FSEC-ESD-217/82/217

CID # 9349
CALL # 10-03

MITG STATION 2, BUILD 1 DISASSEMBLY

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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 GaP doped 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 standard multicouples was also tested. The details of this disassembly were presented in a separate document, FSEC-ESD-217/82/214. Only the Station 2 build (GaP doped SiGe) will be discussed in this document.

One build of Station 2 was performed. This build reached full operating temperature (1000°C) and was at significant temperatures for ~ 1000 hours. The testing of this build was described in detail in FSEC-ESD-217/82/213. This document presents a commentary on the disassembly of this build.

The general appearance of the components from this build was excellent. Some of the deposits observed in Station 1 were missing. The tube and foils were much cleaner and the smell of hydrogen sulfide present in Station 1 was absent in Station 2. The outgassing tube of Station 2 smelled like a freshly fired shotgun.

The technical discussion concentrates on the completely fractured multicouples since these are the more interesting. The message is that the multicouples failed at the cold end. Cracks traversed the zone from the edge of the cold stud assembly in a generally dome shape upward into the SiGe for as much as 30 mils.

There was some failure in the bonds on some elements, but multicouple 1, 3, and 4, which had separated shoes, had at least some of the break in the SiGe. Multicouple 5 was completely severed at the bond between the cold shoes and the stud assembly.

The multicouple shown in Figure 1 is typical of the separated specimens of those tested. Multicouples 1, 3, and 4 were clearly broken at the cold shoe. The assemblies were held together by the power wire. Figure 2, 2A, and 2B show the multicouples. Multicouple 5 was completely separated. The power wires were corroded through and brittle. Multicouples 2, 6, 7, and 8 appear intact but all show cracks and appear broken close to the cold stud assembly when examined at 30x. Multicouple 6 appears to be mostly intact. This was the best performing multicouple electrically, and this is borne out by its appearance. Multicouple 6 is shown in Figure 3. Figure 4 shows a detail of Multicouple 8. Note the poor coverage of the glass over the hot shoe. Two hot shoes are exposed. Also, there is a fracture area at the cold end.

Some of the heat collectors of Station 1 multicouples showed extreme curling of their edges. Others showed no curling at all. None of the Station 2 multicouples showed appreciable heat collector curling.

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 multicouple cold ends are so gross that subtle problems will be masked. Also, some of the detailed observations of the multicouple 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 of multicouple 5. The power leads of all other multicouples were in good condition and showed little evidence of braze problems.

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Figure 1. Multicouple 1

Figure 2. Multicouple 5

Figure 2A. Multicouple 3

Figure 2B. Multicouple 4

Figure 3. Multicouple 6

Figure 4. Multicouple 8

A summary of the module resistances before and after testing is presented in Table 1. The final after test values were made with all power and instrumentation wiring cut away. A summary narrative of the Station 2 Build disassembly is given in Chapter II. A detailed narrative of the Station 2, disassembly 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 2 Module Resistances

<u>Multi- couple</u>	<u>Build 1 as Installed</u>	<u>Build 1 after Test</u>	<u>Build 1 All Leads Cut Away</u>
	Ω	Ω	Ω
1	82	291	579
2	24	232	420
3	41	119	175
4	10.3	314	438
5	9.7	∞	(2)
6	9.8	9.2	12.1
7	41.7	89.6	157
8	110	0.6	121 ⁽³⁾

(2) Module leads were brittle and disintegrated when cut. Appeared to have been attacked chemically.

(3) There was a short on the power leads of Multicouple 8. A whisker from the + nickel weld touched the -16 gauge wire.

II. MITG STATION 1 DISASSEMBLY NARRATIVE

The disassembly of the MITG assemblies in Vacuum Station 1 is discussed in this chapter. Only GaP silicon germanium multicouples were tested in Station 2. Standard silicon germanium multicouples were tested in Vacuum Station 1. The disassembly of these multicouples is the subject of a separate report (FSEC-ESD-217/82/214).

This document records those observations made during the disassembly of Station 2, Build 1. 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 are presented in the following sections.

A. Build 1 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 1 was operated for more than 1100 hours. This included more than 200 hours at 1000°C hot junction temperature. The disassembly showed a very clean envelope. The general appearance was superior to either Station 1 builds. There were few deposits in the module outgassing tube. What was there was light gray in color. There was no 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 a deposit in the module ionization gauge as there had been in Build 1 of Station 1.

The significant feature of this disassembly was that all multicouples had detectable fractures at the cold end. Each 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. More of the multicouples were at least partially attached than was the case in Station 1 builds.

There was a strong indication that most multicouples had at least one layer of foil trapped between the cold stud face and the aluminum housing. The leg to leg isolation resistances were much lower than those in Station 1 ($\sim 600 \Omega$), and three multicouples had continuity to the heat collector (300K - 500K Ω). The leg to heat collector resistances are presented in Table 2.

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

1. Station 2 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 3.

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 $4.E-5$ 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 0946 on 9 November 1982. Atmospheric pressure was achieved in the chamber at 0956.

2. Power and Instrumentation Wiring Inspection

Inspection of the power wiring shows that the Multicouple 8 external power leads are shorted at the transition between the 10 mil nickel wire

TABLE 2

Station 2, Build 1 Leg to
Heat Collector Resistance⁽¹⁾

<u>Multicouple</u>	<u>As Built Leg to Heat Collector Resistance⁽²⁾</u>	<u>Post Test Leg to Heat Collector Resistance</u>
	Ω	Ω
1	> 100K	400K
2	> 100K	> 100 MEG
3	> 100K	> 100 MEG
4	> 100K	> 100 MEG
5	> 100K	> 100 MEG
6	> 100K	300K
7	> 100K	> 100 MEG
8	> 100K	500K

(1) Similar measurements were made for Station 1 but were not recorded. To the best of the author's recollection, all values in that build were > 100 MEG.

(2) The meter used to perform continuity checks at fabrication did not measure to higher values.

TABLE 3

Instrumentation Thermocouple Resistances
Prior to Breaking Vacuum

Channel	Resistance + to -	Resistance + to Gnd	Resistance - to Gnd
	Ω	Ω	Ω
1	14.2	7.8	10.4
2	12.7	∞	∞
3	9.7	∞	∞
4	12.2	6.9	11.6
5	13.4	∞	∞
6	∞	∞	∞
7	12.5	4.5	10.9
8	12.0	5.6	12.0
9	11.2	4.3	12.0
10	11.7	4.4	11.5
11	7.3	4.4	6.5
12	7.0	3.1	6.6
13	∞	∞	∞
14	7.7	∞	∞
15	11.7	∞	∞
16	∞	∞	∞
17	7.8	3.3	7.8
18	7.8	3.0	6.6
19	12.6	4.4	9.3
20	12.0	7.3	10.1
21	12.5	6.4	9.6
22	10.9	∞	∞
23	∞	∞	∞
24	12.0	3.8	10.2
25	12.0	∞	∞
26	∞	∞	∞
27	12.3	∞	∞
28	12.0	4.0	7.6
29	6.2	3.2	7.6
30	6.0	1.9	4.8
31	3.8	1.5	3.6
32	4.2	∞	∞
33	∞	∞	∞
34	5.9	2.5	4.4
35	4.4	∞	∞
36	∞	∞	∞
37	9.6	2.8	9.8
38	7.8	2.7	9.2
39	7.5	2.7	8.4
40	12.0	5.0	9.4
41	∞	∞	∞
42	∞	∞	∞
43	∞	∞	∞
44	∞	∞	∞
45	9.8	∞	∞
46	9.1	∞	∞

to the 16 gauge nickel plated copper wire. A whisker from the + nickel weld shorted to the -16 gauge wire. On removal of this short, the data logger showed a change in resistance from 0.6 Ω to 121 Ω .

A complete inspection of the remainder of the wiring showed no anomalies. A summary of the power wiring and module resistance is presented in Table 4.

A detailed inspection of the multicouple hot junction thermocouples was not performed after their removal from the housing. The interleaving of the wrap and thermocouple wires made it impossible to unwrap without first cutting the wires.

3. Insulation Removal and Inspection

This build used new MinK block insulation. The assembly and disassembly was very easy. A careful inspection of the MinK blocks showed no deposits or discolorations. One oil stain, which was there when the unit was assembled, remained.

The foil insulation removal was begun at 1029. There was no hydrogen sulfide odor as was noticed in Station 1 disassemblies. The top photo of Figure 5 shows a general view of the disassembly at this stage. Note the very clean appearance of the foils and housing interior. Approximately 15 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. The deposit on the bottom of the heavy foil is shown in Figure 5A. At $\sim$ 20 layers below the central plate, the foils became less ductile and the edges where overlapped began to weld. The three

TABLE 4

Module Resistances at Disassembly⁽²⁾

Module	Resist at Installation	Resist after Test	Resist after Wires Cut	Module after Cut		Cut Module Wires	
	Module + to -	Module + to -	Module + to -	+ to Gnd	- to Gnd	+ to Gnd	- to Gnd
	Ω	Ω	Ω	Ω	Ω	Ω	Ω
1	82	291	579	420K	420K	81K	∞
2	24	232	420	504K	252K	840K	∞
3	41	119	175	∞	∞	∞	126K
4	10	314	438	∞	∞	∞	∞
5	9.7	(1)	(1)	(1)	(1)	∞	126K
6	9.8	9.2	12.1	∞	126K	∞	∞
7	42	89.6	157	4.3K	50K	504K	∞
8	111	.6 ⁽²⁾	121	77K	32K	∞	∞

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

(2) External (to multicouple) short. Removed when wires cut.

(3) All measurements at room temperature.

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Figure 5. Top View of Partially Disassembled Module

Figure 5A. Deposit on Heavy Foil

Figure 5B. Deposit on Interleaved Foil

or four foils closest to the heater were brittle at the edges and welded together. The remainder of the foil was bright. A detail of this overlap region is shown in Figure 5B.

4. Heater Removal and Inspection

The heater top surface was exposed at 10:48 A. M. The external surface was as it was at installation. Removal of the cover showed no grayish-white deposit around the top edges of the box and/or the inside of the top cover as was found in the Station 1 disassembly. Photographs of these components are shown in Figures 6 and 7.

A test of the heater wire showed good ductility. There is no evidence that the internal atmosphere has caused a problem in the heater. The heater was set aside and the multicouple removal was begun.

Figure 6. Heater Box

Figure 7. Heater Box Cover

5. Multicouple Removal and Inspection

The first thing of note on observing the multicouples was the lack of extreme distortion of the heat collectors that occurred in Station 1.

All heat collectors were firmly attached to their multicouples. All were 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 1120. The following paragraphs describe the multicouples as they were removed and given their first inspection.

a. Multicouple 1. The cold stud now required 5 in-lb. torque to remove. There was no evidence of coining of the housing. There was some evidence that foil was trapped between the cold stud and the housing. There was slight 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.

This multicouple was essentially intact; however, the cold end hardware was loose and hanging on the power leads. A grey deposit was noted near the cold end of the wrap. There was no hydrogen sulfide smell coming from the cleaved end of the multicouple as had been the case with the Station 1 multicouple. A black deposit was noted on the foils opposite the deposit on the wrap. The power lead ceramics were removed and the cold end hardware was lifted off at the power leads. A very light deposit showing colorful interference rings was noted. This interface is much cleaner than anything seen in Station 1.

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

b. Multicouple 2. The cold stud nut required < 5 in-lb. but > 4 in-lb. torque to loosen. Removal was routine. The module entered the foil basket. There was no evidence of coining of the aluminum housing. The white deposit was observed on the housing and there was a grey deposit on the foils opposite that on the wrap.

This multicouple remained nominally intact and showed no outward sign of distress. The foil again appears to be trapped between the cold end hardware and the housing.

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

Figure 8. Multicouple 1

Figure 9. Multicouple 1

Figure 10. Multicouple 2

Figure 11. Multicouple 2

c. Multicouple 3. The cold stud nut required <5 inch-pounds of torque to break away.

The white and gray 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. Again, there is evidence of trapped foils at the weld end.

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 required 5 in-lb. to loosen. The cold shoe break is entirely in the glass bond. This is an

Figure 12. Multicouple 3

Figure 13. Multicouple 3

Figure 14. Multicouple 4

Figure 15. Multicouple 4

old break. The power leads are eaten away as were multicouples 4 and 5 in Station 1. There is a heavy black deposit on these lead but the glass is relatively clean.

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 aluminum housing. The module was removed intact. It showed no visible sign of distress although the outpower was obviously cycling during operation. The usual black and white deposits were found on the foils and the housing. No evidence of trapped foils, however, there was no evidence that there was any seating pressure at all.

Multicouple 6 is shown photographically in Figures 18 and 19.

g. Multicouple 7. The stud nut of this multicouple required 5 in. lb. to loosen. There was no evidence of coining of the aluminum housing. This multicouple appears intact.

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 required <5 in lb. torque to loosen. There was no evidence of coining of the aluminum housing. This multicouple

Figure 16. Multicouple 5

Figure 17. Multicouple 5

Figure 18. Multicoupler 6

Figure 19. Multicoupler 6

Figure 20. Multicouple 7

Figure 21. Multicouple 7

appears to be intact. The usual deposits were observed on the wrap, foil and housing.

Inspection of the hot end of this multicouple shows very poor welding and flow of the heat collector glass wafer. The edges of the hot shoes are exposed on the side which shows a "16" in pencil. A look into the cavity between the shoes is available. The intra-shoe glass is very porous. It has not flowed well and may have continuous void paths between shoes. What is visible is very disturbing. A check of resistance between the shoes and the heat collector shows 500 K Ω . It is not possible to determine if this continuity is due to plating of hot shoe material than the glass voids. This specimen should be sectioned and studied metallographically since there is clearly something similar going on here.

Multicouple 8 is shown photographically in Figures 22 and 23.

Figure 22. Multicouple 8

Figure 23. Multicouple 8

B. Macro Examination Conclusions

The pertinent conclusions from the initial macro examination of the Station 2 multicouples are presented below.

1. The instrumentation was in better shape than the Station 1 builds. Only Multicouple 6 hot junction thermocouple bead appeared damaged.
2. The internals of the Station 2 housing were cleaner than Station 1. There was no H_2S smell and fewer black deposits.
3. The insulation foils were very clean, but were welded together in the overlap region. It is not clear if this was diffusion bonding or an attack caused by an outgassing constituent. This area should be examined metallographically.
4. The Station 2 multicouples showed less physical damage than those of Station 1. Four multicouples were visibly cracked and four were apparently intact. Only one cold assembly was sheared off (Multicouple 5). The break was entirely in the bond between the cold assembly and the glass.
5. The cold assemblies were removed from Multicouples 1, 3, and 4 by slipping them over the wires. Inspection of the exposed surface showed fewer deposits on the cold side of the break than was typical in Station 1.
6. The deposits on the hot side of the break are more noticeable in this build than they were in Station 1.
7. The leg to leg isolation is much lower in these multicouples than it was in Station 1. Typical values of 500 Ω were

recorded for all Station 2 multicouples. This is a most unsettling development. Great care must be taken to explain this change in leg isolation with time at temperature.

8. The hot bond is much more ragged in this build than it was in Station 1. Hot shoes appear to have line of sight of each other. The intra-shoe glass is very porous. The low leg isolation resistance may be due to this poor hot bond.
9. There is continuity between the hot shoes and the heat collector on 3 of the 8 multicouples. This is not good and its cause must be determined. It may be simply the result of the porous glass at the hot end. This would be the least damaging cause. Significant effort to establish the cause of the loss of heat collector isolation should be undertaken, since this is a feasibility issue.
10. The isolation resistances are ohmic. Meter lead polarity change produces no change in the measured value of resistance.

III. VISUAL EXAMINATION OF MULTICOUPLES FROM STATION 2 BUILD 1

I shall examine the multicouples that have broken into two pieces first as they yielded most information in Station 1.

Separated 1 - 3 - 4 - 5

Not Separated 2 - 6 - 7 - 8

Some of the separated couples required trimming the power leads and slipping the cold stud off - in all cases, the fracture was complete.

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

A. Multicouple 1

Fracture - primarily through the SiGe except for 2 corners.

Cold End - Brilliant interference colors over entire fracture surface except 1 corner (W/plate?) and 1 leg (SiGe)--Glass - cold bond fillet mostly pale blue-green - external clad - mostly white and vitreous but appearance of lt. brown discolored coming from legs; egg crate - dark (brown?) appears cracked in several places - cracks probably glass to Si/Ge interface (does not resolve in microscope well). One corner shows all structures broken away down to W cold stud surface, parts of 3 legs.

Power Lead - one empty hole, one wire in cold stud - pulled cleanly out of SiGe leg, shows all of 180° bend over - not badly chewed up as #2 station 1 - has grayish crystalline surface - no evidence of fracturing from SiGe - think unbonded.

Hot End - Shall use same notation to identify sides, i.e.:

- * Fracture Surface - generally bright and metallic - fractured corner is 2-3. Fracture surface shows curious spherical button from central wires toward 2-3 corner, approximately 2 legs diameter - hollow on hot end, bump on cold end - possibly suggestion of break initiating at wires??

Glass - outer coat - as on cold end although a bit darker - a bit more impurity in it?? Egg crate - quite dark - Marshall tried scraping at e.c glass to isolate a corner leg - says glass crumbled - says deposit on top of glass. Dug down several mils into glass but did not isolate electrically - I tried scraping neighboring e-c glass - did not find it crumbly or easy to dig out. Power lead - remaining lead shows no evidence of attack - fracture of glass around lead shows distinct copper-colored deposit over 1/2 of glass - possible shunt??

Side 1 - glass coat uniformly olive-drab color - two large chips out, exposing Si/Ge. Hot end bond cover glass sound. Some suggestion of crack

between W and bonding glass - not sure it penetrates.

Side 2 - glass coat sound - uniform dark color except white band at cold end - glass cover at hot end loose, broken in spots, 2 small round flaws - suggestion of peripheral crack, W to bonding glass.

Side 3 - coat like side 2, except for chip knocked out by Marshall - hot end bond - suggestion of crack W to bonding glass - also bonding glass appears to wet multicouple poorly - think a bad hot end bond - may be functional.

Side 4 - glass coat uniform dark color - one large oval chip, penetrating, as side 1 - one smaller flaw nearby, hot end glass coat generally good - questionable very thin crack - trivial; W to bonding glass joint dubious - clearly see separation over most of side - can see down in a little way - think probably a marginal but functional bond to heat collector.

Should be examined in section.

* Fracture Surface Revisited - by naked eye, room light, can see P-N checkerboard pattern over half of fracture surface.

B. Multicouple 3

Cold End

Fracture Surface - Mostly through SiGe except for 3 corners as before. Corner fracture seems below W plate in glass bond - black deposits in corners,

heavy in 2 moderate in 1. Rest of fracture shows brilliant refraction colors as before. Si/Ge layer seems quite thin, flat in this case - also has a round shaped bump touching wire hole as in Couple 1, but not so high (deep). Power leads - both gone from cold end but edges of holes show evidence of a corrosive-erosive reaction. Glass cold end bonding fillet generally gone - residual surface generally blackish. Outer glass clad - where not messed up shows whitish central zone, approximately .001" darker penetration from both sides; egg crate glass dark - see no cracks.

Hot End - Hot end - Hot end T/C broke off - into box. Fracture surface bright metallic looking - corners 1-2 and 3-4 broke above and below W plate; "spherical" depression same size, location as in couple 1 - but less deep. P-N checkerboard not visible as in #1. Power leads both in SiGe. Wire appears sound but holes in SiGe appear filled with clinker-like reaction product, not a nice braze - Glass clad coat and egg crate generally dark in color. Egg crate appears sound.

Side 1 - Glass coat sound, uniform olive-drab color - hot end glass coat has some shrinkage flaws - seems like a relatively deep crevice between W and hot bond glass.

Side 2 - Glass coat sound, uniform O-D color hot end coat sound. W to hot bond glass has slight crevasse over part of side.

Side 3 - Glass coat sound, uniform O-D color except chip out exposing SiGe, cold end-2 corner - hot end coat sound half way, big cracks one end. W bond pretty good except bond glass not wetting couple glass well.

Side 4 - glass coat OK, O-D color, one small round flaw - hot end coat has shrinkage cracks - W-glass bond pretty good except one end.

C. Multicouple 4

Cold End

Fracture Surface - messy - seems to be in Si/Ge, very shallow, in 15 legs, at W stud to glass bond in a 12 leg area, under W plate most of the rest. Surface generally dirty looking - egg crate glass looks very thick - must be at very bottom of SiGe. Some brown, some yellow, no refraction colors as before. Power leads both in other end - holes only here - residual glass in holes looks OK. Edge glass generally quite dark - not in usual pattern. Crack too close to cold stud to show familiar structure.

Hot End - fracture surface confirms earlier notes; 10 or so W connectors visible. Only 7 legs are cleanly fractured - no colors - seem metallic. Can't observe glass well - 2 places looks like egg crate bond cracking. Power leads - broken - corroded - reacted off at the fracture plane. Can't see much except holes in SiGe are full and no clean wire fracture shows -

Side 1 - glass coat has large flaw at hot end - looks like something collapsed underneath; color O-D except white band at cold end - hot end coat is badly cracked and opened - questionable bond W to bonding glass - seems cracked over a half of side.

Side 2 - Glass coat sound, uniform olive drab color - hot end coat has a bad sink-hole, one end. Bond to W looks pretty good.

Side 3 - Glass coat sound, uniform olive drab color; hot end coat sound; bond to W pretty good except one end, glass to glass not wetting - shows crevasse.

Side 4 - Glass coat one round flaw, cold-1 corner-color uniform, olive drab color except white band cold end - hot end coat, one big shrinkage crack - W to bonding glass poor joint, shows deep crevice over entire length.

D. Multicouple 5

Cold End

Fracture Surface - fracture is entirely at the plane between the W stud and the cold end glass band. - W surface is generally blackened but shows a small stain, semicircular - kind of copper-colored, middle of one side - also, some other edge stains, etc. Could be fracture site but doesn't really look that way - nothing of power leads shows except clean hole.

Hot End

Surface of glass bond is smooth, gray color, no chips, cracks, except one section of edge fillet - suggests non-adherent bond that separated clearly - glass did not wet W.

Power leads - corroded - reacted through at fracture plane - no clean fracture surface of wire showing - holes in SiGe all full of "clinker" - not a nice braze. Nothing much to see.

Side 1 - glass clad uniform, olive drab color w. small white band at cold end. Sound except one small round defect - hot bond coat shows several large shrinkage cracks - glass to W bond not wet at edge -

Side 2 - Glass coat uniform OD - sound except very thick crack one corner - trivial. Hot bond coat not bad - bond to W is interesting - glass fillet mostly broken off - bond under thermopile looks OK - others may be similar, i.e., lack of wetting confined to fillet.

Side 3 - Glass clad sound, uniform olive drab color, hot bond clad not bad but not touching glass clad - W to glass bond - glass fillet lifted way up.

Side 4 - glass clad uniform olive drab, one round defect - hot bond cover, some shrinkage, one area looks bad - like unbond to thermopile. Only one like this I've seen so far - think I see hot connector down inside, think it may not be bonded - W to glass bond - separation of fillet.

Summary on fracture surface -

#5 looks like poor bond to cold stud - all others are similar to station 1 breaks - suggest no unique surface of weakness - fracture surface partly in Si/Ge, partly in several different interfaces in the glass - strange bump in fracture surface in #1 and 3 is curious and provocative - don't know what it means.

Now looking at the four that did not separate.

E. Multicouple 2

Side 1 - Glass clad sound and uniform - olive drab color at cold end - crack in glass close to end - runs all along just up the leg from fillet. Guess it penetrates the glass clad at least. Hot end clad pretty good - bond to W heat collector looks good - no fillet waving about - glass down into square recess, fillet looks bonded to W.

Side 2 - glass clad - uniform olive drab color except light band near cold end - thin crack, parallel to heat collector near middle of legs - seems trivial - At cold end bonding fillet is copper colored - no crack in glass clad - BUT - crack in surface between glass fillet and cold stud, about half length of side - hot bond coat has several big shrinkage cracks - looks bad - can see way down inside two cracks - big void - not good: W to glass at hot end looks good like side 1.

Side 3 - Glass clad olive drab color mostly but band of white glass at cold end. The midplane crack from Side 2 comes around the corner. - At cold end - no crack in glass clad - glass fillet lightly copper colored. Definite crack at interface of glass bond to stud - extends approximately 1/3 side - not connected to similar crack side 2 - hot end bond cover pretty good - W to glass bond looks good - BUT - glass to thermopile bond poor in one corner.

Side 4 - Glass clad mostly sound, uniform olive drab, but one round flaw - At cold end, no crack in glass clad - but crack at glass - stud

interface noted on side 3 comes around corner, proceeds halfway up side then passes up through the fillet. At hot end, generally sound except for 3 black spots on hot bond cover glass - also some shrinkage flaws.

F. Multicouple 6

Side 1 - Glass clad sound - few dark stripes 1 legs. At cold end glass fillet is small but very copper colored - no visible cracks. Hot end, bond coating is separated from thermopile over 1/2 length w, deep crevice. W to glass bond strange. For 1/2 length glass fillet not bonded to W, other half well bonded to W but not bonded to thermopile - deep crevice.

Side 2 - Glass clad has 5 dark stripes and legs - 3 thin cracks // legs - 1 small round flaw - cold end - fillet again small, copper colored. Hot end - bond cover has bad shrinkage holes - one Si conductor clearly visible. W to glass bond in fillet is bad - fillet is lifted and segmental.

Side 3 - Glass clad - lots of dark stripes, one thin crack, one small round flaw - Cold end glass fillet small, copper colored - one small crack at 3-2 corner between fillet and stud - approximately 20% of length - no other cracks visible. Hot end - bond cover glass very bad - 2 Si shoes fully exposed, seem to be adequately bonded to legs - pbly not functionally harmful - W to glass bond in fillet marginal - fillet not lifted but appears not wetting well.

Side 4 - Glass clad - some stripes - 3 round flaws - deep - pbly penetrate - two thin crack // legs Cold end - glass fillet small, copper colored - not wetting

on half of side - no cracks visible hot end - bond cover glass fair - W to glass bond fillet lifted - nonwet.

G. Multicouple 7

Cold end stud badly mislocated - displaced in 3+1 direction by full width of overhang.

Side 1 - Glass clad uniform olive drab - 2 thin cracks // to legs, 2 small chips, non-penetrating. Cold end - can't see well due to overhang - no glass fillet, no visible cracks. Hot end - looks good - bond cover glass sound except for small crack - trivial - W to glass bond looks sound.

Side 2 - Glass clad uniform olive drab color but one moderate 4 small round flaws and many thin cracks, irregular pattern. Cold end - no glass fillet - crack runs full length right at cold stud surface - hot end looks good - bond cover glass is sound - has large black stain, W to glass bond looks good - fillet wets.

Side 3 - Glass clad has a few stripes, one moderate one small round flaw and a thin crack. Cold end - stud is pushed off just past edge of thermopile small bonding fillet. Crack starts at stud surface in one corner, proceeds a little into glass clad, proceeds in long flat arc back to stud surface - covers most of length - hot end - bonds look good - like Side 2.

Side 4 - Glass clad - slightly mottled color, one moderate round flaw, no cracks. Cold end - small fillet - no visible cracks - hot end bond cover glass

good - W to glass bond shows fillet not wetting - glass to thermopile shows non-wetting crevice.

H. Multicouple 8

Cold stud is mis-oriented - slot does not line up with T/C. Heat collector unusually clean.

Side 1 - Glass clad uniform olive drab color - except:

curious effect associated with crack (1) - glass to cold side of crack is quite white except for a few black stains (different from olive drab color) that appear to be coming through the crack - crack 2 is normal - uniform olive drab color all around. Hot end - bond cover glass badly separated; parts of 3 Si shoes visible - shoe bond seems OK - W to glass bond shows moderate lifting of fillet from W. Cold end again - small green fillet - no cracks visible except #1.

Side 2 - Glass clad uniform olive drab color, sound except one thin circular crack. Cold end - small green glass fillet - crack in glass clad starts at stud in corners, proceeds in flat arc, corner to corner - 0.020" $\pm$ max height of arc - hot end - bond cover glass has shrinkage holes - poor. W to glass bond - as in Side 1.

Side 3 - Glass clad uniform olive drab color - some thin cracks - one chip flaw at corner cold end - small green fillet - long crack in glass clad in flat arc as Side 2. Hot end shrinkage, fillet as Side 2.

Side 4 - Crack in Side 1 that blocked the olive drab color - comes around the corner - does the same thing - crack also alters the color - Although not so extremely. Glass looks different on both sides of crack; no suggestion of something coming through the crack.

One moderate size round flaw. Hot end - as before - shrinkage not bad. W-glass fillet lifting a bit.

CONCLUSIONS

1. Station 2 not different than station 1 - some modules differ in details - generally less blackening inside and out - but nothing really mechanistically different.
2. Station 2 modules scrutinized more carefully as I had a better idea of what to look for - I did not scrutinize the heat collector bonds very well for Station 1. Looked more carefully now since G.E. reported cracks.
3. Four couples separated, four did not. But the four that did not separate all show some degree of cracking at the cold end. All four of these are still bonded - no movement of the cold stud occurs -

MOST IMPORTANT - THESE 4 COUPLES CAN SHOW US WHERE THE FRACTURE STARTS - THEY ARE ALL PARTIALLY FRACTURED - SHOULD BE POTTED AND SECTIONED WITH CARE AND UNDERSTANDING.

4. Bonding of the heat collector seems a bit variable and perhaps marginal, based on appearances of glass fillets - strong enough since more of the 16 broke - but should be examined internally - intermittent bonding would introduce a thermal impedance.
5. Note comments on fracture surface following notes on couple 5.
6. Curious crack on couple 8, with its effect on glass clad discoloration should be examined carefully - it should throw light on where the glass discoloration comes from - which may be related to shunt resistance.
7. The braze used to install the power leads is again indicated to be unacceptable - it has resulted in one case of non-bonding and several of melting off of the power leads.

APPENDIX A

Transcription of Tape Made
During MITG Module Disassembly

A. STATION 2 DISASSEMBLY TAPE TRANSCRIPTION

This is a record of the disassembly of MITG Test Station 2. The system has been backfilled with dry nitrogen and the filling is complete at 9:56 A. M. on Tuesday, November 9, 1982. We are preparing to remove the ionization gauge. The bag is being flooded with dry nitrogen and we will then remove the gauge and plug the hole with another gauge. 9:59: The ionization gauge has been removed and bagged. The smell in the tube is not nearly as rank as it was in the other disassembly. It should be noted that the pumps have been running on this system for another month. It's possible that the volatile deposit has been evaporated during the time since the disassembly of unit one. 10:10 A. M.: We are beginning to take the cover off the vacuum station. We are going to put some of the Mink into a plastic bag to make sure that it isn't contaminated by the atmosphere. We will then have some of it in case we have to go back to see what is in the Mink. 10:11 A. M.: The top has been removed. I am taking the top blocks of Mink and putting those into a plastic bag, removing the one thin cover, and the back flat plate. The Mink is being removed now. The general appearance of the unit is extremely clean. There is no indication of any deposit on any of the Mink. The discoloration that is on the top blocks of the Mink was there when it was installed. It is residual oil. There is no indication of any problem at this level of disassembly. There is a small chip of Mink insulation in the Number 3 Module wiring. It does not seem to have caused any problem. The wiring looks very clean. There's no obvious problem. I am now going to check for short circuits which we determined existed on Module 8. We are looking at Module 8. The power wires are touching at the heavy wire. A whisker from one of the power wires is touching

the other 16 gauge wire that is the source of the short circuit on Module 8. I am going to remove the short circuit on Module 8. That is done. I am going to check and see what we have as a resistance on the automatic data logger. The data logger shows that the resistance on Module 8 is 73 ohms, which is not a terrible resistance in relation to the other ones. There is a possibility that Module 8 may be in better shape than the data indicates because of the short that occurred on its power wiring. Close inspection of Modules 4 and 5 show that the wiring, up to that point, is continuous. The internal wiring between the 16 gauge wires and the terminal strips is intact, showing continuity. The open that the modules are reading is apparently on the module side.

Inspection of the individual module wiring shows everything in very good order. There is some slight discoloration on the thermocouple and power feedthrough ceramics. This seems to be trivial. It is localized. It appears to be something bleeding out of the surface of the ceramic.

10:29 A. M.: We are beginning the disassembly of the foil insulation pack. The foils look extremely clean. The system is very clean internally. There is no indication of anything floating around. There are no deposits anyplace on the exterior surface of the module or the interior surface of the vacuum chamber. There is a slight discoloration on the outgassing tube. This tube was stainless steel. It was operated quite hot and that's not surprising. The discoloration disappears as you go into the foil pack.

10:36 A. M.: The tube has been removed. There is no deposit at the interface of the heavy foil as there was in Unit 1. The foil is extremely clean at

this level. The bore of the hole does not have the black deposit that at this level was very apparent in Station 1. In general, the insulation is much cleaner in this build than it is in Station 1. The bore looking down into the insulation pack seems to have some slight discoloration right at the last two or three layers, but the majority of the bore is clean and bright. 10:40 A. M.: We are down to the level of the discolored foils in the other build, but there is no discoloration showing in this build. We are about 20 foils below the heavy foil. We are beginning to get a discoloration around the edges of the foils in the overlapped area only at about 22 foils below the heavy plate. The center part of that foil is clean. The edges show a discoloration. We are photographing the discoloration on this foil. As we get below this location the discoloration seems to go away. This is probably a deposit that preferentially deposited as it was going out through the conductance path of the foil itself, found a convenient condensing temperature, and dropped out. At this level the foils are beginning to get brittle at the edges in the areas that were discolored on the previous foils. They seem to be somewhat embrittled. This is different than what we observed in Build 1. At four layers deeper, the embrittlement and the discoloration around the edges is completely gone. My guess is that we are looking at chemical attack of a deposit which is reacting with the moly at this intermediate level. 10:46 A. M.: We are down at the bottom level of the disassembly. We are beginning to remove the heavy plate. The bottom two or three foils were welded together and stuck to the folded over foils. A preliminary look at the heat collector shows that everything is in place. The heat collectors are not nearly as curled in this build as they were in the previous build.

We are beginning to remove the cover from the heater. There is nothing of any real note inside. The inside of the system looks extremely clean and bright. There is no evidence of any deposit. There is a slight discoloration on the edges of the heater cover. There is a hint of a deposit on the inside of the graphite. It is nothing like as severe as in the previous build. It seems to have interference fringes. It's very thin. This build probably benefited significantly from having had the heater and the carbon block baked to a higher temperature.

10:50 A. M.: The heater wire is ductile. It bends 180° with no problem. It can be re-bent. There appears to have been a very good atmosphere inside the heater box. The lack of deposit inside of the heater box may be due to the fact that the heater box was vented with four 1/4 inch holes. The deposit that is showing up on the foils has a whitish appearance and we simply may have boiled that out into the insulation in this build as opposed to the previous one. The internals of the unit are extremely clean and bright. There is no evidence of any deposit. The heat collectors are not curling. The edges of some of the heat collectors show some distress, but that's the way they were when they were installed. There is nothing unique or sinister in the appearance of any of the surfaces. They are very clean, very bright, and show no evidence of attack.

Module 1 hot junction thermocouple is intact. the Saureisen is intact. It appears to be a good bond. Module 2 also appears to be intact. The Saureisen is in place. Module 3 Saureisen is in place. Module 4 Saureisen

is in place. There is no evidence of any problem with the hot junction thermocouple. Module 5 Saureisen is in place and the hot junction thermocouple looks good. Module 6 does not seem to have the Saureisen in place. There is no evidence of the Saureisen or the bead of the thermocouple on Module 6. Module 7 shows no evidence of the bead or the Saureisen. Module 8 shows the Saureisen in place. The bead is apparently alright. The heater thermocouples show slightly different end conditions. The Saureisen appears to be off of heater thermocouple 46.

Examination of the heavy plate on the underside shows the discoloration in the foil area where it was folded over in the same manner as the edges of the foils where they were folded over. There is a very light deposit inside the bore of the tube at the hot end. The cold end bore is clean. There is no indication there that whatever that deposit was was deeply into the bore of the tube as it was in the previous Station 1 build.

We are cutting the power wires to the Number 1 Module in preparation to its removal.

Module 5 power wire was loose inside the module. When the wire was cut, it came out.

Module 4. The cold shoe separated from the module in extraction or it hung up in the foils. The break in the cold shoe appears to be entirely through the glass and some of the glass exposes the shoes at the cold end. Some of the parting in the glass is between the glass and the tungsten. There

is no evidence of cracking inside of the module itself.

This is an inspection of the insulation foil pack after the removal of the modules.

Module 1

The foil beneath the Module 1 heat collector is somewhat discolored by a white deposit. The foils inside the pathway to the housing are bright for the most part but at levels they seem to have a white deposit perhaps 20 foils in from the hot side. The cold shoe is clearly against a foil and not against the housing. The cold stud would have been trapped with the foil between it and the housing. You can see a piece of foil setting there and the imprint of the stud on it. I have removed the internal foil from the 1-2 face and there is a white deposit one layer deep, which does not look particularly sinister. The general condition of these foils is somewhat more brittle than the foils in Unit 1.

Module 2

There is a white deposit at the base of the right side of the insulation similar to those that were observed in Unit 1. In general, that deposit is not as heavy and there does not seem to be any mark on the aluminum housing. I believe that the insulation was between this stud and the housing, as it was in the case of Module 1, although it isn't nearly as clear-cut an indication this time.

Module 3

This module opening looks exactly like the Module 1 and 2 opening. There is a clear indication that the cold stud was against the foil rather than against the aluminum housing.

Module 4

This module looks like the previous ones. It's impossible to tell whether the module is properly seated.

Module 5

There is a deposit at the base of this module which is different from the others. It has a reddish color. This is the module which had the cold end broken off. This is the only module in which a shoe was separated from the silicon germanium pile. My suspicion here is that we are looking at a deposit of silver from the aluminum-silver braze. Although it is not possible to say that with certainty, it's definitely a different color in this hole than it is in the others.

Module 6

This hole is extremely clean. There is no indication of any problem. There are no indications of coining or any marks whatsoever in the housing.

It doesn't look like it was very well seated. However, it doesn't seem like it was touching the foils or held up by the foils either. It is difficult to see the upper edges. You can only see the two vertical sides of the hole and the lower edge because of the geometry.

Module 7

This module appears like all the others except 5. The hole is quite clean. There are no deposits throughout its length. I see nothing here to be in any way alarmed about.

Module 8

Module 8 shows the same as all but 5. There is no great deposit. There is no deposit at all, as a matter of fact. There are no indications that there was any pressure on the seat in the aluminum. I believe that it was bottomed on the insulation rather than on the aluminum, but I can't say that with any certainty.

Conclusions

I would conclude from the first inspection of the Station 2 that the instrumentation is in very good order. The general impression is of an extremely clean generator interior. The foils look very good and bright. There is much less deposit inside of this unit than there was in Unit 1. My general impression is that there is nothing going on that is in any way

a problem, although that does not speak to what's happening within the modules themselves. Four of the individual modules have separated from their cold shoes; four are still intact.

Inspection of the Modules after Removal

Module 1

The power leads are still attached to Module 1. The indication is that it is broken in the cold bond and the silicon germanium. Inspection of the hot shoe area shows no cracks, nothing particularly sinister. The thermocouple has a slight discoloration and it appears that the wires have been broken in the disassembly. One wire is still in the Saureisen, still attached to the heat collector. The other wire is broken below where the bead was, and I believe this was broken in the disassembly. There is a separation at the hot shoe on the side that the thermocouple was attached. It does not appear to me that this occurred as a result of the operation since the separation appears to be fused. There are indications of chips coming out of the side of the glass. The chips appear to run down to the silicon germanium. They look like voids rather than cookie cutters. The sides are sloped. They are on two sides of the unit. The one side clearly does not run down as far as the material. The number 13 is written on the side of this module, and it is still white at the base in the color of the original glass where it was heavily under the wrap. There is a slight discoloration throughout the body of the glass. I don't see anything that looks sinister about this excepting the blow holes that are in the glass

which are obviously manufacturing problems and, of course, the cold stud being broken away.

Module 2

The hot junction thermocouple was not on Module 2 when I made the inspection. In general, the heat collectors in this run are much less curled, although they are curled. They are much less curled than they were in Station 1. The cold stud is attached rigidly. The bond has survived, and the power leads are intact. A slight tugging on them causes no motion. The cold end seems to be in good shape. This module was not a particularly good module. I am inspecting it in detail, but I see nothing unusual about it. It looks like it did when it went in. There is a slight discoloration to the surface of the module. There are small blow holes at the hot side where the mold was not completely filled, due to the mount on which this was prepared. There are no cracks or crevices at the hot end. I have now looked at all the sides. There is one small surface defect at the side cover of the glass. There is considerably less discoloration to this sample than there was in the Station 1 samples. The general appearance of this module is quite good, although its performance was quite poor. It's not clear why we aren't getting any output from it from just the appearance of the bond at the cold end. It seems to be intact. This module is marked Number 10. The surface of the glass is very, very clean in one location. It's quite white, has a slight tan color to it, and is extremely clean. It looks very pretty there. There may be a slight

crack at the cold end on the surface that's marked 10. It should be noted that the cold shoe of this module is somewhat off center, so that the stud is not centered on the module at all. It's offset toward the face that has the thermocouple hole. I think I see what is wrong with why this does not have a thermocouple. The cold side is not bonded over the location that has the hole. The slot for the thermocouple is 90° out of position. It would certainly lead to a strange behavior of the thermocouple wires, since there was no convenient way that they could get around the cold stud. I am impressed with the extreme cleanliness of the exterior of this module. Throughout its entire length the cold stud, the cold shoe, it is just a very, very clean module. There is no indication of any distress at all. Yet, it has essentially zero output. Whatever damaged area is internal to the parts that we are observing here.

Module 3

This module's cold stud is separated from the thermopile. It is not completely separated because the power wires are still attached and are holding the cold stud in place. I have diked off the power leads and removed the ceramics of this module so that I could expose the cold side. The break is through the thermoelectric material. The shoes are not visible. The cold side of this break is quite pretty. It has interference fringes with a very light deposit. Not a very high mag is required. It is very interesting in that the corners of the cold stud are clearly the ones that were broken for the longest length of time. The very edge of the cold stud has a thick deposit on two legs. The other legs are quite bright and very pretty

interference fringes. There is very little deposit on the cold surface. There is essentially no deposit on the hot surface. The hot side in the corner has failed first. The deposit is essentially on the cold side in two areas. Actually, in all four corners there is some indication that there was a deposit there that has been there for some time. The majority of this surface, however, is clean and bright like it's a new failure, like perhaps it was cracked at the edges but broken off when it was removed. In general, the fracture pattern shows very little, if any, deposit - just some interference fringes and a rather lovely set of colors.

The braze to the power leads is black in color but much less deterioration than we have seen in the other systems. Both power leads are well bonded at this time. There is no indication that there is infusion into the silicon germanium by the braze. However, there is a general unhealthy look in terms of surface deposit around the braze. One of the elements is more reacted than the other. The nickel wires are quite ductile. There doesn't seem to be any embrittlement in the wires by the braze. I am bending them rather vigorously, and there is no problem with them. All in all, a very interesting failure. There does not appear to be much reaction. The surface of the silicon germanium elements is quite smooth. The granular appearance is quite good. The grid structure is quite regular. The glass thickness does not seem to be nearly as variable as it was in the Module 1 builds. This seems to be a much better job of manufacturing than we saw in the Station 1 builds.

Module 4

This is another one that is quite lovely. The break is in all three zones, through the shoes, through the elements, and in the glass bond. It is difficult to see a pattern. There is very little discoloration of the surface. The surface seems to be relatively deposit free, although it seems like a fairly large amount of it was exposed. The interference rings grow in from the outside and increase in deposit thickness, I would guess, from the inside out. That is, there is an infusion from the outside in from the way that these rings are deposited. This is definitely different than what we saw in the Station 1 disassembly. I would say that this module was considerably cleaner than the module in Station 1 in that the individual multicouples are definitely cleaner in the disassembly. It seems like the cracks were not as gross. Although they were through everything the parting was not sufficiently severe to allow any infusion, or perhaps there was just simply less trash in the glasses in the elements themselves. These elements look really quite good. Most of the break in this element is between the glass and the tungsten. Some of it is between the glass and the cold stud, but most of it is between the cold shoe and the glass. Six of the elements are separated in the silicon germanium. The studs are broken off there. There is very, very little indication of anything going on from the hot shoe. This may be why the cold end looks better, because there's nothing to come across and deposit from the hot end. It's sealed by the bond to the tungsten. It's an altogether lovely sight. The glass is quite white, quite clean in the breaks. There is no evidence of any

diffusion or plating of anything on the surface of the glass. It is really too bad that this broke since it looks like we would have had a very good module here if the cold end had hung together.

Module 5

The resistance pull of Module 5 is very unsettling. The resistance is on the order of 100 ohms between any two elements. The resistance of an individual P-N couple is about 5 ohms. Resistance of any other place on the hot side of the break is about 100 ohms. The resistance between the two power leads of Module 4 is approximately 200 ohms. These resistances are far lower than were observed in the Build 1 case. Resistance of the cold side of Module 4 to any point on the surface is not measurable - would have to be more than several megohms. This, again, is considerably different from what was observed in Station No. 1 in that the hot and cold sides had thousands of ohms on both surfaces. The light coating on the surface of the cold shoes from these modules appears to be nonconductive. The cold shoe of Module No. 3 has some zones that are quite conductive, that do not, however, extend over the entire surface. It is not good news. The resistance that they are showing is relatively low in those areas which are conducting, although the entire system is not conducting. Going back to Module 4, there are a number of zones here which appear to be conductive also, although it's not a general distribution across the element as it was in the Station 1 modules.

Reexamination of Module 1

The module is showing continuity from any point on the cold surface on the hot side of the break to any other part of the hot side of the break on the order of 1000 ohms. In addition, it is showing continuity to the heat collector on the order of 400,000 ohms. This is a clear indication of diffusion through the glass of one of the components of this material. This is a feasibility issue and is extremely disturbing. Close examination of the cold shoe of Module No. 1 shows that there is a granular deposit covering the glass and making a continuous pathway across the various glass interfaces. This is probably what is causing the continuity. It is to be expected on the cold side, but I find it extremely disturbing on the hot side. Continuity from the hot side of the break to the hot shoe on Module 1 is 300,000 ohms. Continuity between any two elements is about 1000 ohms. There is no continuity between the peripheral glass of the module and either the heat collector or the cold side of the break.