SELECTIVE INFRARED SOLDERING - A TWO PART INVESTIGATION

BY

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Introduction

This paper is the result of a two phase process development investigation to develop a method for soldering selective areas of a Printed Wiring Assembly (PWA) without allowing remaining areas to reach reflow temperatures. The investigation was targeted towards developing a process for soldering stacking connectors onto a Mark 50 torpedo PWA after the thru-hole components have been wave soldered to the Printed Wiring Board (PWB). Part I of the paper discusses the initial assumptions going into development along with a comparison of four possible reflow options. Part II talks about the final process development using Infrared Reflow and special shielding fixtures to select the areas of the PWA which will be reflowed. The process has been successfully transitioned from development to manufacturing on the Mark 50 program and is also being used and considered for use on several additional DOD programs.

PART I

Definition of Solder Joint

Based upon an investigation into DOD-STD-2000, WS-6536D, and MIL-STD-454J the ideal solder joint for a connector pin through a plated-through hole (PTH) is defined as follows:

Per DOD-STD-2000-1B para. 4.19.1, A plated-through hole used for lead or wire attachment shall be solder filled such that the solidified solder is not only continuous from one side of the printed wiring assembly to the other but also extends onto and covers the terminal areas on each side of the printed wiring assembly. Solder may be depressed on the component side of the lead attachment connection provided that wetting to both the lead and the terminal areas is acceptable. No depression of solder in a plated-through hole with a part lead shall exceed 10 percent of the hole depth as measured from the surface of the terminal area.

Per MIL-STD-454J figure 5-20, the solder may be recessed to a maximum of 25% of the board thickness, however, the concave fillet must wet the hole 360° at the upper edge. Pad coverage on the board surface should be 80% or greater with good wetting 360° around the hole. The surface of the solder should have a satin luster and freeze-line patterns (quilting) present and not be cracked, gritty, or granular in appearance (figure 5-21). There can be no voids present where it is not possible to see the bottom of the void (figure 5-23).

Per WS-6536E para. 3.4.5.3.2, the connector pin is considered a Type II component for mounting purposes. Visually, the angle formed by the solder to the basis metal at the periphery and intersecting points of the solder shall be no greater than 60 degrees (para. 3.5.5.1(c)) on the component side of the plated-through hole terminations.

Honeywell has identified that the solder fillet height on the stacking connector pin must be 0.040 inch maximum on the side opposite the connector body in order to eliminate interference with the next connector.

Materials Evaluation

Exposure of the connector to reflow temperature (>183°C) for 12 minutes in a vapor phase reflow soldering system using 3M FC-5312 fluid in the primary zone with a Freon TF secondary zone showed no degradation of the connector material or the markings on the connector body. Additional exposure of the connector to 9 runs in an IR oven (see profile in Appendix A for temperatures) also showed no degradation of the connector material or the markings on the connector body.

Submersion of the connector into the boiling (72°C) sump of a vapor degreaser containing Prelete (93% 1,1,1-Trichloroethane) solvent for 15 minutes showed no degradation of the connector material or the markings on the connector body under 40X optical evaluation.

Solder Processes

The connector cannot be wave soldered in order to prevent solder from covering the pins completely. We will make the assumption that the connector will be soldered to the PWB after the through-hole components are wave soldered. In order to prevent the through-hole components from undergoing a second reflow of their joints, the method of connector attach should only reflow the solder on the connector pins and the remainder of the PWB must remain below the reflow point of the solder (183°C).

Infrared Reflow Test Results

The infrared oven involves using an array of heater panels to deliver the required heat to the area where reflow is to occur. The infrared process uses a combination of infrared heating (40%) and convection (60%) to transfer the necessary thermal energy to the circuit card and connector pins where the solder preform has been placed. Due to the fact that the IR radiation can be shielded by using a reflective material, it is possible to use the 60% convection portion of the heat source to bring the entire assembly to a temperature below the melting point of solder and use the remaining 40% of the heat source (IR radiation) to only heat an unshielded portion of the assembly to the reflow temperature.

Using a Vitronics SMD-318 IR oven, a thermocoupled PWB was used to profile the oven such that the connector pins were able to reach reflow temperatures. At the point on the profile where both connectors had reached the reflow temperature of 183°C, the average temperature on the PWB surface was 212°C, a difference of +29°C. After the standard profile had been developed, a double layer of aluminum foil was wrapped around the PWB such that only the connectors were exposed, thus allowing convective energy to heat up the entire PWB but the IR radiation to reach only the connectors. Running the shielded PWB through the oven and making some minor adjustments to account for the effects of the shielding, we were able to bring the connectors to reflow temperature while maintaining the temperature across the remaining board surface area below reflow temperature. At the point on the new profile where both connectors had reached the reflow temperature of 183°C, the average temperature on the PWB surface was 140°C, a difference of -43°C due to the effects of the aluminum foil shielding preventing the IR radiation from hitting the PWB surface and providing the additional 40% of the heating energy needed to reach reflow temperature.

Actual reflow of solder preforms to the connector pin/PWB was accomplished using one, two, and three solder preforms with the aluminum foil wrapped around the PWB to shield all areas of the board surface except the connectors. Alpha 611 flux was applied to the pin and preforms using a syringe. Photographs of the joints to include cross-sections are included in Appendix A of this report as are the actual reflow parameters used.

Vapor Phase Reflow Test Results

Vapor Phase reflow soldering uses a computer controlled system which allows the assembly being reflowed to be immersed in the vapors generated by an azeotropic fluorocarbon compound. The vapor phase process uses the latent heat of the fluorocarbon vapor to reflow the solder preforms onto the connector pins and thereby form the actual solder joint.

Using a modified HTC 1826 vapor phase system, a thermocoupled PWB was used to profile the system such that the connector pins were able to reach reflow temperatures. At the point on the profile where both connectors had reached the reflow temperature of 183°C, the average temperature on the PWB surface was 187°C, a difference of +4°C. After the standard profile had been developed, a double layer of aluminum foil was wrapped around the PWB such that only the connectors were exposed, thus allowing the vapor to condense on the aluminum foil and the connector instead of the PWB and connector. Running the shielded PWB through the vapor phase system using the same profile, we were able to bring the connectors to reflow temperature while maintaining the temperature across the remaining board surface area below reflow temperature. At the point on the profile where both connectors had reached the reflow temperature of 183°C, the average temperature on the PWB surface was 158°C, a difference of -25°C due to the effects of the aluminum foil shielding preventing the condensation of the fluid directly onto the PWB surface thereby reducing the amount of heat being transferred to the board surface.

Actual reflow of solder preforms to the connector pin/PWB was accomplished using one, two, and three solder preforms with the aluminum foil wrapped around the PWB to shield all areas of the board surface except the connectors. Alpha 611 flux was applied to the pin and preforms using a syringe. Photographs of the joints to include cross-sections are included in Appendix A of this report as are the actual reflow parameters used.

Laser Reflow Test Results

Laser soldering is accomplished through the use of a continuous wave Yttrium-Aluminum-Garnet (YAG) laser operating at a wavelength of 1.06 microns with a maximum output of 50 watts. The laser system is numerically controlled in order to accurately focus the beam at the required point on the object to be soldered. The advantage of using the laser system is its ability to achieve a very rapid heating and cooling of the solder which results in a very fine, homogenous grain structure. The small area of heat concentration developed around the focused beam also prevents damage to adjacent components on the PWB.

Thermocouples were attached to the connector pin, annular ring, and PWB surface. The board was mounted on the laser X-Y table and the laser was targeted to the middle of the upper portion of the gold plated pin. Thermocouple readings taken show that the top of the pin is very rapidly heated to 237°C which is well above the reflow temperature of 183°C. The heat is then conducted to the bottom of the pin which sees a maximum temperature of 105°C and to the plated through hole which sees a maximum temperature of 93°C. The plated through hole normally would not show a large increase in temperature until the reflow actually occurs, however, due to the epoxy present for thermocouple attachment, the heat was transferred through the epoxy more rapidly than through the air (as radiant energy from the pin). One other situation leading to the rapid heating of the plated through hole would be caused by heat transfer due to the pin actually touching the plated through hole due to the movement inherent in the pin itself. The PWB surface next to the area being soldered reaches a maximum temperature of 51°C which is 186°C below what the pin actually sees during the soldering operation

The actual point of focus of the laser beam seems to have an effect on the geometry of the joint formation. If the beam is focused on the preform only, the solder joint forms evenly on both sides of the PWB, however, if the beam is focused such that it hits both the pin and the preform, there is a tendency for the solder to gravitate to the lower side of the PWB and form a more massive joint in that location. This phenomena seems to be caused due to the excessive heat being applied to the pin and the solder having a tendency to reflow faster and thus give gravity a longer period to exert downward forces on the molten mass.

The following process parameters were used for the laser reflow tests:

Laser current:	13 amps
Beam defocus:	.005 inches
Time:	9 seconds
Laser Power:	86.4 Joules per connector pin
Beam angle:	35 degrees from vertical (Experiments have shown that a vertical beam overheats the pin and results in thermal damage.)

Alpha 611 flux was sprayed on both the top and bottom of the connector to enable the flux to get on the entire pin surface. The assembly was then dried in an oven at 80°C for 10 minutes to prevent ignition of the solvents in the wet flux by the laser beam.

Photographs of the joints to include cross-sections are included in Appendix A of this report.

Hot Gas Reflow Test Results

Using an SRM100 microprocessor controlled hot gas (nitrogen) system from SRTechnologies, it is possible to deliver a precisely controlled pattern of hot gas to the area to be reflowed while the surrounding areas are flushed with ambient temperature nitrogen to keep the remainder of the assembly cool.

The bottom heater was set to a temperature of 350°C with a nitrogen flow of 90 CFH to overcome the mass of the connector body. The top heater was set up with a .600 inch by .500 inch matrix (on .100 inch centers) of heaters operating at 200°C and the nitrogen flow at 60 CFH. Alpha 611 flux was sprayed on both the top and bottom of the connector to enable the flux to get on the entire pin surface.

Thermocouples were attached to the connector pin, annular ring, and PWB surface. Thermocouple readings taken show that the top of the pin is heated to 187°C which is just slightly above the reflow temperature of 183°C. The bottom of the pin sees a maximum temperature of 198°C and the plated through hole sees a maximum temperature of 177°C. The PWB surface next to the area being soldered reaches a maximum temperature of 179°C.

The following process parameters were used for the hot gas reflow tests:

Time:	Preheat	2 minutes 5 seconds
	Reflow	15 seconds
Temperature:	Top heater	200°C
	Bottom heater	350°C
	(The reason for the higher temperature at the bottom is to compensate for the sideways flow required to efficiently heat the joint area.)	
Nitrogen flow:	Top	60 cubic feet/hour
	Bottom	90 cubic feet/hour

This particular scenario would need to be repeated several times in order to reflow one connector due to the fact that the machine is only capable of supplying enough output to activate a .600 X .500 heating area.

Photographs of the joints to include cross-sections are included in Appendix A of this report.

Conclusions

A solder volume of 0.0001037 cubic inches (two .070 X .040 X .020 preforms) appears to be ideal for the required joint formation (this is 72% of the volume currently used by Honeywell). Pretinning of the connector pins does not appear to be a necessary step in the process, however, the specification drawing for the connector will need to be changed in order to reduce the gold thickness to comply with the military specifications. The current specification drawing for the connector pins states that the pins will have 50 - 120 microinches of gold plating on the surface. X-ray Fluorescence measurements of the gold thickness on several of the connector pins shows an average of 53.35 microinches of gold (see Appendix A). If the plating specification were changed to 50 - 95 microinches of gold, the pins would not require pretinning per WS-6536 which only requires pretinning if gold plating is in excess of 100 microinches. The solder appears to wet the surface of the pin and the joint seeks a natural height based upon the solder volume used (the height is extremely repeatable). The only area of non-wetting could be the surface of the pin inside the plated through hole and this could be eliminated by prefluxing the pins prior to putting on the preforms thus allowing the flux to flow down into the plated through hole. Additional Scanning Electron Microscopy work is necessary to fully evaluate the intermetallic growth for each soldering method.

The connector is able to reliably withstand the processing environments present in all four of the methods examined.

Based upon the results of our work, it is obvious that all four reflow methods are capable of reflowing the preforms on the connector pins and forming a solder joint. A short discussion of the results from each process being tested along with an evaluation as to the practicality of using the particular method will follow.

The least desirable of the methods evaluated was the hot gas system. The system is not designed to heat a connector using the attached bottom heater and thus it is necessary to increase the bottom heater temperature to a point where the entire area around the connector is heated almost to reflow temperature. The joints were not identical in formation and there was evidence of extreme graininess on the joint surfaces due to the slow cooldown caused by the PWB being at such a high temperature during the operation. The small area being reflowed (.600 X .500) means that the cycle time to do each connector is increased dramatically due to moving the connector in relation to the heater assembly. Results of our trip to Honeywell indicated identical results with respect to the joint formation and time required for assembly of an individual connector. Rework of bad joints would be a major consideration when using this method. The cost for a hot gas system of this type is approximately $35,000.

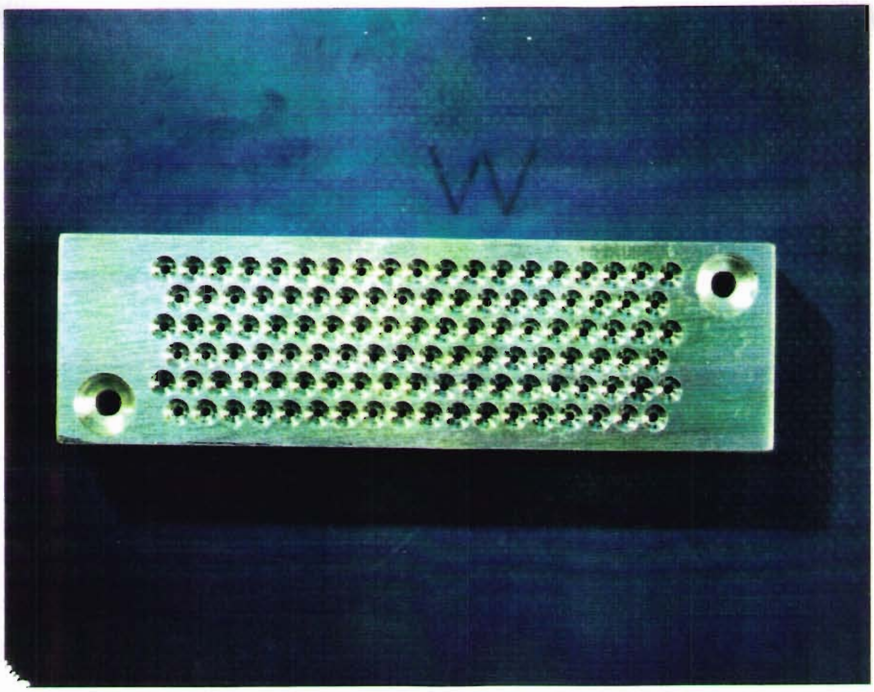
The vapor phase reflow system produced very good joints with very similar geometries. The main drawback to this method is the ability to maintain the surface of the PWB at a considerably lower temperature than the connector. Additional work would be required to further shield the PWB surface from the condensing liquid in order to reduce the surface temperature even more. Cycle time for a complete assembly with any number of connectors is approximately ten minutes. The vapor phase process is a batch process and due to the effect of such a large PWB mass, it would only be possible to put a single assembly into the machine at one time. The cost of a computer controlled vapor phase system is approximately $150,000 which does not include the cost of the fluid at $800 per gallon.

The CW-YAG Laser produced excellent joints of a very repeatable geometric shape while maintaining the PWB surface at a temperature well below 183°C. The key parameter to utilizing the laser system is the focal point of the beam. The beam must be focused on the preform only and not be allowed to deviate and strike the pin. Although the laser can only do one joint at a time, the numerical controller allows an entire connector to be done without operator intervention. Assuming a cycle time of 10 seconds for each joint, each connector would take approximately 20 minutes to solder, therefore, a PWB with 2 connectors would take about 40 minutes to solder. The cost of a numerically controlled CW-YAG Laser system is approximately $130,000.

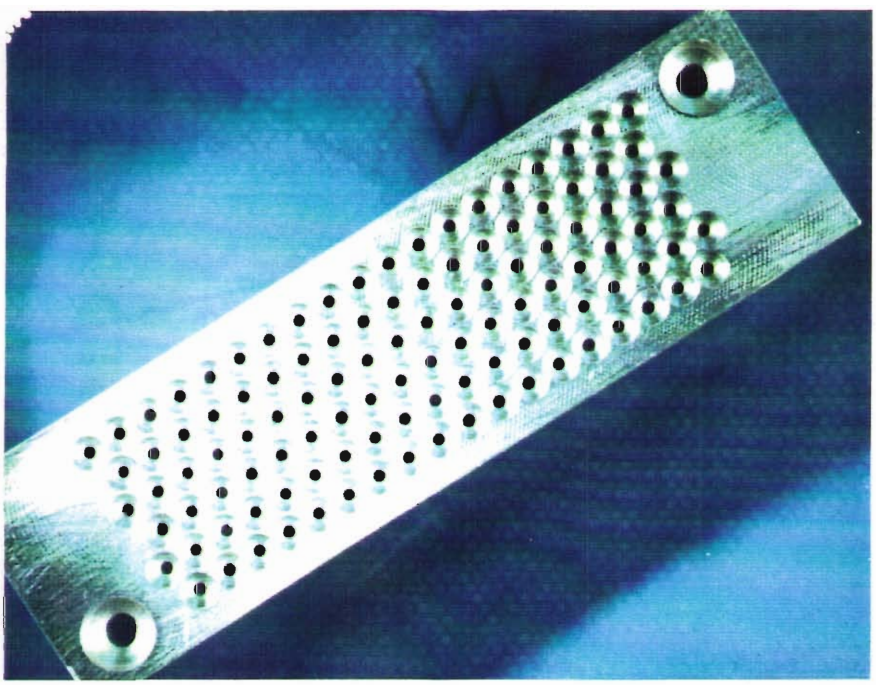
The Infrared Reflow Oven appears to be the best process to use for soldering of the connector. The joint consistency and surface finish is superb and the use of a shielding material to keep the non-connector areas cool works extremely well. Cycle time for each assembly with any number of connectors is approximately 12 minutes. The IR is an in-line system, therefore assemblies can be run sequentially on the belt. Running assemblies sequentially means there is no waiting period between assemblies and so the throughput for this method is much greater than any other method investigated. The cost of an Infrared Reflow system is approximately $30,000.

APPENDIX A

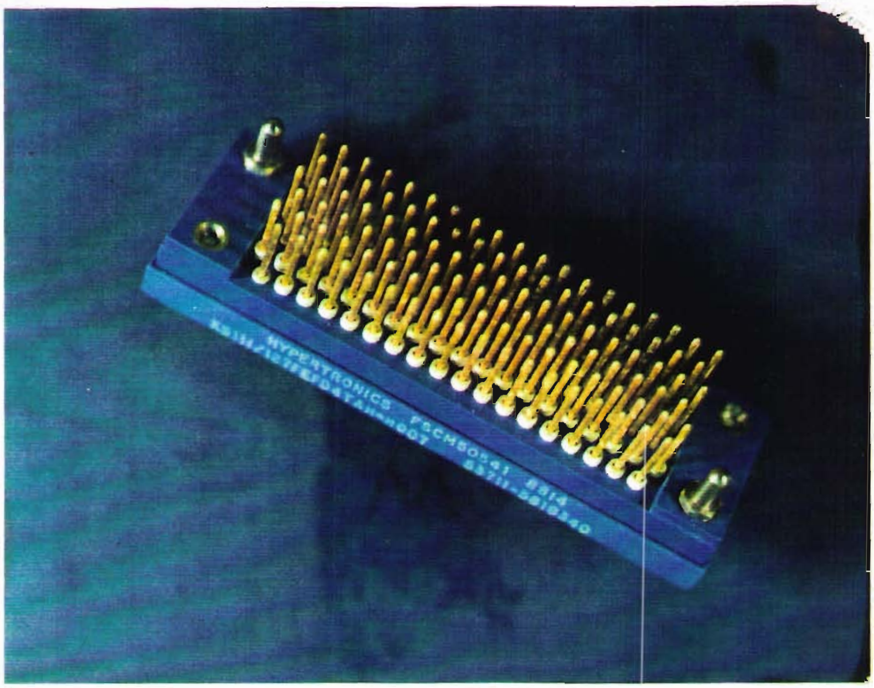
Experimental Data, Photos, and Charts



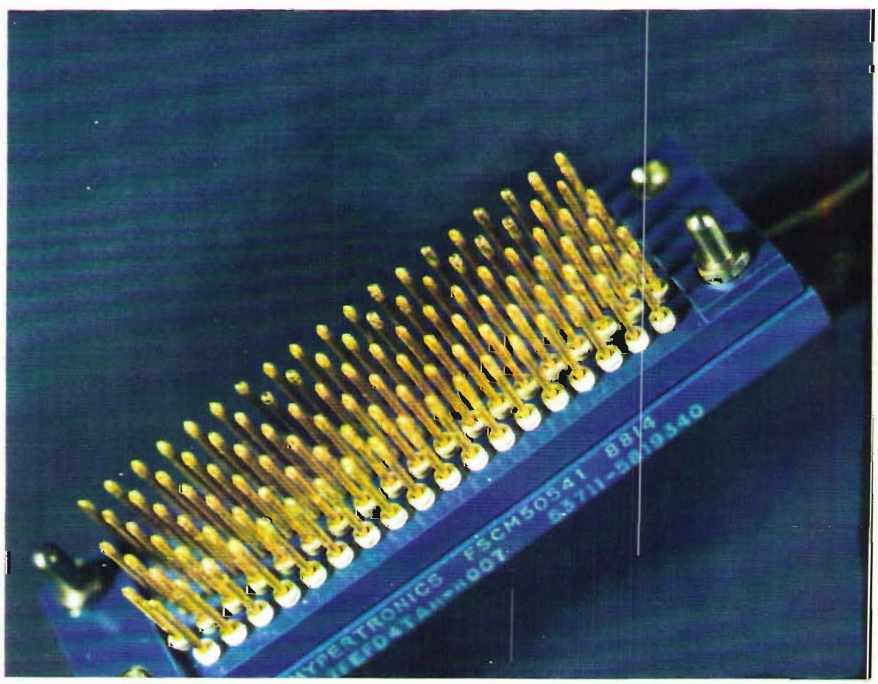
PREFORM PLACEMENT TOOL



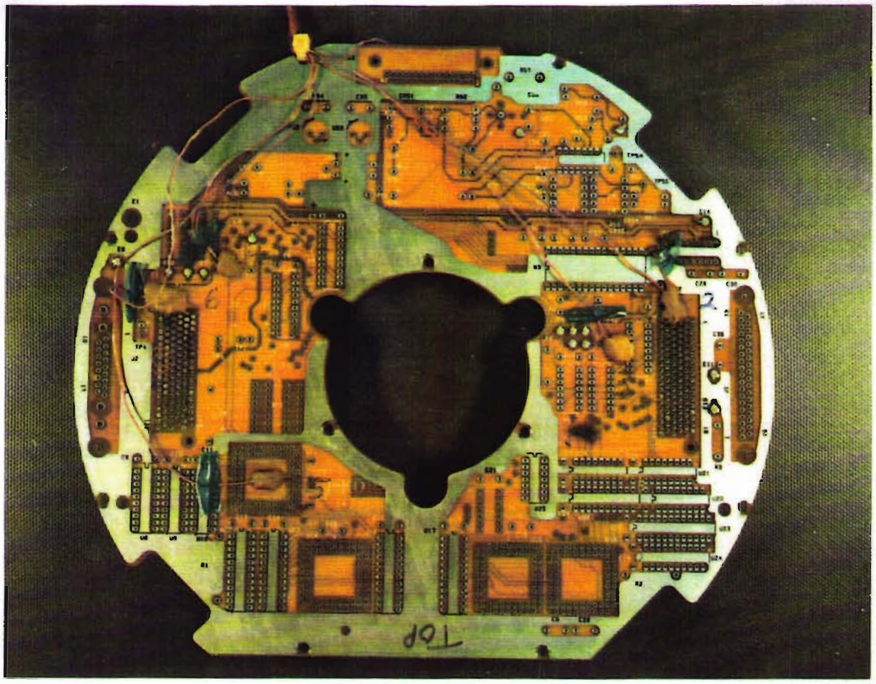
PREFORM PLACEMENT TOOL



PREFORMS (2) IN PLACE ON CONNECTOR



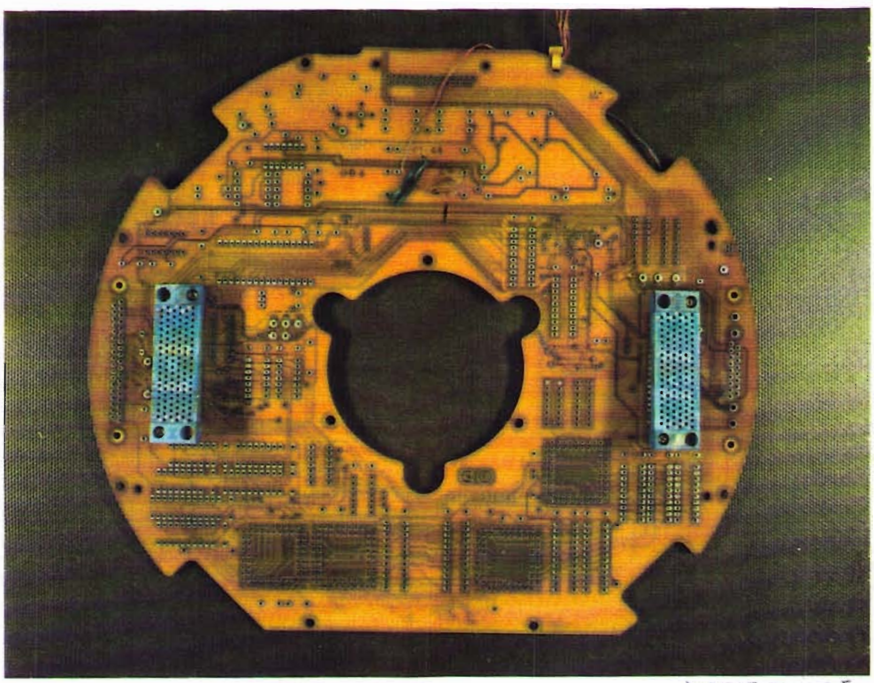
PREFORMS (2) IN PLACE ON CONNECTOR



#4 IN PTH

DIRECTION OF TRAVEL IN IR OVEN ↓

FRONT SIDE OF PWB WITH THERMOCOUPLES
FOR IR AND VAPOR PHASE TESTS

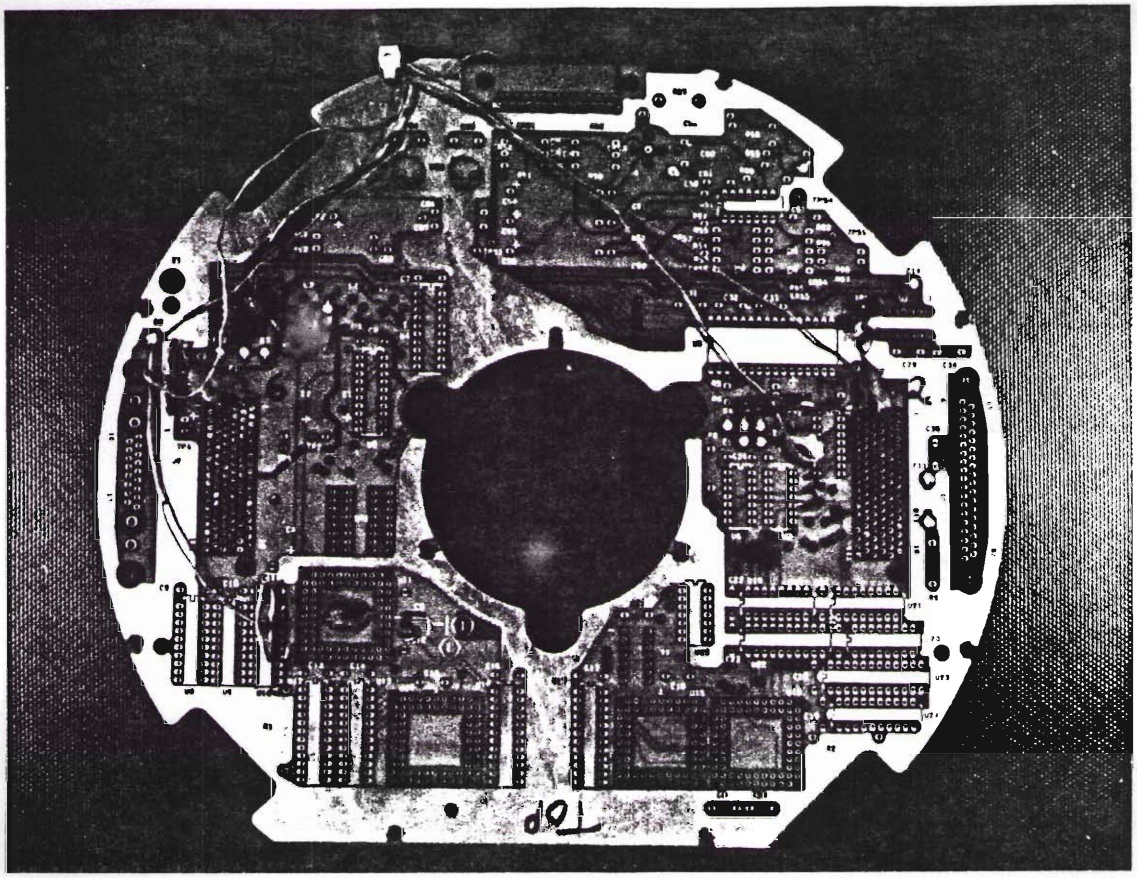


DIRECTION OF TRAVEL IN IR OVEN ↓

BACK SIDE OF PWB WITH THERMOCOUPLES
FOR IR AND VAPOR PHASE TESTS

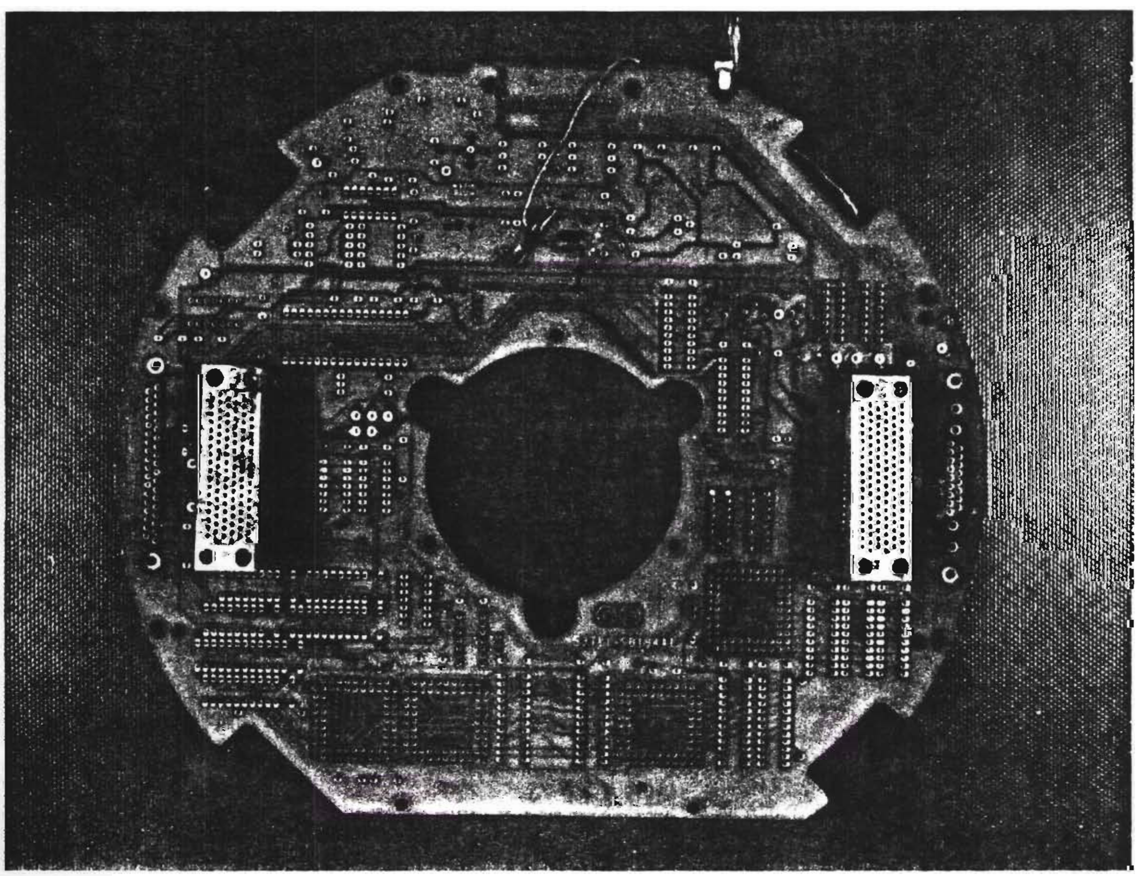
THERMOCOUPLE PLACEMENT FOR IR & VAPOR PHASE TESTS

THERMOCOUPLE PLACEMENT FOR IR & VAPOR PHASE TESTS

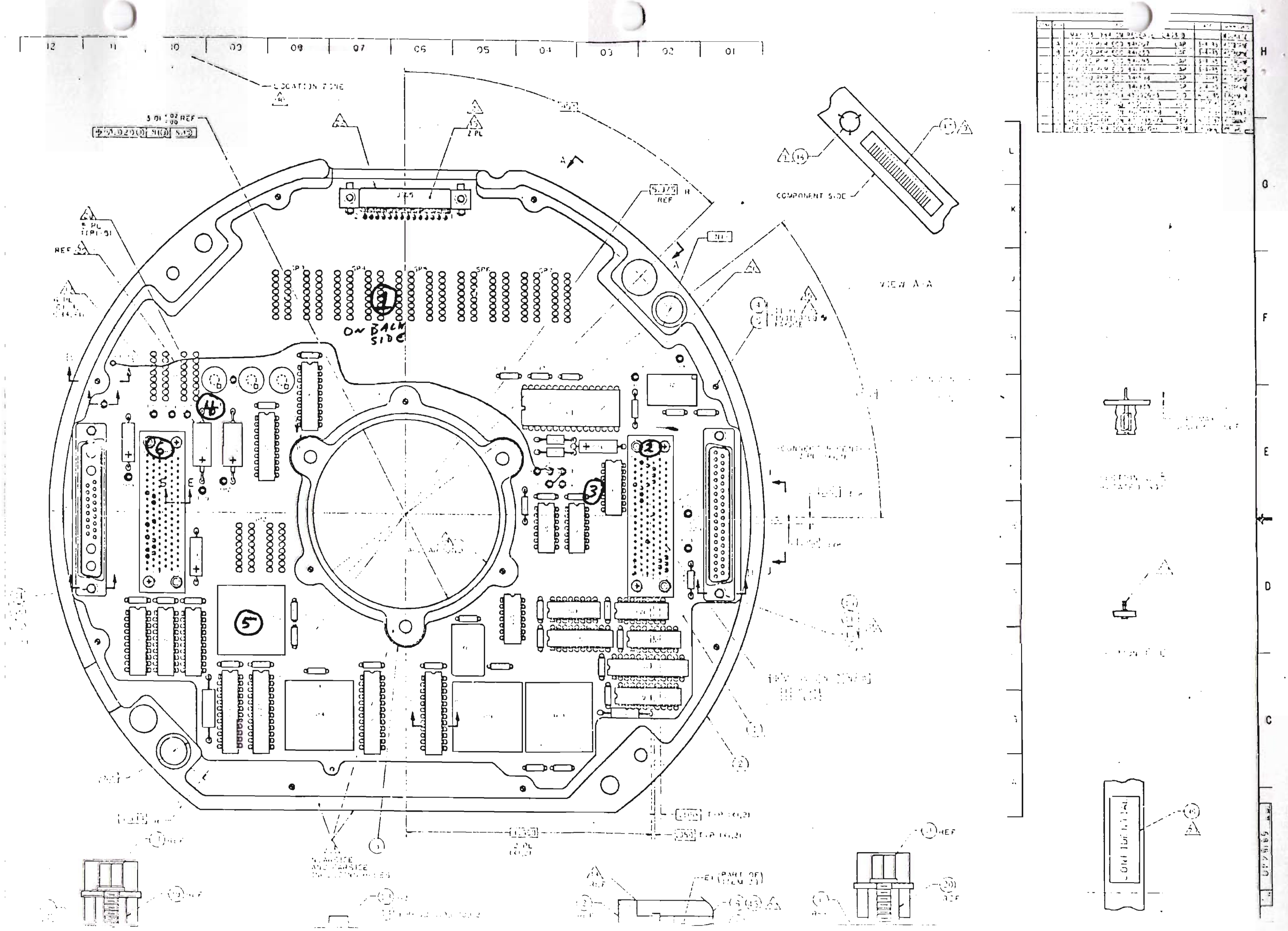


#4 IN PTH

DIRECTION OF TRAVEL IN IR OVEN ↓

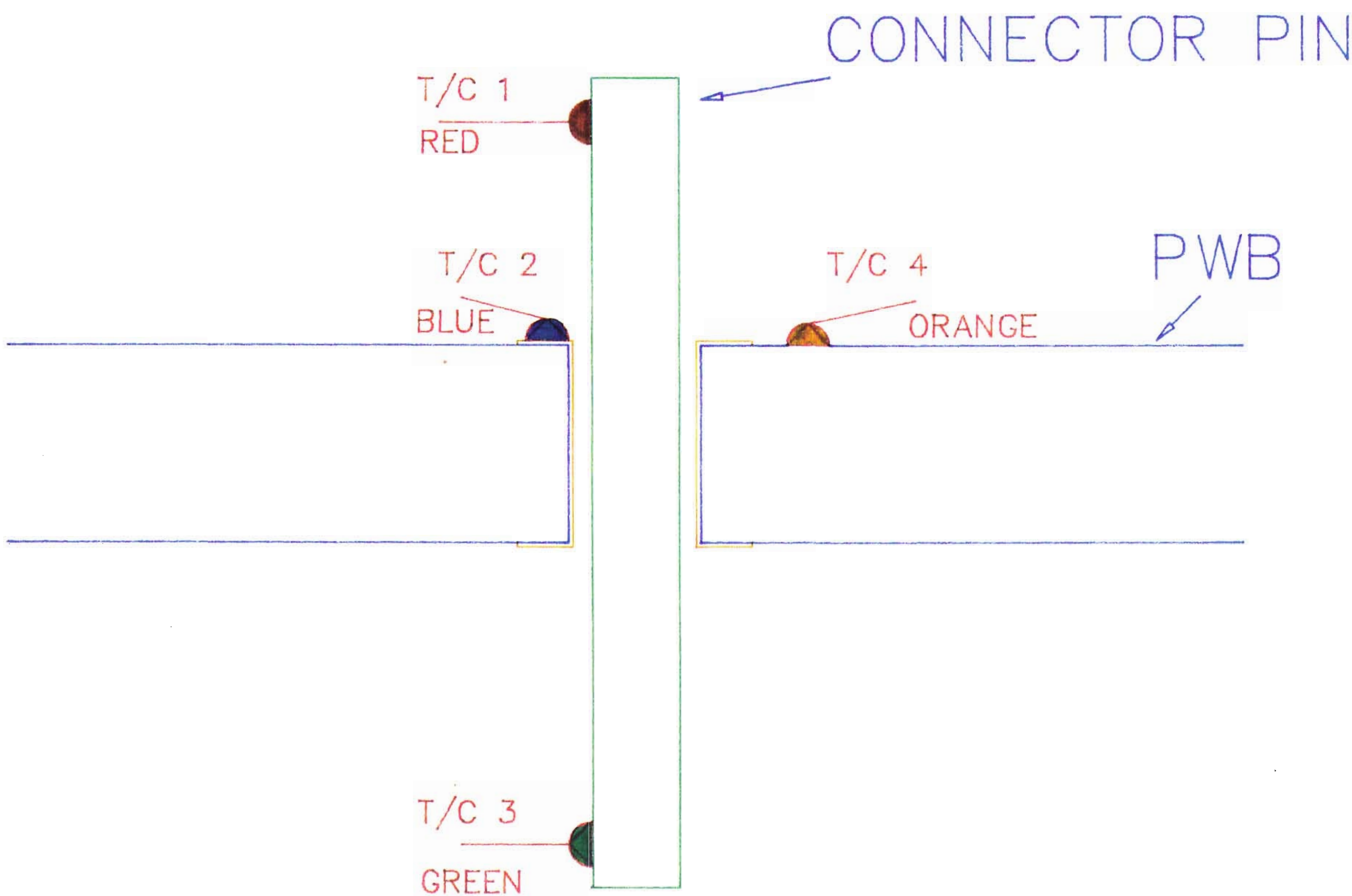


DIRECTION OF TRAVEL IN IR OVEN ↓



#4 IN CENTER OF PTH #1 ON BACK SIDE AT P...R

THERMOCOUPLE PLACEMENT FOR LASER & SRT TESTS



VAPOR PHASE

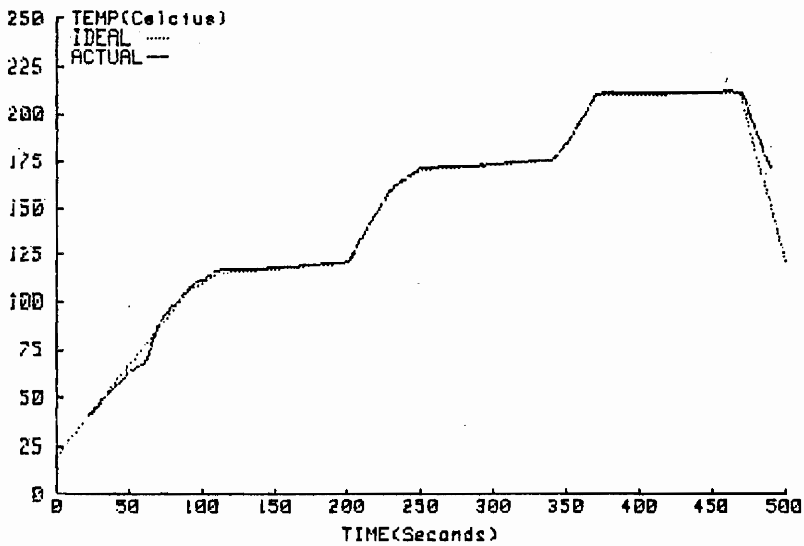
THE FOLLOWING IS A COMPLETE SUMMARY OF THE RUN INFORMATION.

DATA FILE	OP CODE	DATE	TIME	PROCESS TYPE	NUM BOARDS
NONE	0001	21 Jun 1988	12:24:57	PRO_01	1

BOARD #	WORK ORDER #
1	MARK50-14

MAXIMUM TEMPERATURE ATTAINED(Celsius)=211.8

TIME ABOVE 183 DEGREES CELSIUS=131.8 SECONDS



Vitronics 7-Zone Program

Profile: P121 vp (UNSHIELDED PWA)

Zone	1	2	3	4
Set	325	290	225	350
Actual	326	291	226	351

»»»»»»»»»»»»»»»»»»»»»»»»»»»»»

Process Ready

Zone	5	6	7
Set	290	225	350
Actual	291	225	351

^ = 5° high ↓ = 5° low ^ = 25° high (Temp. Shut Down at ± 25°C)

Communication Display
To controller : SF
From controller : B10
Scanning Temperatures

F1 = Edit Values
F2 = New Profile
F3 = Shut Down

F5 = Plot

Belt
Speed: 9
(in/min)

Vitronics 7-Zone Program   Copyright 1986 Vitronics Corp.

MARK 50 - 9

Profile: MARK 50 Torpedo (SHIELDED PWA)

Zone	1	2	3	4
Set	350	325	325	390
Actual	350	325	326	390

»»»»»»»»»»»»»»»»»»»»»»»»»»»»»

Process Ready

Zone	5	6	7
Set	325	325	390
Actual	325	325	390

^ = 5° high ↓ = 5° low ^ = 25° high (Temp. Shut Down at ± 25°C)

Communication Display
To controller : 08V0168
From controller : B10

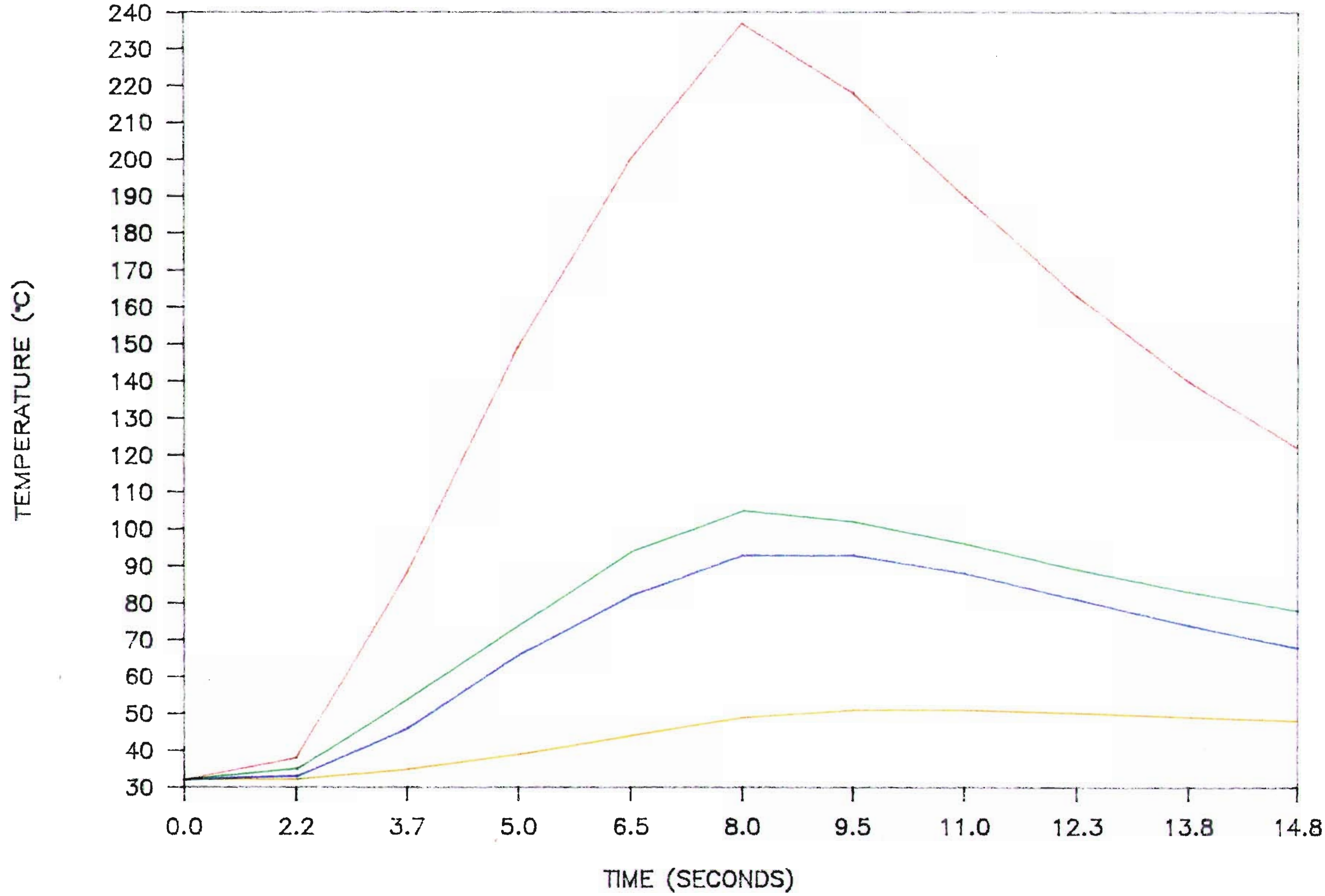
F1 = Edit Values
F2 = New Profile
F3 = Shut Down

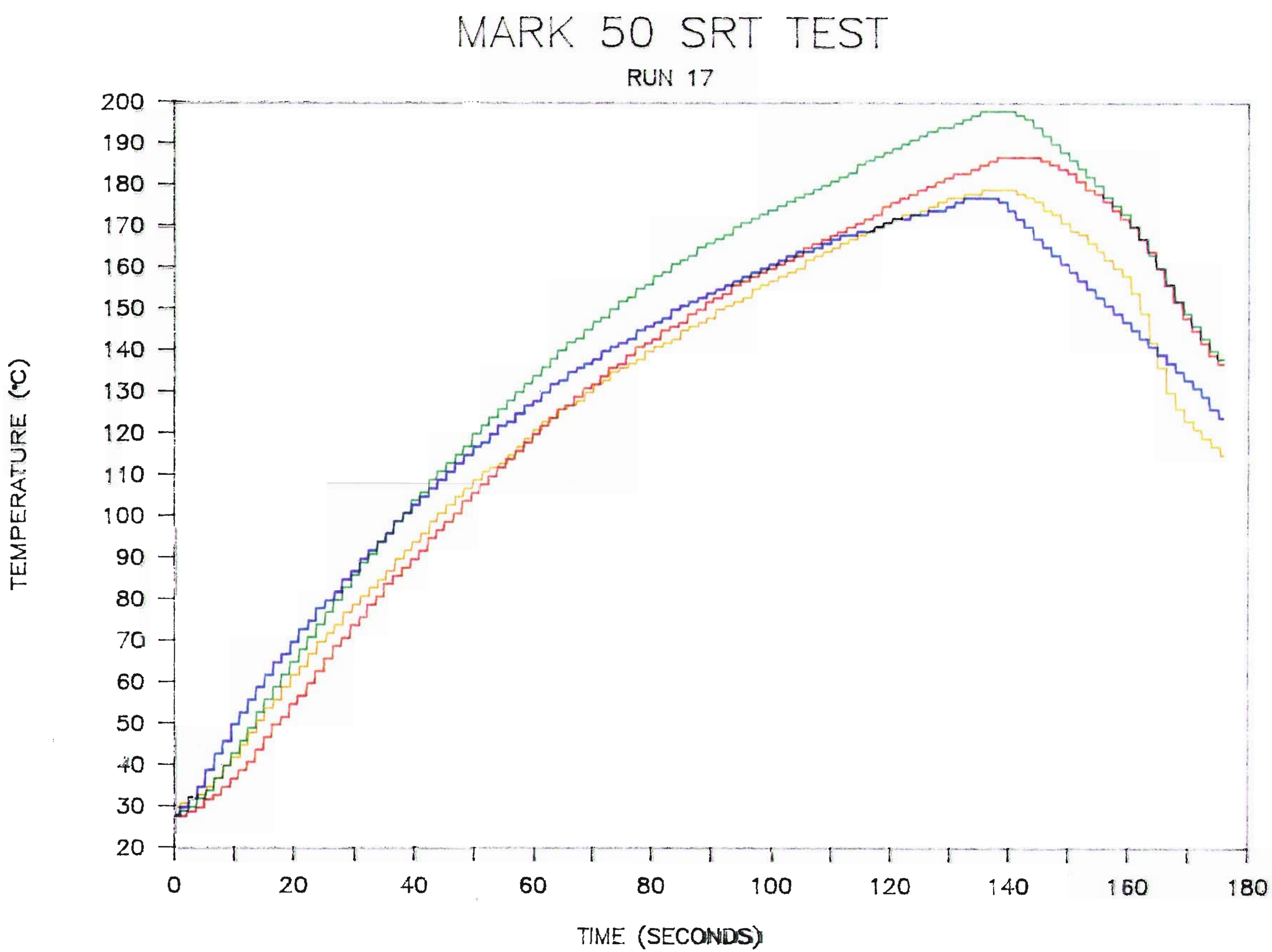
F5 = Plot

Belt ↓
Speed: 9
(in/min)

MARK 50 CW—YAG LASER TEST

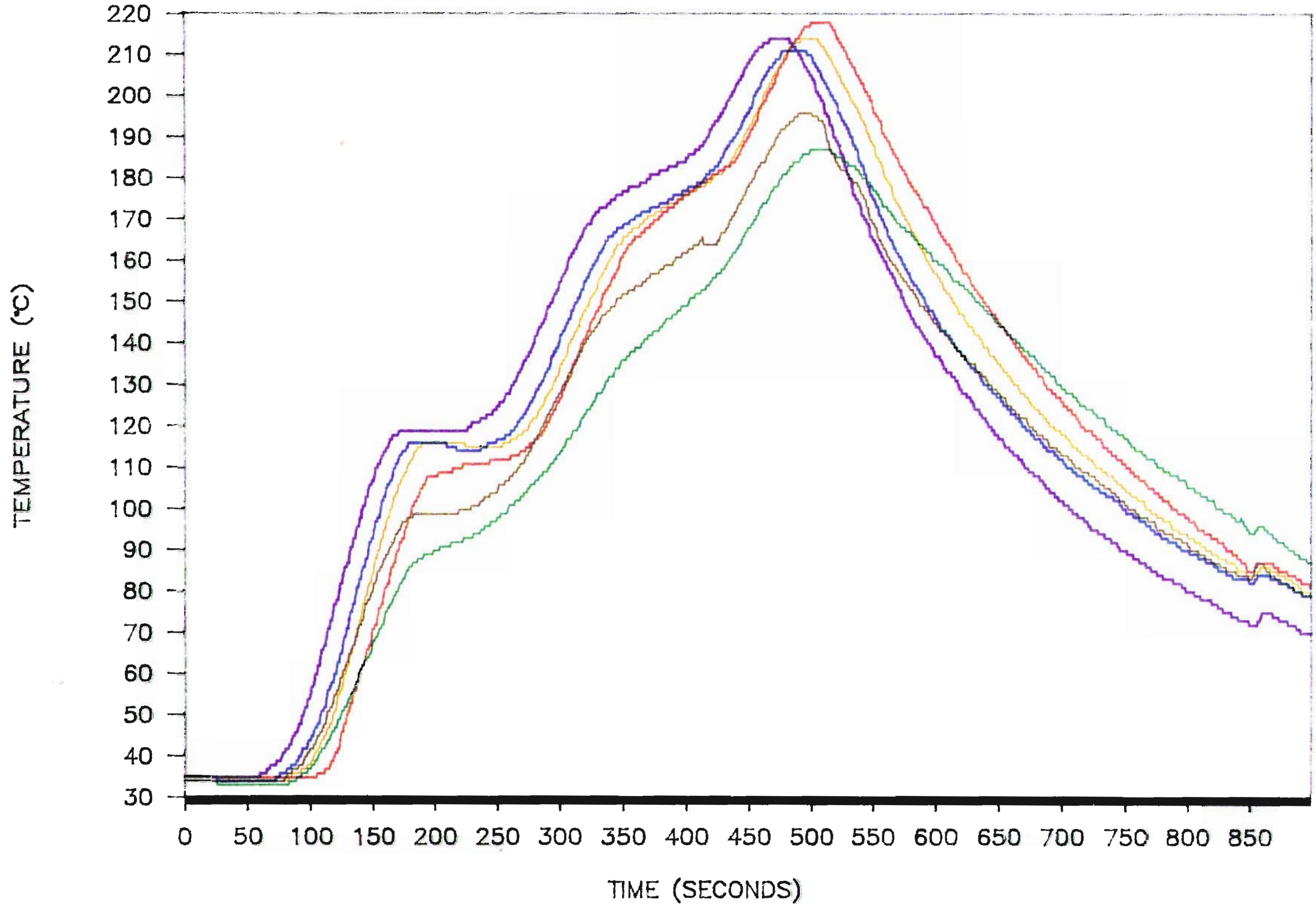
RUN 11

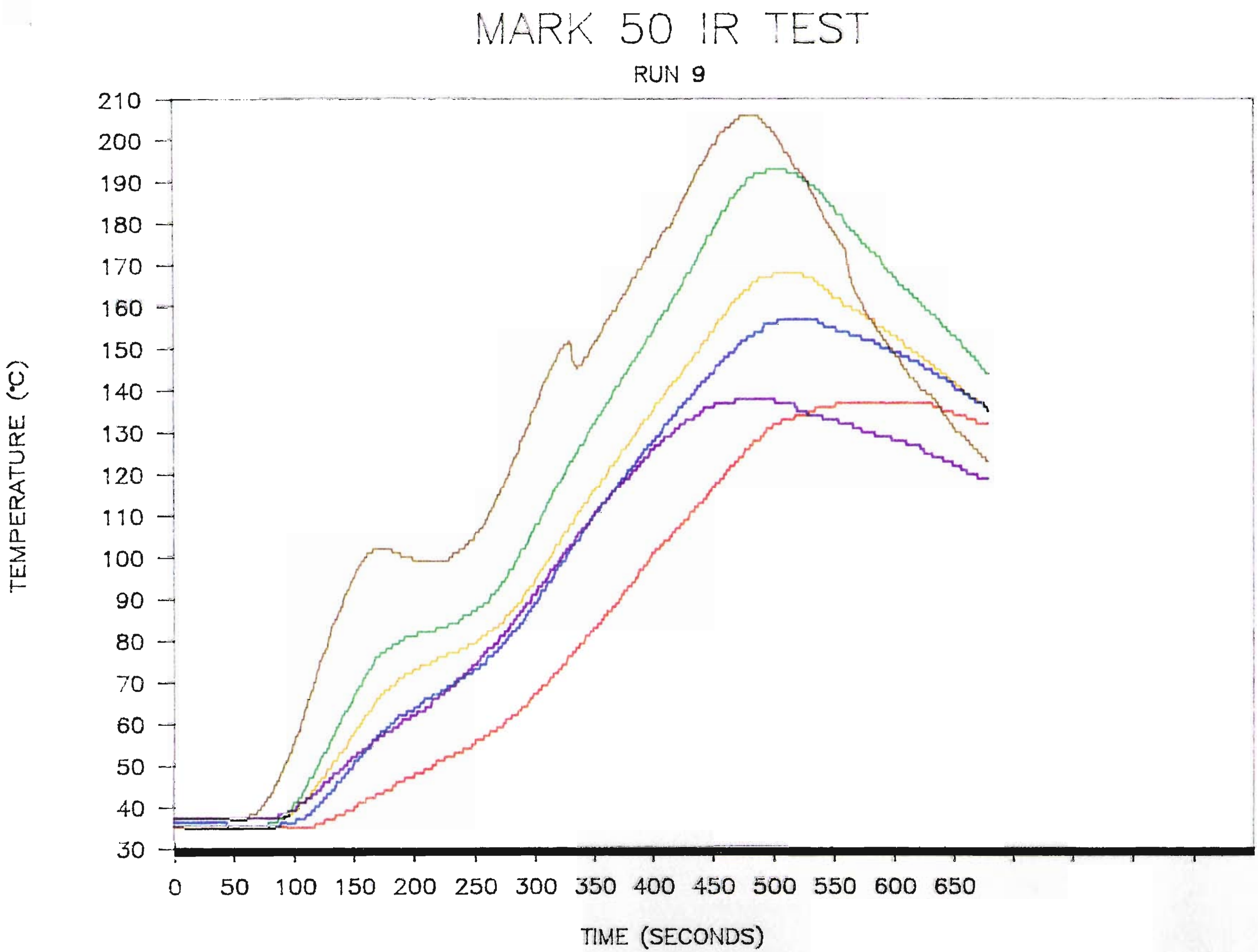



MARK 50 SRT TEST
RUN 17
TEMPERATURE (°C)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
TIME (SECONDS)

MARK 50 IR TEST

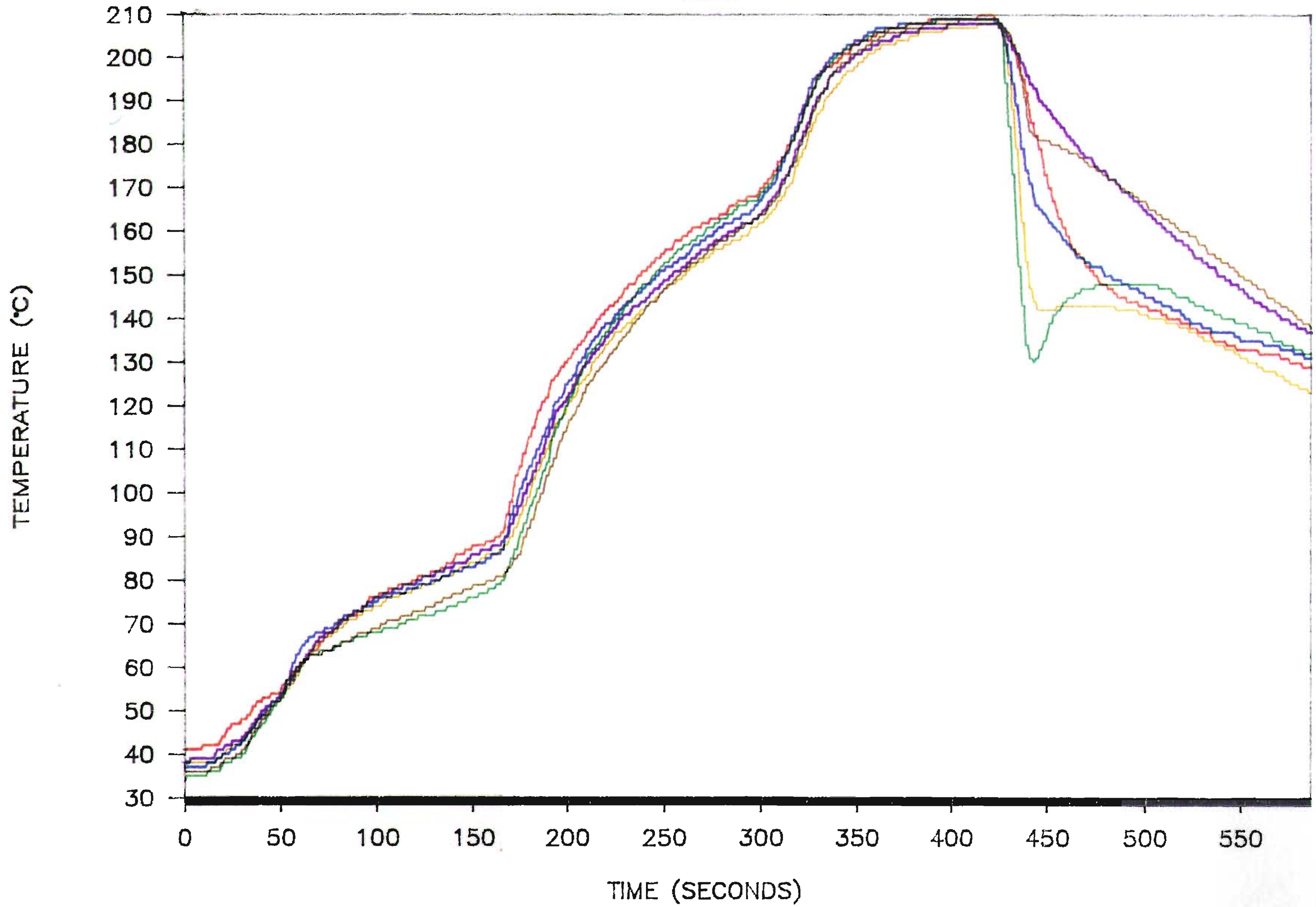
RUN 5




MARK 50 IR TEST
RUN 9
TEMPERATURE (°C)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
0
50
100
150
200
250
300
350
400
450
500
550
600
650
TIME (SECONDS)

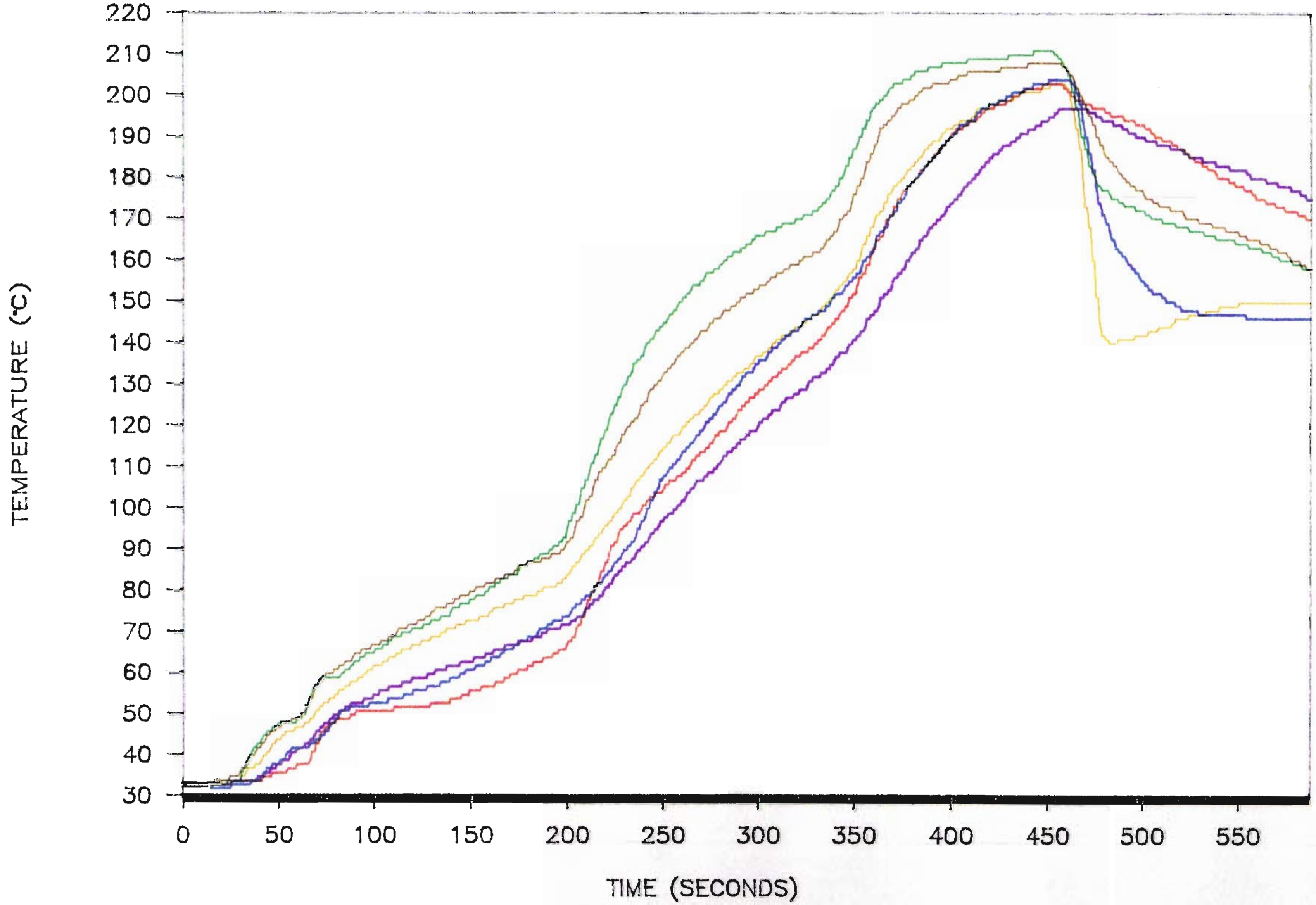
MARK 50 VAPOR PHASE TEST

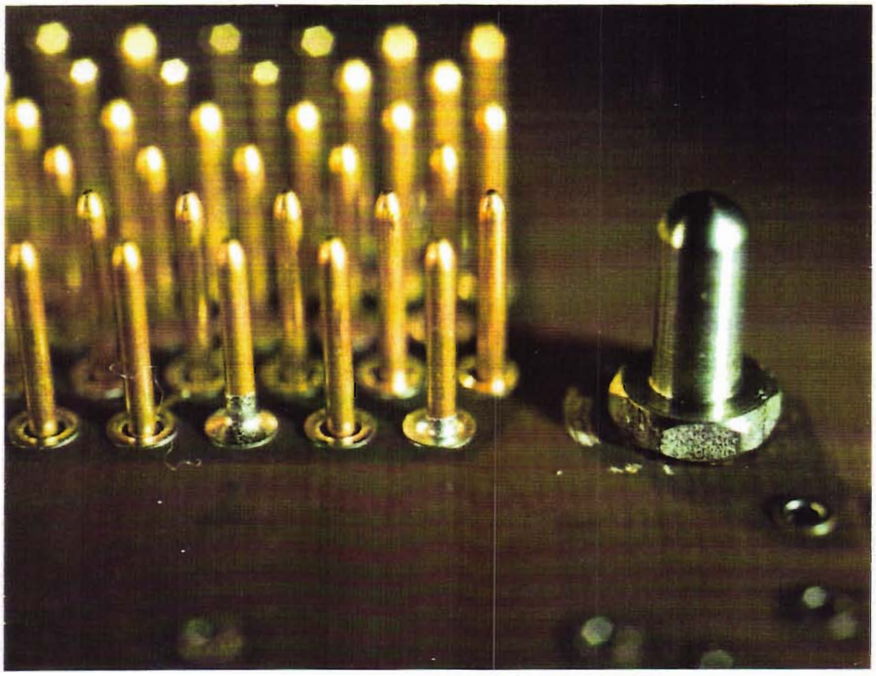
RUN 13



MARK 50 VAPOR PHASE TEST

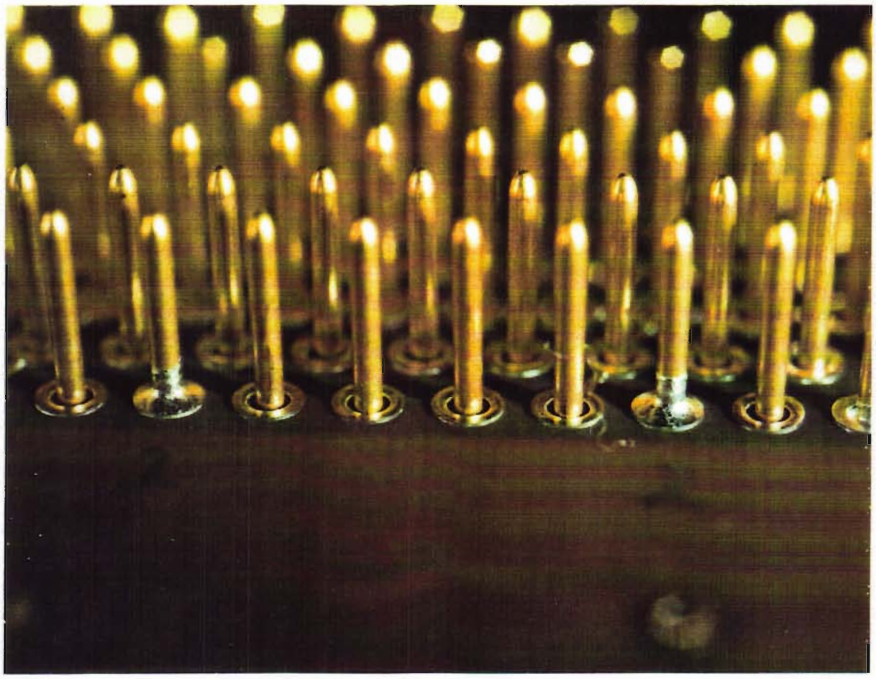
RUN 14



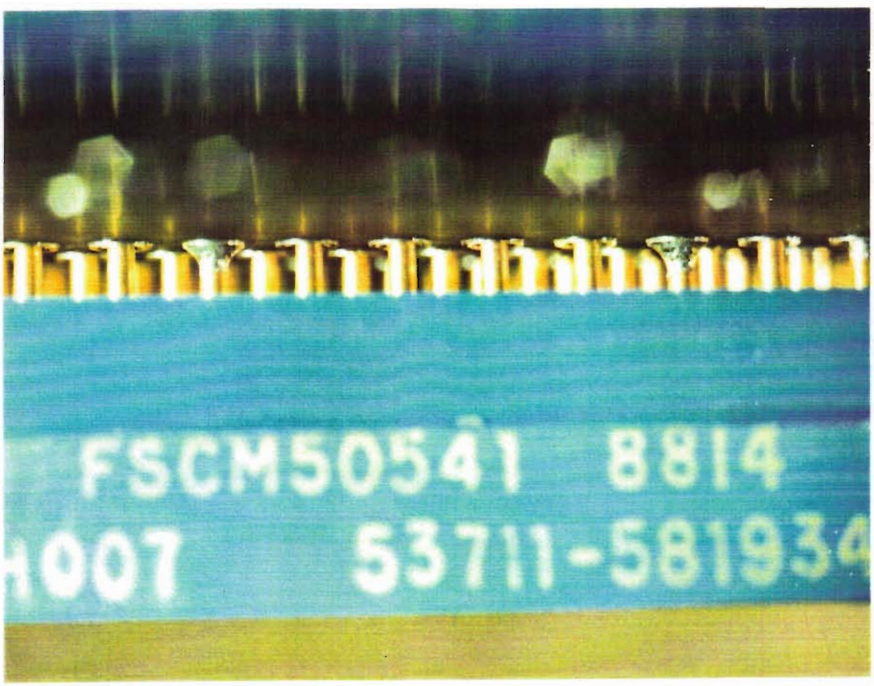


PIN 1 - TOP SIDE - 1 PREFORM - IR
PIN 3 - TOP SIDE - 2 PREFORMS - IR

PIN 1 - BOTTOM SIDE - 1 PREFORM - IR
PIN 3 - BOTTOM SIDE - 2 PREFORMS - IR

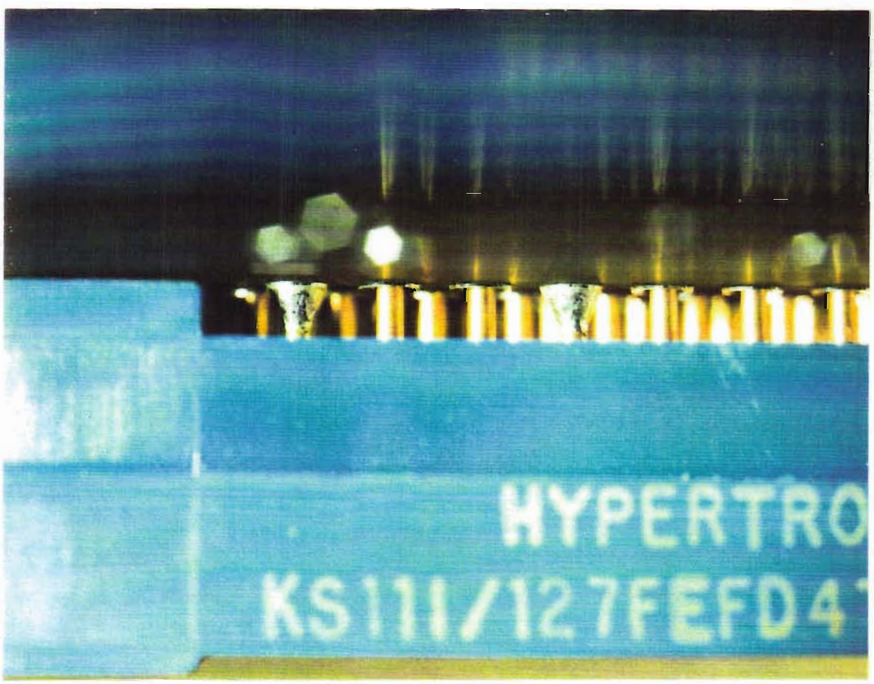


TOP SIDE - 2 PREFORMS - IR

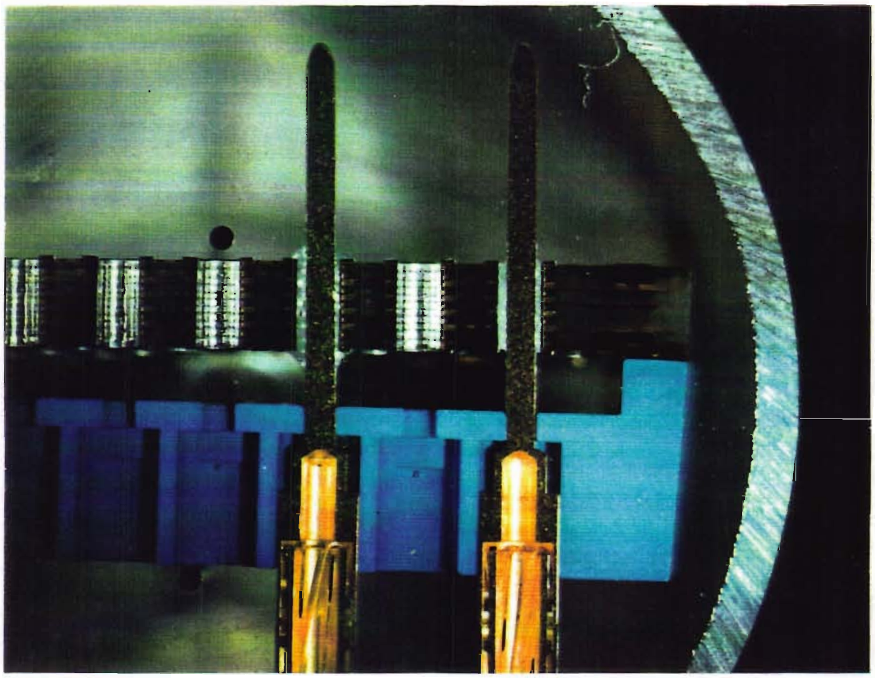


BOTTOM SIDE - 2 PREFORMS - IR

TOP SIDE - 3 PREFORMS - IR

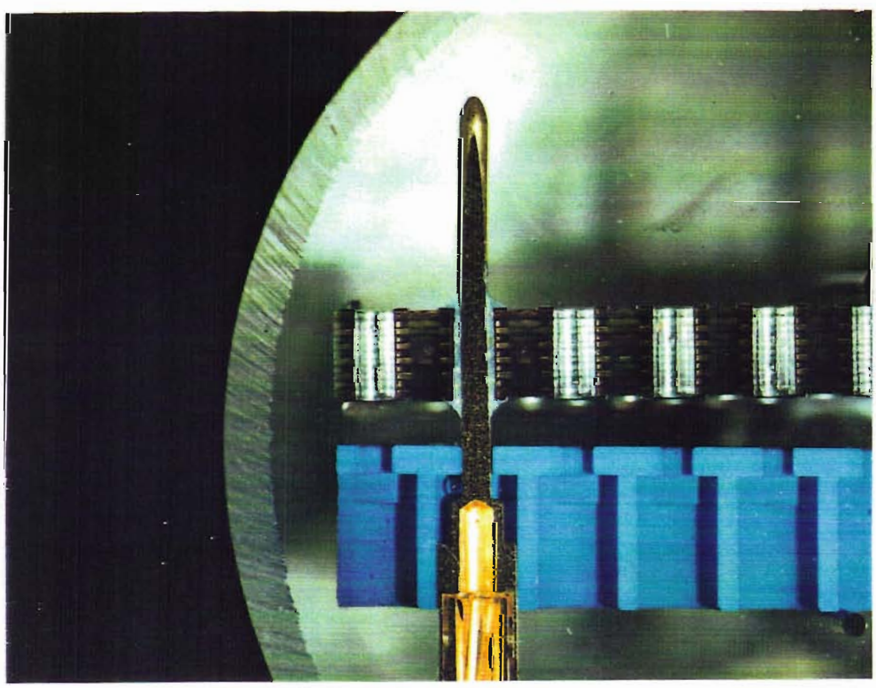


BOTTOM SIDE - 3 PREFORMS - IR



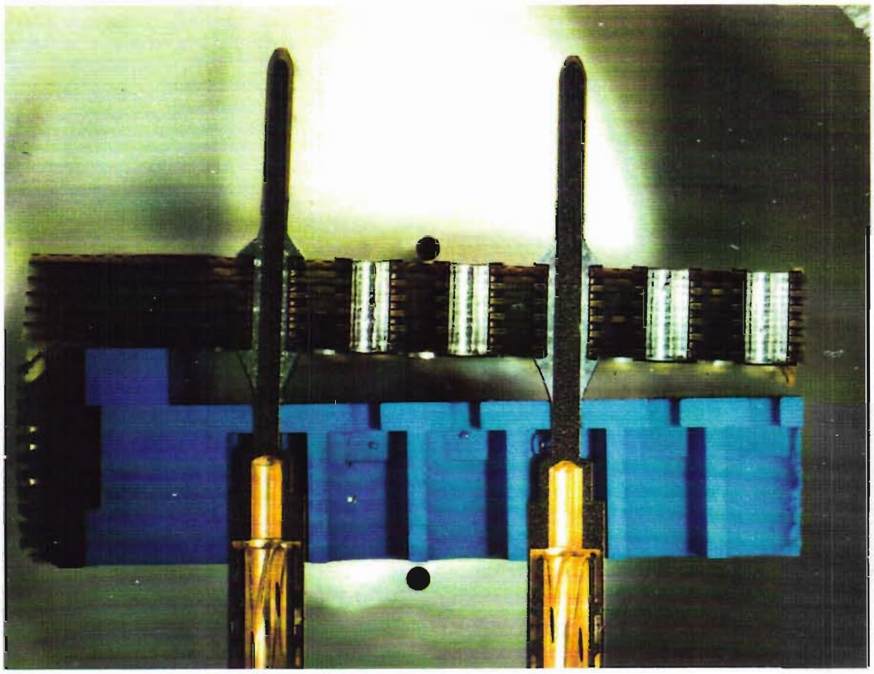
2 1

PIN 1 - CROSS-SECTION - 1 PREFORM - IR
PIN 3 - CROSS-SECTION - 2 PREFORMS - IR



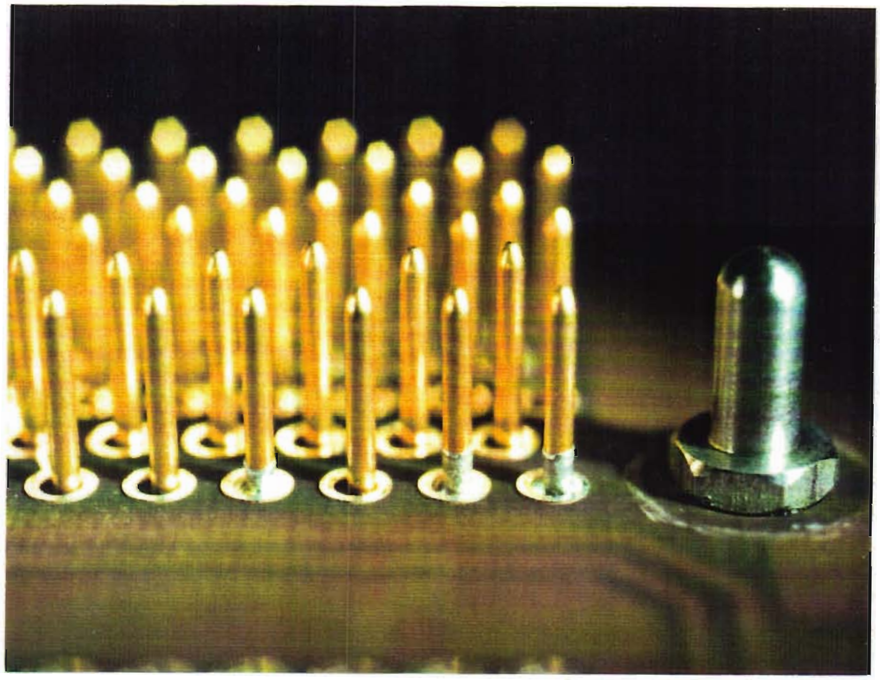
2

CROSS-SECTION - 2 PREFORMS - IR

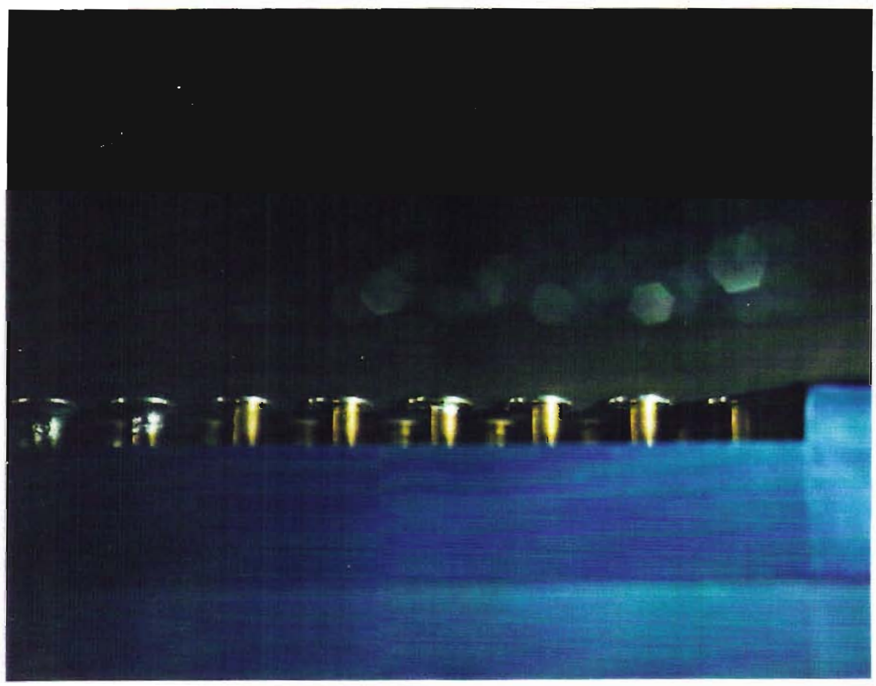


3 3 1 sec f/8

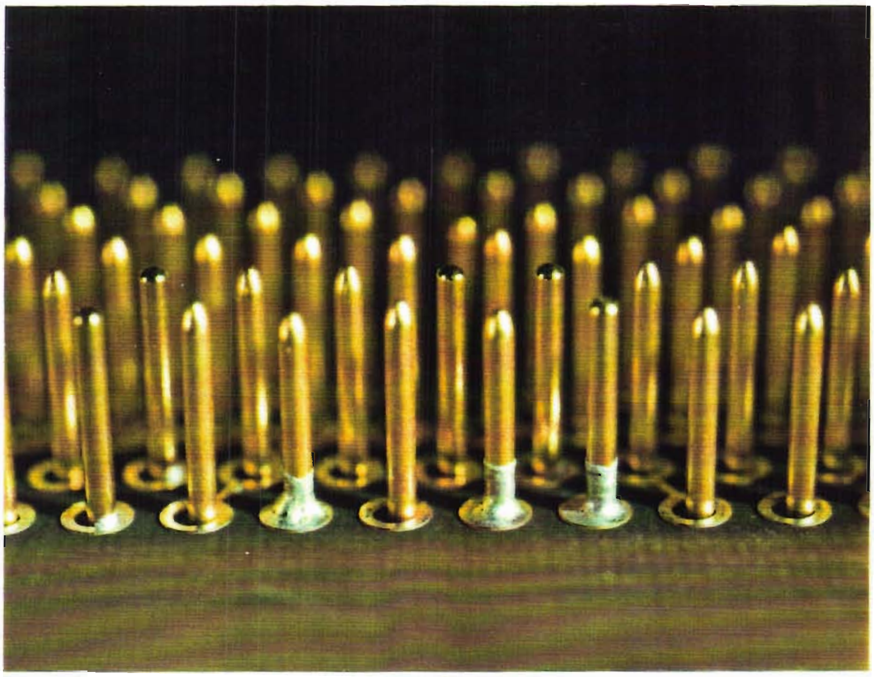
CROSS-SECTION - 3 PREFORMS - IR



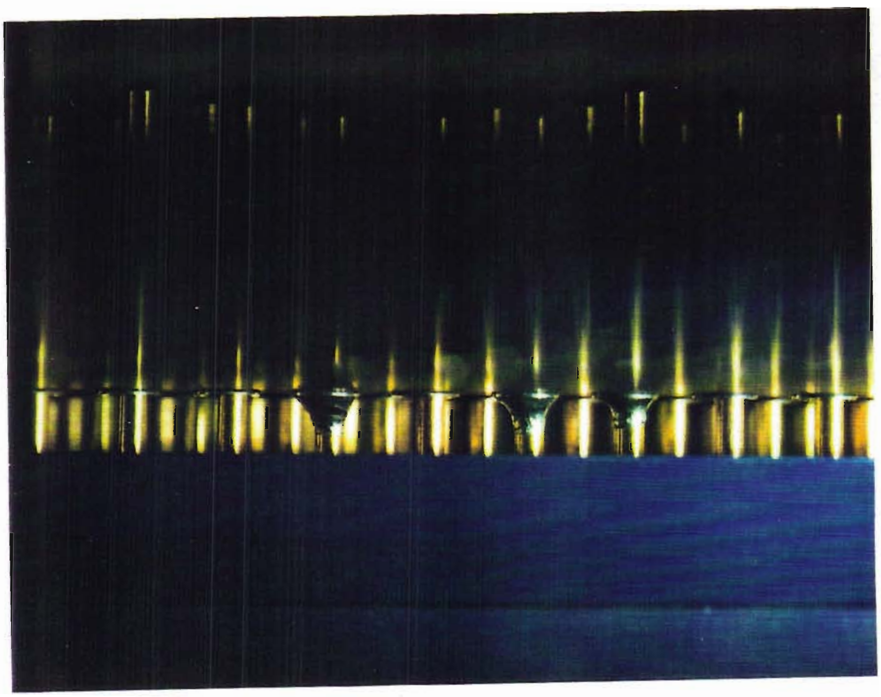
TOP SIDE - 1 PREFORM - VAPOR PHASE



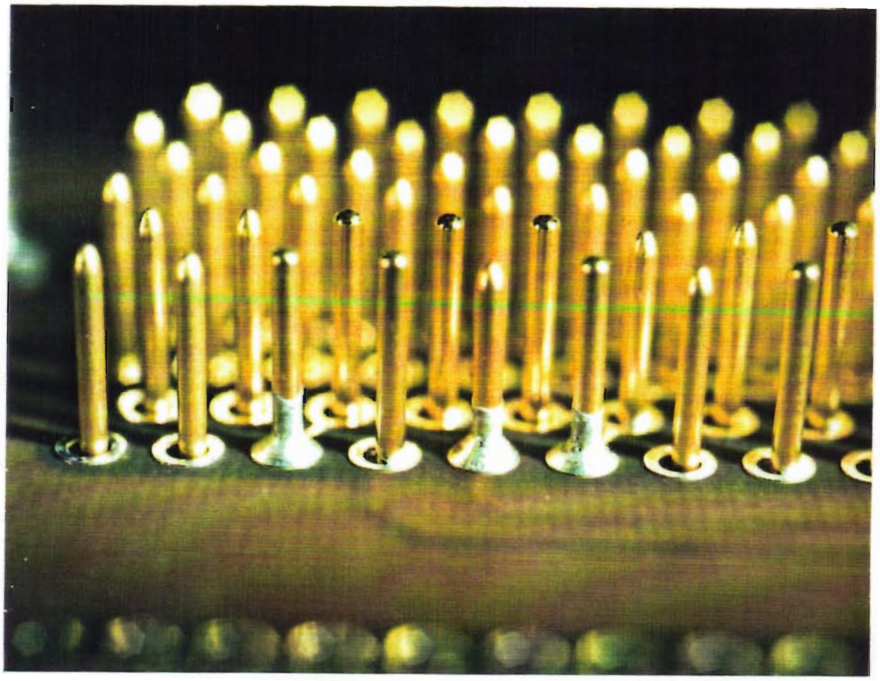
BOTTOM SIDE - 1 PREFORM - VAPOR PHASE



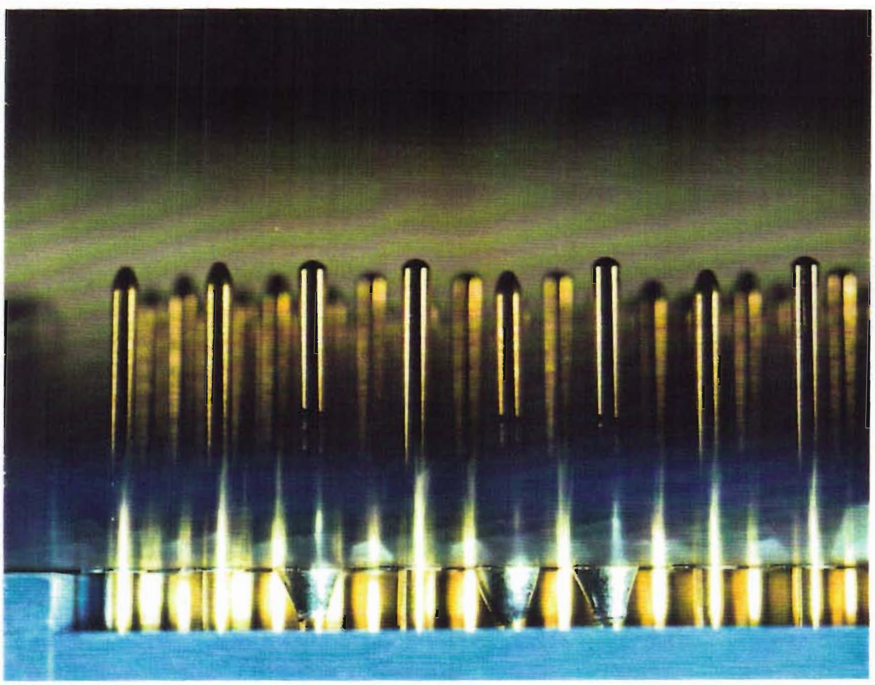
TOP SIDE - 2 PREFORMS - VAPOR PHASE



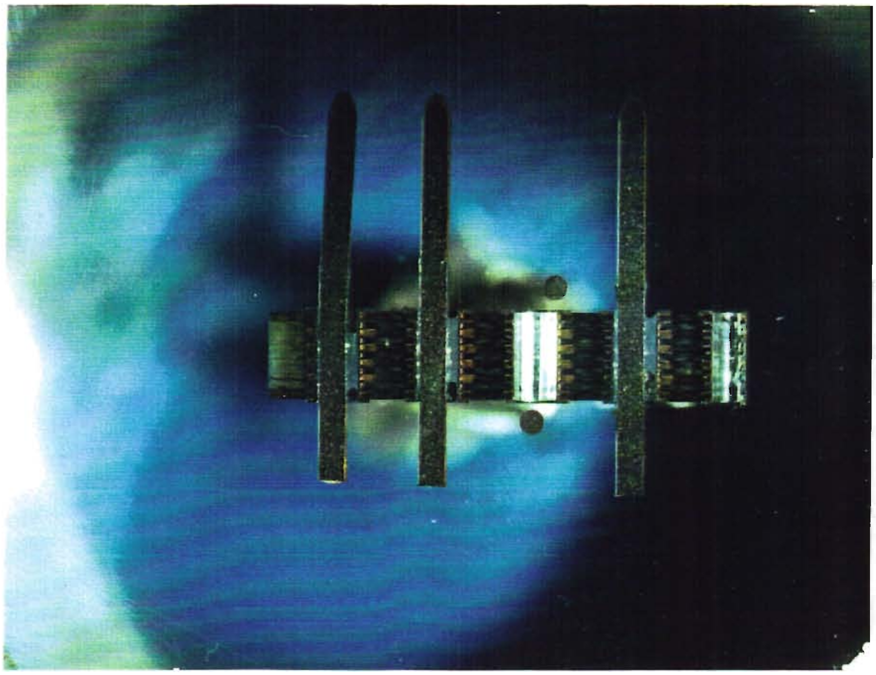
BOTTOM SIDE - 2 PREFORMS - VAPOR PHASE



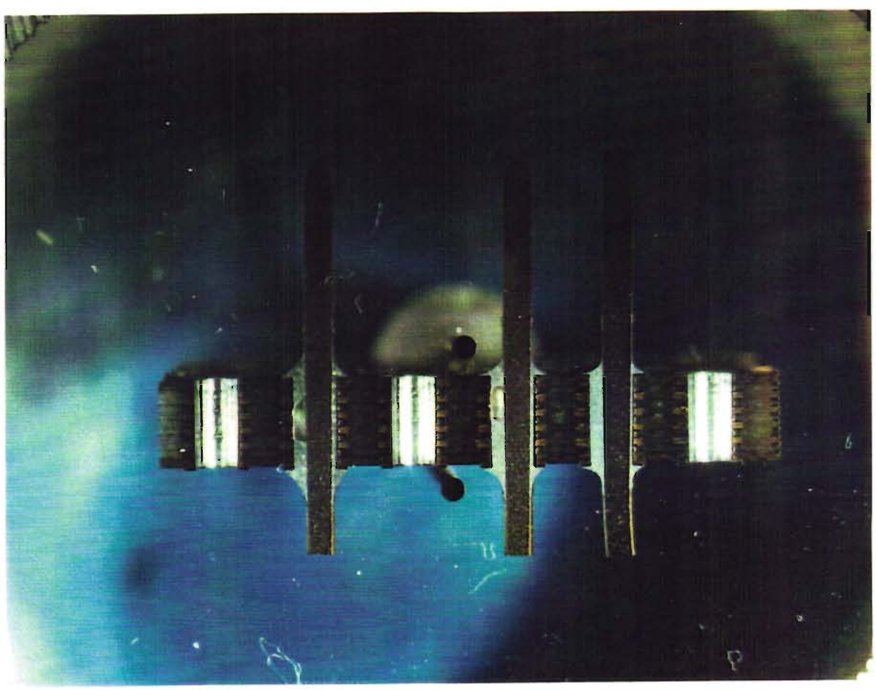
TOP SIDE - 3 PREFORMS - VAPOR PHASE



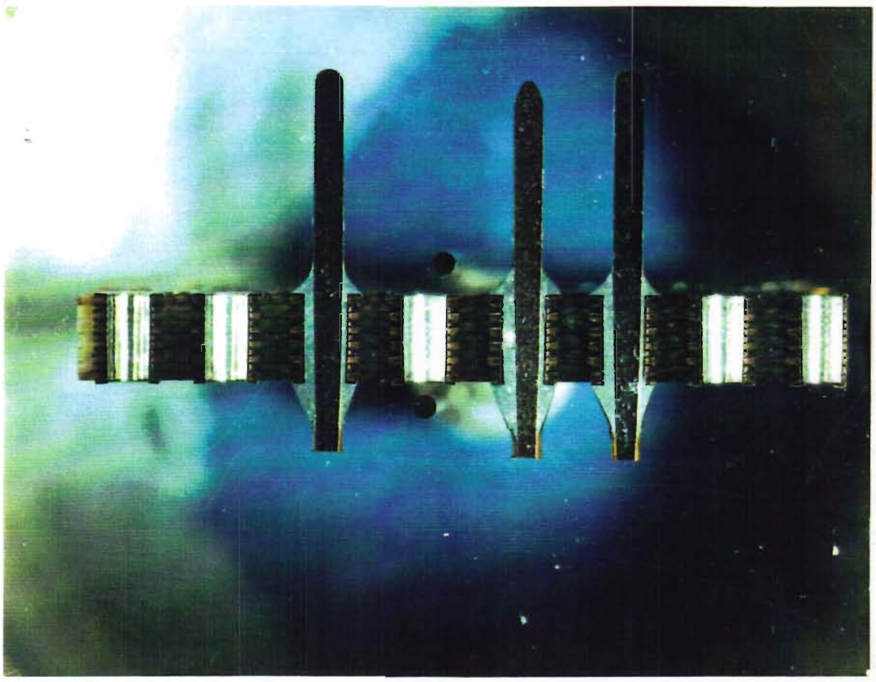
BOTTOM SIDE - 3 PREFORMS - VAPOR PHASE



CROSS-SECTION - 1 PREFORM - VAPOR PHASE



CROSS-SECTION - 2 PREFORMS - VAPOR PHASE

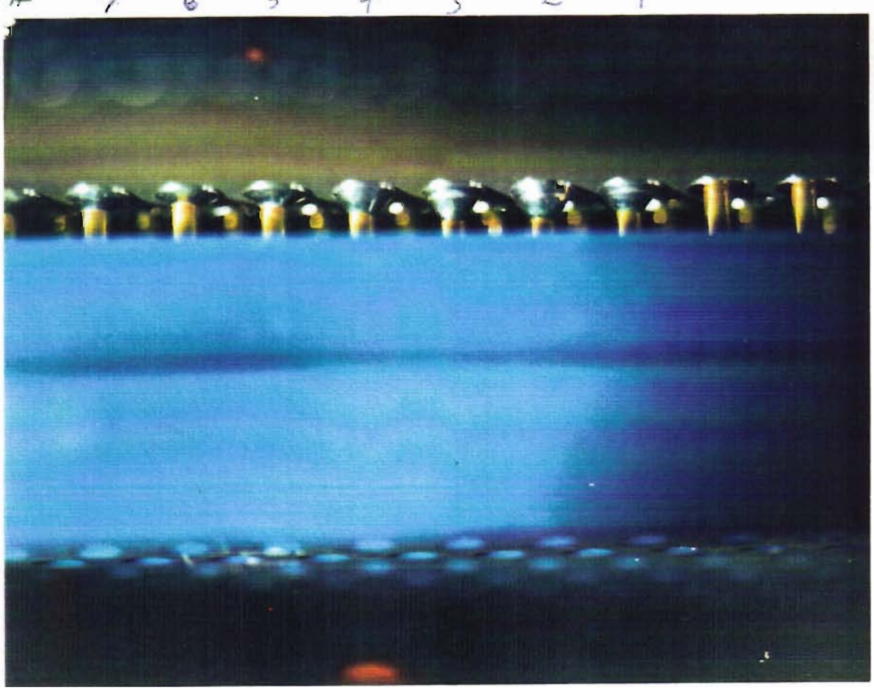


CROSS-SECTION - 3 PREFORMS - VAPOR PHASE

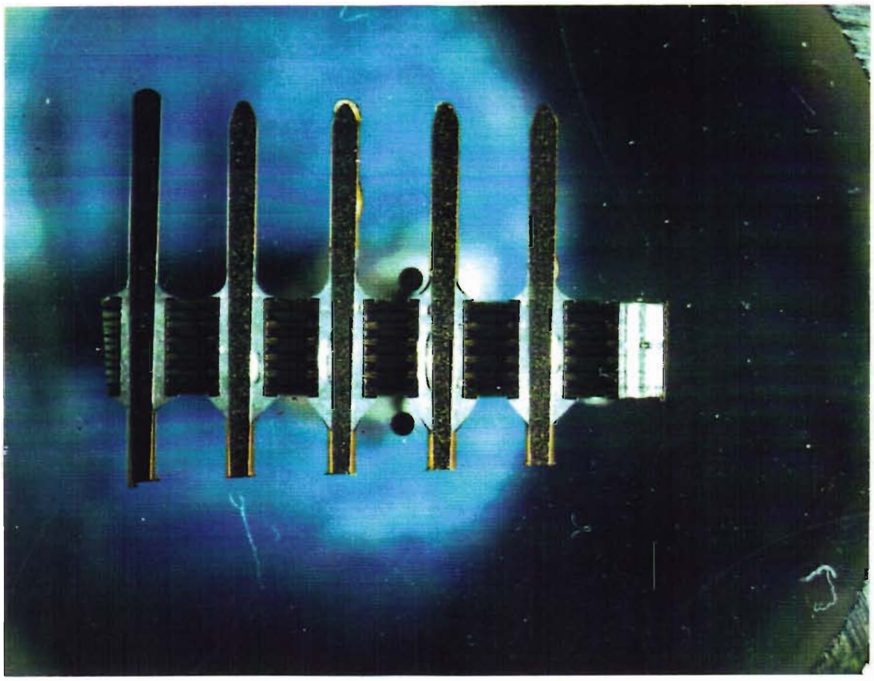
PIN # 7 6 5 4 3 2 1 Ø

TOP SIDE - 2 PREFORMS - LASER

PIN # 7 6 5 4 3 2 1



BOTTOM SIDE - 2 PREFORMS - LASER

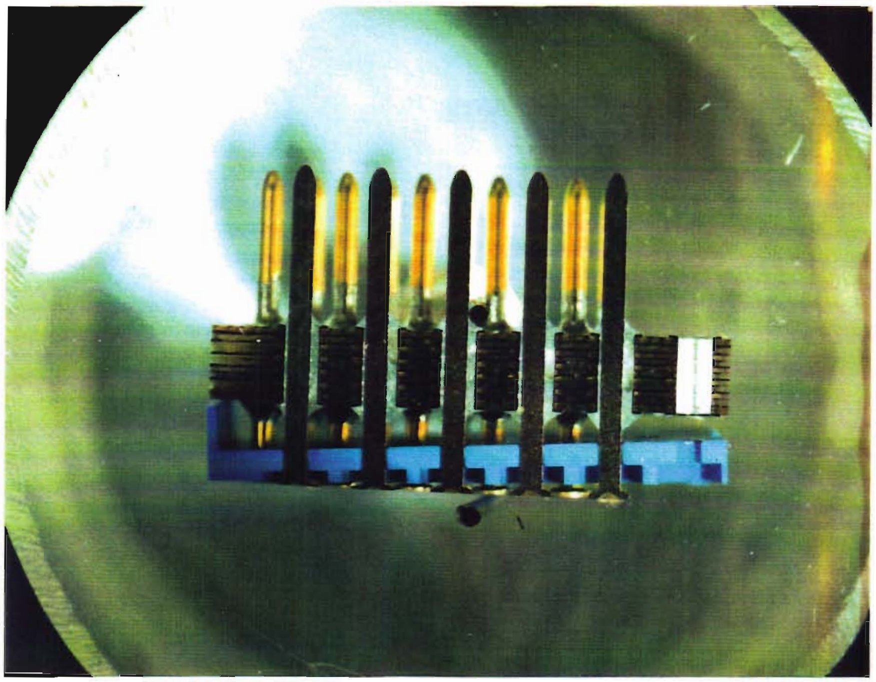


PIN # 5 4 3 2 1

CROSS-SECTION - 2 PREFORMS - CW-YAG LASER
PINS 1-4 - BEAM AIMED AT PIN AND PREFORM
PIN 5 - BEAM AIMED AT PREFORM ONLY

TOP SIDE - 2 PREFORMS - SRT

BOTTOM SIDE - 2 PREFORMS - SRT



CROSS-SECTION - 2 PREFORMS - SRT

X-Ray Fluorescence Measurement Of Gold Thickness On Mark 50 Connector Pins

Au/Ni   Beam Size   6 mils   Memory 10

Press START for Measurement   20 sec   X = 3347.50   Y = 2815.75   Z = 905.00

Meas No	Au Thk	+/-µinch
1	57.33	1.25
2	57.60	1.25
3	49.89	1.11
4	52.78	1.16
5	46.10	1.04
6	56.41	1.23

Trendline   Au
50.00   100.00   150.00

EXIT | MENU | PrnOFF | HISTO | P-STAT | CLEAR | P-SCRN | START

PART II

Overview

One of the critical assembly issues on the Mark 50 torpedo program is the soldering of high I/O (111 or 135 pin) stacking connectors to the PWAs. Due the hierarchy of the assembly operations, it is necessary to attach the connector following the wave soldering of the components. During connector soldering it is required that no other joints, which have already been reflowed, undergo a second reflow of their solder. Previous assembly of the connector was accomplished using manual methods which were extremely time consuming and required large amounts of rework. The goal of this development program was to develop a cost effective method of assembling the connector which was capable of producing repeatable solder joint configurations and minimizing the amount of rework required. The joints must also meet all requirements of WS6536 and the Mark 50 Environmental Stress Screening (ESS) plan.

In Phase I of the project, several different assembly reflow methods were evaluated to include vapor phase, hot gas, Infrared, and laser. Based on test results, it was determined that the Infrared reflow process would be the best process to use for soldering the connector. Based upon the down-selection, Phase II of the development work was limited solely to development of the IR process.

IR Theory

IR soldering is not a new process, it has been used in the defense industry for many years for soldering of hybrid microcircuits and printed wiring assemblies. There are two basic types of IR systems available, the first type utilizes bulbs to emit the IR energy while the second type uses an emitter panel. The system which we are using is of the emitter panel or area source type.

PWB laminates typically absorb IR radiation in the 4-8 micron wavelength range. Since the successful reflow of an assembly depends upon the ability of the material to absorb IR radiation (emissivity) and thus increase temperature, it follows that the IR source must be capable of efficient radiation in the same range as the emissivity of the material being heated. As seen in figure 1, the emissive power of several different IR sources is compared and it can be easily seen that the emmissive power of the area source (panel) falls directly in the range of where the PWB laminate material will absorb IR energy most efficiently.

One of the interesting facts concerning IR soldering is that the typical IR process involves only about 40% direct IR energy transfer to accomplish heating while the remaining 60% is accomplished through "natural" convection. Figure 2 shows the correlation between panel temperature and wavelength. When we use this information along with the information from figure 3 concerning wavelength versus absorptivity of air, it is possible to tailor the IR system to give us either increased convective energy or increased IR radiative energy. As an example, an IR panel can be set to 450^{o}C where the wavelength of radiation is 4.0 microns and the absorptivity of air is less than 0.2 and the PWB will be primarily heated by direct impingement of IR radiation. Alternatively, an IR panel can be set to 371^{o}C where the wavelength of radiation is 4.5 microns and the absorptivity of air is approximately 0.9 and the PWB will be primarily heated by convection.

Taking the aforementioned facts into account, it is possible to use both IR radiation and convection and control the use of each in order to heat up specific areas of the PWB to temperatures required for reflow while keeping the remainder of the PWB below the reflow temperature. Specially designed fixtures can be utilized to shield portions of the assembly from direct IR radiation while still allowing convective energy to impart a portion of the heat required. It is through these methods that we are able to accomplish the selective soldering of the connector while keeping the remainder of the assembly below the reflow temperature.

Fixturing

During Phase I, a simple shielding fixture consisting of a double layer of aluminum foil was wrapped around the printed wiring board (PWB) so that only the connectors were exposed, allowing convective energy to heat up the entire PWB, but IR radiation to reach only the connectors. Naturally, it would be difficult to use aluminum foil in a production environment since it's application would be operator sensitive. Thus, an important consideration in carrying out further process development was the development of an appropriate fixture for shielding the components already soldered to the board while at the same time allowing the Infrared energy to impinge upon and thereby solder the connectors.

Initial experiments with an aluminum sheet-metal shield showed that this was not a good material to use since there was barely any difference in temperature between the shielded and unshielded sections of the PWB. This is due to the fact that the air mass inside of the shield and consequently the PWB gets heated rapidly owing to the high thermal conductivity of aluminum. When using foil, the components are tightly wrapped with hardly any air mass entrapped.

The second material evaluated was titanium since it has one of the lowest thermal conductivities among metals which would not only prevent excess heating of the solder joints on the PWB, but would not "soak up" heat from the IR oven (which could cause inconsistencies in heat loading and oven throughput). It was also decided to plate the titanium material with a bright finish in order to reflect IR energy from the shielded area. Earlier experiments with an unplated titanium shield showed that it was indeed desirable to use a bright finish since the thermal gradient between the inside of the shield and the unshielded area was not substantial (although much better than that obtained with aluminum). Gold plating was chosen rather than chromium, since it was difficult to find a local vendor who could plate chromium on titanium.

A set of drawings for the two types of fixtures used along with pertinent data on the fabrication of the fixtures is attached in Appendix A.

Solder Preforms

The solder preforms used in this assembly technique were donut shaped in order to fit over the connector pins. The preforms were coated with RMA flux to aid in reflow (flux quantity was 1% by weight). Several critical factors influenced the choice of preform size. The preform must remain small enough in outside diameter so as not to interfere with adjacent preforms during reflow and must have an inside diameter which allows it to fit smoothly down onto the pins without binding. The height of the preform will affect the fillet height on the pin and therefore must also be closely controlled. Initial experiments were attempted with two preforms (.070" OD X .040" ID X .020" HT each) which had a volume of 1.037 x 10^{-4}, however, the final preforms chosen were .071" OD X .038" ID X .038" HT (volume of 1.074 x 10^{-4}) and thus only one preform was needed per pin. By using only one preform, we were able to better control the rise of solder on the pin and thus remain within the .060" limit as decided by previous experimentation.

A fixture was designed for mass application of the preforms to the connectors and drawings will be found in Appendix B.

Flux application

Two methods of RMA flux application were tested in order to find the best method. The first method was the application of flux by the use of a spray bottle and the second was application by using a squeeze bottle. The preferred method is the squeeze bottle since with this method the flux can be applied directly to the board in the preform area. With the spray bottle, the flux gets sprayed onto the connector pins, consequently, there is a tendency for the solder fillets to rise higher onto the pins which could cause interference when the connectors are mated. The manual application method seemed to be the cause of uneven heights in the solder fillets and may be overcome by automating the flux application step in the process.

Process Development

Initial IR process development consisted of using a board with thermocouples placed as shown in Figures 4 and 5. This board was used to narrow down the very wide range of parameters, both in temperature and belt travel speed, that could be theoretically used on the machine. The next step was to increase the number of thermocouples and change their locations in order to get a more precise indication of temperatures across the board and at the connectors. Figure 6 shows the increased configuration of thermocouple attachment with all attachments made on the connector pin side of the board.

Experiments with these thermocouples on a blank board showed that although the center of the connector pin matrix reached solder temperature, the remaining pins, especially those closer to the center of the board, did not attain solder reflow temperature even though the IR energy into the connector was high enough as indicated by signs of board scorching. All of the above experiments were conducted using the fixture described above. At this stage, it was decided to increase the convective energy on the board by cutting a hole in the center of the fixture. Experimentation showed the best hole size to be one and a half inches. A tubular fixture with slots, nicknamed "chimney", which can be rotated, can be inserted into this hole for more precise control of convective energy.

In order to obtain a correlation between the mass of the board and temperature profile along the connector pins, it was decided to weigh each of the PWB assemblies. A chart indicating PWB assembly numbers along with their mass is found in figure 7.

The first assembly to be profiled was the lightest, assembly # 5819254 with a mass of 479 grams. Three sets of temperature profile data were obtained and have been attached to this report as data items P322, P323, and P324 (Appendix C). When comparing the temperature gradients at the connector pins, it can be seen that by keeping the temperature in the IR furnace constant and varying the conveyor belt speed, temperature gradients and solder liquidus times at temperature can be altered. Similarly, by placing a refractory material such as titanium at one end of the connector opening, temperature gradients and solder liquidus times at temperature can be altered.

The next assembly to be profiled was the heaviest, assembly # 5818425 with a mass of 751 grams. Four sets of data were obtained and have been numbered as P325, P326, P327, and P328. With the exception of profile P325, where the conveyor belt speed was set at 4 inches per minute, the temperatures in the IR furnace were changed while keeping the belt speed constant at 3 inches per minute. Again, it was found that the temperature gradients and solder liquidus times could be predicted.

Having obtained thermal profile data on the heaviest and lightest boards, it was decided to take a medium weight board and theoretically estimate what it would take to bring the connector pins to solder temperature. This was done by extrapolating the known profiles (the ones with maximum number of pins at solder reflow temperature with a minimum of other areas on the PWB surface attaining solder reflow temperature). The profiles that came closest to meeting the above criteria were profile numbers P324 for the lightest board and P328 for the heaviest board. It can be seen that the temperature settings on the IR furnace for profiles P324 and P328 differ only in zones 3 and 6, with the higher setting of 445 degrees in these zones for the heaviest board as compared to a temperature of 400 degrees for the lightest board.

On comparing the belt speeds for the above two profiles, it can be seen that profile number P328 for the heaviest board was run at 3 inches per minute, whereas profile number P324 for the lightest board was run at 4.5 inches per minute. It was estimated that for the medium weight board, it was best to use the temperature settings of the heaviest board and use the conveyor belt speed of 4.5 inches per minute used on the lightest board.

Profile number 331 was run based on the above theoretical estimates and as can be seen, it bears out the temperature/belt speed relationship which has been established. Mention must be made here that thermocouple number 11 broke loose from the board and consequently, the readings shown by it should be ignored.

A graph has been plotted (figure 8) showing the relationship between the weight of a Mark 50 PWB in grams and IR belt conveyor speed in inches per minute. The graph is based on data using the two boards discussed above (# 5818425 weighing 751 grams and # 5818440 weighing 622 grams). There appears to be a straight line correlation between weight of board and conveyor speed, therefore, by keeping the keeping the temperature in the IR furnace constant for a group of boards such as medium to heavy weight boards, or light to medium weight boards, it is possible to theoretically predict the appropriate conveyor speeds and thereby achieve connector reflow soldering with ease.

Thermal Cycling and Metallurgical Analysis

In order to meet the ESS requirements of the Mark 50 program, sample assemblies of soldered connectors were subjected to thermal cycling from -55^{o}C to 125^{o}C. Metallurgical cross sectioning was done at 0 cycles, 15 cycles (system requirement), and 100 cycles. As seen in the photographs (figures 9, 10, and 11), the metallurgy of the joints has not changed appreciably during the cycling and there is no evidence of fracturing or grain boundary sliding which could potentially lead to a premature failure of the solder joint. The evidence of gold intermetallics at the pin to solder interface is minimal and the tin/lead phase appears homogenous throughout the joint.

The geometry of the joint appears identical from joint to joint across the connector (be aware that the sectioning did not always cut at the same cross-sectional point on the pin and thus geometries may appear slightly different) with minimal sub-surface voids caused by outgassing. All indications are that the process produces a repeatable, high quality solder joint capable of withstanding the ESS requirements imposed upon the program.

Military Requirement Adherence

[Note: Figure and paragraph numbers in this section refer to figures and paragraphs in the specification being discussed.]

Several areas of the process need to be addressed with relation to specific military specifications.

Based upon an investigation into DOD-STD-2000, WS-6536D, and MIL-STD-454J the ideal solder joint for a connector pin through a plated-through hole (PTH) is defined as follows:

Per DOD-STD-2000-1B para. 4.19.1, A plated-through hole used for lead or wire attachment shall be solder filled such that the solidified solder is not only continuous from one side of the printed wiring assembly to the other but also extends onto and covers the terminal areas on each side of the printed wiring assembly. Solder may be depressed on the component side of the lead attachment connection provided that wetting to both the lead and the terminal areas is acceptable. No depression of solder in a plated-through hole with a part lead shall exceed 10 percent of the hole depth as measured from the surface of the terminal area.

Per MIL-STD-454J figure 5-20, the solder may be recessed to a maximum of 25% of the board thickness, however, the concave fillet must wet the hole 360^{o} at the upper edge. Pad coverage on the board surface should be 80% or greater with good wetting 360^{o} around the hole. The surface of the solder should have a satin luster and freeze-line patterns (quilting) present and not be cracked, gritty, or granular in appearance (figure 5-21). There can be no voids present where it is not possible to see the bottom of the void (figure 5-23).

Per WS-6536E para. 3.4.5.3.2, the connector pin is considered a Type II component for mounting purposes. Visually, the angle formed by the solder to the basis metal at the periphery and intersecting points of the solder shall be no greater than 60 degrees (para. 3.5.5.1(c)) on the component side of the plated-through hole terminations.

The solder fillet height on the stacking connector pin must be 0.040 inch maximum, per the assembly drawing requirements, on the non-component side of the connector body in order to eliminate interference with the next connector.

All of the above mentioned requirements, with the exception of the fillet height, have been complied with and are repeatable utilizing the process and controls which have been developed. Additionally, a special technology package for use of IR soldering has been submitted to the Navy as required. A copy of the Westinghouse process specification for the process can be found in Appendix D.

Althought the fillet height is closer to .060" on the joints being formed, there is still sufficient clearance for the connectors to mate. It is our opinion that the specification for fillet height be changed to a maximum of .060". This decision had been previously approved by Steve Mihalick in Cleveland. Figures 16 and 17 in this report shows a cross-section of a mated connector. The solder does not interfere with the gold contact even though the fillet exceeeds the .040" maximum. If the preform height were changed to .030" the fillet would probably remain below the .040" maximum.

One additional consideration is the military's ban on forced air cooling of solder joints. Although the IR system has cooling fans below the belt after the assembly exits the reflow zone, the joint has already fallen below reflow temperatures before reaching these fans. Since the joint is no longer molten, the forced cooling has no effect upon the metallurgy of the joint during its formation and simply serves to cool the fixture for easier operator handling.

Cleaning Process

A cleaning process was developed for the PWAs utilizing a Detrex in-line defluxer with an integral distillation system. The solvent used was Dow Prelete, a 1,1,1-Trichloroethane based mixture. The parameters required to sufficiently remove flux and other residues were as follows:

Spray nozzle	Spray Pressure (PSI)	Flow Rate (GPM)
Pre-Clean Top	21	10
Pre-Clean Bottom	19	10
Immersion Left	34	23
Immersion Right	34	23
Distillate Top	23	10
Distillate Bottom	23	10

Belt Speed 1.7 Feet Per Minute

Transition to Production

We have worked closely with engineers from Westinghouse Oceanic Division (Cleveland) on all aspects of this development program. It has been our intention that the process be easily integrated into the Cleveland assembly operation with minimal transition problems. As a part of the development program, we assembled the first 26 Heathkit boards in the Advanced Interconnection Technology Laboratory (AITL) in Baltimore with the assistance of the engineers from Cleveland. By training those engineers and letting them have actual hands-on experience, we were able to jointly eliminate the potential problems which could occur in normal transition of a process to production.

The shielding and preform fixtures which were fabricated during the development program have been given to the Cleveland operation along with the full drawing packages. We have also assisted in the procurement of the production IR system and will help in the set-up if necessary. The machine ordered is slightly larger in order to allow for future changes if needed due to work load (throughput) or design modifications, however, the process parameters developed at AITL are directly transferable to the larger machine.

Conclusions

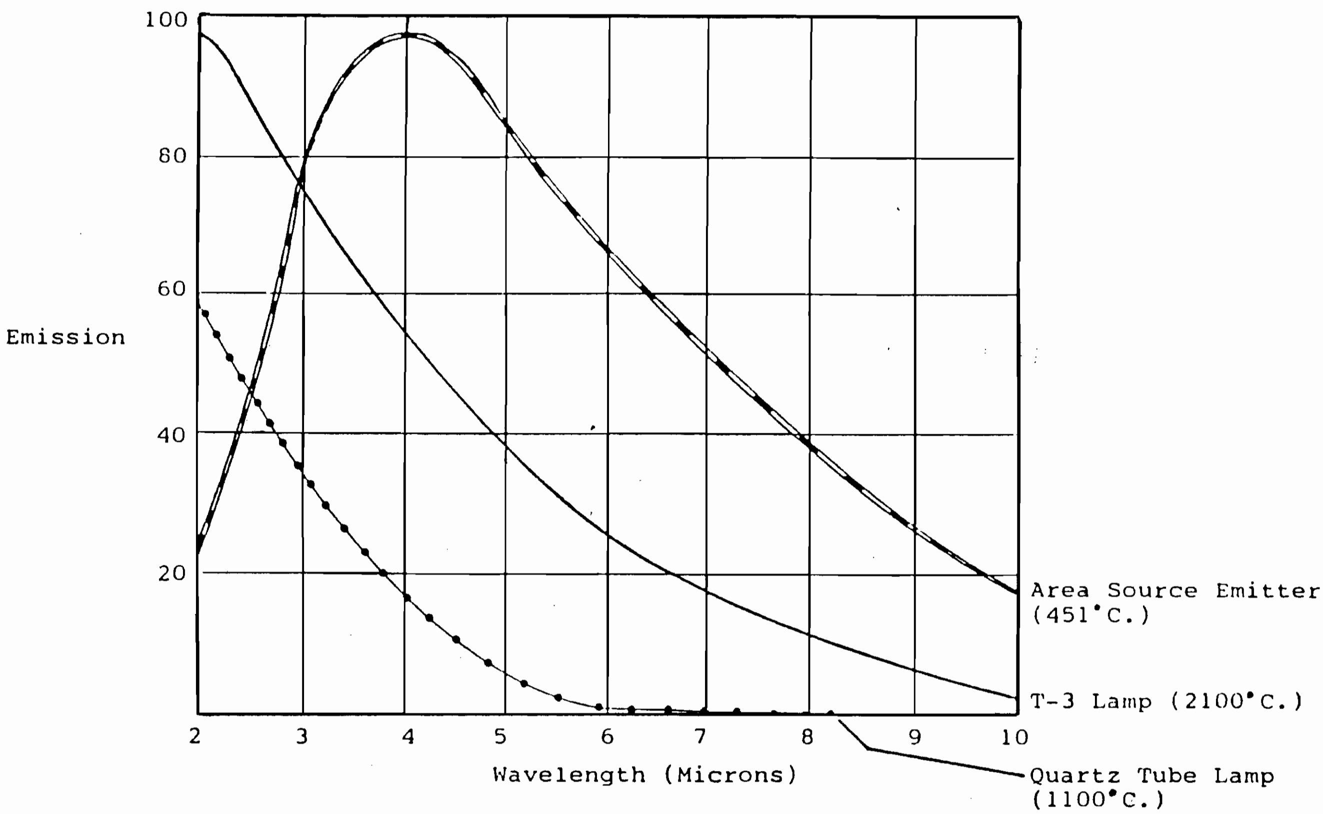
The use of Infrared technology for selective soldering of components on pre-assembled PWBs seems to be a feasible alternative to manual assembly methods. Assembly time is reduced dramatically (by a factor of ten) and rework becomes almost non-existent. Joints are repeatable and all aspects of the process adhere to applicable military specifications. A portion of one completed connector can be seen in figure 12.

Several areas of the process can be targeted for further improvement if required. The Mark 50 program has attempted to obtain a standard profile and fixture to be used on PWBs of varying masses and component configurations. The process would be better suited to high volume runs of a single board configuration so that the same profile and fixture could be used and belt speed would not need to be varied. The close proximity of adjacent components and plated-thru holes to the connector also posed a major problem when trying to reflow the connector pins without reflowing adjacent solder which had already been reflowed once. Use of this process could be simplified greatly if the process were taken into account during the design stage and adjacent components and plated-thru holes were kept a specified distance from the outer connector pins. Increasing the preform flux content to eliminate any additional liquid flux application would probably alleviate the uneven fillet height and also further reduce assembly time.

ferences

Stephen J. Dow, The Use of Radiant Infrared in Soldering Surface Mounted Devices to Printed Circuit Boards, Vitronics Corporation, 1984.

Michael L. Martel, Forced Convection: The Dark Horse, Circuits Manufacturing Magazine, February 1989.



Efficiency Emission Spectra of Exemplary Radiators

Figure 1

IR Temperature vs Wavelength

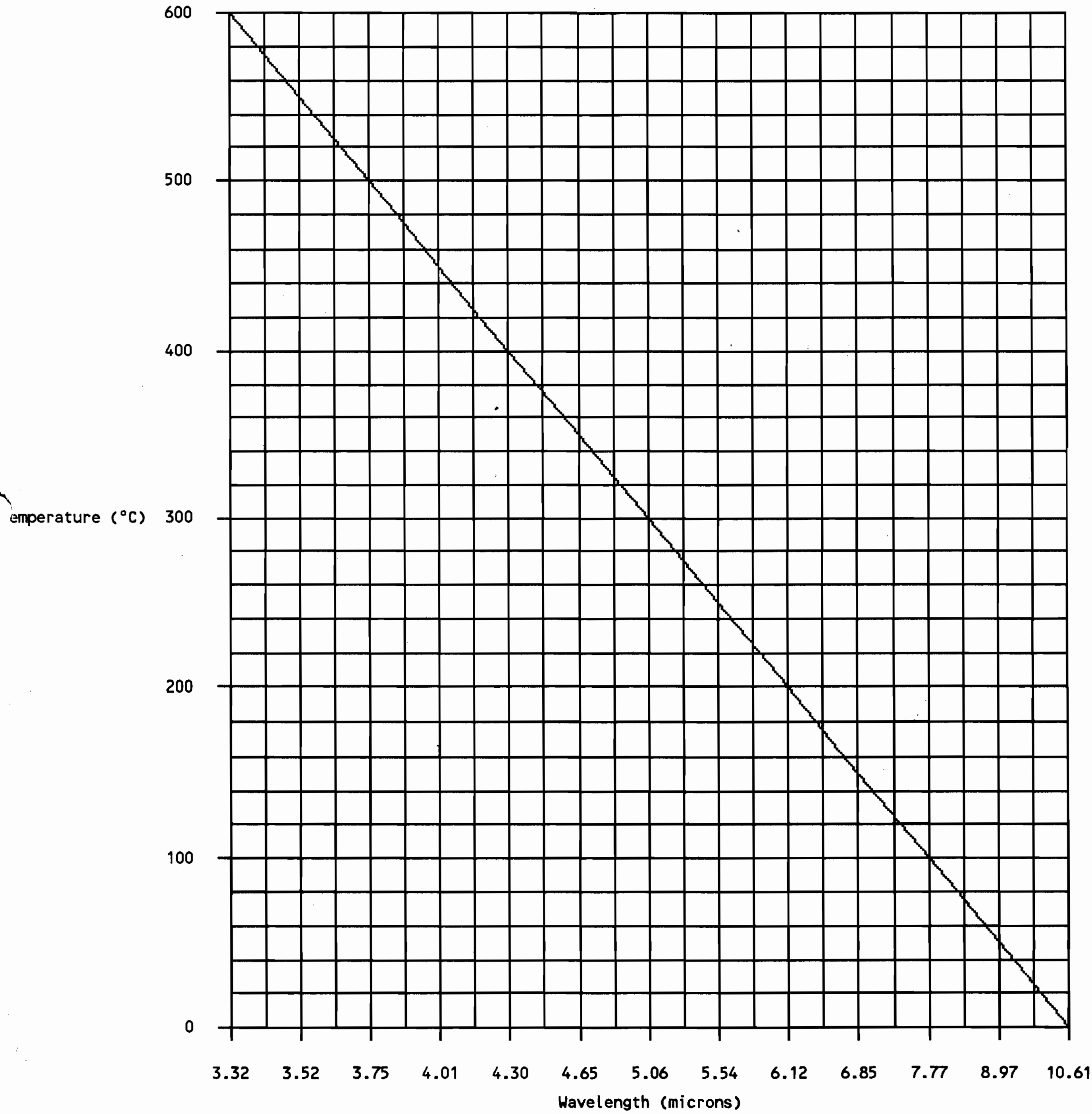


Figure 2

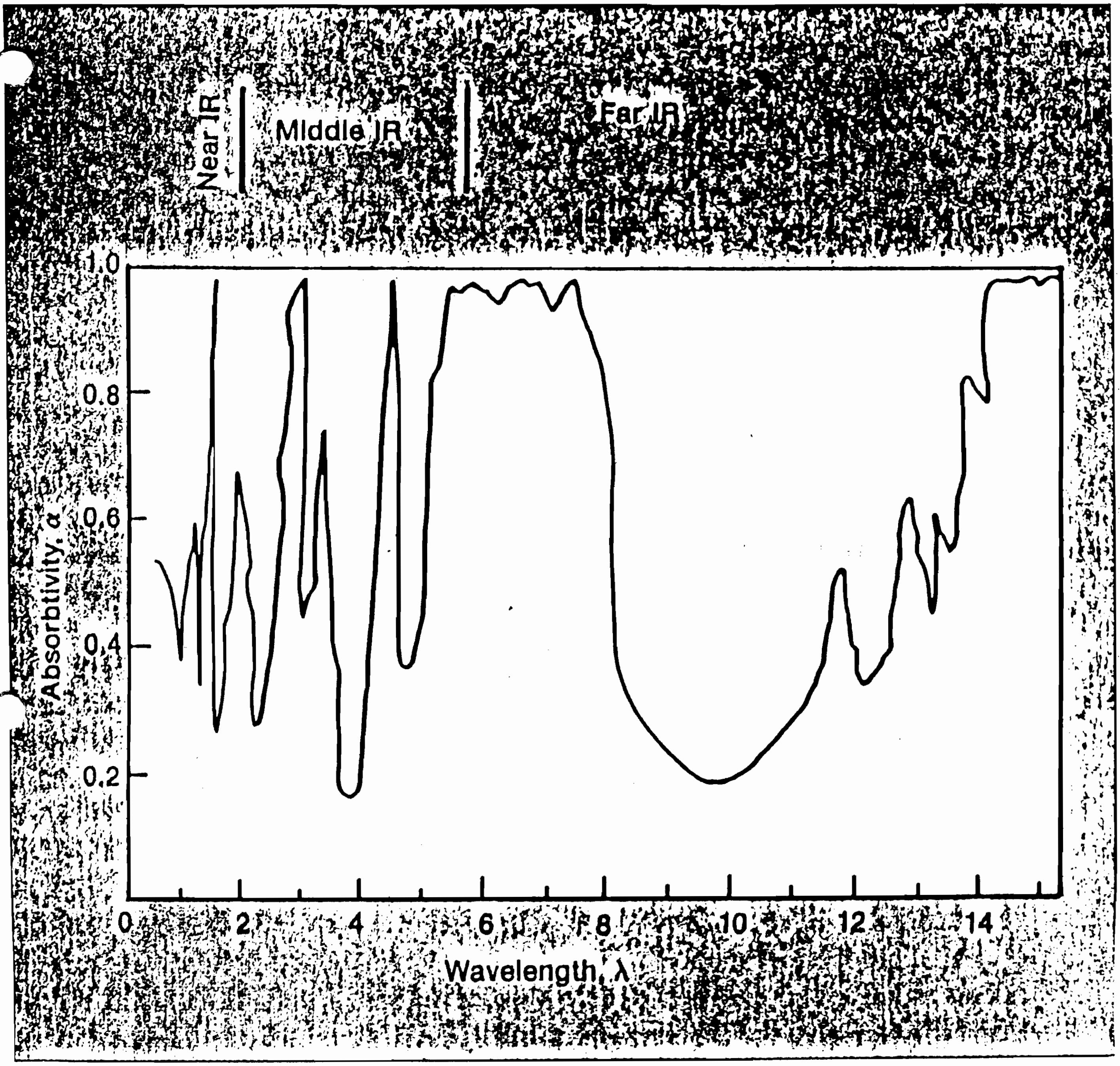


Figure 3

Wavelength vs Absorptivity of Air

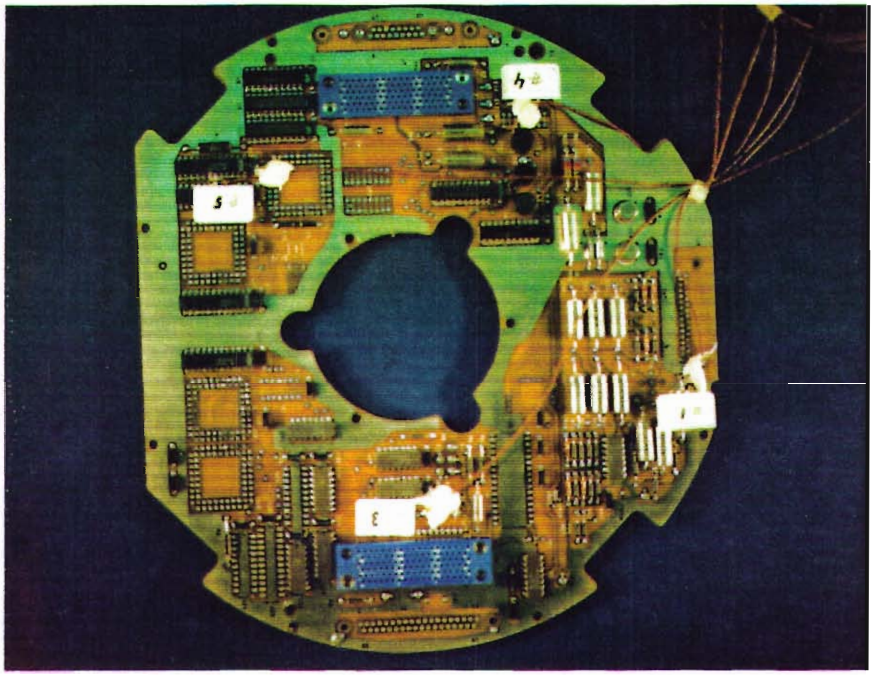


Figure 4

Front side of thermocoupled PWA

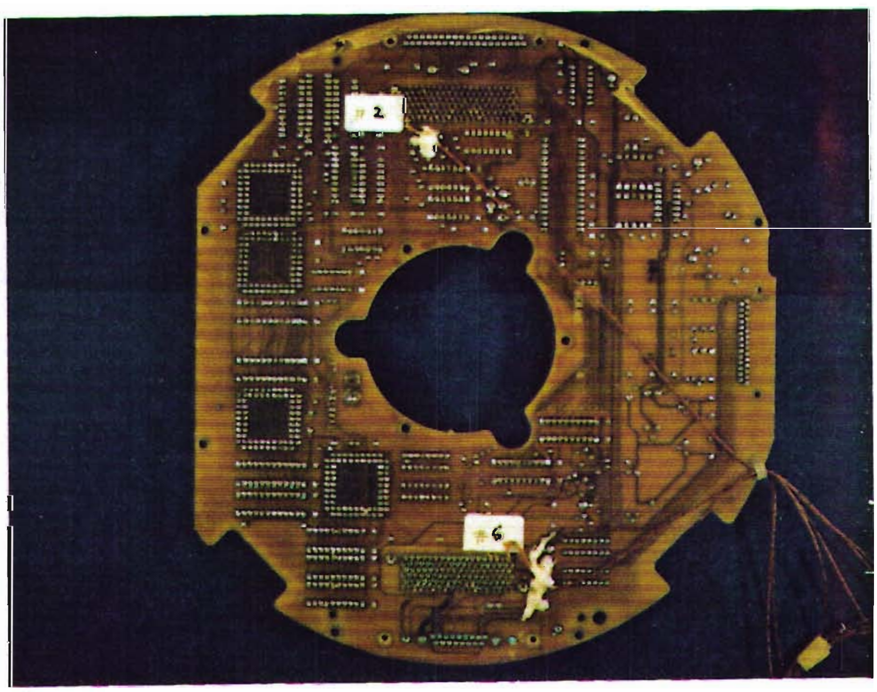


Figure 5

Back side of thermocoupled PWA

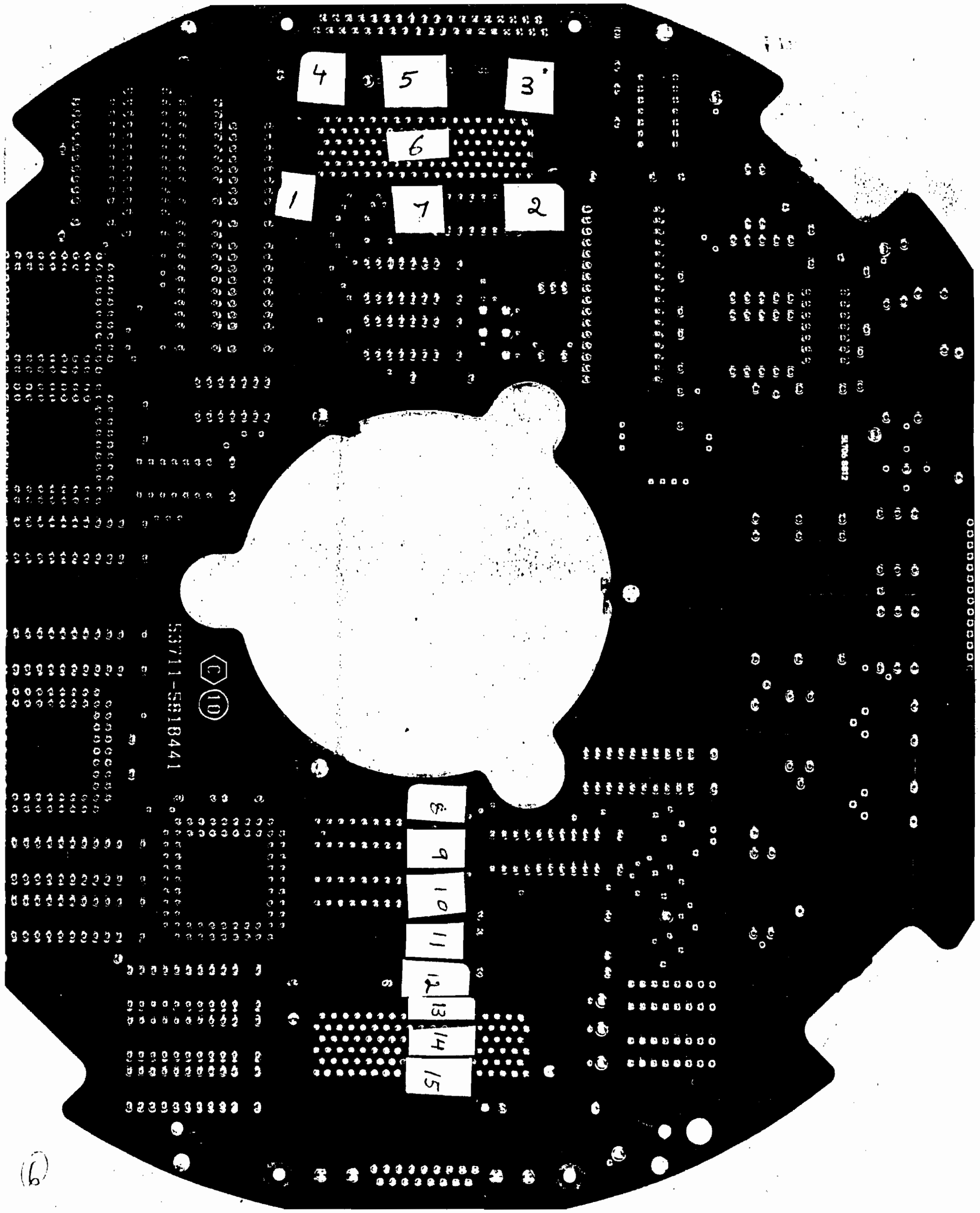


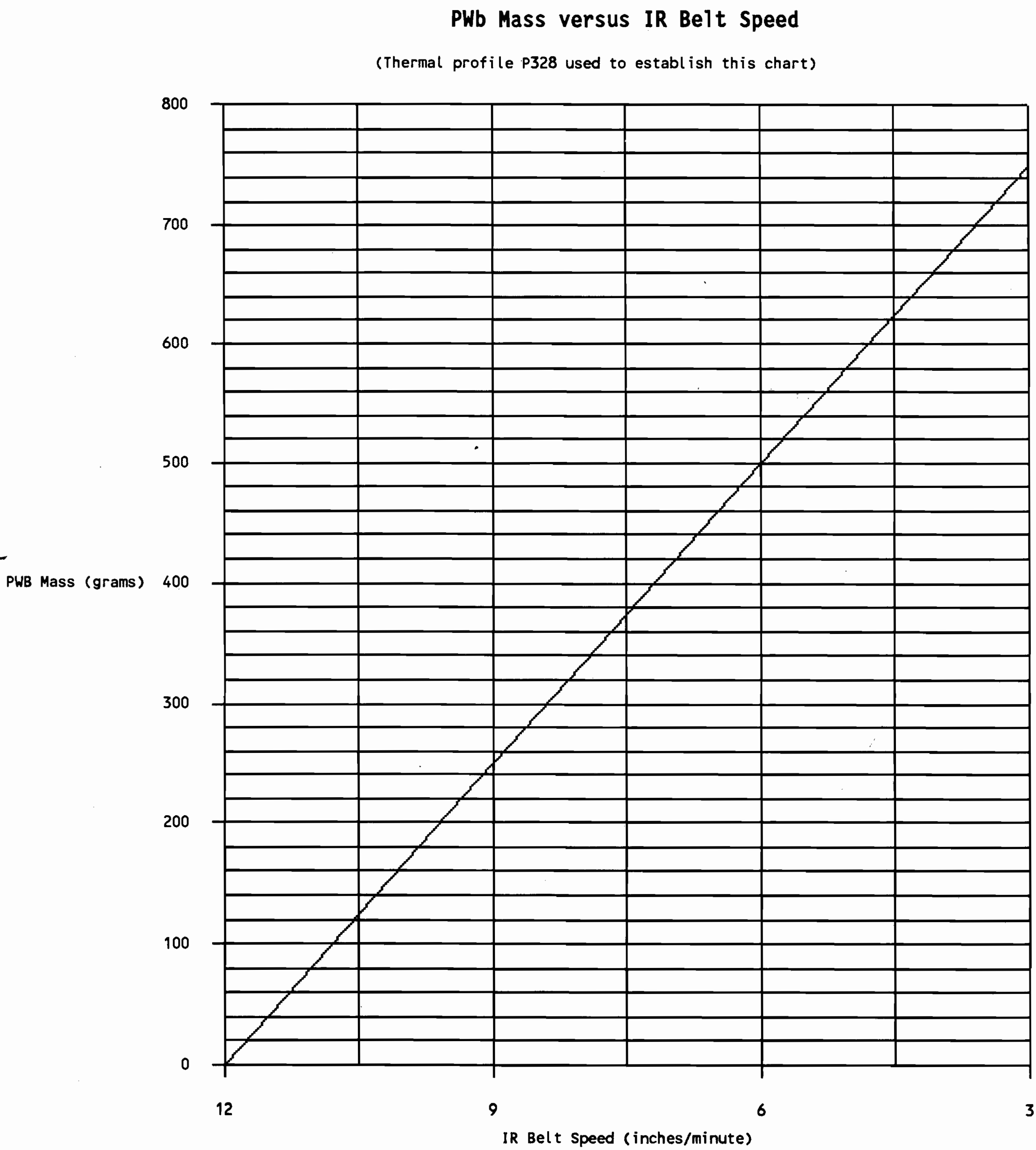
Figure 6

Thermocouple configuration for final profiling.

WEIGHT OF BOARDS
(grams)

BOARD NUMBER	HeathKit 1	HeathKit 2
5818288	611	
5818440	627	622
5818448	595	597
5818418	742	735
5818431	681	675
5818425	745	751
5819254	485	479

Figure 7



(Data valid for Vitronics SMD 318 system with additional preheat only)

Figure 8

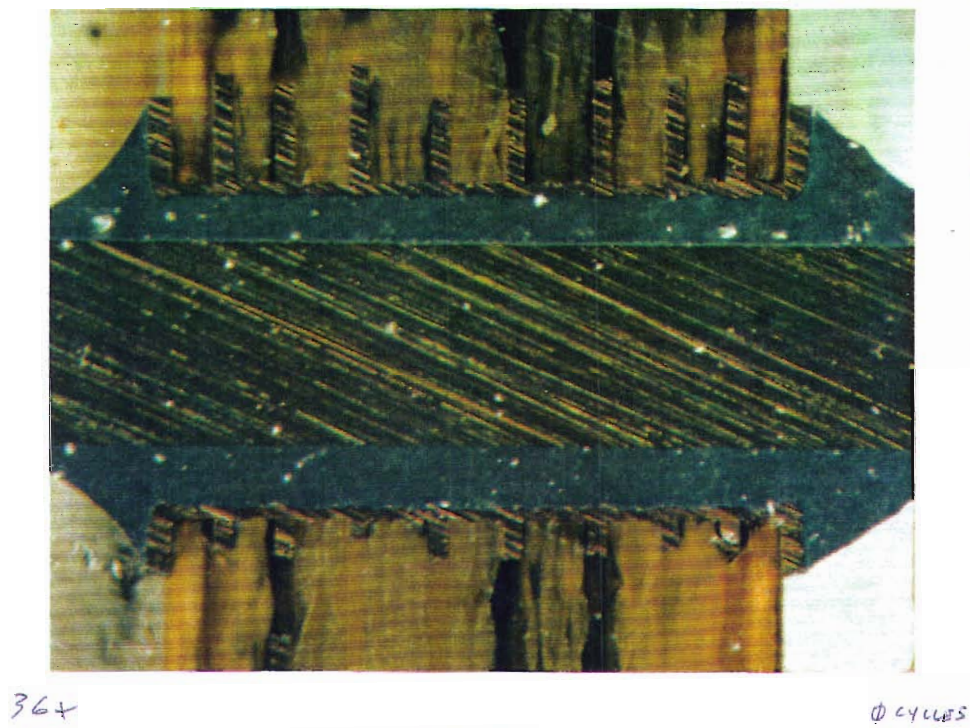


Figure 9

Cross section prior at 0 cycles
(Optical photo)

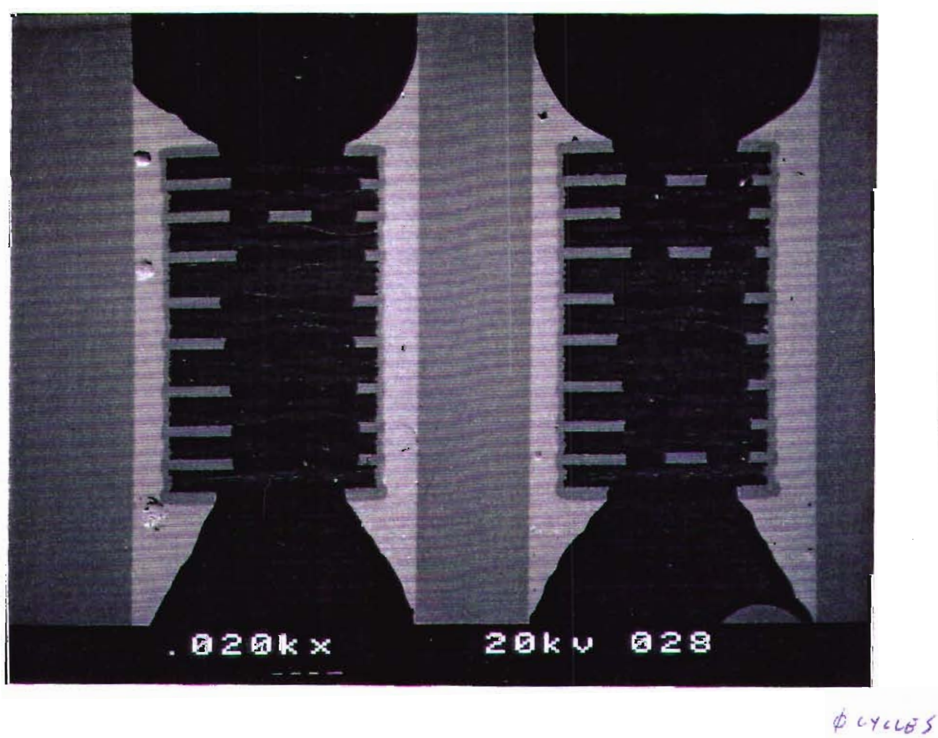


Figure 10

Cross section at 0 cycles
(SEM photo)

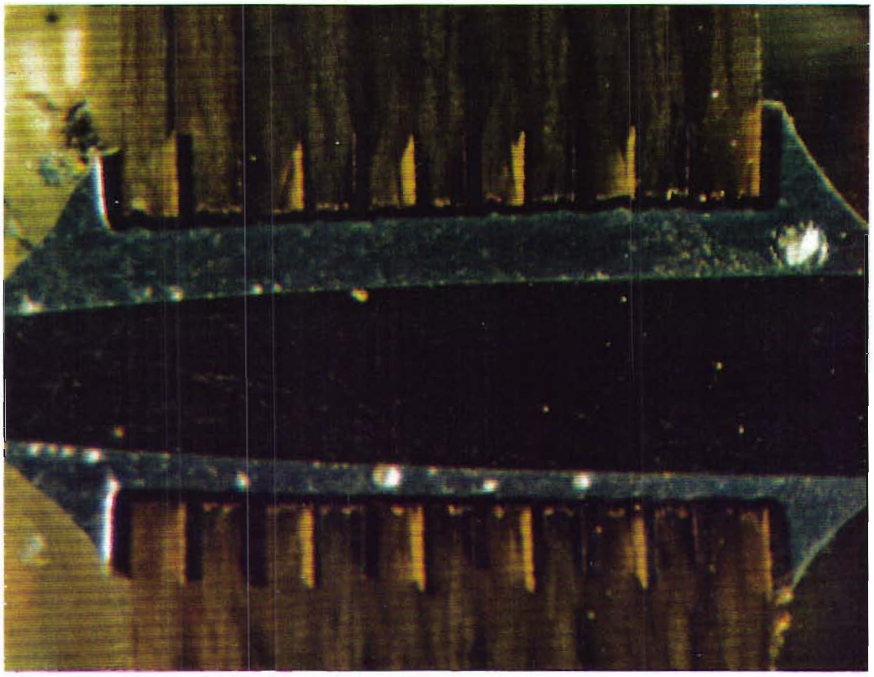


Figure 11

Cross section prior at 15 cycles
(Optical photo)

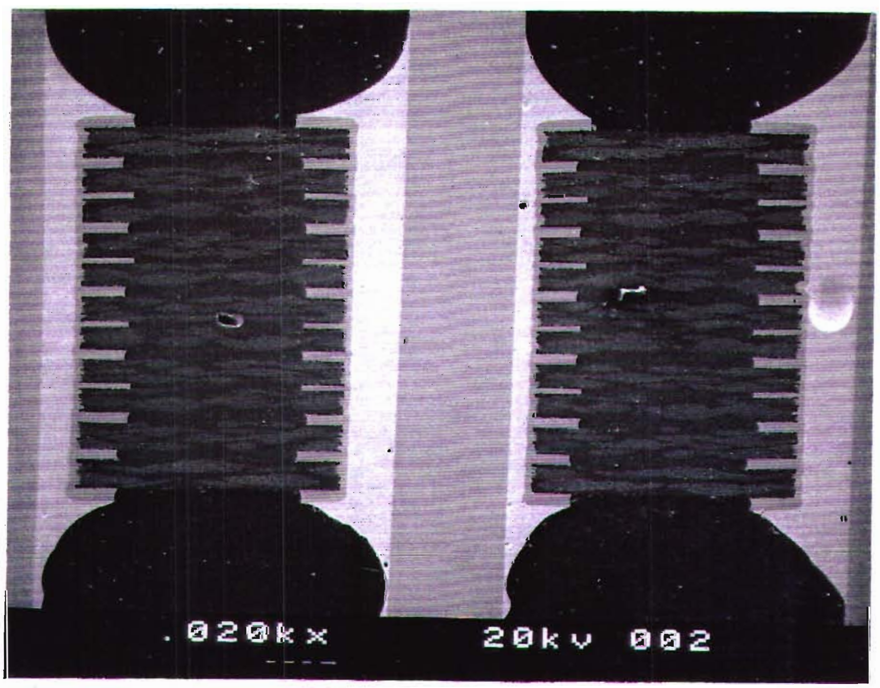


Figure 12

Cross section at 15 cycles
(SEM photo)

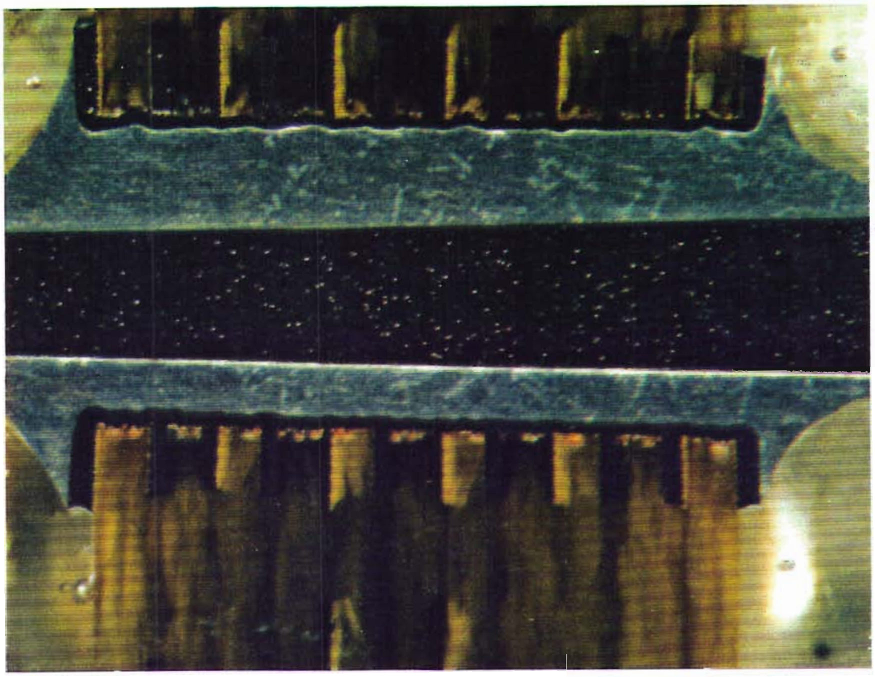
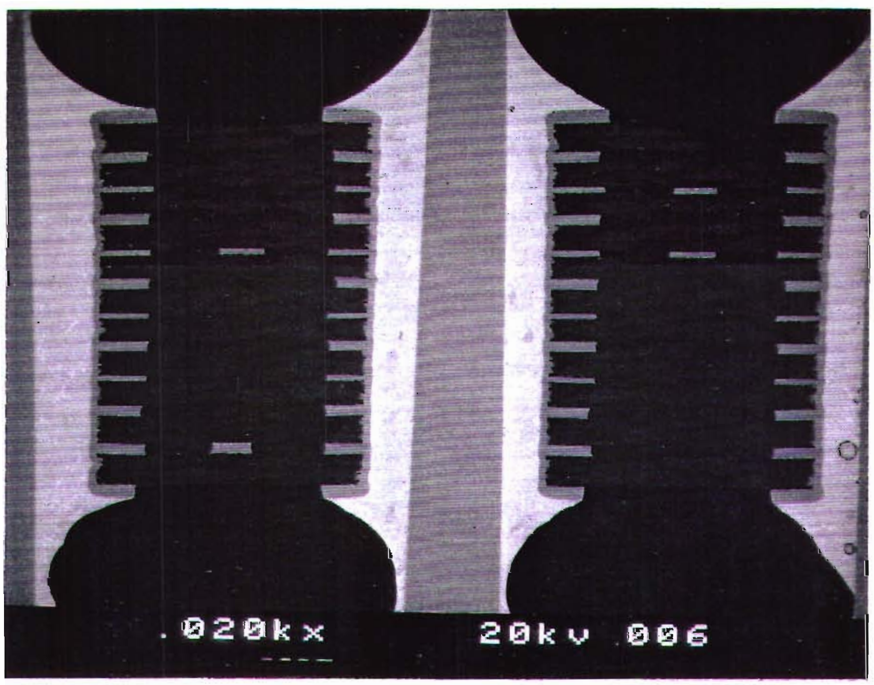


Figure 13

Cross section prior at 100 cycles
(Optical photo)



100

Figure 14

Cross section at 100 cycles
(SEM photo)

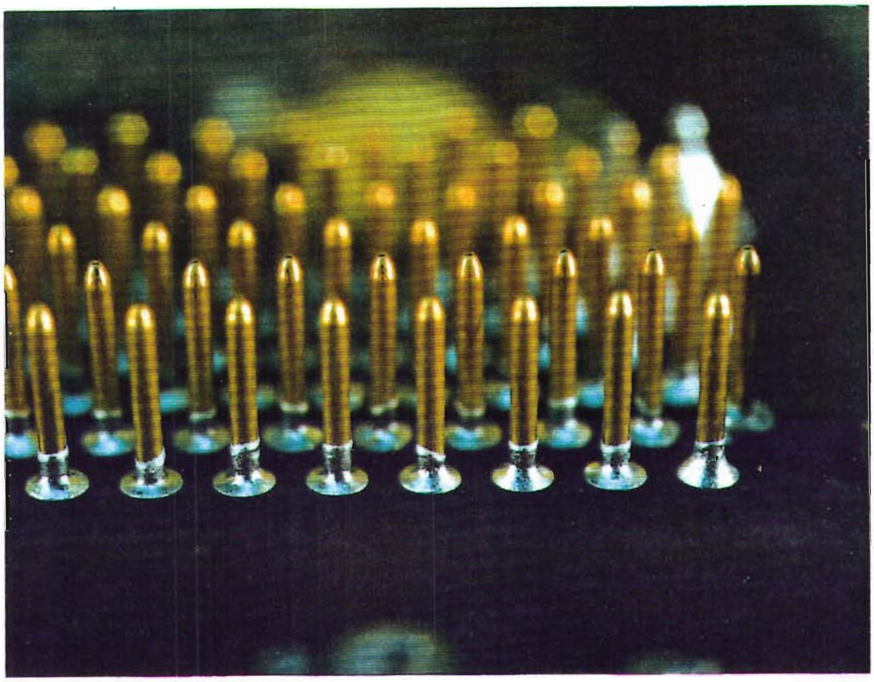


Figure 15

Section of connector following IR soldering operation (top view).

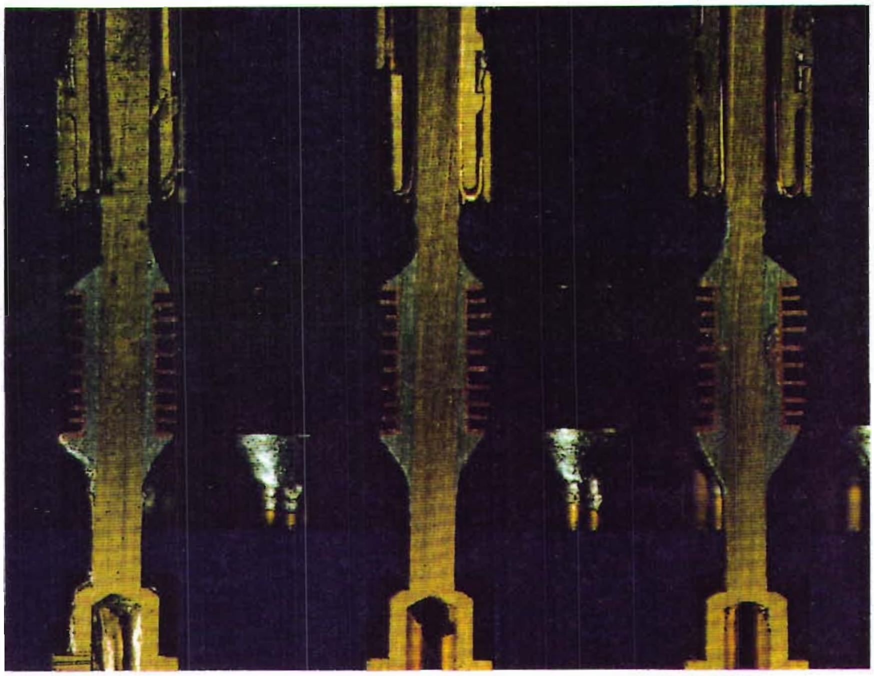


Figure 16

Crossection of connector showing fillet height and mating surfaces. (Note that there is no solder interference in the gold to gold mating area.)

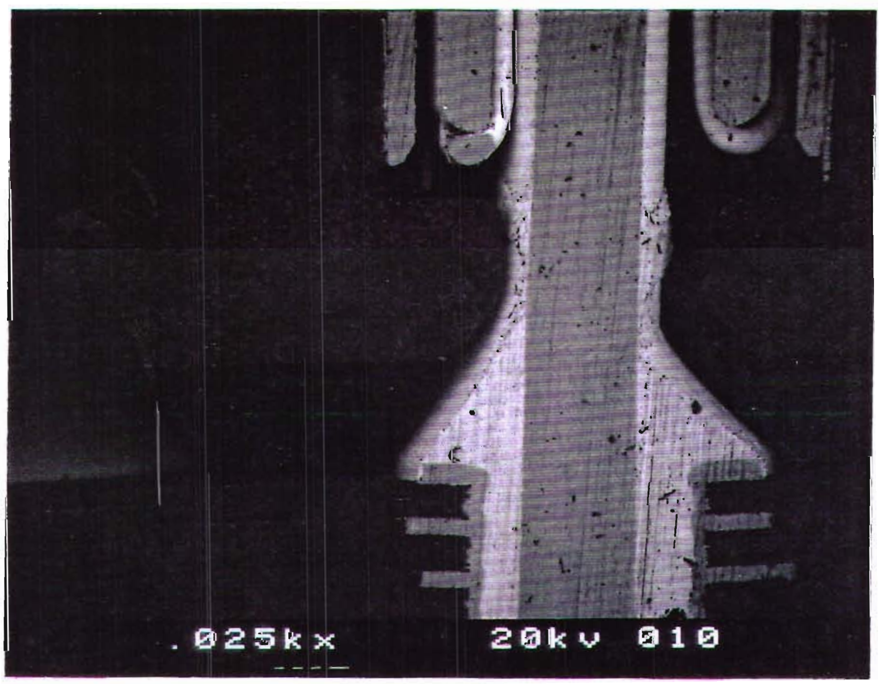
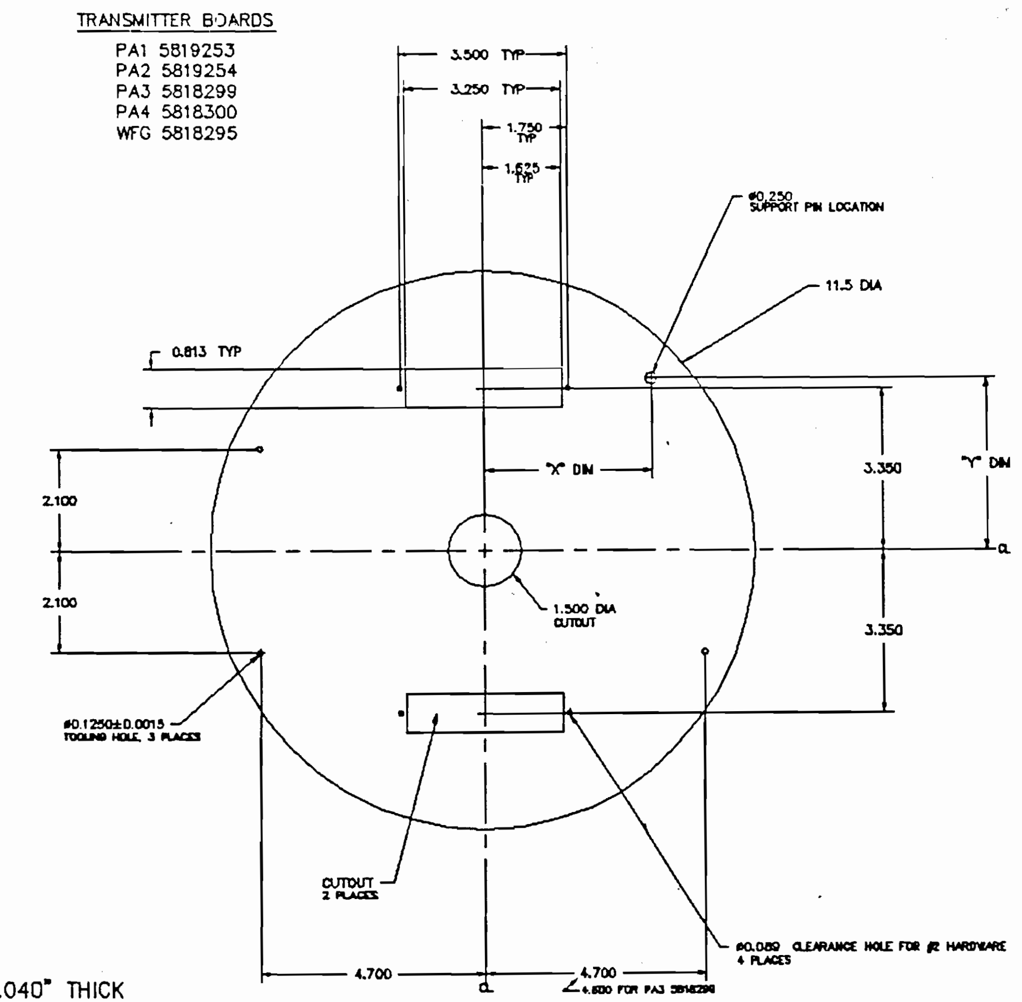


Figure 17

SEM Crossection of connector showing fillet height and mating surfaces. (Note that there is no solder interference in the gold to gold mating area.)

Appendix A

Set of Drawings for Two Types of IR Shielding Fixtures (includes pertinent fabrication data)



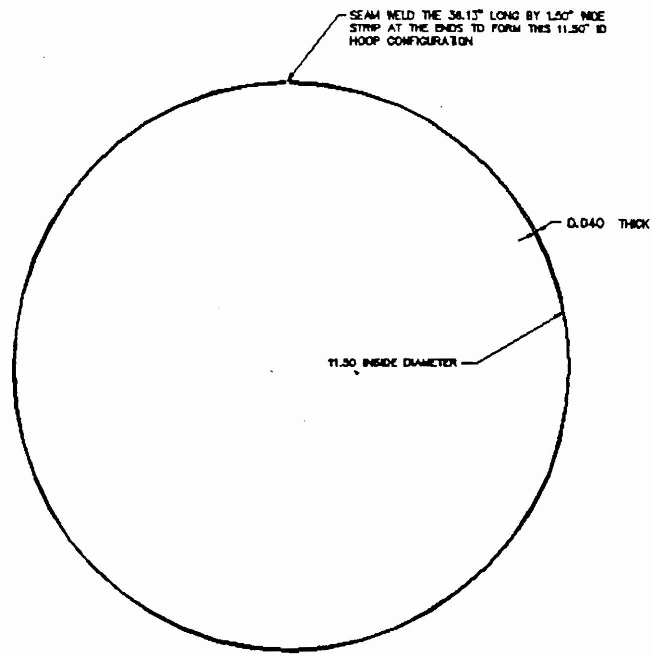
FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

ASSEMBLY	"X" DIM	"Y" DIM
5819253/5819254	3.545	3.545
5818295/5818299/5818300	4.700	2.400

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
+ −	+ −	+ −	DATE: MAY 4, 1989			
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE	FSCM NO.	DWG. NO.
QUANTITY:			EXT: 5-8769 M.S.: V29	A	97942	2A (135fin)



FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

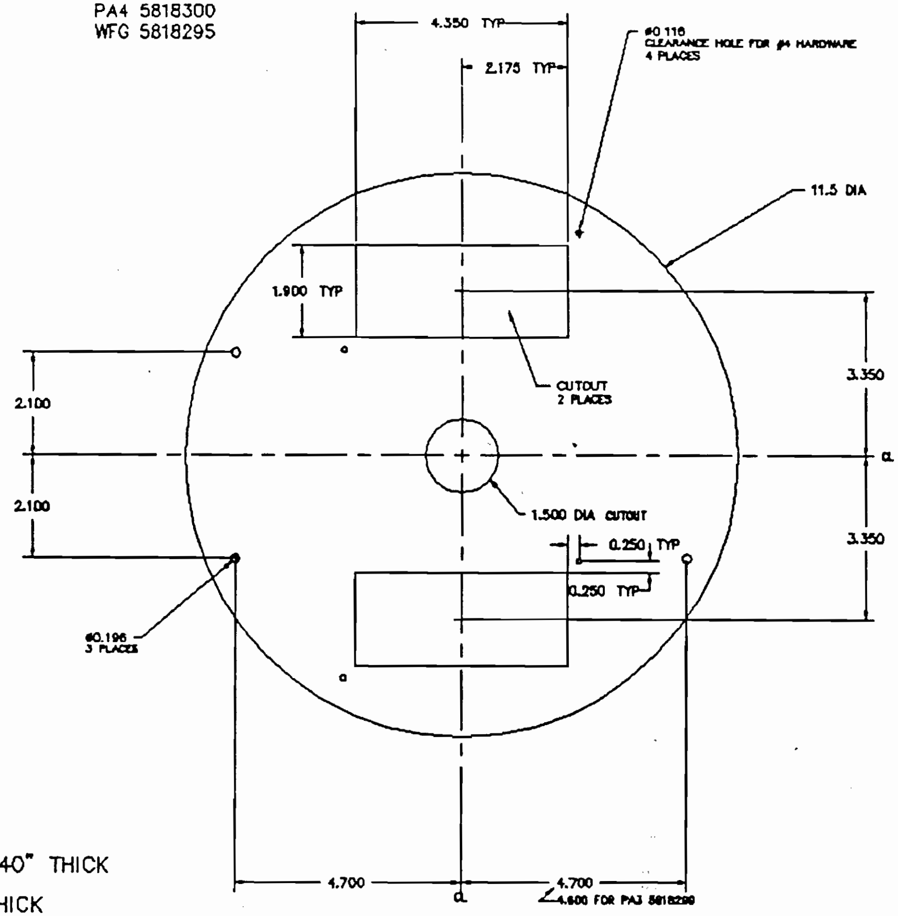
PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
+ –	+ –	+ –	DATE: MAY 4, 1989			
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE A	FSCM NO. 97942	DWG. NO. 2 B
QUANTITY:			EXT: 5-8769 M.S.: V29			

TRANSMITTER BOARDS

PA1 5819253
PA2 5819254
PA3 5818299
PA4 5818300
WFG 5818295

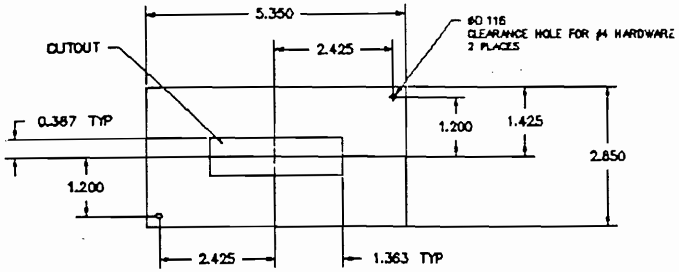


FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR			
+ −	+ −	+ −	DATE: MAY 4, 1989	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE	FSCM NO.	DWG. NO.
QUANTITY:			EXT: 5-8769 M.S.: V29	A	97942	2c

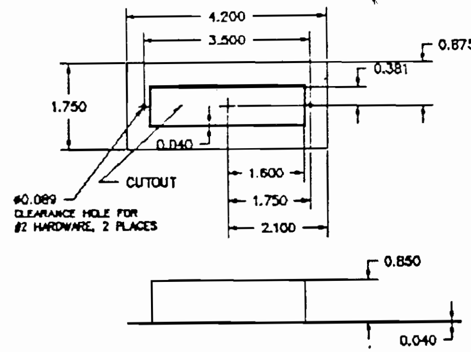


QUANTITY = 2

FABRICATE FROM TITANIUM 6–4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK PER MIL–C–26074

GOLD .000050" THICK PER MIL–G–45204



QUANTITY = 2

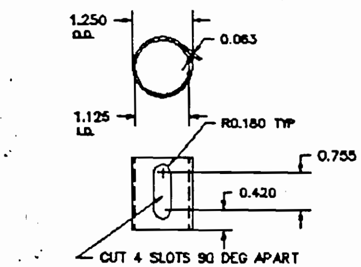
FABRICATE FROM TITANIUM 6–4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK PER MIL–C–26074

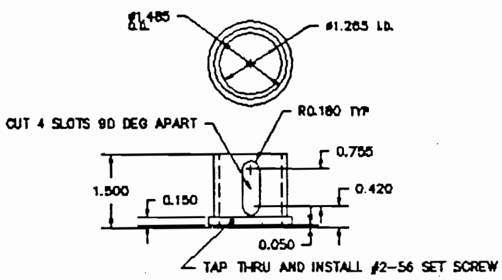
GOLD .000050" THICK PER MIL–G–45204

ADDITIONAL PARTS NEEDED: .750" LONG ALUMINUM RODS OF .250" DIA WITH A CLEARANCE THRU HOLE FOR A 1.5" LONG #4–40 SCREW. THREE ARE NEEDED.

.850" LONG ALUMINUM POST OF .250" DIA ONE IS NEEDED.



FABRICATE FROM ALUMINUM
QUANTITY = 1 PER FIXTURE

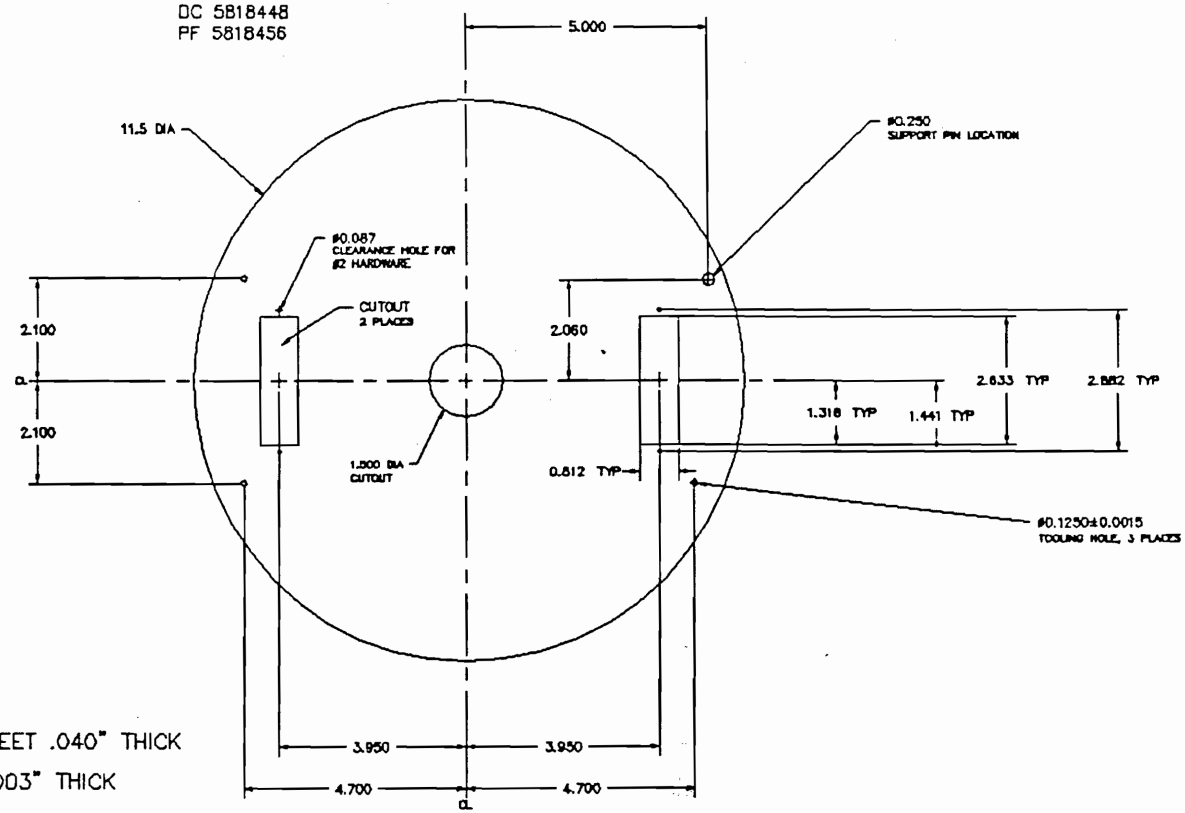


FABRICATE FROM ALUMINUM
QUANTITY = 1 PER FIXTURE

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM
+ –	+ –	+ –	DATE: MAY 4, 1989	
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE A / FSCM NO. 97942 / DWG. NO. 2D
QUANTITY:			EXT: 5–8769 M.S.: V29	

RECEIVER BOARDS

BFMR1 5818288
BFMR2 5818472
SC1 5818418
SC2 5818425
SC3 5818431
DF 5818440
DC 5818448
PF 5818456

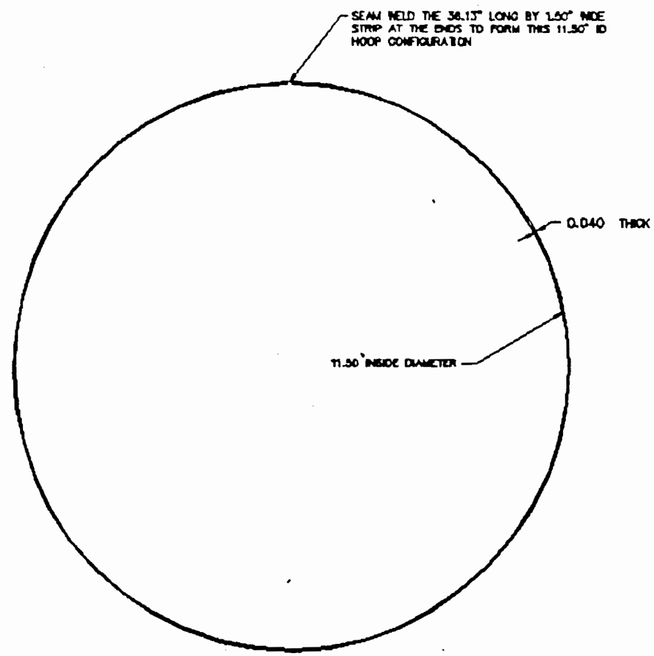


FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR			
+ –	+ –	+ –	DATE: MAY 4, 1989	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE	FSCM NO.	DWG. NO.
QUANTITY:			EXT: 5-8769 M.S.: V29	A	97942	1 A (111 pin)

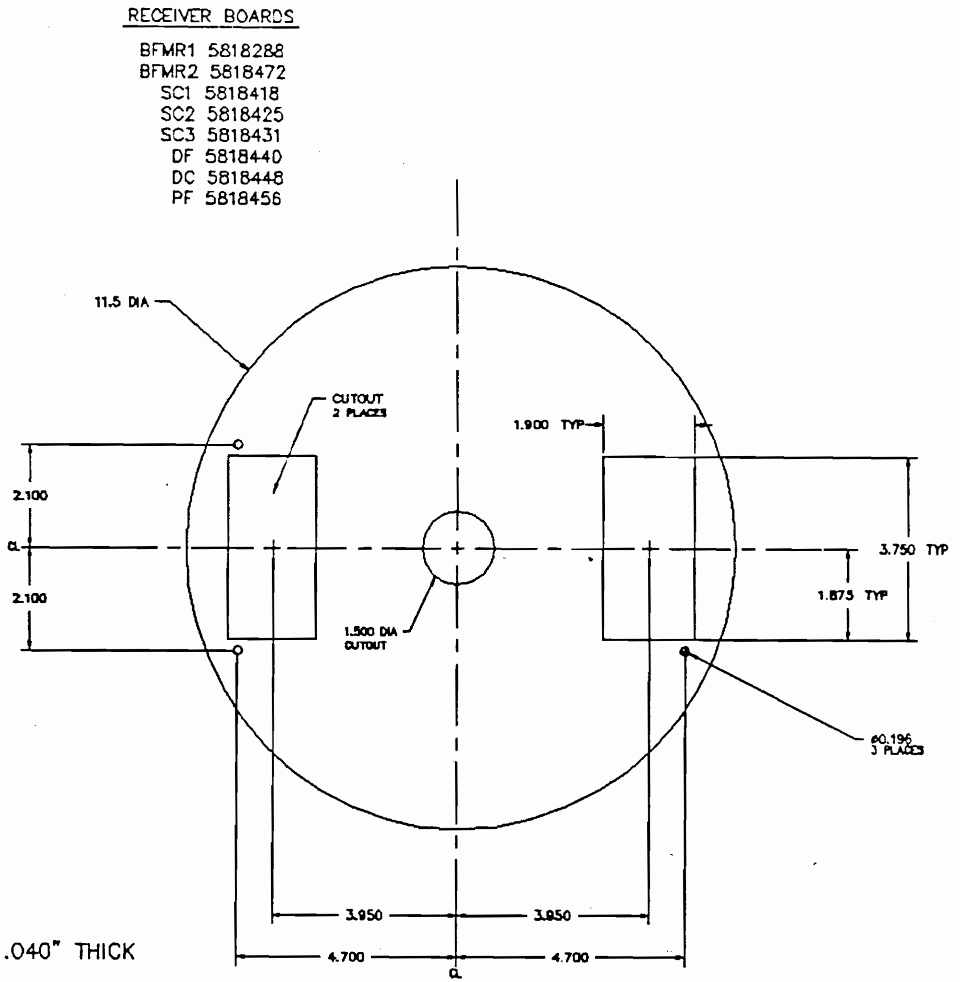


FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR			
+ −	+ −	+ −	DATE: MAY 4, 1989	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
MATERIAL:			ENGINEER: GEORGE HIRA			
QUANTITY:			EXT: 5-8769 M.S.: V29	SIZE A	FSCM NO. 97942	DWG. NO. 1e

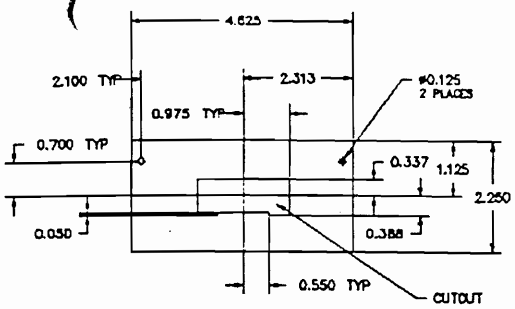


FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203		
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR			
+ −	+ −	+ −	DATE: MAY 4, 1989	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM		
MATERIAL:			ENGINEER: GEORGE HIRA	SIZE	FSCM NO.	DWG. NO.
QUANTITY:			EXT: 5-8769 M.S.: V29	A	97942	1c

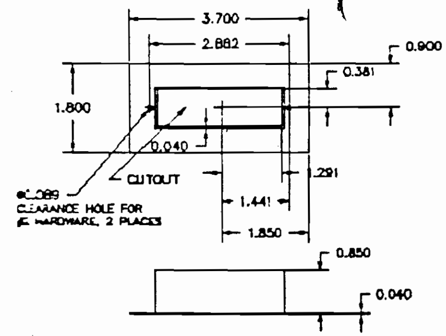


QUANTITY = 2

FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204

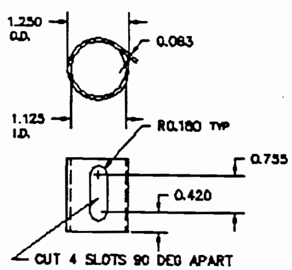


QUANTITY = 2

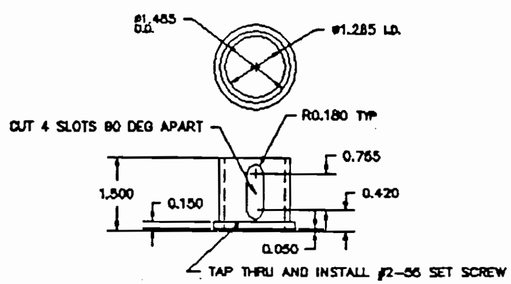
FABRICATE FROM TITANIUM 6-4 SHEET .040" THICK

PLATING: ELECTROLESS NICKEL .0003" THICK
PER MIL-C-26074

GOLD .000050" THICK
PER MIL-G-45204



FABRICATE FROM ALUMINUM
QUANTITY = 1 PER FIXTURE



FABRICATE FROM ALUMINUM
QUANTITY = 1 PER FIXTURE

ADDITIONAL PARTS NEEDED: .750" LONG ALUMINUM RODS OF .250" DIA WITH A CLEARANCE THRU HOLE FOR A 1.5" LONG #4-40 SCREW. THREE ARE NEEDED.

.850" LONG ALUMINUM POST OF .250" DIA ONE IS NEEDED.

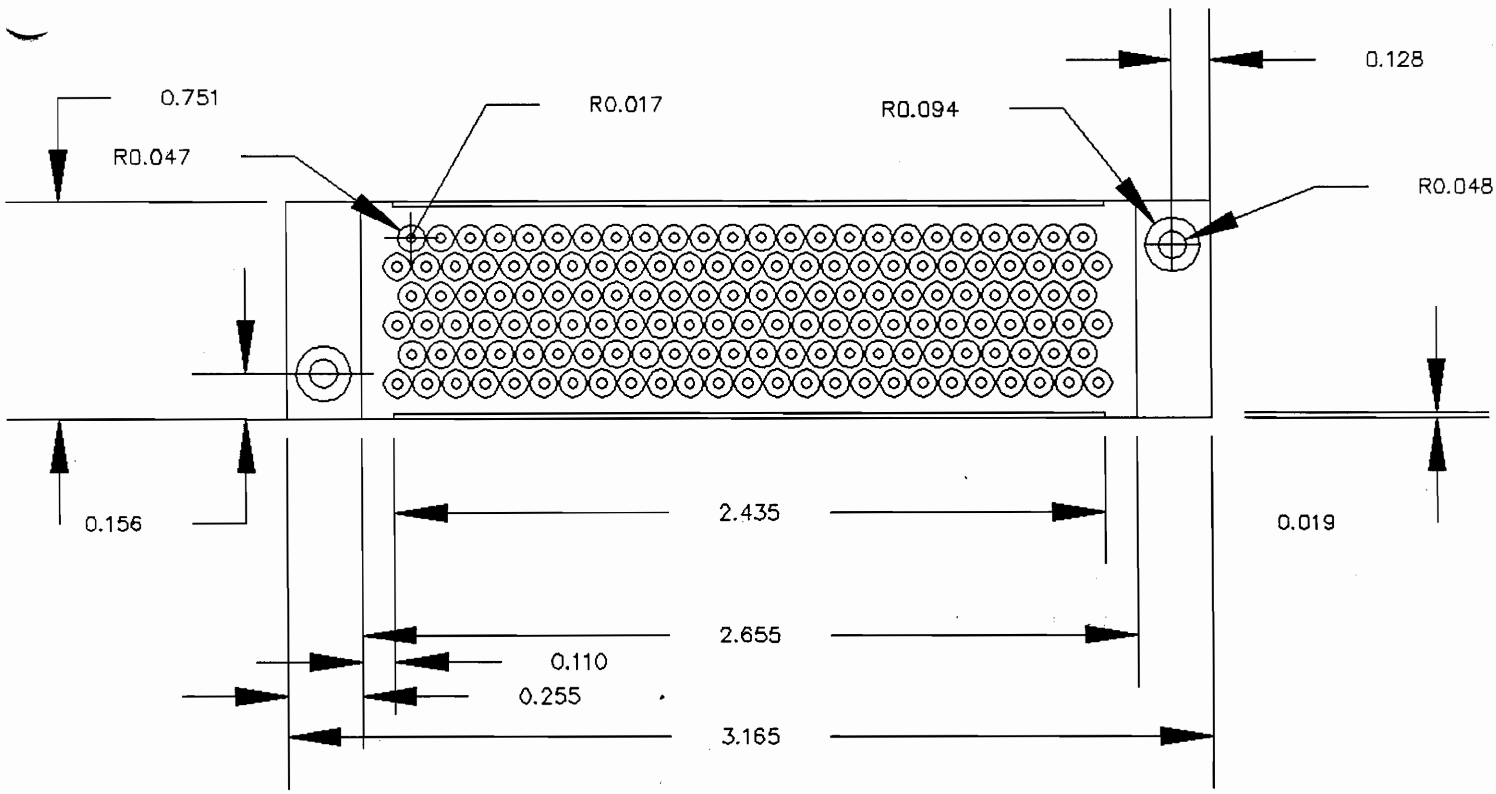
TOLERANCES			CHARGE #: A51701AAAAEX3	WESTINGHOUSE ELECTRIC CORP. BALTIMORE, MARYLAND 21203
2 PLACE	3 PLACE	ANGLES	AUTOCAD FILE: \WALTER\AITL\IR	
+ −	+ −	+ −	DATE: MAY 4, 1989	IR REFLOW SOLDERING FIXTURE FOR MARK 50 TORPEDO PROGRAM
MATERIAL:			ENGINEER: GEORGE HIRA	
QUANTITY:			EXT: 5-8769 M.S.: V29	SIZE A · FSCM NO. 97942 · DWG. NO. 1D

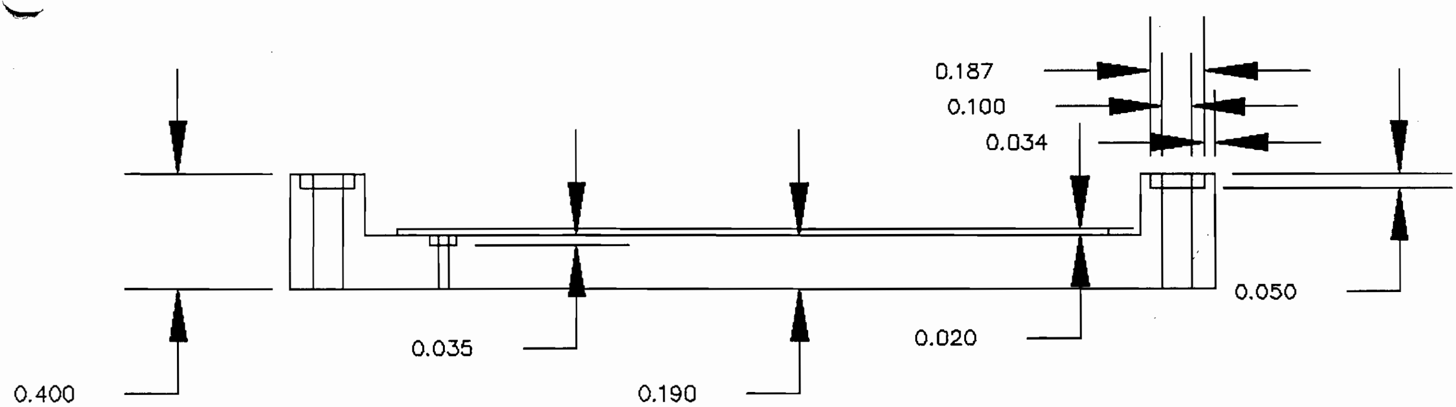
Appendix B

Set of Drawings for Preform Application Tooling

135 PIN CONNECTOR PREFORM TOOL

Pattern to match connector drawing 5819277





Appendix C

Experimental Data

The data in this appendix consists of printouts of the parameter sheets from the IR furnace along with graphs of the temperature profiles recorded with the various parameters. Each data set consists of four pages as follows:

Page 1 -	Shows a cross sectional view of the IR furnace with temperature set points and actual recorded temperatures along with belt speed. Temperatures are in ^{o}C and belt speed is in inches per minute.
Pages 2, 3, 4 -	Shows actual temperatures recorded at locations on board surface. Numbers correspond to locations seen in figure 6. A line on each graph indicates the reflow temperature of 183 ^{o}C. Thermocouples 1, 2, 3, 4, 5, 6, 7, 13, 14, and 15 are in the connector area and should reach reflow temperatures while thermocouples 8, 9, 10, 11, and 12 should remain below reflow temperature.

P322

Prof # 1254

Vitronics 7-Zone Program   Version 2.2C   Copyright 1987 Vitronics Corp.

	Zone 1	Zone 2	Zone 3	Zone 4	
	Set 400	Set 400	Set 400	Set 445	
	Act 400	Act 400	Act 400	Act 446	
Process Ready		Set 400	Set 400	Set 445	Belt Speed:
		Act 400	Act 400	Act 446	
		Zone 5	Zone 6	Zone 7	4 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-19-1989 08:26

↑ = 5° high   ↓ = 5° low   ↑ = 25° high   Shut Down at ± 25°C

Communication Display

To controller : SF
F m controller : B10
S nning Temperatures

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

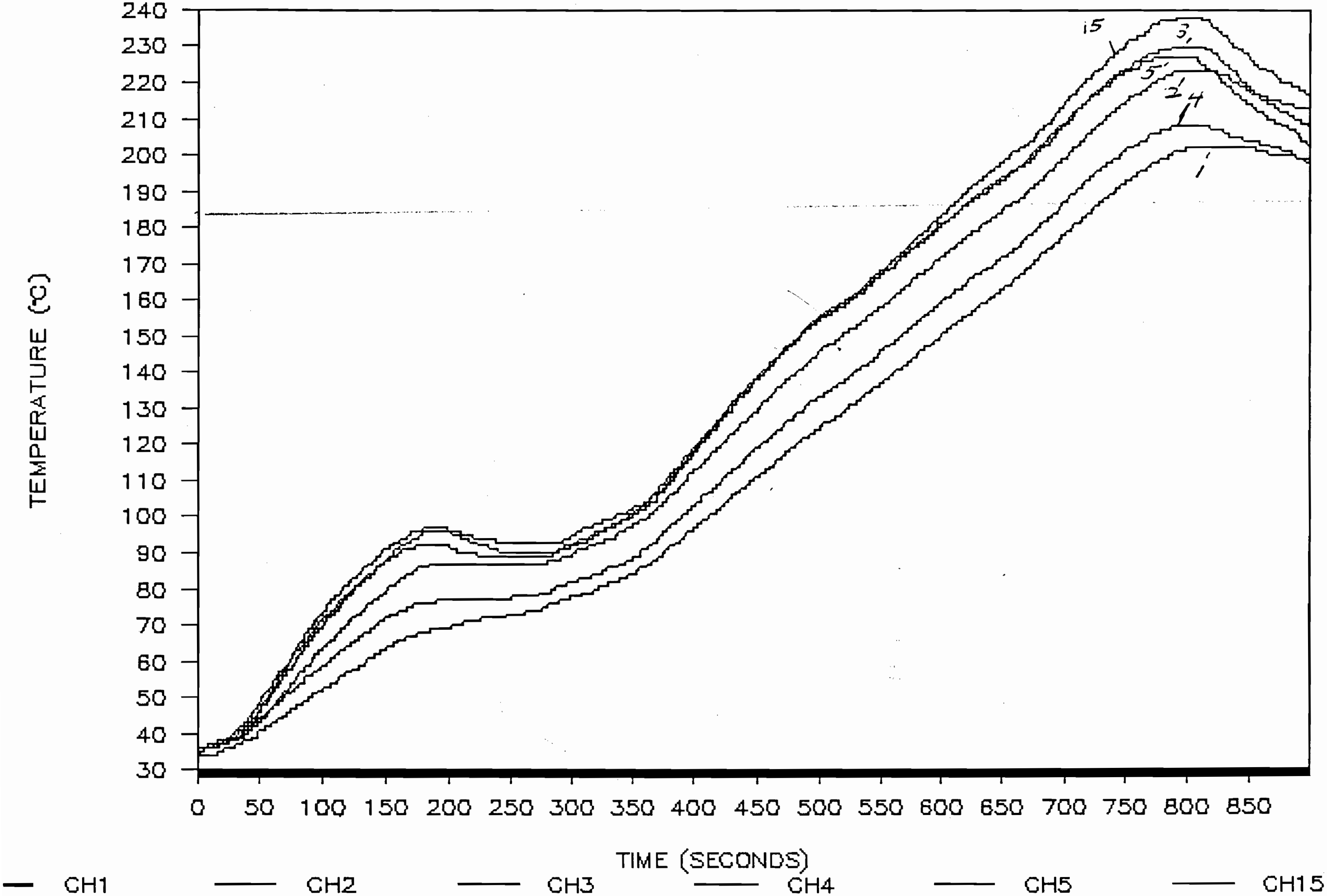
P322

WT. OF BOARD = 479.4 gms

NO CHIMNEY

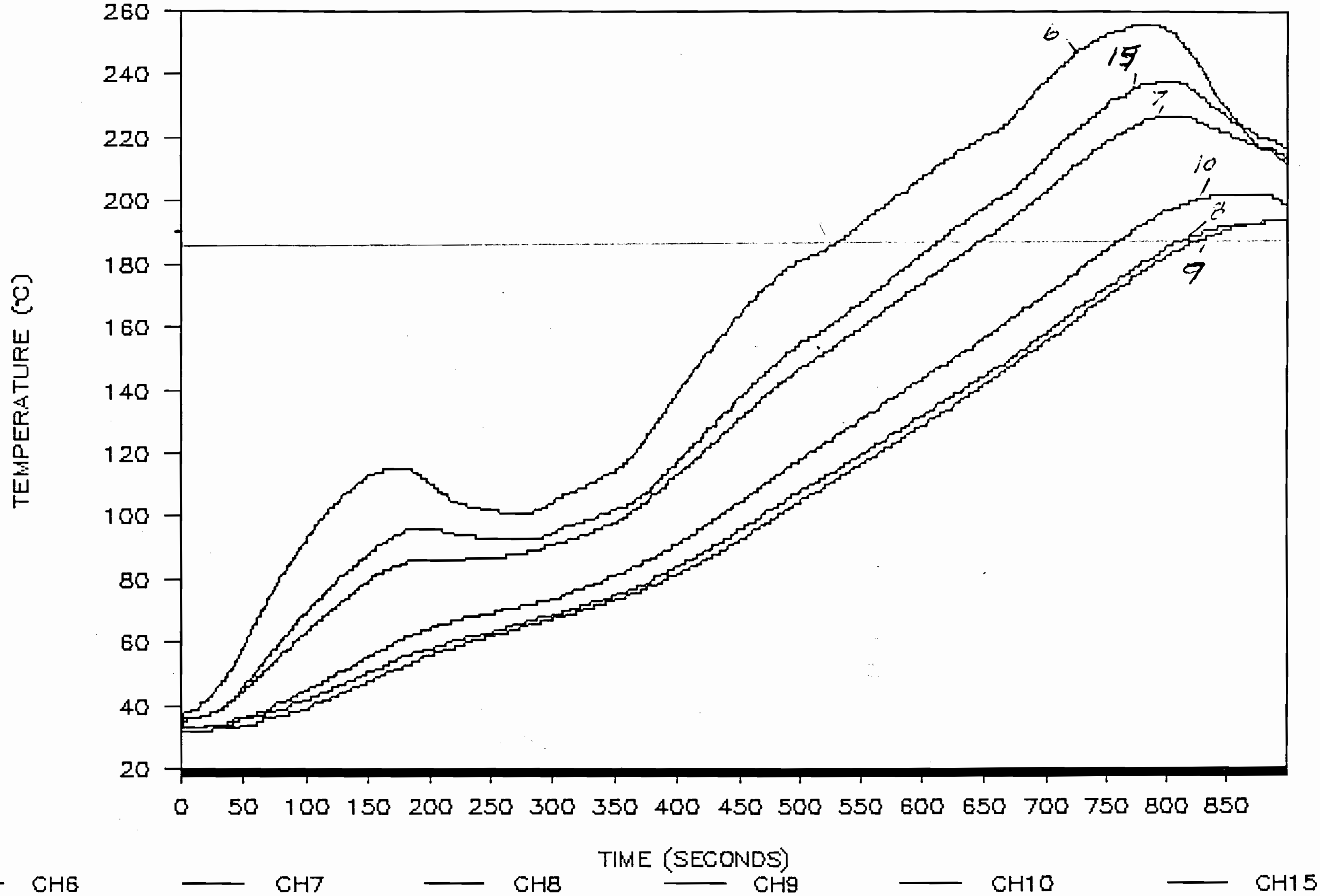
THERMAL PROFILE DATA

22–1



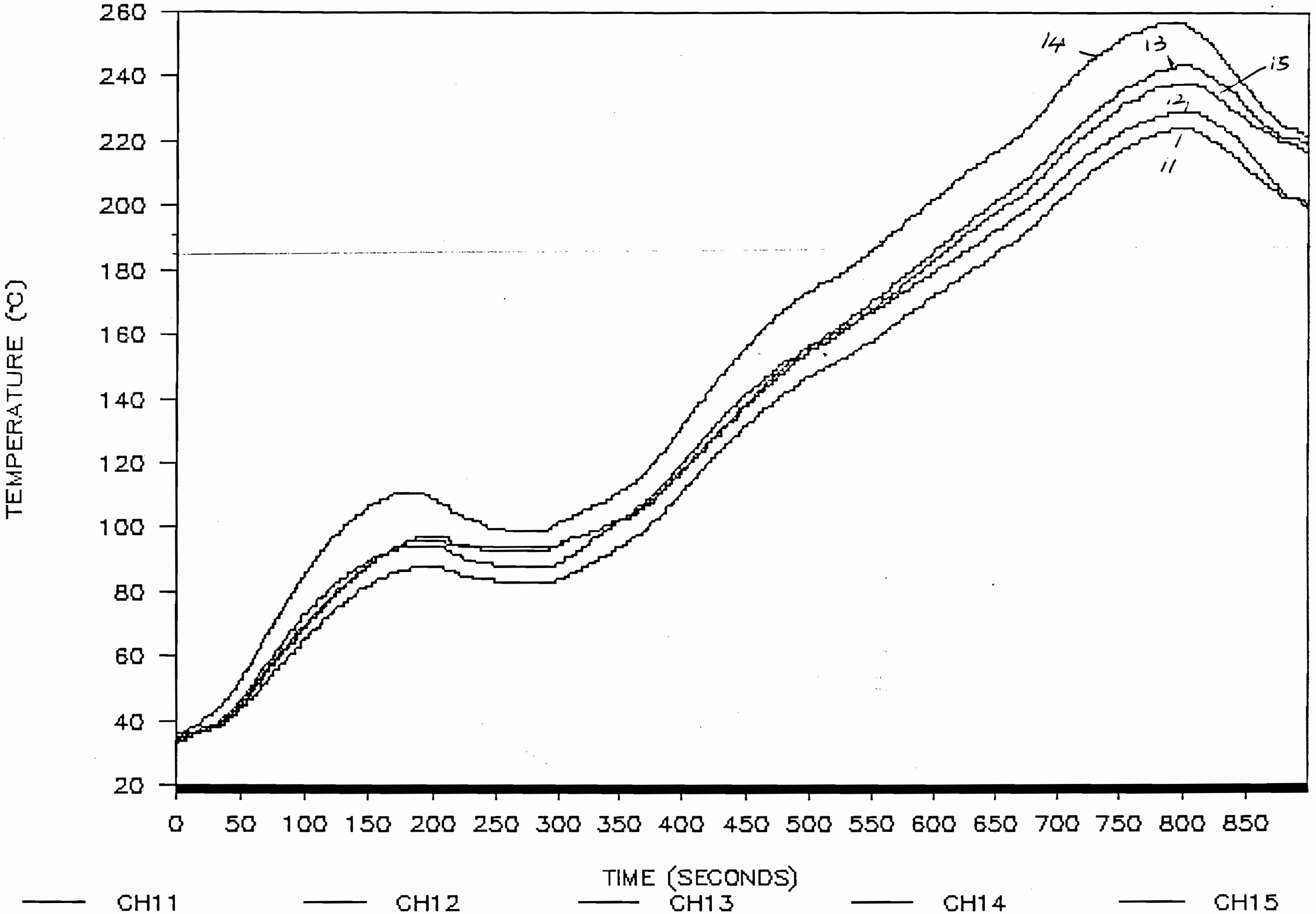
THERMAL PROFILE DATA

22–2



THERMAL PROFILE DATA

22–3



P323

BOARD #7254

Vitronics 7-Zone Program Version 2.2C Copyright 1987 Vitronics Corp.

Zone 1	Zone 2	Zone 3	Zone 4	
Set 400	Set 400	Set 400	Set 445	
Act 399	Act 400	Act 400	Act 445	
Process Ready	Set 400	Set 400	Set 445	Belt Speed:
	Act 400	Act 401	Act 445	
	Zone 5	Zone 6	Zone 7	4.5 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-19-1989 09:20

↑ = 5° high ↓ = 5° low ↑ = 25° high Shut Down at ± 25°C

Communication Display

To controller : B10
From controller : M20
Scanning Temperatures

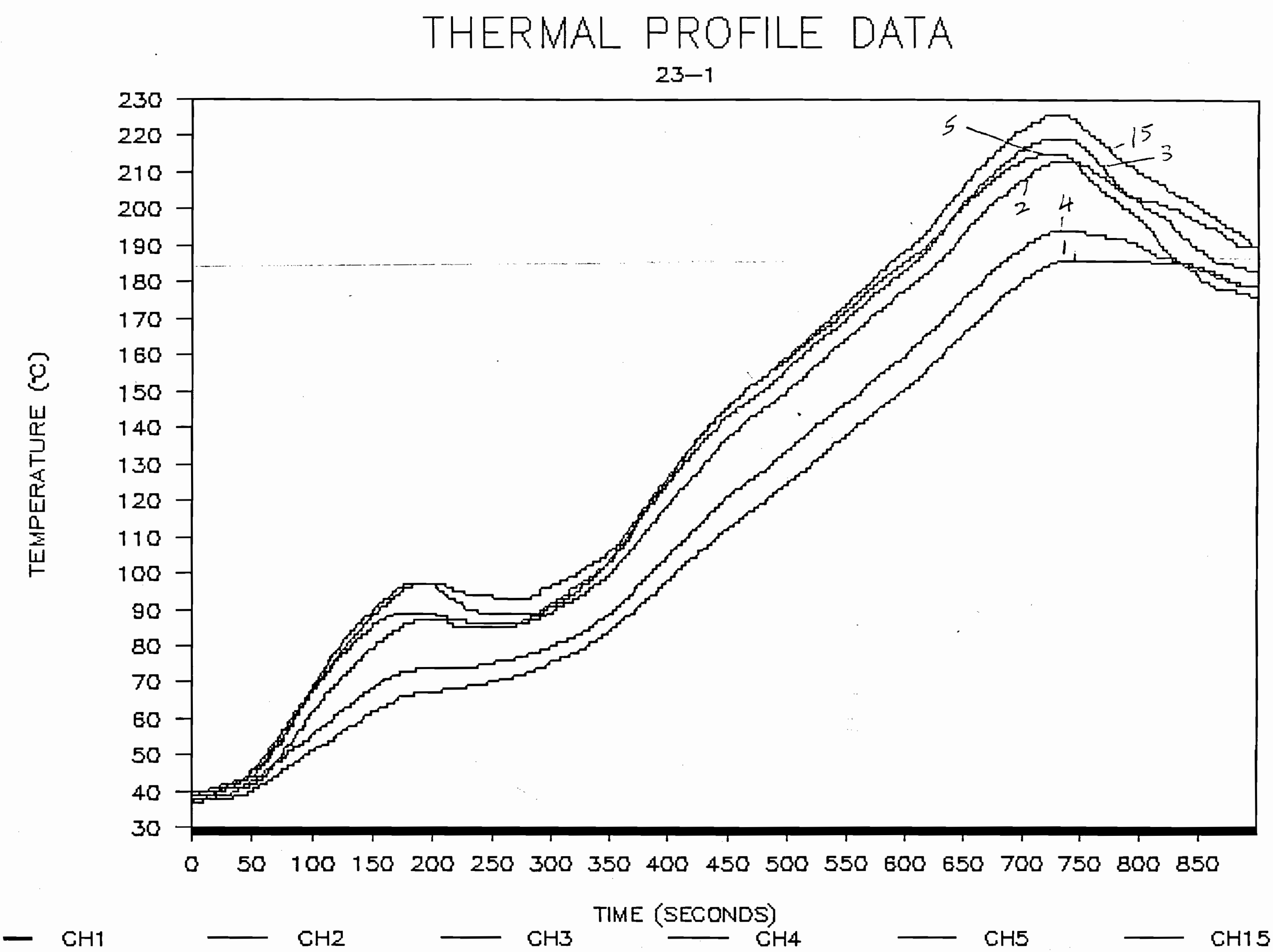
F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

P 323

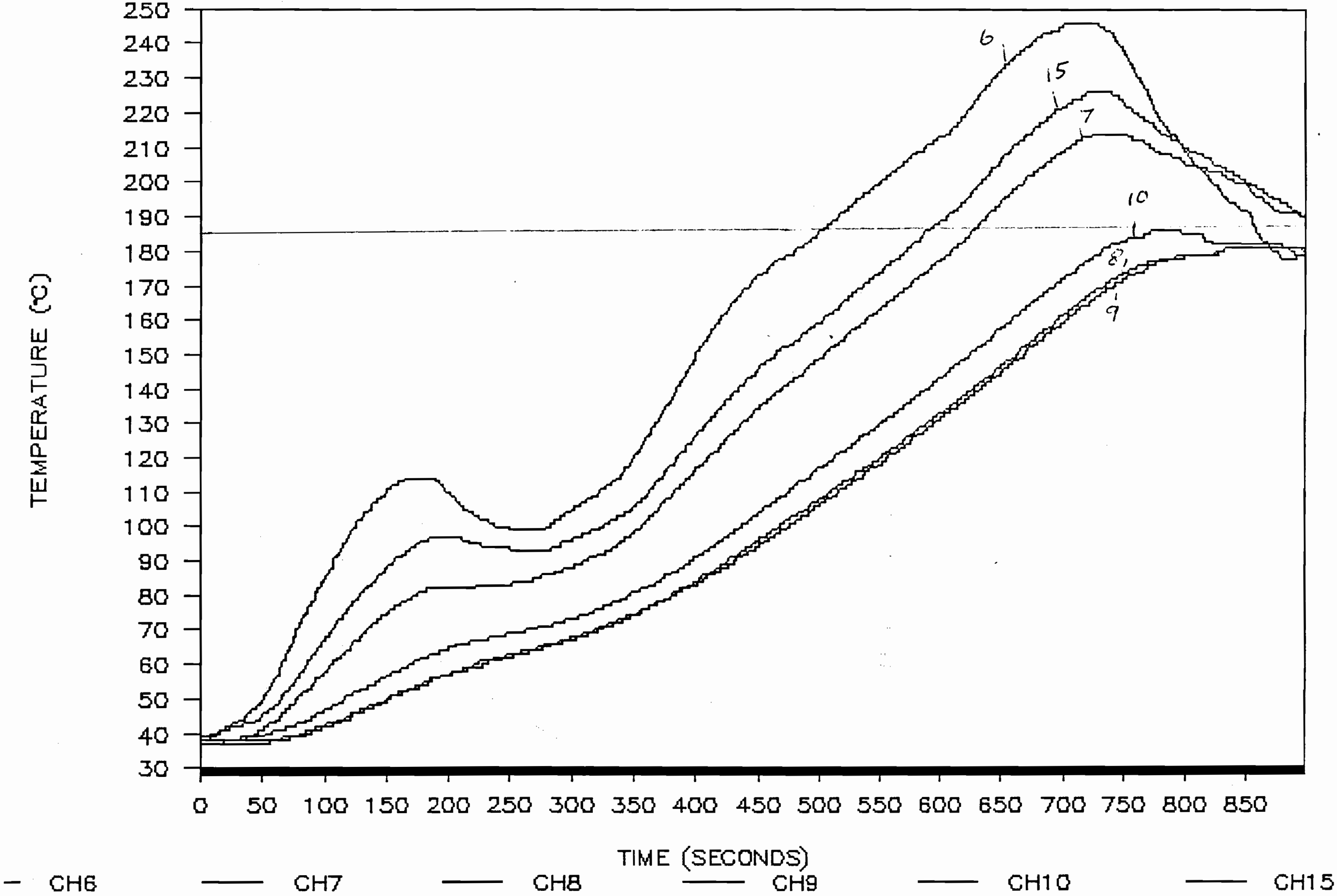
Wt. of Board = 477.
gm

NO CHIMNEY


THERMAL PROFILE DATA
23—1
TEMPERATURE (°C)
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
TIME (SECONDS)
5
15
3
2
4
1
CH1
CH2
CH3
CH4
CH5
CH15

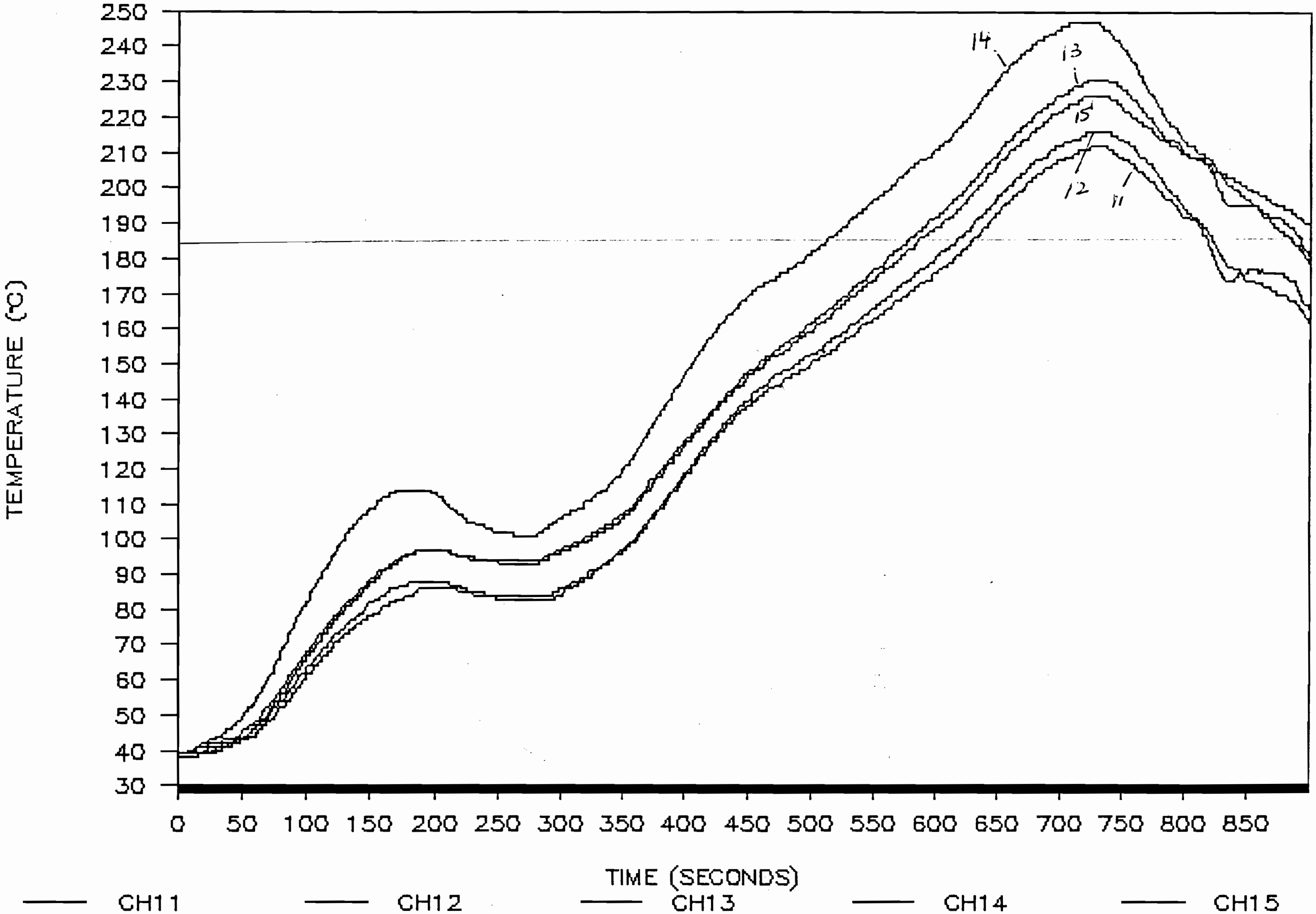
THERMAL PROFILE DATA

23–2



THERMAL PROFILE DATA

23–3



P324 BOARD 9254

Vitronics 7-Zone Program   Version 2.2C   Copyright 1987 Vitronics Corp.

	Zone 1	Zone 2	Zone 3	Zone 4	
	Set 400	Set 400	Set 400	Set 445	
	Act 402	Act 401	Act 401	Act 446	
Process Ready		Set 400	Set 400	Set 445	Belt Speed:
		Act 401	Act 402	Act 447	
		Zone 5	Zone 6	Zone 7	4.5 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-19-1989 12:08

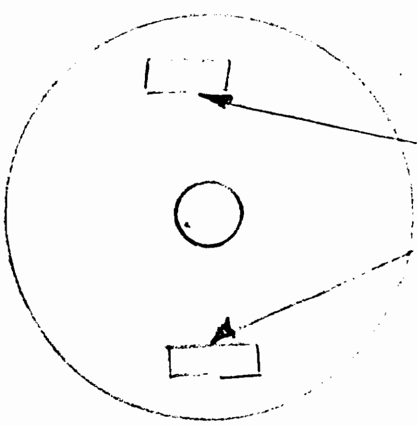
↑ = 5° high ↓ = 5° low ↑ = 25° high Shut Down at ± 25°C

Communication Display

To controller : SF
From controller : B10
Scanning Temperatures

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

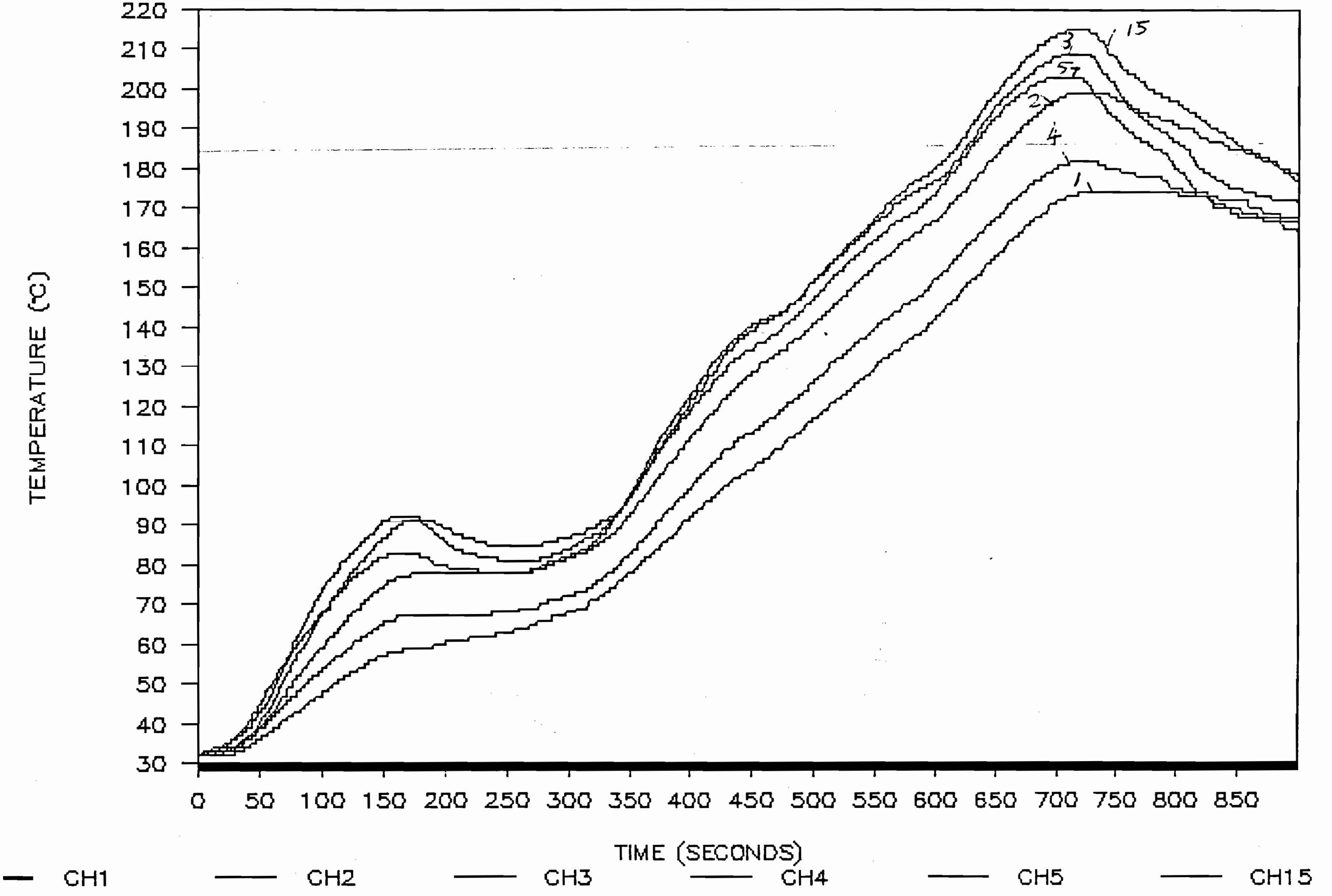


A SMALL SHEET OF TEFLON JUST ENOUGH TO COVER THIS SIDE ("INSIDE") ONLY INSERTED TO PREVENT OVERHEATING OF [illegible]

P324
WT OF BOARD: [illegible]
NO CHIMNEY
ONE SIDE SHIELD EACH ON BOTH CONNECTORS (INSIDE ONLY - NOT OUTSIDE)

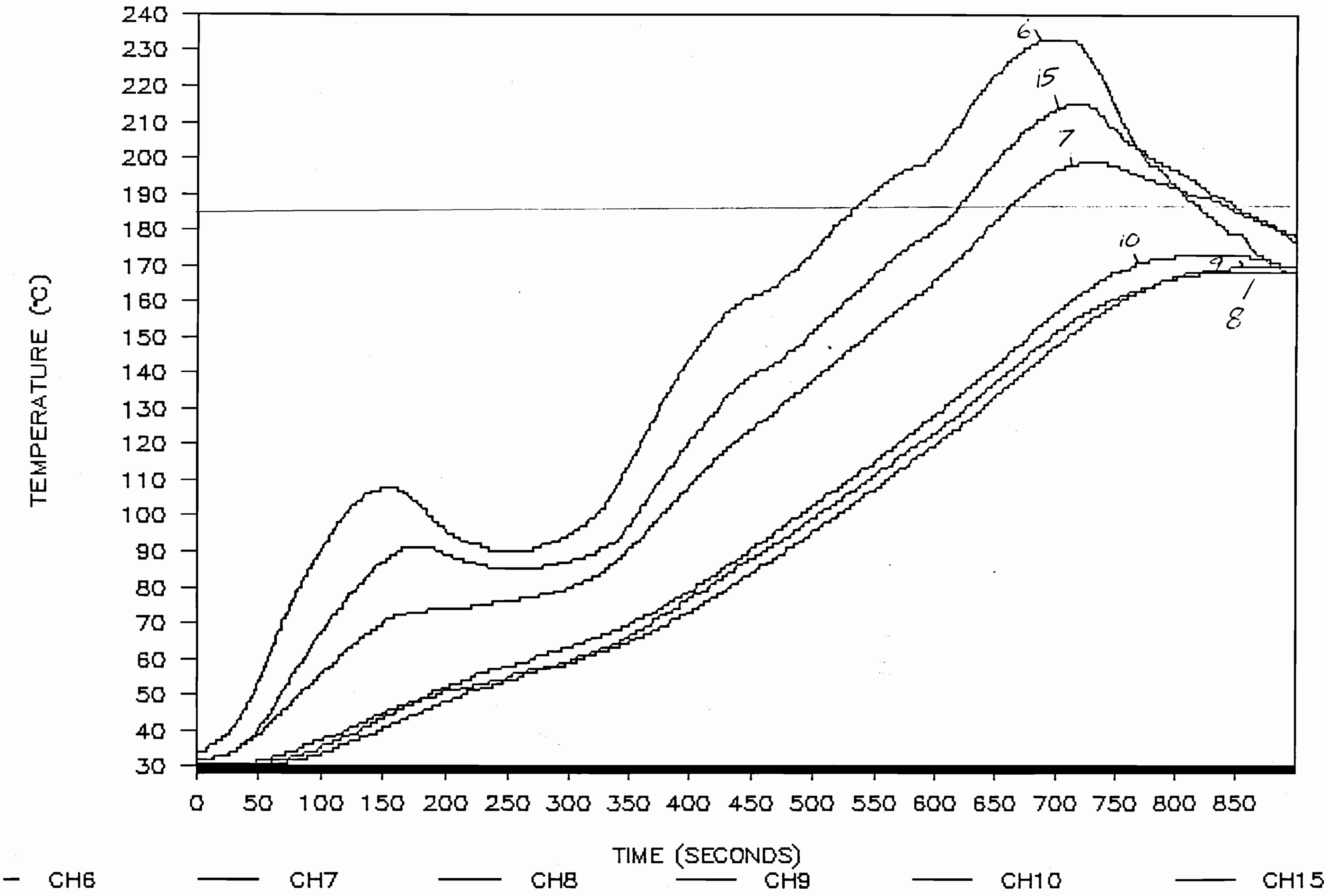
THERMAL PROFILE DATA

24—1



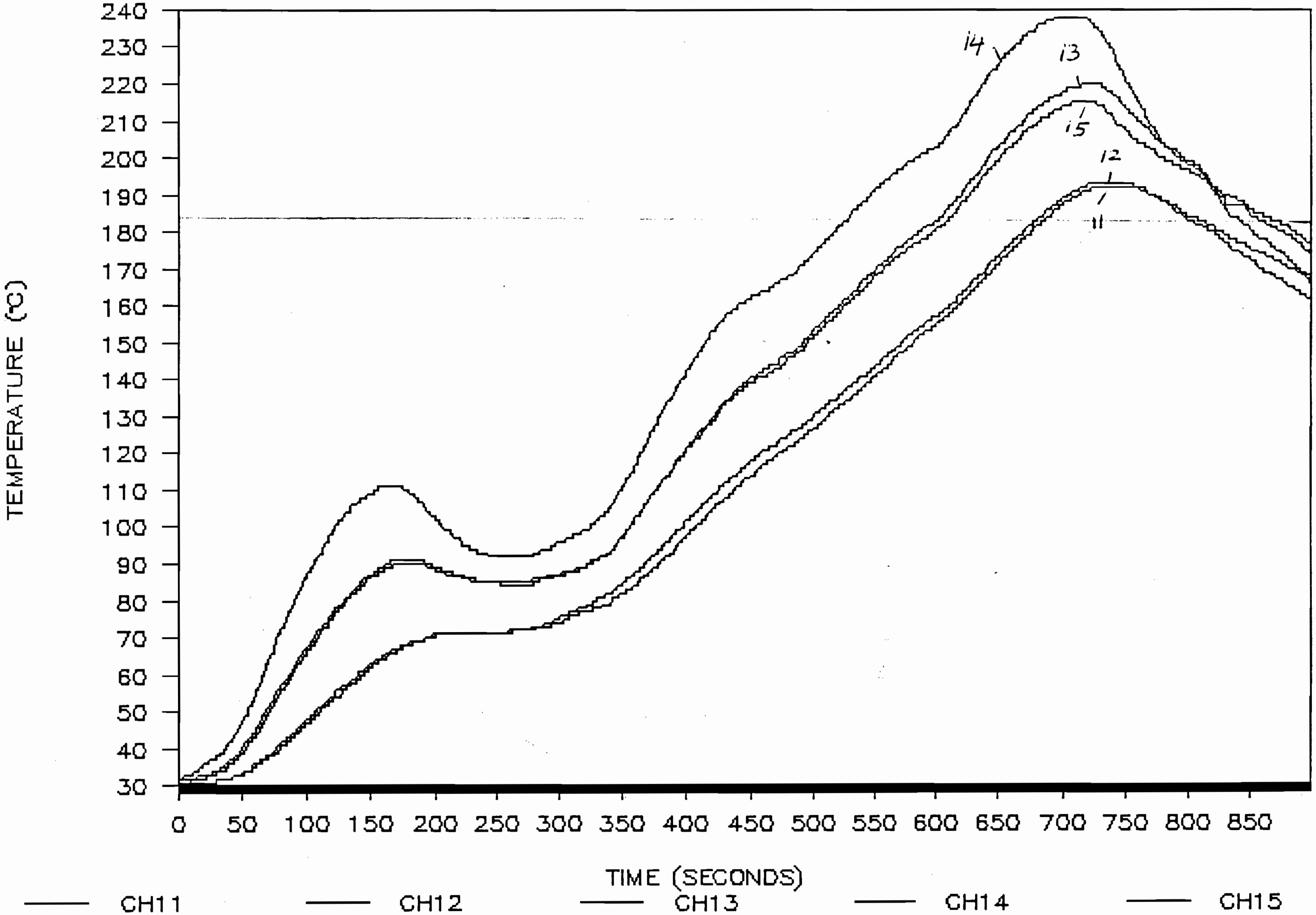
THERMAL PROFILE DATA

24–2



THERMAL PROFILE DATA

24–3



P325

Board # 581(8 ... 5)

Vitronics 7-Zone Program Version 2.2C Copyright 1987 Vitronics Corp.

	Zone 1 Set 400 Act 400	Zone 2 Set 400 Act 400	Zone 3 Set 400 Act 400	Zone 4 Set 445 Act 446
Process Ready	Set 400 Act 401 Zone 5	Set 400 Act 399 Zone 6	Set 445 Act 446 Zone 7	Belt Speed: 4 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-20-1989 09:59

↑ = 5° high ↓ = 5° low ↑ = 25° high Shut Down at ± 25°C

Communication Display

To controller : M20
From controller : B10

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

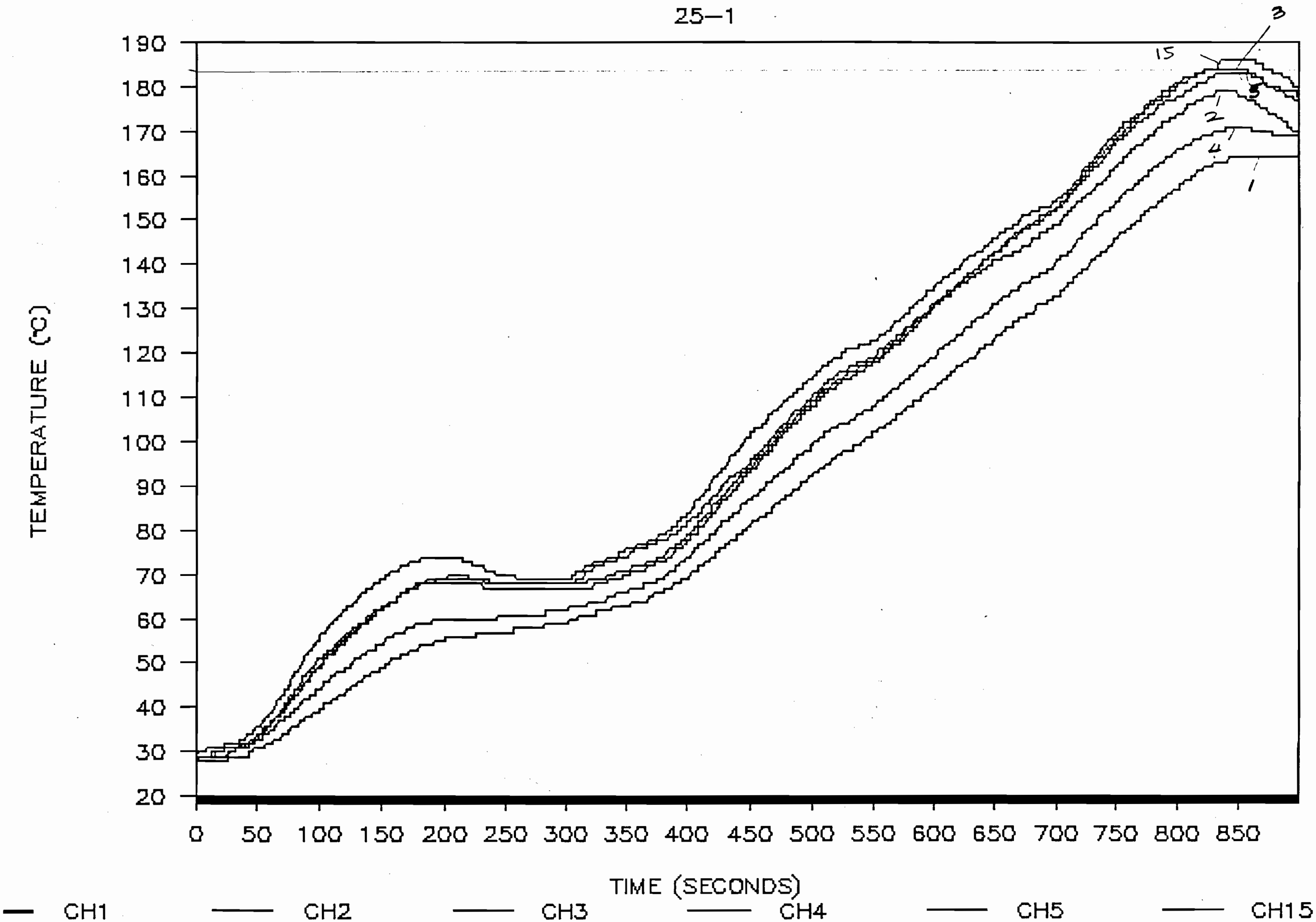
P325

Wt of Board 751gm

NO CHANGE

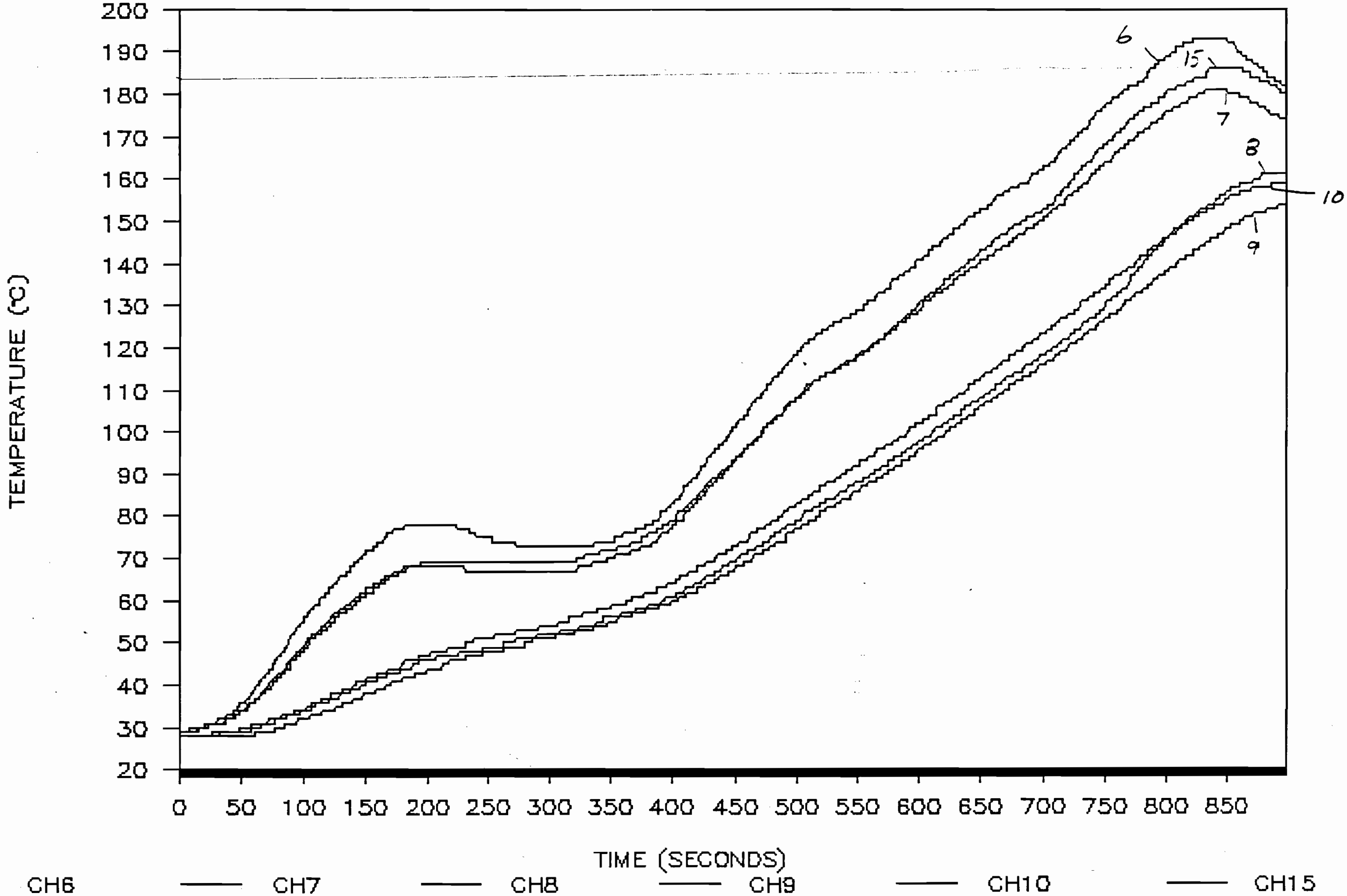
THERMAL PROFILE DATA

25–1



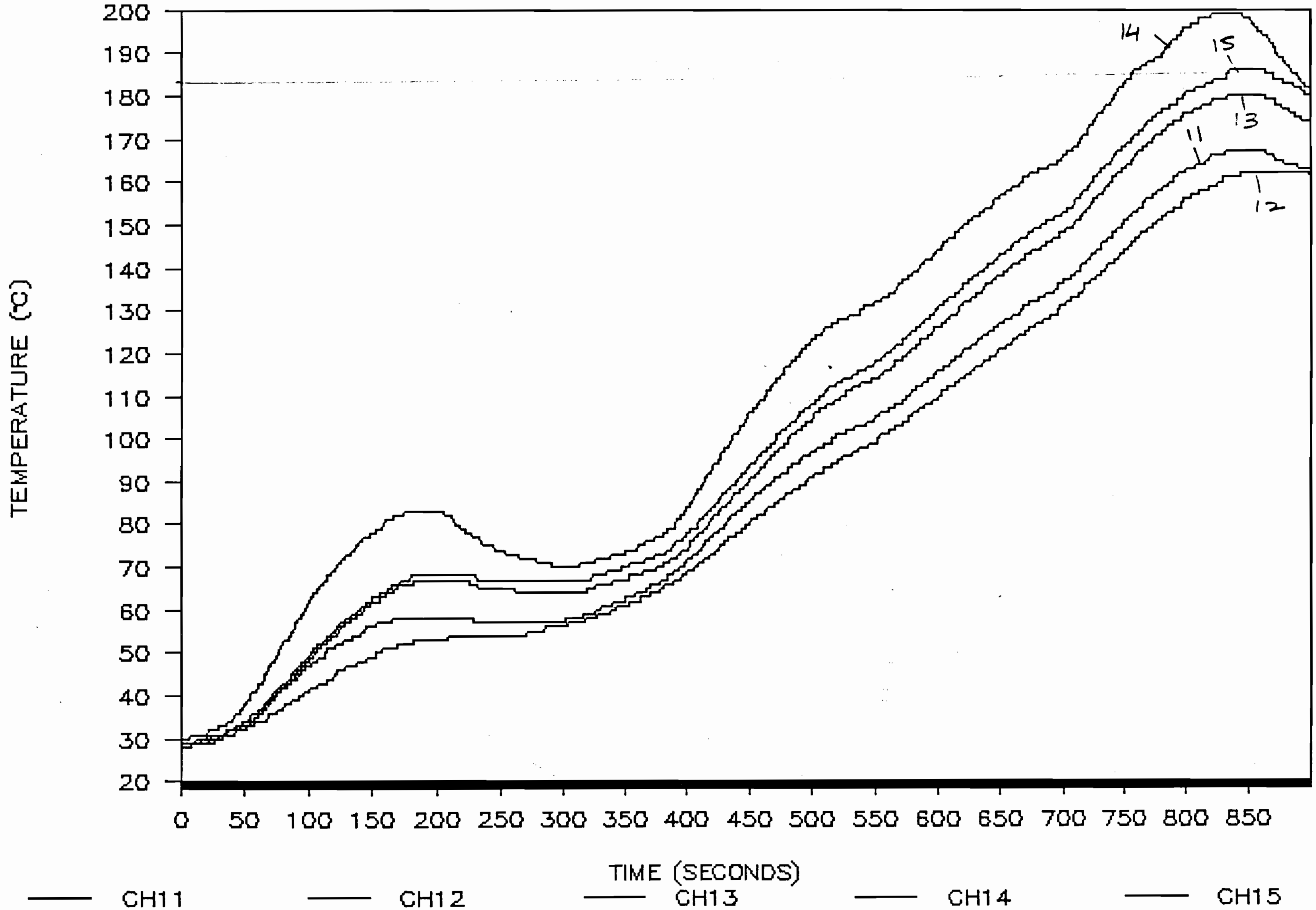
THERMAL PROFILE DATA

25–2



THERMAL PROFILE DATA

25–3



P326

Board # 8[illegible]

Vitronics 7-Zone Program   Version 2.2C   Copyright 1987 Vitronics Corp.

	Zone 1	Zone 2	Zone 3	Zone 4	
	Set 400	Set 400	Set 400	Set 445	
	Act 401	Act 401	Act 401	Act 446	
Process Ready		Set 400	Set 400	Set 445	Belt Speed:
		Act 401	Act 401	Act 446	
		Zone 5	Zone 6	Zone 7	3 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-20-1989 12:01

↑ = 5° high   ↓ = 5° low   ↑ = 25° high   Shut Down at ± 25°C

Communication Display

To controller : M20
om controller : M20
Scanning Temperatures

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

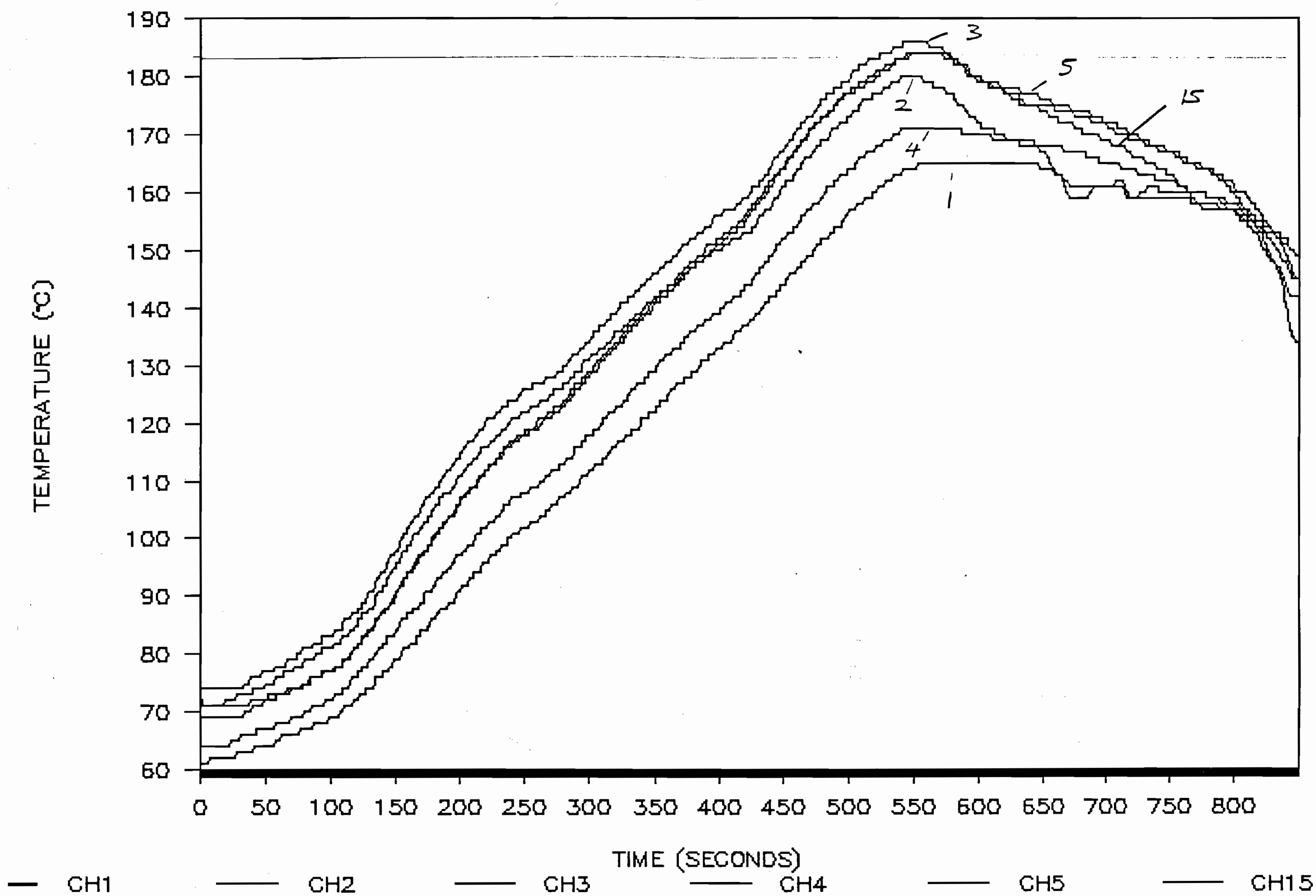
P326
WT. OF BOARD = 751 gms
NO CHIMNEY

NOTES: 1. SINCE THE SPEED IS SLOW (3 ipm), THE TEMPERATURES WERE RECORDED ONLY AFTER THE CCA WAS PARTIALLY INSIDE THE IR FURNACE. THIS WAS DONE SO WE WOULD HAVE THE HIGHER TEMP. DATA ON CHART. THERE IS A 900 SEC. LIMITATION ON OUR RECORDER.

2 IN ACTUAL PRODUCTION, SUCH SLOW SPEEDS WOULD NOT BE RECOMMENDED, SINCE THE PURCHASE OF A LONGER FURNACE IS BEING CONTEMPLATED. THE SPEED WOULD BE ROUGHLY 6 ipm (SINCE THE CONTEMPLATED FURNACE IS ROUGHLY [illegible]

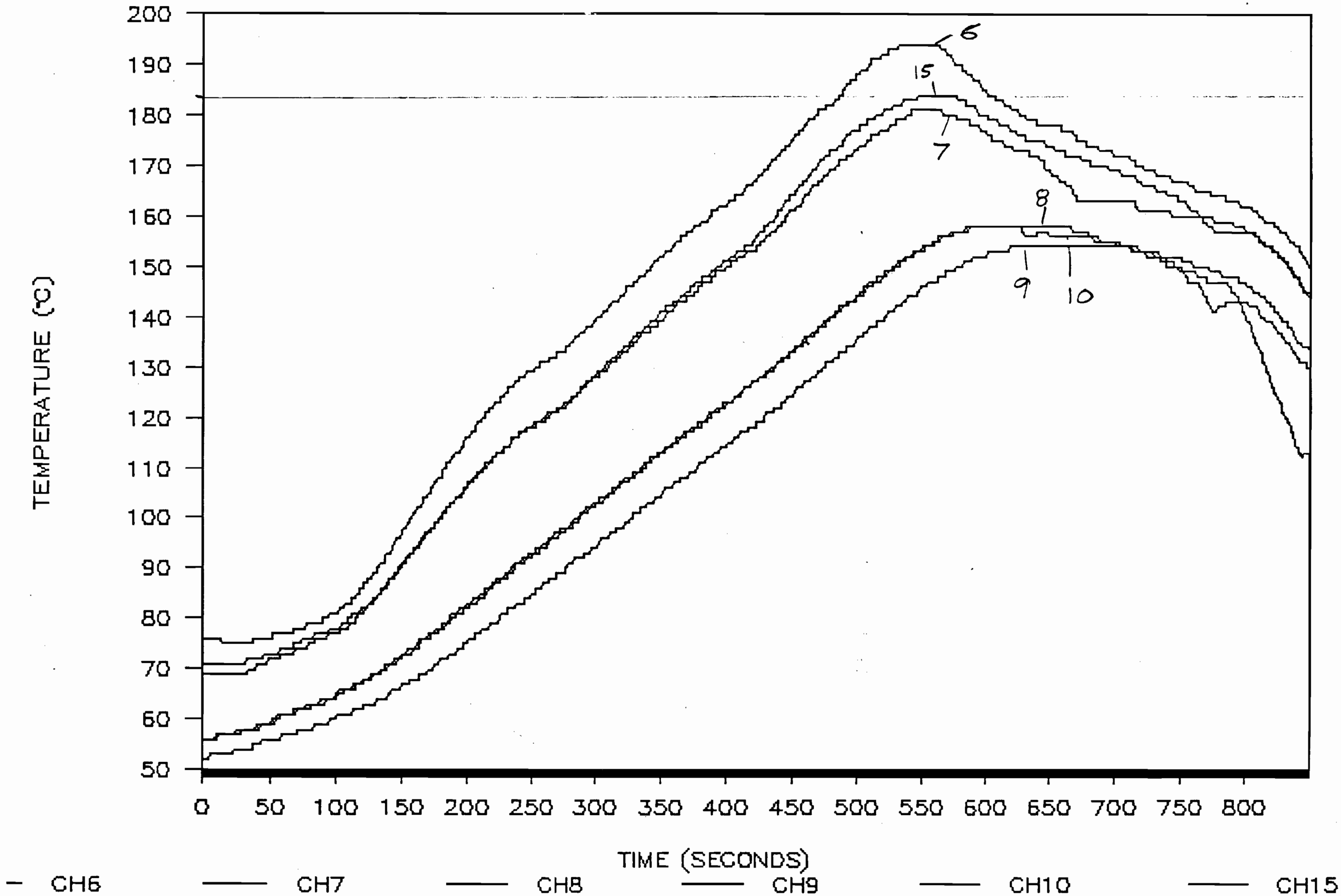
THERMAL PROFILE DATA

26–1



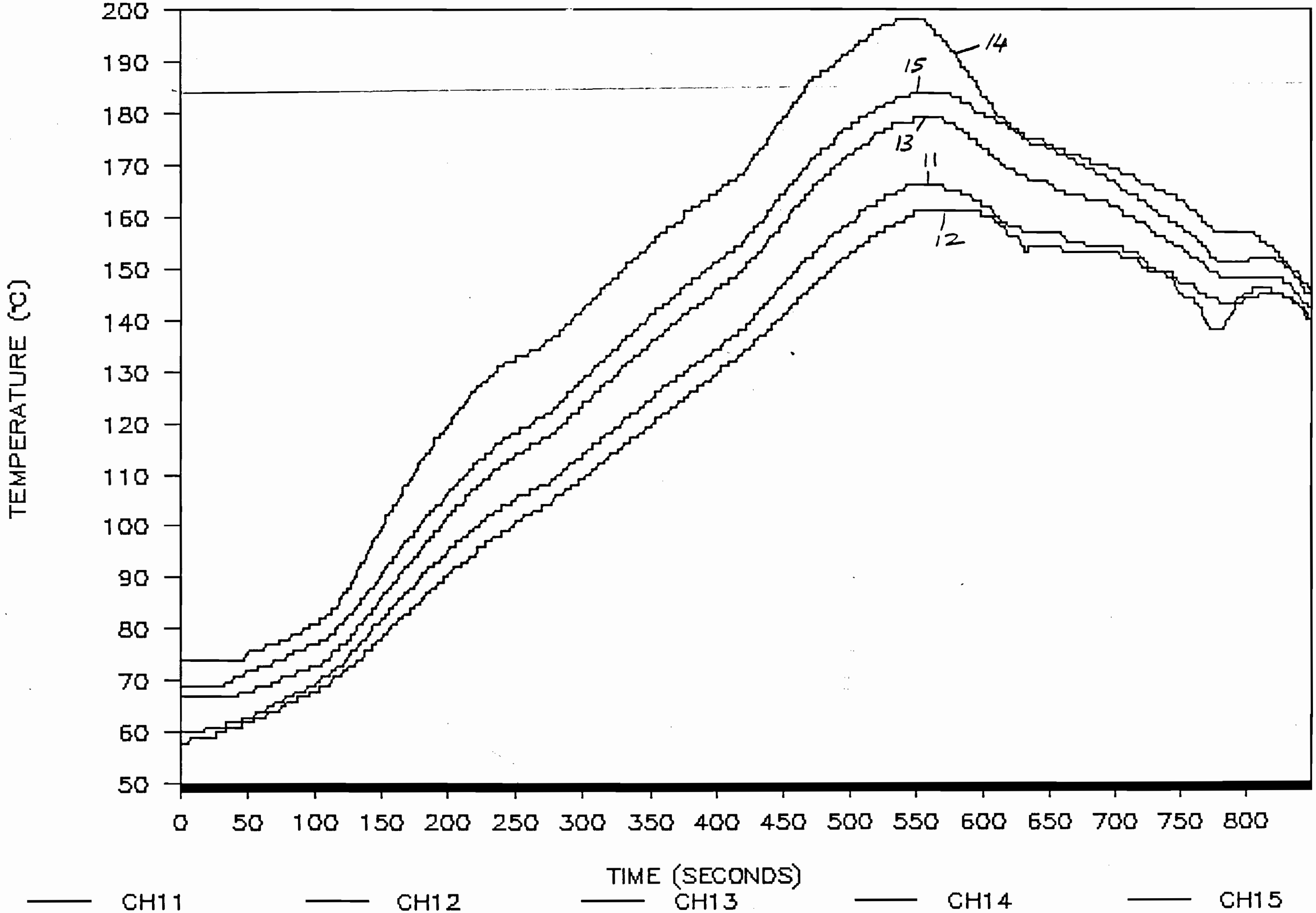
THERMAL PROFILE DATA

26–2



THERMAL PROFILE DATA

26-3



P327

Board 11 8/25

Vitronics 7-Zone Program   Version 2.2C   Copyright 1987 Vitronics Corp.

Zone 1	Zone 2	Zone 3	Zone 4	
Set 400	Set 400	Set 430	Set 445	
Act 400	Act 402	Act 431	Act 441	
Process Ready	Set 400	Set 430	Set 445	Belt Speed:
	Act 401	Act 429	Act 442	
	Zone 5	Zone 6	Zone 7	3 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-20-1989 12:34

↑ = 5° high   ↓ = 5° low   ↑ = 25° high   Shut Down at ± 25°C

Communication Display

To controller : B10
From controller : B10

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

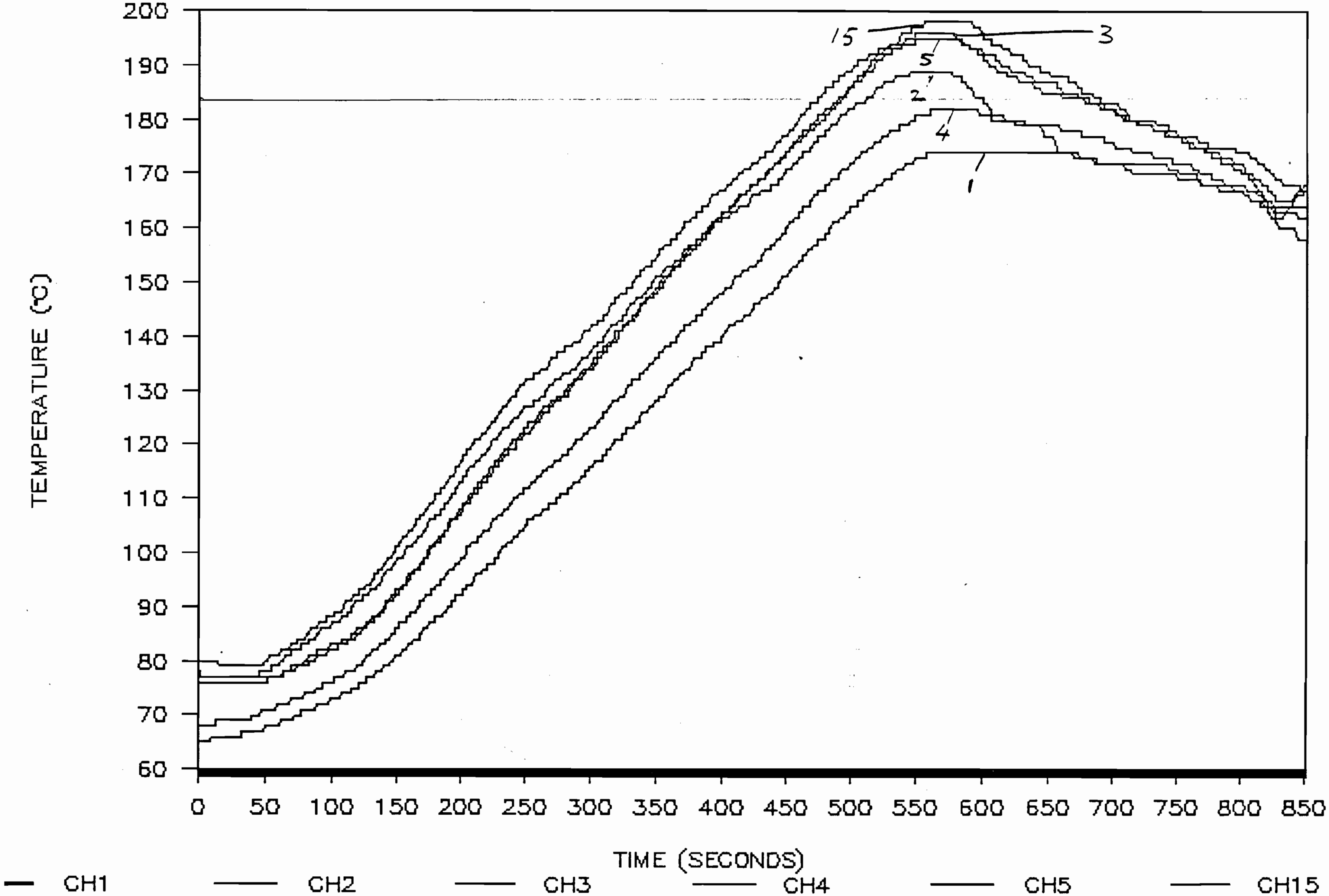
F6 = Set Auto Stop

P327
Wt. of Board = 751 gms
No Humidity

Notes: Please refer to Form #: P326. Same comments apply.

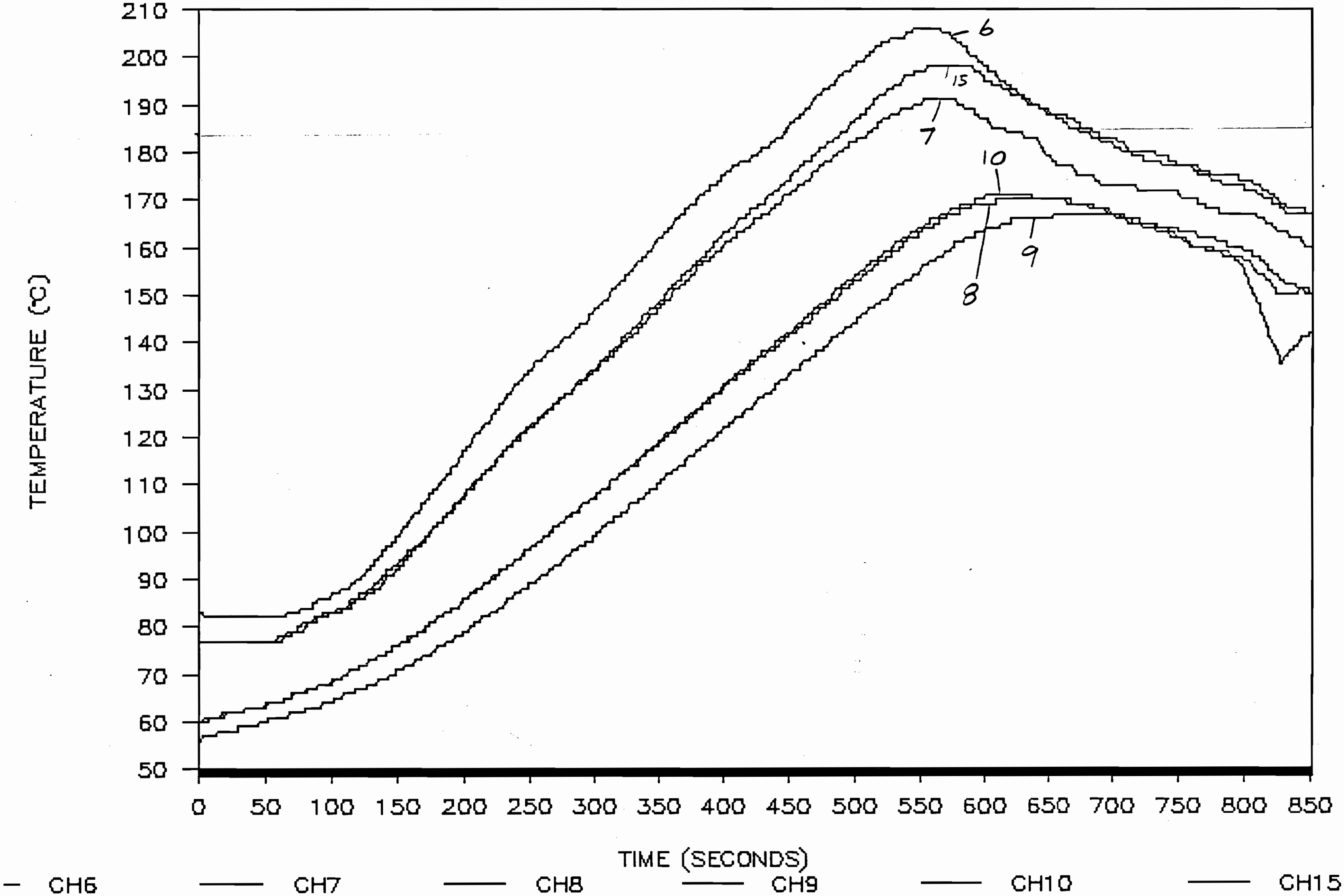
THERMAL PROFILE DATA

27–1



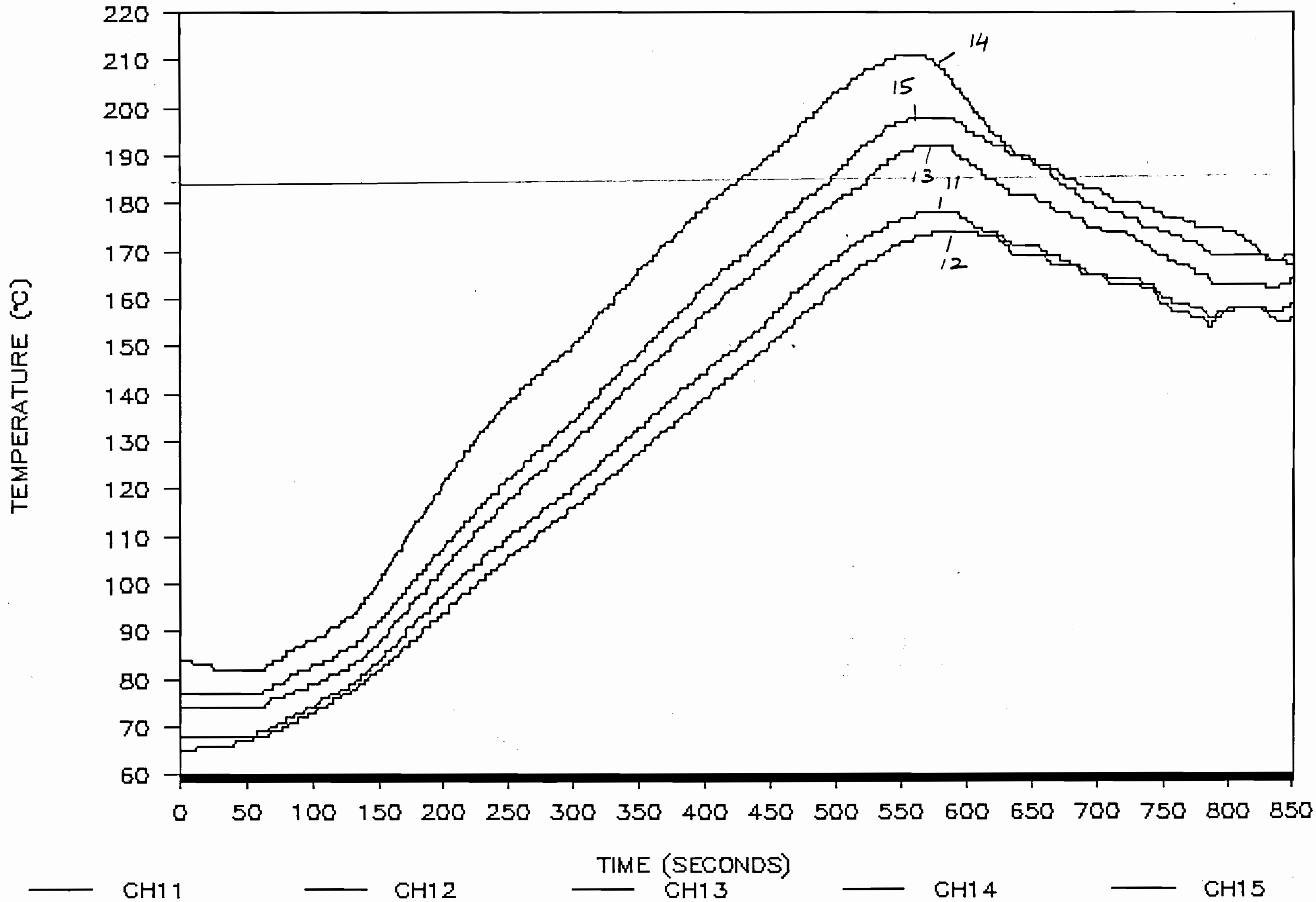
THERMAL PROFILE DATA

27–2



THERMAL PROFILE DATA

27–3



P328

Entry #84..3

Vitronics 7-Zone Program Version 2.2C Copyright 1987 Vitronics Corp

Zone 1	Zone 2	Zone 3	Zone 4	
Set 400	Set 400	Set 445	Set 445	
Act 400	Act 402	Act 447	Act 444	
Process Ready	Set 400	Set 445	Set 445	Belt Speed:
	Act 402	Act 445	Act 443	
	Zone 5	Zone 6	Zone 7	3 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-20-1989 13:31

↑ = 5° high ↓ = 5° low ↑ = 25° high Shut Down at ± 25°C

Communication Display

To controller : SF
From controller : okay

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

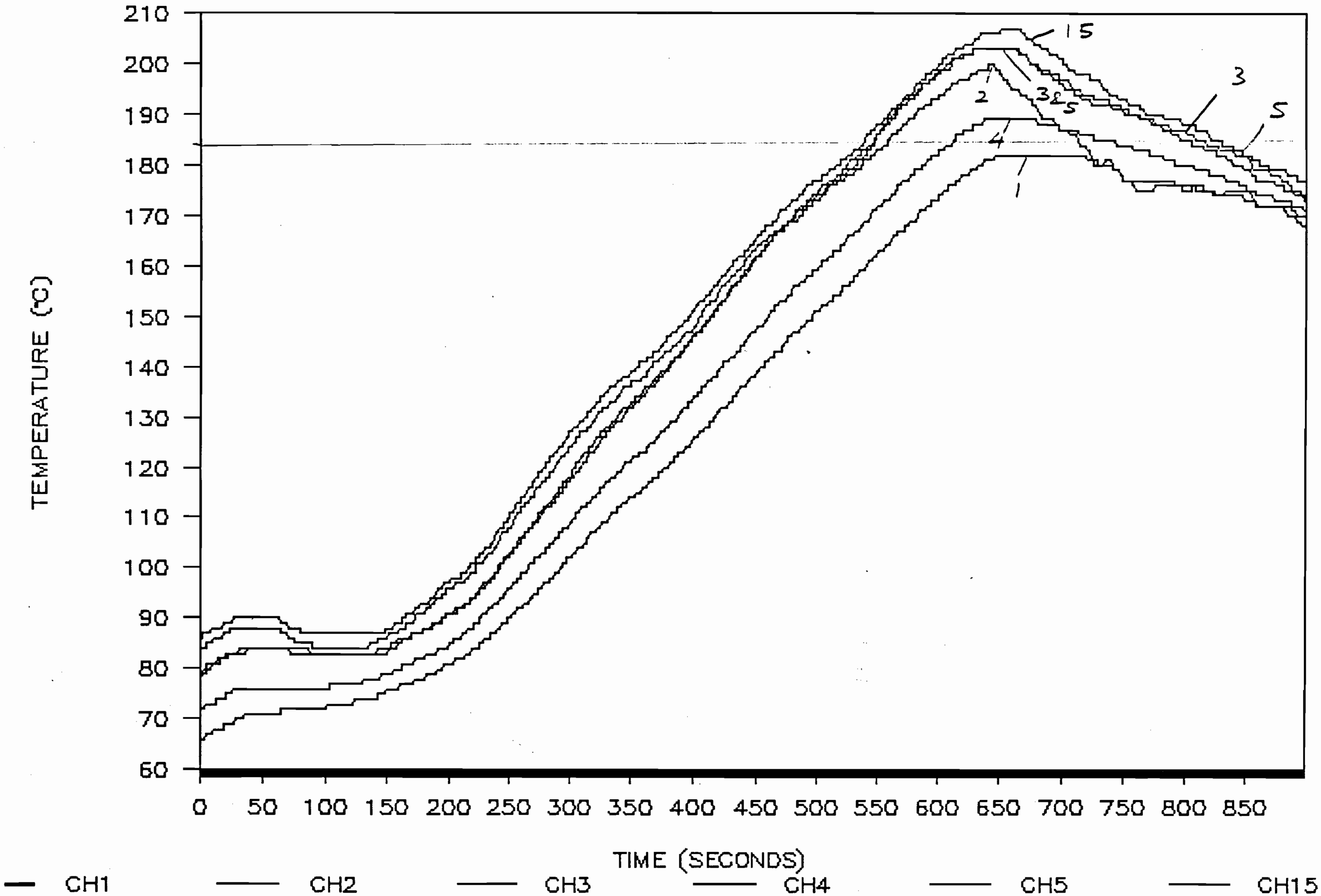
F6 = Set Auto Stop

P328
WT OF BOARD = 751 gm
NO CHIMNEY

NOTES: PLEASE REFER TO RUN # P326
SAME COMMENTS APPLY.

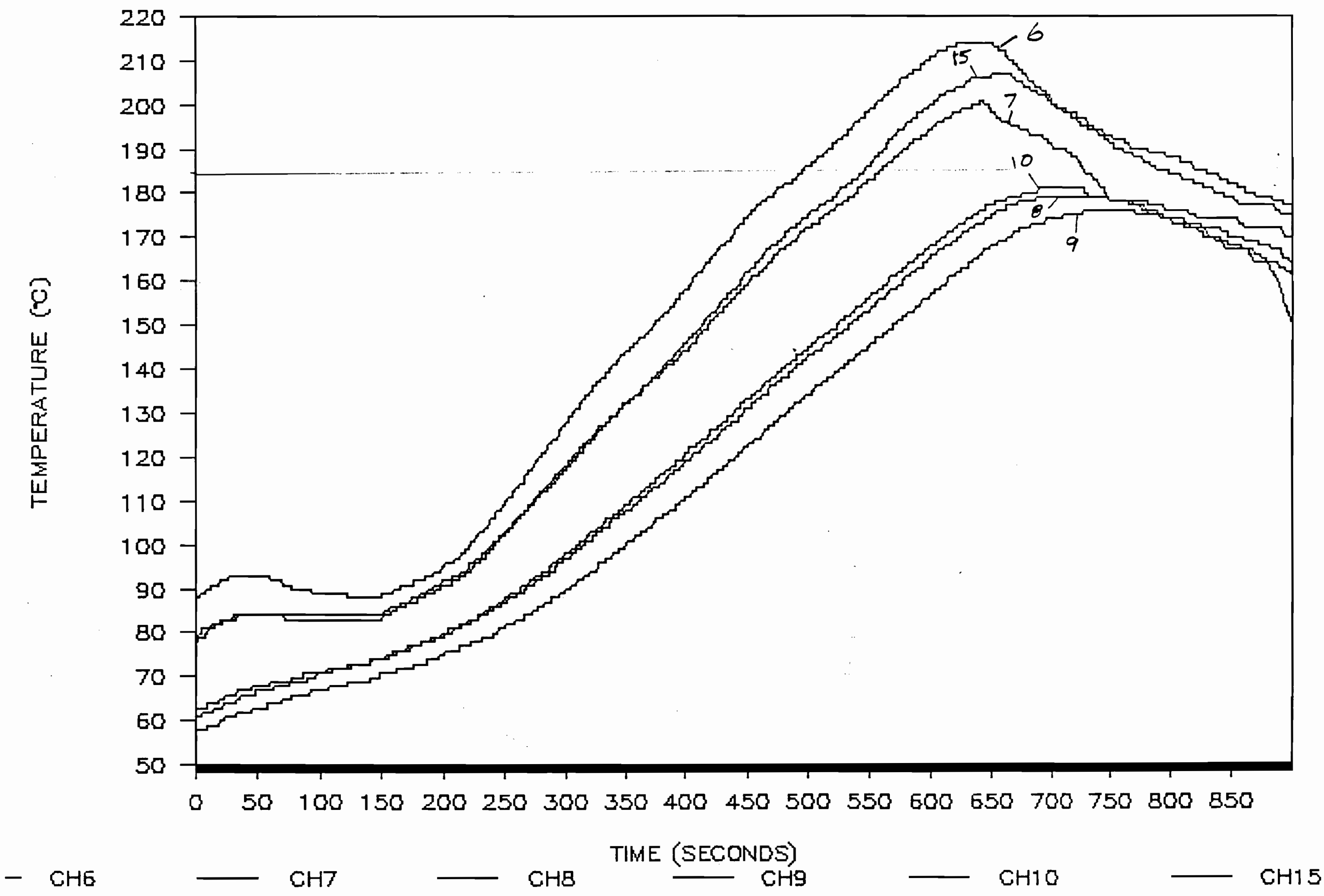
THERMAL PROFILE DATA

28–1



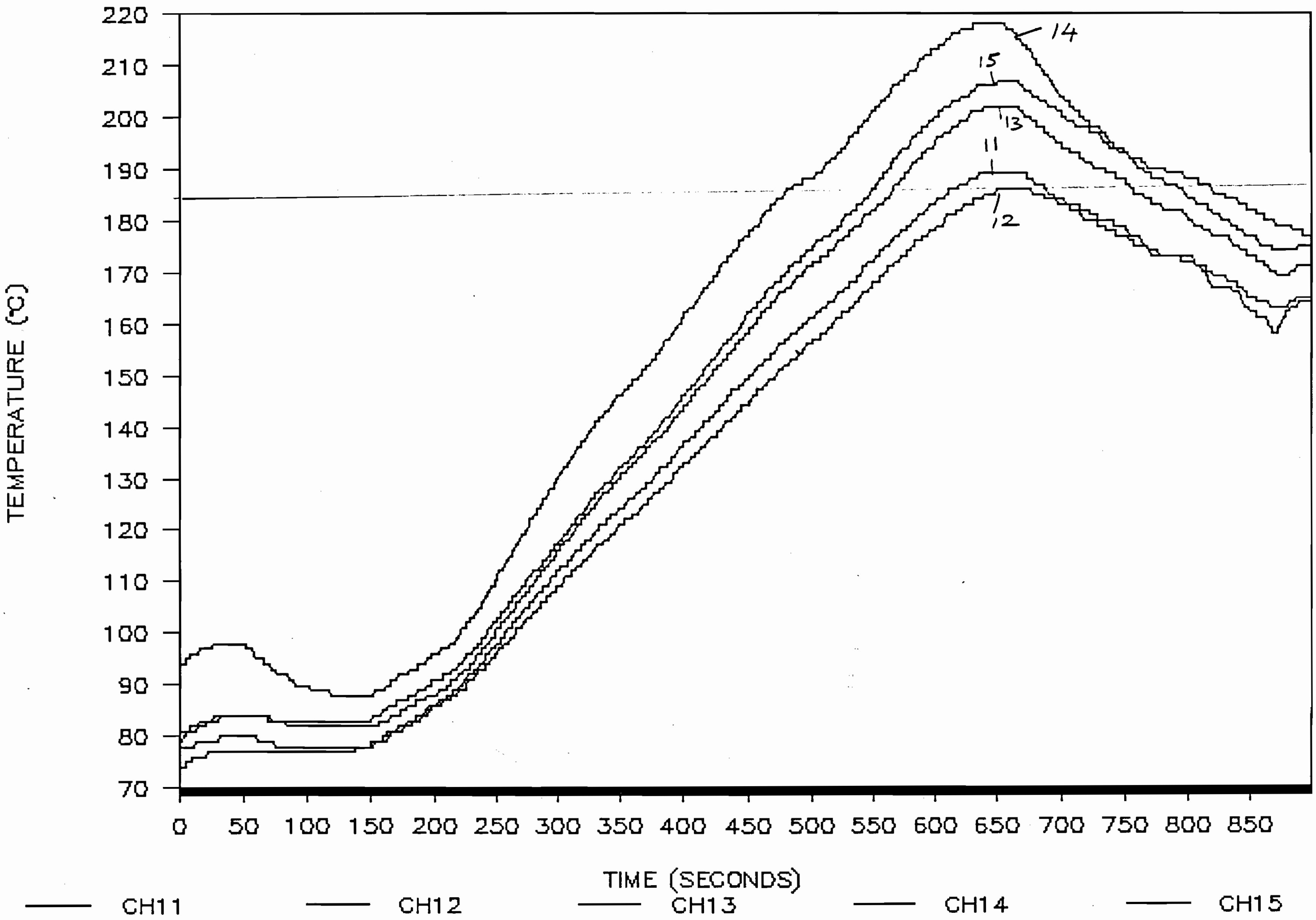
THERMAL PROFILE DATA

28–2



THERMAL PROFILE DATA

28—3



P331 BOARD # 8440

Vitronics 7-Zone Program Version 2.2C Copyright 1987 Vitronics Corp.

Zone 1 Set 400 Act 401	Zone 2 Set 400 Act 401	Zone 3 Set 445 Act 447	Zone 4 Set 445 Act 446	
Process Ready	Set 400 Act 401 Zone 5	Set 445 Act 447 Zone 6	Set 445 Act 447 Zone 7	Belt Speed: 4.5 (in/m)

Part/Prof:Mark 50 Torpedo

Date & Time: 04-24-1989 07:38

↑ = 5° high ↓ = 5° low ↑ = 25° high Shut Down at ± 25°C

Communication Display

To controller : SF
From controller : B10
anning Temperatures

F1 = Edit Values
F2 = New Profile
F3 = Shut Down
F4 = Plot
F5 = Data Log on

F6 = Set Auto Stop

P331
WT. OF BOARD = 622 gr
NO CHIMNEY

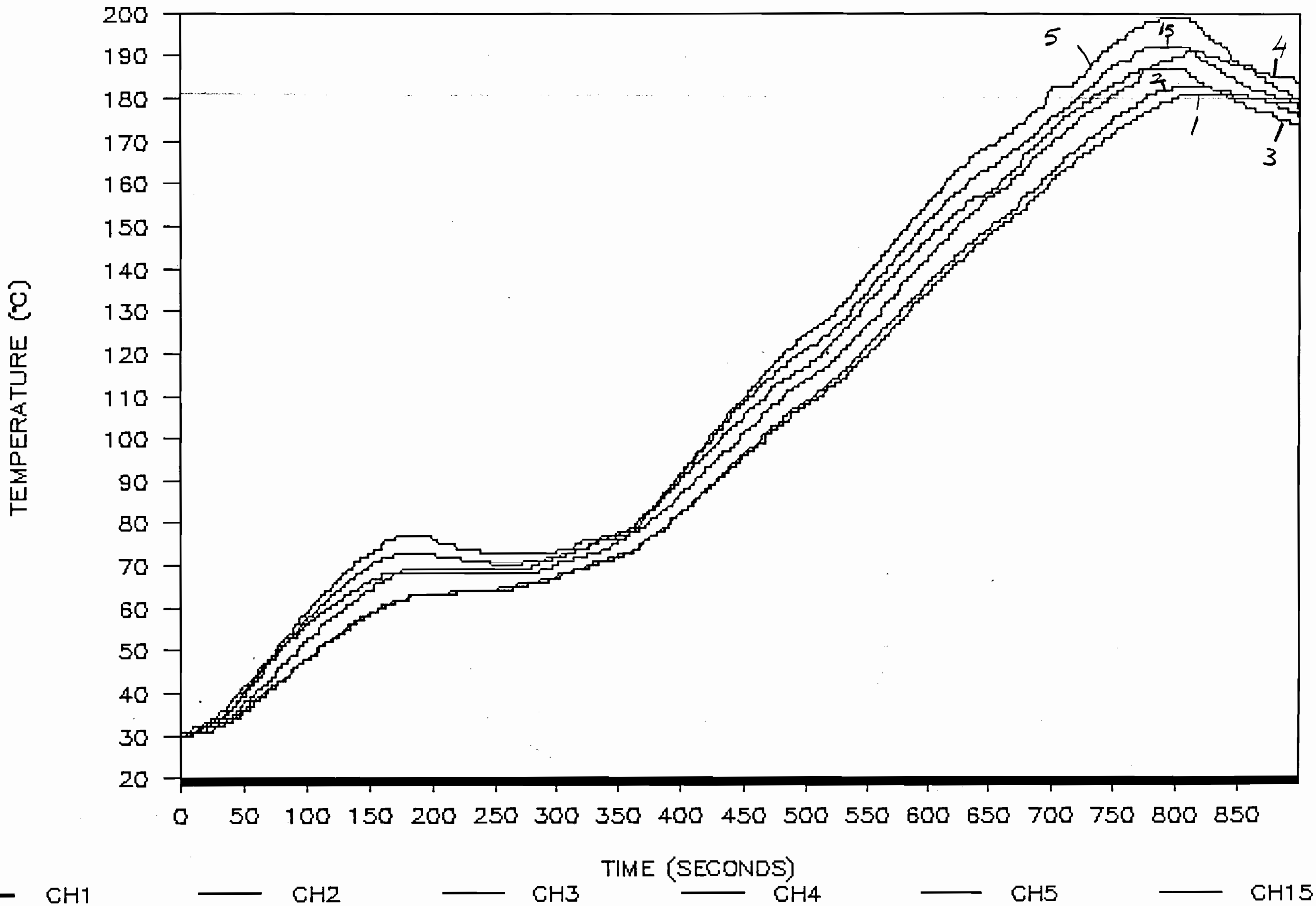
NOTE :

THE TEMPERATURE AND BELT SPEED PROFILE OF THIS BOARD WAS FIRST FIGURED THEORETICALLY AS FOLLOWS:-

- HEAVIEST BOARD (BOARD 842.5, RUN # P328) HAS TEMPERATURES OF 400, 400, 445 & 445 WITH BELT SPEED OF 3.0 ipm
- LIGHTEST BOARD (BOARD 925.4, RUN # P324) HAS TEMPERATURES OF 400, 400, 400 & 445 WITH BELT SPEED OF 4.5 ipm
- THEREFORE, FOR THE BOARD IN BETWEEN, WE WILL KEEP THE TEMPERATURES OF THE HEAVIEST BOARD AND THE BELT

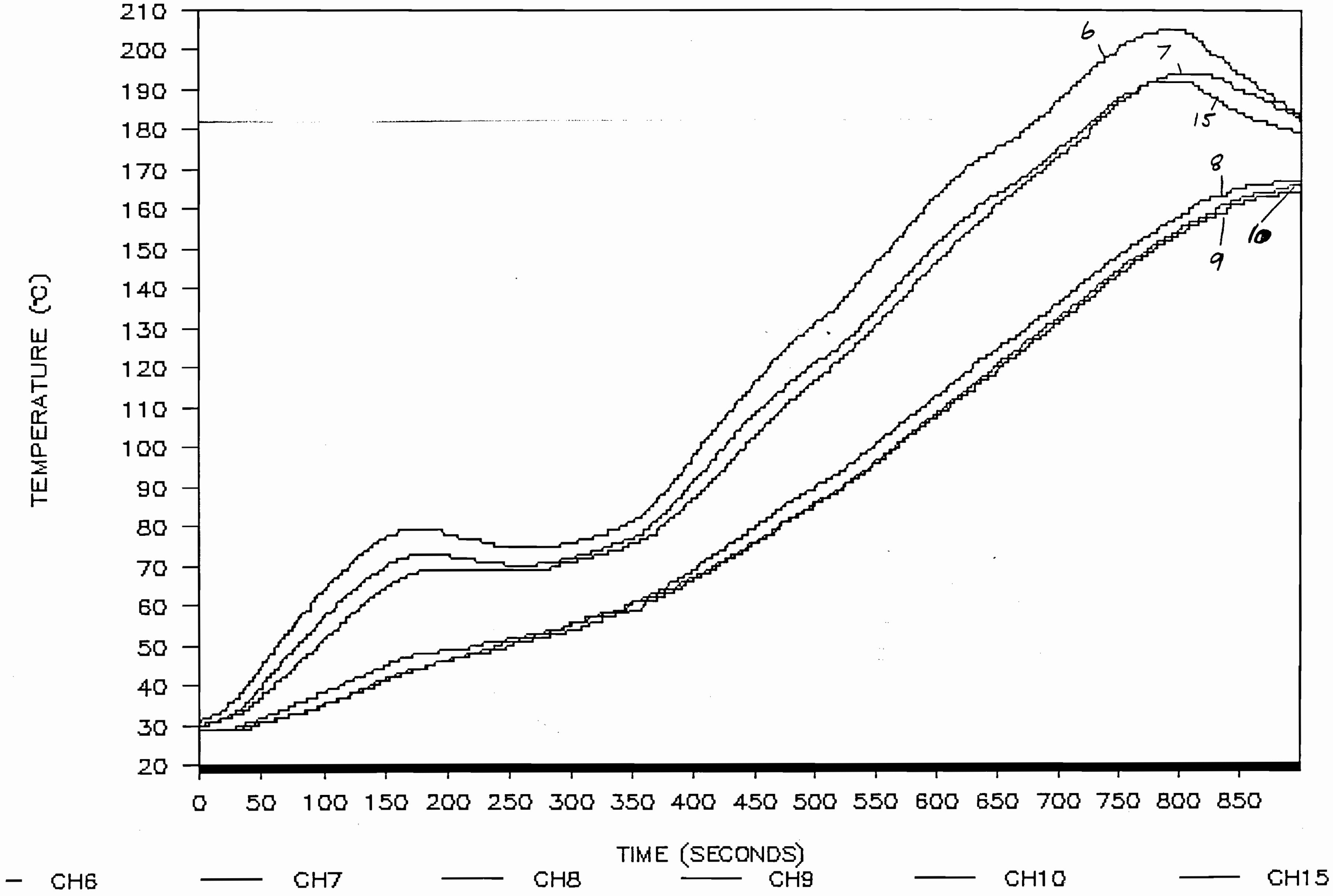
THERMAL PROFILE DATA

31—1



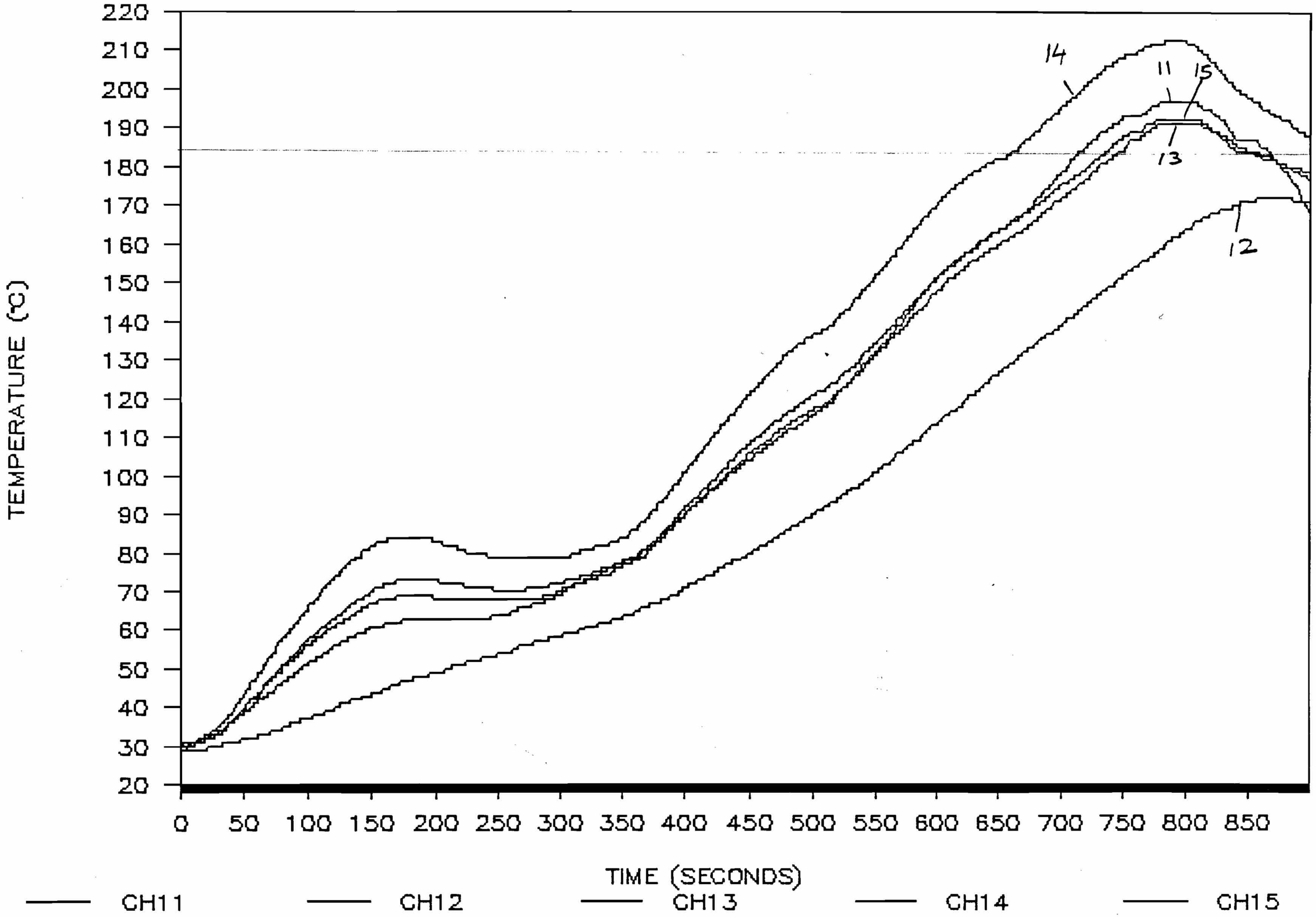
THERMAL PROFILE DATA

31–2



THERMAL PROFILE DATA

31–3



Appendix D

Westinghouse Process Specification for IR Soldering of Thru-Hole Connectors

SPECIFICATION FOR IR SOLDERING OF THRU-HOLE CONNECTORS

9/27/88

1. SCOPE

1.1 This drawing establishes the requirements for the soldering of thru-hole connectors using tin-lead solder with the Convection/Infrared or "IR" process.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein:

2.1.1 Specifications (Government)

WS-6536	Procedures and Requirements for Preparation and Soldering of Electrical Connections

3. REQUIREMENTS

3.1 Safety

Materials used in performing this process may be hazardous. Safety precautions shall always be applied. The environment, equipment, and tools necessary for the performance of any part of this specification shall be designed, fabricated, installed, and used in accordance with the applicable occupational safety and health standards. Additional information on potentially hazardous materials may be obtained from the manufacturers Material Safety Data Sheets (MSDS). (When applicable, Safe Practice Data Sheets (SPDS) and Safe Practice Procedure Sheets (SPPS) are specified herein. When necessary, consult Industrial Hygiene and Safety.)

3.2 Certification

Certification for operators and inspectors shall be in accordance with WS-6536.

3.3 Equipment

3.3.1 IR Soldering System

The IR reflow system shall be mechanized to provide for smooth transition of the workpiece. Temperature control of the various heating zones and conveyor speed shall be computerized. The equipment shall maintain a temperature range of $\pm 9°F$ ($\pm 5°C$) in each heating zone. The conveyor shall maintain speed within $\pm 5\%$.

3.4 Connectors

Connectors shall not be pretinned prior to soldering. Gold plating shall not exceed 100 microinches to preclude the pretin requirements of WS 6536.

3.5 Soldering

Prior to reflow, the connector pins shall be coated with RMA flux to completely cover all solderable surfaces. Preforms shall be used for providing solder to the joint location. The time temperature profile shall be of the "preheat/soak/ramp/soak/spike type. The profile shall activate and outgas the flux, preheat the assembly, and reflow the solder joints. The preheat temperature shall be maintained at 150°C ±20°C. The reflow temperature shall be 183°C and shall not exceed 200°C.

3.5.1. Solvents and Cleaning

Cleaning solvent M53516DN (SPDS M-9) may be used in addition to the solvents specified in WS-6536.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Inspection and monitoring shall be provided by Quality/Operations Procedures to assure that this process is implemented in accordance with the requirements of section 3 and WS-6536.

4.2 Monitoring for equipment used

Monitoring shall be provided by Quality/Operations Procedures to assure process control by periodic checking and calibration of equipment in accordance with the requirements of section 3 and WS-6536.

4.2.1 Monitor IR equipment in accordance with 3.3.1.

4.3 Monitoring for Materials Used

Monitoring shall be provided by Quality/Operations Procedures to assure that the specified materials are used in accordance with the requirements of section 3 and WS-6536.

4.4 Certification is Required for this Process

Monitoring shall be provided by Quality/Operations Procedures to assure that operators are properly certified in accordance with the requirements of section 3 and WS-6536.

4.4.1 Monitor certification in accordance with 3.2.

1988

M. Westinghouse

SIGNATURE AWARD OF EXCELLENCE

BRONZE

Presented to:

Scott E. Dahne
Senior Process Engineer

In recognition of a unique application of automated IR soldering of Mark 50 printed wiring assemblies resulting in defect-free high quality assemblies with a 50:1 producibility improvement.

Paul E. Lego
President and Chief Operating Officer