Examination of that thermocouple shows that the two wires were twisted just before they entered the ceramic and are touching there. Also, they have quite a heavy deposit on them at that location and that deposit is opposite the break in the module. It's rather clear that this deposit caused the short at this location. Quite independent of that material, however, the wires are definitely twisted and it's clear that this thermocouple would not have been producing the proper voltage.

Examination of the matrix of the module legs shows that there is a discoloration and a definite facet nature to the boundary legs on at least two sides. They have a different grain appearance to them. They have a different surface sheen than the internal elements. This may be the tungsten shoes which did not separate in the break. It's not clear what this means, but it's probably significant in terms of the initial failure mechanism.

Carefully observing the power leads, it's quite clear that these leads were destroyed chemically and that they had been broken for a long time. There is a heavy matte deposit and there is clearly a reaction product over the surfaces. The braze system may or may not be adequate, but there is clear evidence that something is causing very severe chemical reaction and that these leads will not last in this environment.

The glass coating around the periphery of Module 5 is quite uniform in thickness and appears quite good. There is no indication of any void at the break that I can see. The general behavior of the glass is as you would expect it to be. There is nothing to indicate that the modules were in any way

defective as far as the thermoelectric manufacturing process is concerned. It does appear that there is a problem with the brazing to the power leads. It does not appear that there is a problem with the hot junction bonds. I am going to probe this element and find out whether that is the case. It is very interesting. The probe of the Number 4 quadrant related to the thermocouple hole shows that if I probe the very corner element and check to any other element I have continuity. The resistance was approximately 15,000 ohms. Polarity reversal does not seem to make any difference in making this resistance measurement with the Simpson meter. Probing the elements directly adjacent to this module says that the leg, immediately on its left, has a resistance of between 10 and 4 ohms, depending on how hard you push on the probe. It is not clear whether this is changing the contact resistance or whether it is measuring the flexing of something at the hot shoe. That resistance is much too high. There is no change in resistance when reversing the lead polarity. There is no continuity between the heat collector and any point on the fracture surface of the module. This is as it should be.

The Module 5 cold shoe is completely black and completely matte in finish. It has a few bright specks, on occasion, which are difficult to identify. The hole for the power lead is clearly visible, but the power lead itself is missing. The two leads are in the envelope which contains the various paraphernalia. Inspection of these leads shows an absence of any bond material braze at all. It just never seems to have caused any reaction with the nickel and there doesn't appear to be anything left there. The appearance of these wires does not jive with the condition of the holes from which they came. I conclude from this that the wires were simply not in contact with the hole and were not brazed as they should have been.

There is a stub of one wire sticking up from the module. The other hole is quite filled over. It is not at all clear what it is that is being observed. The hole in the cold shoe is almost completely plugged with a deposit. It would have been impossible for that hole to have been occupied by a ceramic, since it is almost completely overgrown with this deposit. It is most likely that the deposit was shorting out the power lead; unless, of course, this deposit turns out to be the cold assembly bonding glass.

Detailed examination of all of the modules will be performed by Dr. Kling and will be reported in the following chapter.

III. VISUAL EXAMINATION OF MULTICOUPLER FROM STATION 1 BUILD 2, 13 AUG. 1982

A detailed inspection of the MITG modules is presented in the following Sections.

A. Module 1

Heat collector edges curled toward heat. Heat collector quite clean. Gold foil housing side shows no imprint of contact. Shows apparent light color deposits, thin, on one side.

I shall define sides of thermopile thus:

Side 1 - glass uniform gray color; small flaw cold corner near 2. Cracked all along side; uniform wide gap; can look down in--looks like cold bond separation--visible surface looks like trace of W straps on cold end glass--cannot see bottom of crack but cold stud seems firmly adherent.

Side 2 - Cracked - as side 1--not quite as wide--can see further in--no bottom visible--think at least beyond 1st row of legs--glass uniform dark gray--cold #3 corner has large patch of white ceramic adherent--nature unknown--hot end glass strip looks good--a few small flaws.

Side 3 - glass cover, as 2, white ceramic blob does not come far around corner--Crack, as 2, hot end glass bond--larger flaw than 2 but not bad--glass coat on W of cold stud has red to copper colored spot near middle.

Side 4 - glass cover quite uniform gray color--hot end glass good shape. Crack full extent of side but least wide. Crack goes all the way around est. gap $\approx .010$ ".

Gold foil underneath--crystalline deposit everywhere you can see surface.

Power leads look okay issuing from spaghetti.

B. Module 2

Pictorial views of Module 2 are shown in Figure III-
Separated into 2 pieces.

Cold End - One power lead was gone, one still in place, but pulled out of hot end leaving a clean hole--not bonded--removed wire from cold stud as it was loose--sample is of bent-over end of wire covered with Al foil all

badly reacted--looks a mess--looks like wire is badly reacted but could be mostly the Al-Ag. Suggests Al-Ag foil braze is NG.

Fracture surface is mostly through Si/Ge except at edge it is in the bond over portions of 7 legs. Where entirely in Si/Ge, surface is bright and metallic looking*. Where in bond and nearby on Si/Ge it is dark--black in spots, mostly blue, iridescent--also around central power lead holes, blue, iridescent. 5 other legs show thin gold color stain.

*only sometimes--6 legs bright shiney faceted--11 legs yellow color, less faceted, 14 dark blue, iridescent, partly fractured in bond plane. Looks like fracture started in one corner, grew around periphery--also started centrally at wires, but then did not spread uniformly. 6 bright legs are not contiguous, not in center--are in 3 pairs.

Hot End - fracture surface is all bright, shiny, but there are faceted and smooth fractures—think not P&N because of pattern. CHECK PATTERN—is not P&N difference.

- Smooth
- Bright faceted
- Bond fracture

Power Leads - one removed as noted--other end remains in leg, clearly broken close to fracture plane wire at break appears to be badly reacted. More than half way through.

Side 1 - Glass color metallic near cold end, gray elsewhere--small fuzzy deposit--looking obliquely at fracture surface see multiple cracks, i.e:

Side 2 - Glass had white stripes parallel to foils

Side 3 - Also stripes--otherwise, nothing remarkable.

Side 4 - Most heavily striped.

Glass fractures, generally, a bit below plane of fracture in Si/Ge. On Side 3, edge on look at glass clad break, small copper colored spot. Heat collector curled up toward heat.

C. Module 3

Pictorial views of Module 3 are shown in Figure III-
Heat collector badly curled. Gold foil shows little indicator of compression--
shows a few spots, could be contacts. Unit is all together.

Side 1 - Glass uniformly gray, smooth, small flaw in cold #2 corner.
Cracked clearly fractured all through as cold stud is displaced toward Side 2.

Side 2 - Glass smooth, gray, bubble type flaw near #3 edge. Cracking
most obvious--can look right on through. Looks like fracture is in glass bond.

Side 3 - Hot end glass bond has edge flaws. Glass smooth--2 possible
thin cracks. Major crack appears to be between W of stud and glass of bond.

Side 4 - Glass smooth--small round flaw near #3 edge. Major crack
looks the same.

Gold foil looks fairly clean on under surface.

D. Module 4

Pictorial views of Module 4 are shown in Figure III-
Module in two pieces.

Cold End - Fracture surface proceeds through Si/Ge in 12 legs in a
block, through W plate to glass bond in 3 W shoes (6 leg's, through Si/Ge to
W shoe bond in 17 legs, and transitioned in the rest. Cold stud fracture
surface is mostly black to dark gray over most of surface, lighter gray over
the balance--in the center.

Note - 12 legs fractured in Si/Ge--fracture surface is black and fuzzy looking--where as on hot side the fracture is bright, shiny, faceted. Hard to understand such a pronounced difference on two sides of a fracture, in close proximity.

Looking at the housing side of the cold study, there are faint stain-like patches, mostly around the edge, that could indicate contact with the gold. Looking at the gold foil, I do not see corresponding marks.

Gold foil--looks uncontacted on housing side, has faint indication of a deposited film on stud side, no clear compression marks.

Hot End (Thermopile) - Heat collector is curled moderately. Has prominent gray geometrical stain, back surface, mostly in Side 4. Also, 2 large rectangular clean patches. Marshall says due to contact of top foil.

Looking at fracture surface, Si/Ge fracture is bright as noted--but there are different degrees of brightness and faceting. NOT however, in checkerboard pattern (P-N).

One area where W plate is retained, there is a mass of milky white/gray "glass"?, larger than interleg partitions--looks like fracture through a relatively thick piece of uncontaminated glass.

Power leads both remain in legs, both appear almost completely reacted.

Emil asks about thickness of outer glass coat--estimate 3x to 4x as thick as interleg partitions, just slightly less than diameter of power lead wire--wire=.010" glass $\approx$ .008". Fracture edges of glass all black, level with main fracture surface.

Side 1 - glass uniform dull gray--shows familiar round defect in cold-2 corner. Glass on hot end bond is quite poor--seems to be coming off.

Side 2 - like 1, no round defect.

Side 3 - like 2.

Side 4 - generally like other--one v. fine, straight crack, axially, ends at substantial void on hot end bond--crack seems innocuous.

E. Module 5

Pictorial views of Module 5 are shown in Figure III-
In two pieces--general appearance like mod. 4: cold side of fracture is black, hot side is bright. Fracture surface predominantly thru Si/Ge. In 12 legs, all outside, mostly sides 2, 3, fracture is between Si/Ge and W plate. One little fragment of W plate remained attached but has now come loose and is lying in a hollow--undoubtedly will get lost--not so--salvaged into envelope.

Cold End - almost all fuzzy black except 2 legs with lead wire holes. These are lite gray (broke last?) Also, there are strange little irregular brite spots widely scattered. Looks like someone spattered molten solder about. Think actually these are holes in the black deposit through which the Si/Ge shows--strange shapes--probably due to rubbing off deposit locally. Good place to get a sample of the black deposit for analysis.

Nature of glass: - glass extrusion (?) at edge of W/Mo plate--generally black--shows on one edge of this stud that it is really milky--white until contaminated by the black deposit--half of this glass got screened somehow and is still white.

Crack - fully separated--held together by wires--can see right on through--looking into crack, can see Side 4 area well--fracture surface appears to be between Si/Ge and W plate--Side 2 area is less wide open--can't see through.

Side 2--Glass has some darker stripes, parallel to foils, has ~10 small round flaws--hot end bond a little better than Side 1--Crack all way across-but not so wide open--can't see inside.

Side 3--Glass has 2 dark, 4 moderate stripes, parallel to foil--Crack is quite open--looks like fracture surf is between W plate and glass bond. Thin innocuous crack in glass coat close to hot end bond.

Side 4 - Glass has dark stripes plus light colored square area in cold-1 corner. Crack quite wide but can't see in. Side glass has fractured down the side a bit and screens view.

Cold stud quite loose--moves about.

G. Module 7

Pictorial views of Module 7 are shown in Figure III--
In one piece - heat collector slightly curled--Gold foil is bent a bit but no evidence of pressure.

Side 1 - Glass uniform gray--round flaw in cold-2 corner. CRACK--different. This one comes out between the W surface of the cold stud and the glass bead around edge of thermopile--can't see inside crack.

Side 2 - Mottled stripes on glass--Crack not clearly evident--seems to be hiding in corner between thermopile and glass bead on cold stud.

Side 3 - Similar to 2--Glass is almost milky white in narrow band right at cold end--Very little discoloring contaminant, whatever it is--Crack not evident.

Side 4 - Similar--Crack can be seen coming around corner from Side 1 in the corner between thermopile and glass bead but not wide--extends full length of side.

Think cracks extends all way around periphery but doe not extend to center--Good sample to pot to determine crack growth pattern. (But Marshall later notes movement of stud).

I. Module 8

Pictorial views of Module 8 are shown in Figure III--
In one piece--heat collector V. slightly curled. Gold foil--as Mod 7--but has two slivers of something else (aluminum?) embedded in 1-4 corner.

Side 1 - Glass very litely striped--hot end bond cover badly separated--usual round flaw in cold-2 corner--also--chip of side glass out in that corner--Si/Ge visible.

No evidence of major crack.

Side 2 - Glass mottled and striped--1 strong, 2 weak copper colored stripes. Areas where glass looke almost white--i.e. litely contaminated. 2 small, deep round flaws in cold--3 corner--no evidence of major crack.

Side 3--Glass is almost white over colder half in irregular pattern. Drab color stain seems coming from hot end. One somewhat copper colored stripe. No evidence of major crack.

Side 4 - Usual gray dark color over most of surface, except white zone on Side 3 comes around the corner ~ 1 mm . Thin straight axial crack near 1 side--full length--seems innocuous--no evidence of major crack.

TENATIVE CONCLUSIONS

1. Crack starts at corners, proceeds along edge, then grows toward center. May crack 360° around edge, or 180° and grow toward other side. Based on crack appearances and color patterns on fractured surface.

2. Gold foils were never compressed to point of deformation.

3. Something deposits into the cracks primarily on cold side, that gives interference fringes at first, then a fuzzy black deposit. Substantial deposit can build up on cold side while hot side stays brite. 4 and 5 are worst examples. These were broken for entire duration of the second run--Extent of deposit may indicate how long cracks were open.

Module 5, cold end, would be good source of deposit sample for analysis. Deposit appears to be conductive.

4. Seems to be a source of contamination of the glass in the modules that varies considerably from module to module. May come from module production. I question the stability of the glass in the contaminating environment. The effects may be due to surface deposits.

5. Serious reaction occurs on Ni power lead wires due to Al foil braze. Definitely bad enough to be a source of extraneous resistance--may grow worse with time--Seems able to sever the wire entirely. May be worsened by local overheating after fracture.

6. : Can't say if crack is due to bimetallic warping, or L/A rigidity effect—suggested by Hagan--Cracks starting at edges do suggest warping--but other effect probably also maximizes at corners.

7. The major cold end fracture does not seem to follow any particular interface predominantly. Sometimes it is inside the Si/Ge, sometimes between Si/Ge and W plate, sometimes between W plate and glass. I conclude that there is no "weakest" interface in the cold end structure and the failure path wanders, either randomly, or in response to details of the stress pattern of which we have no knowledge.

APPENDIX A

Transcription of Tape Made
During MITC Module Disassembly

A. STATION 1 BUILD 1 AND BUILD 2 DISASSEMBLY TAPE TRANSCRIPTION

This is an oral record of the disassembly of MITG unit 1 on 6 July 1982. Disassembly was begun at 11:06 hours. The module outgassing tube was released from the chamber feed-through fitting using the top access port. No difficulty was encountered in removing the fitting from the tube. The chamber cover was lifted from the module assembly. No interference with the insulation was noted as the cover was being removed. The top insulation panels of Min-K were removed exposing the foil pack and the module pressure tubulation. This pack and tubulation appeared to be in the same position as when the test was begun. There was no indication that the foil pack had been dislodged by the pump down sequence. This had been a concern of Mr. Beaudry; however, it does not seem to have been a problem. Two complete roughing cycles were logged since the installation of the foil pack. The fin insulation was removed without incident. The wires were observed during the removal of the fin insulation and they were not disturbed. The side panel insulation was removed to expose the module and instrumentation wiring. All wiring was observed while this disassembly was taking place and there was no movement of the instrumentation or power wiring during the insulation disassembly. A careful visual inspection of modules 7 and 8 showed no reason for the high apparent resistance to ground. Nor, for that matter, did it show any reason for the high internal resistance. Detailed checks of the resistance between the power leads at the connector and the weld to the heavy-gauge power lead wire at the module were conducted. The result of those measurements is as follows:

Resistance from pin 25 to module 8- is .3 ohms.

Resistance from pin 26 to module 8+ is .24 ohms.

These resistances were taken with a Fluke 8800A Digital Multi-Meter,

one probe on the terminal board and the other on the wire from the module as it exits the ceramic insulator on the module side of the insulator. In this configuration, module 102A is module 8. Module 107A is module 1. The numbering is counterclockwise. (ED Note: Build 2 numbered clockwise starting at same location). There is a mottled appearance to the surface of the aluminum where it was both hot and alodized. It appears as if something is coming out of the surface of the aluminum and giving it a speckled coloration. I am going to investigate that in more detail. A careful examination of module 8 shows that the power lead is not shorted any place that is visible. The thermocouple at the cold junction does not appear to be shorted as it leaves the ceramic. All of the wires there are quite close. Both of the power lead ceramics are broken but they do not appear to be touching the stud in any way. The hot junction thermocouple is clear at the exit from the ceramic. There is no continuity through the thermocouple. There appears to be a broken wire. The tungsten wire of the hot junction thermocouple is broken at the weld. The columbium wire is intact. Both wires for the cold junction thermocouple are intact. There is continuity on the cold junction thermocouple. However, the cold junction thermocouple is not contacting the cold junction. It is simply in the stud and not very deep into the stud. Both wires of the module have been bridged. These are the ones that I did myself and they appear to have survived the insulation installation with no problem as indicated by the continuity measurement with the multimeter. The thermocouple on the face of the unit opposite the number 8 module is intact. It appears to be installed correctly and there is no apparent problem with it, although the readings of most of these thermocouples were quite erratic. The hot junction thermocouple of module 7 is intact. Both module wires are intact. There is no problem with the cold junction thermocouple that can be determined. Both wires are intact. Neither one has been bridged and there appears to be no short at the exit to the ceramic. The power wires from module 6 are intact. The cold junction

thermocouple wires have never been broken. They are intact. There is no short at the exit of the cold junction thermocouple. The hot junction thermocouple wires are intact. However, there is a short of one of the whiskers to ground at the screw which holds the thermocouple ceramic. There does not appear to be a short between the plus and minus wires. Both of these wires have been bridged. The repair seems to be alright. This is one of the repairs that I made. The thermocouple on the face of the module is intact with no apparent problem. Both face thermocouples are intact. The general appearance is that they should have been giving good readings. The root fin thermocouples are also both intact on face number 3 where I am now working. I am removing a fin root thermocouple. Its bead is still intact. This is the fin root of the number 3 fin. I am removing the fin root of number 4 fin. Its bead is intact. The number 2 face thermocouple I am removing. Its bead is intact. Number 1 face thermocouple - its bead is intact. I am removing the saddle thermocouple for thermocouple number 3. Its bead is intact. I am removing saddle thermocouple 3 and its bead is intact. All six thermocouples attached to the quadrant associated with face number 3 appear to be intact and the reason for the erratic behavior is not obvious. The only thermocouple which shows any sign of the stress is the hot junction of module 6, which is grounded to the mounting screw for the ceramic holding device. The hot junction thermocouple of module 5 is intact, as is the cold junction. However, the cold junction thermocouple is about 1/2 inch out of the stud and is clearly not measuring a reasonable temperature. There should be continuity on all these thermocouples. There is no obvious problem with them. There are no obvious shorts other than the fact that the thermocouple is not in position as it should be. The thermocouple power wires on module 5 are intact with no apparent problems. Module 4's power wires are intact with no apparent problems. The thermocouple for

module 4 hot junction is intact and it appears to be in reasonably good condition. This is the one that the ceramic was broken on and that I did a very close repair job on. The wires are not touching the module nor are they touching the ground at the hot junction. The hot junction thermocouples appear to be intact. The cold junction thermocouple is in place as far into the stud as it can be pushed. The wires are intact and have never been bridged. I am removing the number 2 face. The bead is intact. There is no apparent problem. I am moving the number 1 face number 1 from face 3. The bead is intact. There is no apparent problem. I am removing the thermocouple from the saddle of fin 2. The thermocouple's bead is intact. There is no apparent problem. I am now working on face 2. The cold junction thermocouple is intact. This thermocouple has never been bridged. The power wires are intact. The hot junction thermocouple is intact and is not shorted, although it has been repaired. I believe this is one of the ones I made the repair on. The repair seems to have held up. Yes, it is one of the ones. I recognize my sloppy work. The power leads are intact. There is no apparent short as the leads exit from the device. Module 3 hot and cold junctions appear to be in good shape with no indication of any kind of distress. The thermocouples are also in good shape. Module 2. The hot junction thermocouple is, I believe, shorted as it comes out of the ceramic. It is very hard to see. I am using a magnifying glass. However, I believe it is shorted. The cold junction thermocouple shows no signs of distress. It does not seem to be all the way in, but when I push it it will not go any further, although there is a considerable amount of ceramic outstanding. The same is true on module 3. This should be cleared up so that we don't have the problem with the interference with the insulation on subsequent modules. The ceramic on the hot junction of 2 is broken, but

it does not seem to be contacting anything and it seems to be pretty tight. The power lead ceramics are broken but the cold junction ceramic is not. Nothing is going on here. I am now removing the number 1 fin root thermocouple. Its bead is intact. The number 1 thermocouple on face number 2's bead is intact. The number 2 face thermocouple bead is intact. The number 3 fin root thermocouple bead is intact. There is no apparent reason for the strange readings which we were getting from the face and root temperatures. One must conclude that they were reading as the temperatures indicated. Although I find that hard to believe. I will run further checks on these thermocouples to see if I can identify any problems at the cold junctions. All of the repairs that I made to lengthen the leads to the module 5 thermocouples are intact.

I have now removed the unit from the vacuum chamber and have it in the laminar flow bench where I am making a more careful inspection of the thermocouples. The tungsten wire on the thermocouple fin 1 is broken. This is consistent with the erratic readings which were observed. The thermocouples on both saddle 1 and 2 were indicated as being opened. I haven't checked 2 yet, but 1 is open. The cold junction of thermocouple of module 1 may be shorted where the wires come out of the ceramic. It's very hard to tell, but I believe that the thermocouple is shorted at the exit of the ceramic. The hot junction thermocouple is not shorted at the exit of the ceramic. The wires from the hot junction to the thermocouple to the binding posts are very close but do not appear to be touching. The ceramic is broken as it exits from the holding fixture, but the wires do not appear either to be touching themselves or the ground at the fixture. The cold junction thermocouple was not pushed firmly into place. It was clearly measuring some temperature intermediate between the cold junction and the stud. It is also, I believe, shorted at the exit to

the ceramic. The thermocouple in module 2 at the cold junction is of special interest because it is reading high and it is important to know whether this thermocouple was properly seated and whether there were any problems with it. The ceramic of cold junction module 2 is not broken. It is one of the few that is not. Module 2 hot junction ceramic is loose but does not appear to be broken external to the fixture. Since it is loose, it is assumed that the break is in the ceramic and is within the fixture. There appears to be no short at the exit of the thermocouple wires from the ceramic. The cold junction thermocouple is tight. It does not appear to be shorted at the exit to the ceramic. I see nothing unusual with the cold junction of 2. It appears to be a reasonable reading. The thermocouples coming from the cold junction seem to be discolored somehow in the ceramic. It's very difficult to tell whether the wires are shorted because the ceramic appears to be discolored somehow, which makes it difficult to tell whether the wires are separated. Even though they are going into the holes reasonably well, it is not possible to tell, with my eyesight, if the wires are touching. I am looking through an approximately x2 magnifying glass and I cannot tell whether or not the lines are shorted. The resistance on module 2 from the wires to the nickel, including the weld, was approximately .2 of an ohm. The process of taking the resistance measurement on module 3 first indicated .2 of an ohm but I broke the wire off of the module 3 post. Ah hah! The module 2 thermocouple cold junction tungsten wire was touching the housing. This may have been the problem that we were looking for with the module 2 thermocouple. The resistance of the module 2 cold junction thermocouple is 1.27 ohms. The resistance to ground is unstable at approximately 35 ohms. That touching wire may have been held above ground by the anodized finish of the unit. I

am going to move the wire and see if the resistance value changes. When I moved the wire the resistance became infinite. Therefore, the wire was [touching the tungsten wire of the module to cold junction] touching the casing and was shorted at that point. I'm not sure what this means since the cold junction bead appears to be above ground. That would seem to indicate that it was not touching the stud, although it may be touching the cold junction it is not clear what I should be reading for resistance there. In number 3 thermocouple is 1.14 ohms. It is an infinite resistance above ground. The hot junction thermocouple of module 3 is 1.14 ohms and 7 ohms above ground. The hot junction thermocouple module 1 is 1.4 ohms and 16 ohms above ground. On to module 4.

Module 4

On close inspection, although the wires from the ceramic appear to be clear of any ground they do appear to be shorted about 1/2 inch from the exit from the ceramic on their journey to the binding posts. The number 4 module hot junction thermocouple has a resistance of 1.6 ohms. It is 2 ohms above ground. The cold junction of module 4 has a resistance of 1.3 ohms and it is 1.02 ohms above ground. One leg was .5 above ground. The cold junction of module 5 is infinite above ground and 1.5 ohms resistance. The resistance of the hot junction thermocouple is 1.75 ohms and it is infinite above ground. The power leads of both modules 4 and 5 are intact and show very large resistance across the welds.

Module 6

The face of the module which holds couple 6 and 7 has some strange

deposits that look like corrosion across the face. It is not as distributed as the deposits noted on the face with modules 1 and 8. However, the lumps are quite high. They seem to be covering areas of porosity in the metal and there seems to have been some kind of outgassing from this porosity which has left a build-up around it of an unknown material. I will not disturb this material in case we want to take a sample of it and see what it is. Lumps of it are extremely prevalent on this face. The power leads from module 6 appear to be intact and there is low resistance across the welds. The hot junction thermocouple touching the mounting screw for the ceramic holding hardware. This ear is definitely shorting the thermocouple at this location. The resistance of the module 6 hot junction thermocouple is 2.2 ohms. It is 1.5 ohms above ground. The cold junction thermocouple of number 6 module is least in the stud but it seemed to be as far into the module as it could be pressed. The resistance of the face thermocouple is 1.18 ohms. It is less than 1 ohm above ground. The exit wires from both the hot and cold thermocouple do not appear shorted at the exits from the ceramic. The hot junction thermocouple of module 8 has a resistance of 1.67 ohms. It is infinite above ground. The cold junction thermocouple of module 7 is 1.47 ohms. It is .7 ohms above ground. The resistance of the number 8 module hot junction thermocouple is 3.7 ohms. It is 1.8 ohms above ground. The resistance of the cold junction thermocouple is 1.2 ohms. It is infinite above ground. The resistance of the number 1 module cold junction thermocouple is 1.2 ohms. It is 30 ohms above ground. The resistance of the number 1 module hot junction thermocouple is 2.1 ohms. It is 1.4 ohms above ground.

The thermocouples which do not show continuity to ground may or may not be in contact with the thing which they are measuring. The cold junction thermocouples should be in contact with the glass on the bottom of the module where it is bonded to the hot shoe. The hot junction thermocouples should be teamed into the moly heat collector. The moly heat collector may or may not be at ground potential depending on whether or not it is shorted to the moly foils by the foils touching them. The lack of certainty in this area may be a cause of inconsistency. I will correlate the short and non-short readings with the evaluation of erratic behavior which was made during the course of the experiment at temperature. If the erratic behavior is a function of the thermocouples not being at ground potential, we may be on to something in terms of extraneous voltages in ground loops and instrumentation rebate problems rather than in problems in the thermocouples themselves.

This is a record of the internal disassembly of the Build 1 unit after the test to 600°C. Jim Hardy is disassembling the insulation pack at this time. Jim states that the general condition of the foil pack was as he left it. There is no indication that it puffed up during the pump down. Seigo indicated that he felt that the MIN-K powder in the foil pack in the first several foils was excessive and that we should attempt to keep that from being a problem. Removal of the upper foil pack is continuing. There is no indication that there is a problem with anything at this time. Disassembly was begun at 1315 hours. At 1328 disassembly down to the hard sheet that the tube is welded into is about complete. We have exposed the tube for the module pressure gauge. The inside of the tube is covered with a black deposit. It is unclear what it is, but it is fairly heavy. It's around the entire tube. Jim says it has a burned smell. There is a deposit on the sheet that was welded to it. This deposit is white in color and has spread over part of the sheet. The hole in the moly foil has some discoloration next to the next foil down from the heavy foil that was welded to the sheet. It appears as if the entire inside of the package where the hole goes through has this discoloration and it has migrated somewhat into the foils. The edge of the foils going down into the pack seem to have shown some reaction. The reaction, however, is confined to about a sixteenth of an inch from the hole around the circumference of the hole. As you go farther down in the hole the color changes back to bright. It looks as though something deposited at this level of temperature in the insulation. The majority of the foils surfaces are bright and shiny. It is unlikely that any great damage was done to the insulation. The discoloration at the central hole in the top insulation pack stops at 24 layers below the thick layer which is welded to the pressure monitoring tube. At 1354 the heater block is exposed. There is a small amount of powdery deposit right under the hole. There is absolutely no discoloration of the heater block. It looks bright and shiny, exactly like it looked when we put it in there. The back side of

the heavy plate shows a discoloration which seems to be a hard deposit but doesn't look particularly vicious. Looking through the glass there is no indication of anything except a little pile of dust in the middle right under the hole where the ionization gauge tubulation was placed. Jim Hardy feels that the surface of the carbon block is lighter than it was at the initial installation. Using the Fluke 8800 DVM to measure the resistance to ground from the hot shoes and am preparing to do that now. There is continuity to ground from module 1 to ground but the reading is very shakey. The lowest reading is .7 ohms. The highest reading is 3 ohms. I don't want to put any load on the heat collector. I'm sure that I'm just looking at the contact resistance of the probe because if I push too hard on here I'm going to break something and I don't want to do that. Module 2 is above ground. Module 3 is very stable, .3 of an ohm to ground. Module 4, .25 ohms to ground. Module 6 is .27 ohms to ground. Module 7 is .28 ohms to ground. Module 8 is 1.5 ohms to ground. We're going to do 1 again. 1 is now showing open to ground. It all depends on how I flex it when I take the reading whether it's open or it's to ground. It is just barely touching the insulation. It could have been open or there could be a resistance. Now it's showing .46 ohms to ground as a minimum and that might be because I flexed the hot shoe and made it touch. I cannot get a positive indication on Module 1. All hot shoes are intact. There is evidence of some distress where the hot shoe has been in contact with the insulation in one place. In general there is some discoloration of the hot shoes. There may be a deposit on the hot shoes but they do not look significantly different at this high angle of vision than they did when they were installed. In general, the inside of the module is clean, the insulation is bright. There is no indication of any deposit on any of the secondary surfaces although the hot shoes, themselves, may have been pitted somewhat. We'll have to wait for Val to tell us whether or not there is a discoloration that is different from those that were visible when they were initially installed. We have removed the top from the heater box. The moly wire is ductile. The ceramic beads are discolored approximately as they were discolored originally. There is no indication of any problem on the inside of the box.

The ceramic tube which comes up through the bottom of the carbon block is discolored. However, it may have been discolored when it was inserted. It's hard to tell. It was bright when it was new, however. Module 1, 2, 3 and 7 were removed without incident. There was some indication of a black deposit at each cold shoe.

B. STATION 1 BUILD 2 DISASSEMBLY

This is a log of the disassembly of Station 1 build 2 of the MITG Test. The checks were made on the automated data bus. All systems checked with the manually determined values.

The system was back-filled by equalizing the pressure across the isolation valve with the roughing and turbomolecular pumps. The foreline pressure was roughed to 4×10^{-5} torr and the valve between the foreline and ^{the} chamber was opened. At this time, dry nitrogen gas was introduced into the system while the roughing pump was still running. The system was bled back to atmospheric pressure starting at 10:12 A. M. on October 12. The atmospheric pressure was achieved in the chamber at 10:24 A. M. We are preparing to remove the cover of the chamber at this time. I am disconnecting the ionization gauge wiring. The chamber cover was removed at 10:29 A. M. The block insulation was removed from the module. At 10:30 it is complete.

There is no evidence of any change in the insulation coloration. There is no evidence of any deposit of any kind on the insulation. The wiring looks like it did when we put it in. The zinc coating does not appear to have gotten any lighter than it was at the installation. Val says that the unanodized aluminum legs appear to have a purplish cast. There is a white deposit inside of the tube that is used to outgas the module. We are preparing to take swab of that material at this time.

It is 10:35 A.M. The deposit on the inside of the table has been swabbed. It has an odor described by Hardy as being rank

Hardy is beginning the disassembly of the insulation pack at 10:40 A. M. Disassembly is complete of the top 60 foils down to the hard plate that is attached to the degassing tube. The module tube has a distinct odor of hydrogen sulfide. There is a discoloration on the top foil of the remaining 60 pack which matches the discoloration in the plate welded to the outgassing tube. It has a white appearance. There's a strong smell of hydrogen sulfide coming from the module itself. The third foil above the heavy foil to which the outgassing tube is welded has a bluish-whitish deposit that has the same general appearance of the deposit on the heavy foil. Disassembly is continuing into the lower 60 foil pack. It is now 10:46 A. M. At layer 15 below the heavy plate which was welded there is an increasingly bluish tint to the surface of the moly foils. The blue discoloration is becoming more and more noticeable as we get down to layer 18. The deposit is uniform. The coloration has an interference fringe pattern to it. It's quite thin. The foil insulation is becoming brittle around layer 26-27 below the heavy plate.

It is 10:57 A. M. We are photographing the deposit that is apparent on the surface of the foils. There are about five foils left before we get to the graphite block. Exposing the top cover of the heater box there is nothing unusual in the graphite. However, the heat collector of Module 4 is wrapped around the

heater box. It is severely distorted and has curled around the heat box in a very lovely drape. The top cover has been removed from the heater at 11:10 A. M. The heater looks clean. There is no indication of any discoloration that wasn't in there at the start. The inside of the box and the inside of the lid has a slight gray color which is a deposit of some kind which was not there when we started. With the exception of Module 4, it is clear that all of the heat collectors are still attached to the modules. Module 4 appears to be attached but it is warped so that it is hard to tell whether it has fallen forward onto the heater box. The edges of the heat collector appear to have been touching the graphite and where it has been touching they appear to have been eaten away.

Manipulation of the heat collector on Module 4 shows that at this point it is attached. It is not clear that we can get the heater box out of the housing without knocking this heat collector off. However, it does appear, at this point, that it flexes and is attached to the module. The heater wire has been cut and bent 90° . It shows a fair amount of ductility, which would indicate that the atmosphere in the heater cavity was not too bad or else there would have been severe embrittlement of the moly from oxygen. The heater box is out at 11:17 A.M. The shoes are all exposed. They are all extremely shiny. Probably the old oxide coatings were evaporated at the temperature and pressures that we were testing.

The edges of all of the heat collectors are curled and wrinkled. All of the heat collectors are in place. The inside of the box looks quite shiny, quite clean. There are no deposits. There is nothing that in any way indicates that there is a sublimation problem.

Module 1

The module 1 heat collector shows a very shiny surface. Some of the edges of the heat collector, the lower right-hand edge facing the heat collector, have an extreme curl. The upper right hand and lower left hand have slight curls. The upper left hand quadrant shows a straight section. The surface of the heat collector is very bright and clean. There is no evidence of any kind of discoloration. The joint between the tungsten and the moly looks sound. The hot junction thermocouple bead is not visible. It appears to have been corroded away.

Module 2

This module also looks bright and clean. The lower edge of quadrant 1 is curled slightly. The corner at the edges of quadrant 4 is curled heavily. The entire bottom edge of quadrant 3 is curled, as is the vertical edge of this quadrant. The upper edges of both quadrant 2 and 1 are straight. The

surface is bright and shiny. There is no evidence of any problem at the weld between the tungsten and the moly. The thermocouple bead is visible. It appears to be intact.

Module 3

This module has very badly crinkled corners in quadrant 4. Quadrant 3 is also crinkled. The upper edge of quadrant 2 and 1 is straight. It should be noted that this upper edge is touching the heavy backing foil. The other modules were not touching. The general appearance of the edges that are crinkled is that they are thinner than the edges/^{which} are not crinkled. Module 3 thermocouple bead is visible and seems to be intact.

Module 4

All four edges of this module are crinkled. The upper edges are worse than the lower edges. This is different than it was on the previous module. The thermocouple bead is visible and it appears to be intact.

Module 5

Module 5 is flat. There are no curls to the edges. The thickness of the edges looks like it should. There is no indication of anything unusual about this module. The hot

junction bead is intact and is visible. It appears that there is some discoloration on one of the wires but both of the wires are visible and the bead appears intact. The weld appears intact. There is no indication of any cracks in the surface.

Module 6

Module 6 has a piece out of the corner, but that was out when we started. The edges of the heat collector are straight in all cases. The bead of the thermocouple is visible, but appears to be somewhat corroded. One of the wires seems to be gone. The one wire seems to be dominant. If there is any indication of the other wire, one is certainly dominant.

Module 7

Module 7 has reasonable flatness to the first and second quadrant. The lower corner of the fourth quadrant has some curl. However, the surface looks reasonably good. There is no indication of anything being wrong with it. The thermocouple bead is not visible in a normal location, but it appears that it is intact. It is very difficult to see this bead but it seems that it is intact.

Module 8

Module 8 is essentially flat, very low curl. The No. 2 quadrant has a slight bend at the corner. There is a piece missing

from the first quadrant corner. However, this was missing in the original build. There is no indication of anything loose or fallen in the bottom. The lower insulation basket is quite bright and shiny. There is no indication of any deposit of any kind at this stage of the disassembly. This is an absolutely clean internal. There is no indication of any kind of sublimation at this stage of the disassembly. The heater thermocouples do not appear to have the sourized on their beads anymore, and both beads appear to be attacked. I assume that's from the reaction with the carbon.

Module Removal

The first module was removed at 1345. The stud nut required zero torque to remove. The cold end showed definite discoloration at the wrap. The module has a hydrogen sulfide smell. This is what we identified coming from the tube to the module ionization gauge. It appears that this is actually a phosphorous smell and not a sulphur smell. The gold foil shows no coining marks there.

Module 3

Inspection shows that the power wire was melted at the exit to the module. There was a direct short there and the wire is melted loose from the power wire where the transition is made between the nickel and copper. There is no indication of a particularly vigorous deposit on any of the ceramics that were removed from the cold end. The torquing of the stud nut

from No. 3 module showed 5 inch pounds to break the joint. This module had been torqued to 7-8 inch pounds at assembly. It is different from the others in that I torqued it myself at installation. This was when we repaired the power wires. I expect that this will be the only one

which will have the proper torque readings on disassembly. No. 3 module shows no coining of the gold but one corner of the gold foil was folded over to hold the edge up so that it was not coplaner with the housing face. The cold stud assembly is clearly broken off the module. There's no question that it is broken. There is a dark discoloration there at the cold end and the stud is out of plane with the module itself. It has a hydrogen sulfur smell.

Module 4 Disassembly

Module 4 nut was under five inch pounds torque. It was finger tight. The power wires were fatigued and broke as he was manipulating them. They were intact, however, at the time. The module nut was backed off with the fingers, essentially no torque. Module came apart in two pieces. The cold shoe is completely separated. The gold shows no indication of any coining. It's quite bright. There's nothing in it that would indicate that there is any compression of it whatsoever. This is consistent with the finger-tight stud. The break of No. 4 is different than the previous breaks. This one is partly through the bond and partly through the thermoelectrics. The break has been there for quite a long time. There is a great discoloration of the cold shoe. It's almost completely discolored. The silicon germanium side is

quite bright. No deposit appears on the surface. The cold shoe of Module 4 is totally discolored. There is a film over its entire surface which is black in color. It appears that this module has been broken for a long time and that it was incompletely broken. There is no indication of brightness on any place.

—75 Module 5 was finger tight. The gold was not coined. The break is in the thermoelectrics. There is a heavy, dark deposit on the surface of the cold shoe. The hot shoe is bright.

—75 Module 6 was finger tight. There is a break at the cold shoe. The pieces were not completely severed. The inner-face could not be observed, but it was clearly broken. There is no evidence of coining in the gold at all.

—75 Module 7's stud was finger tight. The gold showed no coining. The module was intact. There is no indication of a break at the cold junctions in the gross sense that all the other modules were broken. There was, however, a discoloration at the cold end on the wrap. This has been characteristic of all the modules that have been removed.

—75 Module 8's cold stud nut was finger tight. There is no indication of any coining of the gold. The module came out in one piece. There is an evidence of a longitudinal crack

completely different from any of the others in one of the faces of the module. The cold bond is quite good. There is indication of the flow in the glass. There is no indication of any cracking in the elements at the cold end. The general appearance of this module is that it is in the best shape of those that were removed and that's consistent with the data which we took on the module.

—>5 Careful observation of the Module 2 cold shoe shows a deposit on those elements which are not bright and shiny. The mating piece of the module is uniformly bright, although the fracture planes are quite diverse. This module appears to have had a matte finish plated from the hot side of the break to the cold side over, perhaps, ten of the legs. A resistance check showed that any part of the matte to any other part of the matte finish had about 50,000 ohms resistance. Carefully examining the bond in the power leads showed a bad chemical reaction between the nickel wires and either the braze or the hose material. This must be looked into carefully, since Dr. Kling pointed out some time ago that the aluminum brazes do form complex systems with nickel. It should be remembered that hot side of the break may have been at temperatures of 600-700° and this may account for the severe reaction. This evidence of chemical reaction is quite severe, and there is evidence that the nickel wires were not completely brazed into their holes. Some of them were pulled out of the holes as the modules came apart on disassembly. The reader is reminded that black deposits were noted at the end of the power lead ceramics in the previous

disassemblies and builds of this module. The black color of the deposits on the cold shoe and around the end of those power leads ceramics appears identical. It seems to me relatively clear that whatever was coming across the crack was going down the ceramic tube and was producing a short on the output of the module.

The cold shoe from Module 5 was completely severed from the remainder of the module during the disassembly. This cold shoe is completely black. There were small, almost pinpoint size, regions that are bright and may have been not broken. However, all of the elements show at least 90% of their area with a black, matte finish. A continuity check of the surface shows that any point to any other point on the surface has a resistance of 50,000 ohms or less. Again, the module power lead wire braze seems to have reacted with the power wire and caused a rather severe chemical reaction. There is a substantial amount of erosion and there is possibly a reaction to such an extent that the wires were corroded through. There is no evidence of bright metal in these power leads. I find that especially disturbing since either the power lead braze evaporated and left no continuity or the nickel wire was corroded through. The entire cross-sectional area of the nickel wire has a black matte appearance.

Careful examination of the hot bonds does not show any significant irregularity. Module 5 hot bond shows a number of

blow holes around the periphery, although the bond, itself, seems quite sound. There appears as if there is a void in such a way that the hot shoes may not be completely covered. There is, however, no evidence of discoloration except on one side where it is possible that there is some vaporization coming out from under the glass. This is the 90° clockwise from the location of the thermocouple. Examination of that thermocouple shows that the two wires were twisted just before they entered the ceramic and are touching there. Also, they have quite a heavy deposit on them at that location and that deposit is opposite the break in the module. It's rather clear that this deposit caused the short at this location. Quite independent of that material, however, the wires are definitely twisted and it's clear that this thermocouple would not have been reading the proper voltage.

Examination of the matrix of the module legs shows that there is a discoloration and a definite facet nature to the boundary legs on at least two sides. They have a different grain appearance to them. They have a different surface sheen than the internal elements. It's not clear what this means, but it's probably significant in terms of the initial failure mechanism. Carefully observing the power leads, it's quite clear that these leads were destroyed chemically and that they had been broken for a long time. There is a heavy matte deposit and there is clearly a reaction product over the surfaces. The braze system

may or may not be adequate, but there is clear evidence that something is causing very severe chemical reaction and that these leads will not last in this environment.

The glass coating around the periphery of Module 5 is quite uniform in thickness and appears quite good. There is no indication of any void that I can see at the break. The general behavior of the glass is as you would expect it to be. There is nothing to indicate that the modules were in any way defective as far as the thermoelectric manufacturing process is concerned. It does appear that there is a problem with the brazing to the power leads. It does not appear that there is a problem with the hot junction bonds. I am going to probe this element and find out whether that is the case. It is very interesting. The probe of the No. 4 quadrant related to the thermocouple hole shows, if I probe the very corner element and check to any other element, that I have continuity. The resistance being approximately 15,000 ohms. Polarity reversal does not seem to make any difference in making this resistance measurement with the Simpson meter. Probing the elements directly adjacent to this module says that the leg, immediately on its left, has a resistance of between 10 and 4 ohms, depending on how hard you push on the probe. It is not clear whether this is changing the contact resistance or whether it is measuring the flexing of something at the hot shoe. That resistance is much too high.

I'm going to check that by reversing the polarity. There is no change in reversing the polarity. There is no continuity between the heat collector and any point on the fracture surface of the module. This is as it should be.

The Module 5 cold shoe is completely black. It's completely matte in finish. It has a few bright specks, on occasion, which are difficult to identify. The hole for the power lead is clearly visible, but the power lead, itself, is missing. The two leads are in the envelope which contains the various paraphernalia. Inspection of these leads shows an absence of any bond material braze at all. It seems just to have never caused any reaction with the nickel and there doesn't appear to be anything left there. The appearance of these wires does not jive with the condition of the holes from which they came. I conclude from this that the wires were simply not in contact with the hole and were not brazed as they should have been. There is a stub of one wire sticking up from the module. The other hole is quite filled over. It is not at all clear what it is that is being observed. The hole in the cold shoe is almost completely plugged with a deposit. It would have been impossible for that hole not to have been occupied by a ceramic, since it is almost completely overgrown with this deposit. It is most likely that the deposit was shorting out the power lead.

Detailed examination of the modules will be performed by Dr. Kling and will be reported in the following chapter.