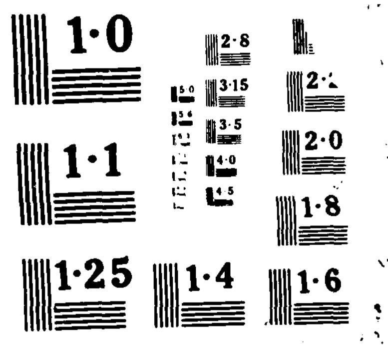
AD-A191 224 SINGLE PHASE LIQUID IMMERSION COOLING OF DISCRETE HEAT SOURCES IN A VERTICAL CHANNEL(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S J HAZARD DEC 87 1/2

UNCLASSIFIED F/G 9/1 NL


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·8
3·15
3·5
4·0
4·5

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SINGLE PHASE LIQUID IMMERSION
COOLING OF DISCRETE HEAT SOURCES
IN A VERTICAL CHANNEL

by

Sherrill John Hazard, III

December 1987

Thesis Advisor: Yogendra Joshi

Approved for public release; distribution is unlimited

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

A191 224

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School

6b. OFFICE SYMBOL (If applicable): Code 69

7a. NAME OF MONITORING ORGANIZATION: Naval Postgraduate School

6c. ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

7b. ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code):

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification): SINGLE PHASE LIQUID IMMERSION COOLING OF DISCRETE HEAT SOURCES IN A VERTICAL CHANNEL

12. PERSONAL AUTHOR(S): Hazard, Sherrill J., III

13a. TYPE OF REPORT: Master's Thesis

13b. TIME COVERED: FROM ________ TO ________

14. DATE OF REPORT (Year, Month, Day): 1987, December

15. PAGE COUNT: 160

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Immersion Cooling; Protruding Heat Sources; Vertical Channel; Flow Visualization

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Natural convection liquid cooling of simulated electronic components was investigated. A single column of eight protruding components was constructed using foil heaters mounted on the back of stainless steel rectangular blocks. These components were attached to a vertical plexiglas wall to simulate a column of 20 pin DIP's. A channel was formed by placing a smooth movable shrouding wall parallel to the test surface. The test surface and the shrouding wall were placed in a water immersion bath. Flow visualization was accomplished using a laser generated plane of light to illuminate suspended particles. Photgoraphs were taken of the flow at the test surface mid-plane for four different power settings at each of three different channel widths. A nondimensional temperature and a modified Grashof number for each heated protrusion at each input power setting and channel width were determined.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Yogendra Joshi

22b. TELEPHONE (Include Area Code): (408) 646-3400

22c. OFFICE SYMBOL: Code 69Ji

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

☆ U.S. Government Printing Office 1986—606-243

UNCLASSIFIED

#19 - ABSTRACT - (CONTINUED)

Visual results indicate two distinct flow regions. Far away from the components, a natural convection boundary layer flow was observed. Near the components, the flow was modified by the protrusions. As the component heat input increased, more pronounced three dimensional effects were noticed. Temperature measurements indicate that as the modified Grashof numbers increased, the nondimensional temperatures decreased for each component. Also, the difference in the nondimensional temperatures for various components decreased with increasing modified Grashof numbers.

Single Phase Liquid Immersion Cooling of Discrete Heat Sources in a Vertical Channel

by

Sherrill John Hazard, III
Lieutenant, United States Navy
B.S., University of Maine at Orono, 1980

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1987

Author: Sherrill John Hazard, III

Approved by: Yogendra Joshi, Thesis Advisor

Anthony J. Healey, Chairman
Department of Mechanical Engineering

Gordon E. Schacher,
Dean of Science and Engineering

ABSTRACT

Natural convection liquid cooling of simulated electronic components was investigated. A single column of eight protruding components was constructed using foil heaters mounted on the back of stainless steel rectangular blocks. These components were attached to a vertical plexiglas wall to simulate a column of 20 pin DIP's. A channel was formed by placing a smooth movable shrouding wall parallel to the test surface. The test surface and the shrouding wall were placed in a water immersion bath. Flow visualization was accomplished using a laser generated plane of light to illuminate suspended particles. Photographs were taken of the flow at the test surface mid-plane for four different power settings at each of three different channel widths. A nondimensional temperature and a modified Grashof number for each heated protrusion at each input power setting and channel width were determined. Visual results indicate two distinct flow regions. Far away from the components, a natural convection boundary layer flow was observed. Near the components, the flow was modified by the protrusions. As the component heat input increased, more pronounced three dimensional effects were noticed. Temperature measurements indicate that as the modified Grashof numbers increased, the nondimensional temperatures

decreased for each component. Also, the difference in the nondimensional temperatures for various components decreased with increasing modified Grashof numbers.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

Symbol	Description	Units
A	Area	m^2
g	Acceleration due to gravity	m/s^2
Gr*	Modified Grashof Number	Dimensionless
k	Thermal conductivity	$W/m\text{-}^oC$
k_f	Fluid thermal conductivity	$W/m\text{-}^oC$
k_{PG}	Thermal conductivity of plexiglas	$W/m\text{-}^oC$
k_R	Thermal conductivity of foam rubber insulation	$W/m\text{-}^oC$
L	Characteristic length	m
Q_{COND}	Energy loss via conduction through the back of the test surface	W
Q_{CONV}	Energy convected into fluid	W
Q_{IN}	Energy into foil heater	W
R	Resistance of precision resistor	Ω
R_A	Equivalent thermal resistance to conduction through plexiglas test surface	$^oC/w$
R_B	Equivalent thermal resistance to conduction through foam rubber insulation	$^oC/w$
T_{AVG}	Average block surface temperature	^oC
T_{INF}	Ambient temperature	^oC
T_B	Bottom surface temperature of the block	^oC

T_F	Front surface temperature of the block	^oC
T_A	Heater temperature	^oC
T_L	Left surface temperature of the block	^oC
T_R	Right surface temperature of the block	^oC
T_T	Top surface temperature of the block	^oC
V_H	Voltage across heater	Volts
V_T	Input voltage	Volts
δ	Uncertainty of variable	Various
β	Coefficient of expansion	$1/^oC$
ν	Kinematic viscosity	m^2/s

ACKNOWLEDGMENTS

The author would like to express his deep gratitude to Assistant Professor Y. Joshi, his thesis advisor, for his guidance and advice in the endeavor.

He wishes to express appreciation to Mr. Mardo Blanco, Mr. Tom Christian, and Mr. Jim Schofield for their superior efforts solving perplexing construction problems.

The author would like to thank the Educational Media Department photography lab personnel for their rapid and continual effort in developing all photographs.

Last but not least, a special word of thanks and sincere appreciation to my wife, Marcella, whose understanding, support, and patience allowed for this work to be completed in a timely and effective manner.

I. INTRODUCTION

A. STATEMENT OF PROBLEM

From the first electronic digital computer, ENIAC (1946), which used vacuum tubes as its basic logic elements, to the present use of integrated circuits, rapid advancements in the miniaturization of electronic components is well documented [Refs. 1,2]. This "boom" in technology has brought us from the small scale integration (SSI) device to the ultra large scale integration (ULSI) device in just 25 years [Ref. 3]. With the 1970 advent of the first one kilobit RAM semiconductor device, the number of memory cells contained on a single device has grown to the familiar 64K and more recently the 256K and 512K devices.

While the component density per chip has increased significantly, the chip dimensions have been considerably miniaturized. For example, a typical 64K RAM chip is only 14.2 square millimeters, approximately the size of a printed letter [Ref. 4]. The drive towards larger capacity and decreased size is expected to continue into the 1990's.

This trend toward higher packing densities has in turn lead to a considerable increase in heat fluxes at both the chip and module levels. For reliable long term operation of the device, these large heat fluxes must be removed, while maintaining the components at acceptably low temperature levels. To get an idea of the magnitude of the decreased size to increased heat flux relationship let us consider a power dissipation of 10 watts on a 5x5 mm chip. This yields a heat flux of 5×10^5 w/m^2, which is only 20 times less than that on the surface of the sun. As seen in Fig. 1, the sun's surface temperature is more than 6000°C while today's chips must be designed to operate at considerably lower temperatures, between 100°C to 125°C [Refs. 5,6,7]. A strong need to keep the devices at these low temperature levels exists, since for every 20°C decrease in chip temperature, the chi failure rates are cut in half [Ref. 5].

B. IMMERSION COOLING: ANALYTICAL AND EXPERIMENTAL STUDIES

Immersion brings the liquid coolant into direct physical contact with the electronic package. It is therefore important that the coolant exhibit several crucial characteristics. It must be dielectric in nature so as not to adversely affect the circuits immersed in it. Also, it must be non-toxic as well as chemically inactive with the materials which compose the immersed portions of the electronic package. Because very high heat transfer rates are attainable with direct immersion cooling, its application has been receiving much attention in recent years [Refs. 3,8-10].

Having decided on the use of immersion cooling, the designer still has the choice of natural convection, forced convection or phase change as the cooling mechanism.

Because of its potentially high-dissipation capabilities, together with such added advantages as no noise and high reliability, natural convection is now generally recognized as an effective and viable means for proper thermal control of electronic packages [Ref. 11].

Two of the earliest studies in this area were conducted at Bell Telephone Laboratories by Baker [Refs. 12,13]. From his first study of free and forced convection cooling [Ref. 12], Baker showed that liquid immersion is an effective means of cooling small heat sources. The free convection cooling by liquid was found to be more than three times as effective as free convection cooling by air for the same device. For forced convection, the improvement was greater for liquid than air by a factor of 10.

In his second forced convection study using two different fluids [Ref. 13], boundary layer analysis showed that the convective heat transfer coefficient would increase significantly as the heat source size decreased. The convective heat transfer coefficient increased by a factor of 15 when the size was decreased from 2.00 to 0.01 square centimeters [Ref. 13]. A similar increase was noted for free convection.

More recently, Park and Bergles [Ref. 14] experimentally studied natural convection from discrete flush mounted and protruding heaters of varying widths, in water and R-113. They documented the increase in heat transfer coefficient with decreasing width. Also, for protruding heaters, the heat transfer coefficients for the top heaters in an array were found to be higher than those for the bottom heaters. This trend was not observed for flush mounted heaters. As the distance between heaters increased, so did the heat transfer coefficients, the effect being greater in R-113 than in water.

Knock [Ref. 15] conducted a flow visualization study in a liquid filled rectangular enclosure with a single protruding heater from one vertical wall. Using water as the coolant, he found the existence of a dual-cell flow configuration where the upper cell was buoyancy driven and the lower cell was shear driven. He also concluded that as the heater height increased, the Nusselt number decreased.

Lin and Akins [Ref. 16] computed transient and steady-state natural convection heat transfer in a fluid-filled cubical enclosure. The flow was initiated by subjecting each of the six walls to a sudden change in temperature. They concluded that the size of the enclosure determined the circulation pattern.

Chu, et al. [Ref. 17] studied the natural convection in a rectangular enclosure with a long horizontal heat source mounted on one vertical wall. A number of different heater sizes and locations, as well as enclosure sizes, were investigated. They concluded that as the heater was moved downward on the wall, both the Rayleigh number and the circulation rate increased. The heater size had little effect on circulation. A secondary flow cell was found to develop at the upper surface when the height of the enclosure was increased.

Yang, et al. [Ref. 11] used a three-dimensional finite difference method to study the natural convection cooling of a chip array in a rectangular enclosure filled with a dielectric liquid. They found the temperatures on the chip surfaces to be oscillatory, with wave forms ranging from simple to complex. The maximum chip surface temperatures occurred on the top row of chips for large gap sizes, but oscillated among all rows for small gas sizes.

It is clear from these studies that only a limited amount of information currently exists on natural convection in liquids from discrete protruding heat sources. The small size of the heat sources results in three-dimensional flow and temperature fields. The capability of numerically simulating these complex flows has only recently been developed for laminar flows, as an example in Yang et al. [Ref. 11]. Detailed measurements of transport are needed to verify such computations. Also, flow visualization studies are needed to examine the various possible flow regimes and the laminar to turbulent transition in such flows.

C. OBJECTIVES

The objectives of this study were:

1. to design and construct a liquid immersed vertical channel with discrete protruding heat sources. This geometry simulates a printed circuit board array with a number of heat dissipating electronic components. The heat sources were eight rectangular stainless steel protrusions, modeled geometrically after 20-pin dual-in-line packages (DIP). These were attached to the vertical card, in the form of a single vertical column.

2. to obtain the steady state natural convection flow pattern visualization within the interrupted channel, for a range of component power dissipation rates and plate spacings. The flow was visualized using a plane of light which illuminates suspended particles in the water.

3. to measure component temperatures for various power inputs and card spacings and develop appropriate heat transfer correlations for this geometry.

This study was also intended to be a basis for future heat transfer experiments using various component array sizes and element spacings. The measurements will be used as a guide toward future experiments and computational efforts.

All objectives were achieved. As well a proving the reproducibility of both the numerical data and flow visualization photographs.

II. EXPERIMENT

A. GENERAL DESIGN CONSIDERATIONS

The channel assembly, seen in Fig. 2, consisted of a vertical test surface with eight rectangular stainless steel blocks protruding from it mounted in a vertical column. A parallel shrouding plate was placed in front of the test surface. This configuration was meant to simulate one column of 20-pin DIP's mounted on a printed circuit board, with the back of another printed circuit board directly in front of it.

Each protrusion was heated by a foil heater mounted on the back (Fig. 3). The foil heater and the stainless steel block together act as a 20-pin DIP model and are hereafter referred to as a heater. A precision $2.0\,\Omega\pm1\%$ resistor placed in series with each heater and its power supply, allowed the input power to be accurately determined. Five thermocouples, one on the center of each exposed face of the heater allowed for surface temperature measurements (Fig. 4). An additional thermocouple was mounted in the center of each heater mounting slot to measure the heater temperature.

The channel assembly was suspended in the center of a one cubic meter tank filled with purified water. Three thermocouples monitor the tank temperature at the top, middle and bottom. A computer-aided data acquisition system was used to measure temperatures throughout the study. A line drawing of the entire system is seen in Fig. 3.

Several criteria were established to be used as guidelines for design and construction. The following is a list of these criteria and their implications.

1. <u>Heater Block Dimensions</u>

As previously noted, each heater was to geometrically model a 20-pin DIP. Micrometer measurements of an actual 20-pin DIP were made and each heater block was cut from solid 304 stainless steel to these dimensions (Figs. 6, 7). Stainless steel was used to prevent chemical reaction with the water of the immersion bath, and because it has a thermal conductivity in the same range as an actual DIP.

2. <u>Heating Element</u>

Each block was to be heated individually and must be able to withstand temperatures in excess of 100^{o}C, the boiling point of water. There was also the necessity to be able to accurately determine the temperature at the heater's surface, as well as having an even heating of the block.

During design, both an imbedded resistor and a cartridge type heater were considered, but the inability to accurately determine the temperature at their centers forced their elimination. The resistance type foil heater, however, met or exceeded all the requirements set for the heating element and had the advantage of ease of installation.

3. Heater Location

The goal of this study was to model a single column of DIPs in a vertical channel. After examining several actual printed circuit cards, a configuration of eight protruding heaters in a single column was decided on. The heaters were spaced on one inch centers as found in many actual applications.

4. Visualization Technique

Visualization was accomplished with an eight milliwatt helium neon laser and a cylindrical lens (Fig. 8). The beam of light was split into a plane which illuminated particles suspended in the immersion bath water (Fig. 9). The particles were Pliolite, an inert pigment used in the manufacture of paints and adhesives. The particles have a specific gravity of 0.93, which results in a large suspension time in water.

This technique allowed for the visualization of a single two-dimensional plane of the flow field. Other planes can be examined by minor realignment of the laser-lens assembly. The method also has the benefit of allowing the bath to remain electrically nonconductive.

5. Thermocouple Design and Placement

To accurately measure the temperature of each block face, individual thermocouples were employed. However, if the thermocouple protrudes above the surface, it will affect the flow field. Therefore a groove was cut on each face to accommodate the thermocouple. If the thermocouples are placed significantly below the surface, they will not accurately reflect the surface temperature. To minimize this problem, 0.003 inch copper-constantan thermocouples were used, and they were placed in 0.02 inch radius grooves (Fig. 10). The larger groove allowed for the thickness of the bonding agent. The grooves were cut so that the bead of the thermocouple will be located at the center of each surface.

6. <u>Other Considerations</u>

The test surface was constructed of plexiglas to allow for easier milling of heater mounting slots. The back of the test surface was covered with foam rubber insulation to minimize conduction losses through the test surface. The outer surfaces of the immersion tank were also covered with foam rubber insulation to minimize heat transfer with the ambient air. Styrofoam blocks covered with teflon were floated on the surface of the bath to prevent contamination of water and minimize heat losses through the free surface.

B. COMPONENTS

1. <u>Heater</u>

The heater assembly (Figs. 11, 12) consisted of a 0.94 inches (23.88 mm) long, 0.31 inches (7.87 mm) wide and 0.24 inches (6.10 mm) high 304 stainless steel block (Fig.

13). A resistance type foil heater was bonded to the back of each block using Omega Bond 101, a high thermal conductivity adhesive. The blocks have one groove cut into each side face with one end of the groove at the face center. A 0.04 inch diameter hole was drilled through the block from the front surface to allow for the passing of the thermocouple lead (Figs. 11, 12).

The foil heater consisted of a network of Inconel 600 conductor mounted on Kapton and is 1.37 inches (34.80 mm) long, 0.30 inches (7.62 mm) wide, and 0.007 inches (0.18 mm) thick (Fig. 14). Notches and holes were cut in the Kapton which align with the grooves and hole in the block. They allowed the passage of thermocouple wires, and also aided in the proper alignment of the foil heaters during bonding with the block. During the bonding of the foil heaters to the block, weight was applied to ensure uniform thickness of the adhesive and to also prevent curling at the edges. The power leads were soldered onto the protruding tabs of the foil heaters after the bonding agent had cured (Fig. 15).

The thermocouples were bonded in the grooves by placing a small drop of Eastman 910 adhesive on the thermocouple bead. The thermocouple was then placed in the designated groove. Using a straight pin, pressure was applied by hand until the adhesive set. After allowing for three hours of cure time, the remainder of the groove was filled with Omega Bond 101 and smoothed to the level of the block face with a straight edge. The Omega Bond 101 experienced little shrinkage after curing. This procedure was repeated for each thermocouple.

2. Test Surface and the Shrouding Wall

Both the test surface and the shrouding wall were constructed of 1/2 inch (12.70 mm) thick plexiglas cut into a 12.0 inch (304.80 mm) square. Eight 0.015 inch (0.38 mm) deep, 1.41 inch (35.81 mm) long and 0.31 inch (7.87 mm) wide mounting slots were cut into the test surface on one inch (25.40 mm) vertical centers. This allowed the foil heaters to be mounted flush with the test surface while only the block protruded. Four 0.06 inch (1.524 mm) diameter holes were drilled through the test surface to conform to the grooves in each block. This allowed the thermocouple lead wires to pass through the test surface. One 0.12 inch (3.048 mm) diameter hole was drilled for the power leads to pass through (Fig. 16).

3. Test Surface Back Containment

Since all the wiring penetrated through the test surface, and the immersion bath was water, it was necessary to have a waterproof containment for the wiring. This was accomplished by fabricating a five sided box onto which the test surface was mounted (Fig. 17). The box was 12 inches (304.80 mm) square by 2.25 inches (57.150 mm) deep and was constructed of 0.50 inch (12.70 mm) plexiglas. A thin groove was cut around the edges of the open face for a large O-ring gasket. The test surface was screwed over the open face with 20 stainless steel screws and compressed the O-ring to form a watertight seal. A 2 inch (50.80 mm) diameter plexiglas snorkel was mounted into the back of the containment box and extended to an elevation above the surface of the immersion bath. The wiring runs from the back of the test surface up through the snorkel.

4. Test Surface Support

Support for the test surface and shrouding wall was provided by an H style bracket which spanned the width of the tank (Fig. 18). The cross members between the span supports hold adjustable hangers to which the test surface and shrouding wall were attached, forming the vertical channel. These adjustable hangers allow the width of the vertical channel to be varied. They also allow the vertical adjustment of both the test surface and the shrouding wall.

5. Immersion Tank

The immersion tank was constructed such that the interior dimensions render a one cubic meter volume. The walls of the tank were 0.75 inch (19.050 mm) glass set in an aluminum frame. The glass was sealed watertight with Dow Corning 732 RTV adhesive/sealant (RTV) (Fig. 19).

6. Immersion Bath Filtration and Purification

Tap water was used and to ensure its purity and a resistivity of at least 0.1 megohn-cm, a Barnstead cartridge filtration/purification system was employed (Fig. 20). It consisted of four stages. The first stage contained a colloid/organic purification cartridge, followed by a high capacity deionization cartridge. The third stage was a high purity deionization cartridge, while the final stage was a 0.45 micron and larger filter cartridge. A suction was drawn from the bottom center of the tank with a small magnetic pump. The water passed through the four stage filtration/purification system and was returned to the top of the tank. Proper filtration/purification took approximately 10 hours and one change of the colloid/organic and deionization cartridge was required. The filter cartridge did not require changing during a single filling of the tank.

C. ASSEMBLY

In addition to the thermocouples on the heater block assemblies, measurements of the mounting face temperature were made by placing a single thermocouple at the center of each mounting slot. These were bonded using Eastman 910 adhesive. This was the first step in the test surface assembly process.

Once the heater assemblies, described in Section B, were ready, they were mounted on the test surface. For each heater block assembly the thermocouple wires and power leads were passed through their respective holes in the test surface (Fig. 21). A layer of Eastman 910 adhesive was then applied to the bottom of the slot. Next, the heater assembly was firmly pressed into the mounting slot. This procedure was repeated for each heater assembly (Fig. 22).

Ten pounds of weight was distributed over all the protruding heaters and remains in place until the adhesive fully cured. Following the curing, the test surface was turned upside down and each lead was firmly cemented in this penetrating hole. The thermocouple and power leads were then assigned locations and routed through the snorkel. Next, the test surface was secured in place over the opening in the back containment box. The screw heads were covered with RTV and smoothed with a straightedge to the level of the test surface. The seam between the containment and test surface was also sealed with RTV.

Omega Bond 100 was used to fill in above the foil heater tab and in the seam around each heater assembly. This provided a watertight seal around each heater assembly and the test surface and also ensured a smooth and flat test surface (Fig. 23). Male plug-in connectors were then attached to each thermocouple lead wire and banana plug connectors to the power leads.

D. INSTRUMENTATION

1. Power to the Heaters

Each heater was run in series with a precision resistor that was measured to have a 2.02 ohm resistance. All eight heaters were in parallel with a Hewlett Packard model number 6200B, 0-10 volts, 0-10 amperes, power supply. Both the source voltage and the heater voltage were measured independently. The current to each heater was then calculated by subtracting the heater voltage from the source voltage and dividing by the resistance of the precision resistor. The power input to each heater was calculated by the product of the heater voltage and heater current. Both voltages were measured by a Hewlett Packard model 3852S data acquisition system containing a Hewlett Packard model 44701A integrating vollmeter, all controlled by a Hewlett Packard model 300 computer.

2. Temperature Measurement

The thermocouples described earlier in Sections A.5 and C were referenced individually to an ice bath, as seen in Fig. 24. Each reference thermocouple was connected such that its constantan lead was connected to the constantan lead of the measurement thermocouple. The copper leads of each measurement and reference thermocouple were connected directly to a Hewlett Packard model 44705A relay multiplexer and inserted into the data acquisition system. The data acquisition system then measures the ice referenced voltage of each thermocouple. The voltages were converted directly into temperatures in the controlling computer program by using a fourth order polynomial, fit to the thermocouple manufacturer's calibration data for copper-constantan thermocouples over a 10°C to 70°C range, with a maximum curve fit uncertainty of 0.00663°C RMS.

III. EXPERIMENTAL PROCEDURE

A. APPARATUS PREPARATION

A stainless steel, propeller type, variable speed stirrer was used to stir the immersion bath. Stirring was performed to remove temperature stratification and to disperse the particles for flow visualization. While stirring, the floating styrofoam blocks were removed and the test surface and shrouding wall, mounted on the support bracket, were lowered into the immersion bath and positioned near the center of the tank. The styrofoam blocks were then replaced on the surface of the immersion bath. Stirring continued for 5 to 10 minutes.

The laser was energized next. The cylindrical lens was placed in the beam path and rotated to obtain the plane of light of greatest intensity normal to the test surface. The laser was positioned to allow the plane of light to fall directly on the center of each heater. The light plane passed through both the front wall of the tank, through a 0.125 inch by 12.0 inch slit, and the shrouding wall. The slit was used to obtain a well-defined plane of light and also to prevent extraneous scatter light from entering the tank. A 35 mm camera and tripod were set up to visualize the flow through the right hand wall of the tank. Two, 2 inch wide strips of thin cardboard were positioned to allow the camera to only photograph the space between the test surface and shrouding wall. A data back on the camera allowed for easy sequencing of the photographs for later analysis.

Crushed ice was placed into a stainless steel Dewar flask along with the ice reference thermocouples. A mercury thermometer inserted into the ice base ensured that the ice bath was at 0±0.05°C. The data acquisition system and the computer was then turned on. The internal voltmeter in the data acquisition system requires a minimum one hour warm-up period. During this hour, no current was passed through the heaters. The tank was allowed to achieve quiescence. After one hour passed, a visual inspection of the illuminated particles in the tank was performed to ensure that the immersion bath was quiescent.

The temperature acquisition program, contained in Appendix D, was loaded and the temperatures of all heater surfaces and the immersion bath was measured. When the results showed all surfaces to be within 0.10°C of each other, and the tank temperature stratification to be less than 0.10°C, the experiment was ready to begin. A chance exists that the tank may need to be restirred, and allowed to sit to quiescence for approximately one hour.

B. TEST PROCEDURE

1. Initial Instrument Settings

Once the immersion bath was quiescent and the temperature of the heaters and the bath were within the required values, a sampling of all thermocouple temperatures was performed and printed. This record was saved and labeled as the baseline for the run. The power calculation program, contained in Appendix D, was loaded, and the power supply was set to zero and energized.

The power was increased incrementally and the output from the power calculation program was checked. This was performed repeatedly until the desired power setting was achieved. For this study, four power settings, 0.2, 0.5, 1.0 and 2.0 watts, were used for each channel width.

2. Instrument Readings

Thermocouple temperature measurements were taken every 10 minutes until successive temperature measurements remained unchanged to within 0.10°C. At this point, it was assumed that steady state had been achieved. This process took between one and two hours, depending on the channel width and power setting.

Once steady state was attained, the thermocouples were monitored once more and the temperatures and voltages recorded. Single thermocouples on various heater assemblies were also sampled over a period of several minutes to detect any temperature oscillations with time.

The total voltage drop across the power supply and across each heater was measured. The power for each heater was then calculated and printed by the computer program. After all the data had been recorded, and with the power supply and laser on, flow visualization photographs were taken.

3. Photographic Technique

A Nikon F3 series camera with a 50 mm f2.8 lens, a MF-18 data back, a MD-4 motor drive, and a MT-2 intervelometer was used for the photography. The film used was Kodak ASA400 Tri-X Pan black and white print film. The first picture taken was a blank and the data back was set to display the date. The laboratory lighting was turned off. Using a flashlight the camera was set to f2.8, and the focus adjusted. The intervelometer was set for the required exposure length. Four photographs of each channel width and power setting were taken as shown in Table 1.

TABLE I

PHOTOGRAPH EXPOSURE VARIATIONS

Picture #	f	Exposure Time
1	2.8	20 sec.
2	2.8	30 sec.
3	4.0	20 sec.
4	4.0	30 sec.

4. Experiment Completion

Once the photographs were taken, the laboratory lighting was turned on and the laser and power supply were turned off. The propeller stirrer was started and the water immersion bath was mixed for 5 to 10 minutes. The immersion bath was now left to become quiescent again. After quiescence was achieved, the apparatus was ready to start another run with the same channel width at a different power level.

5. Channel Width

The channel widths, also called spacings, for this study were as follows;

a. no shrouding wall

b. 2.91 inches (73.810 mm)

c. 0.47 inches (11.913 mm).

These spacings were measured from the test surface to the shrouding wall. Each heating element protrudes 0.22 inches (5.598 mm) into this spacing, in front of the test surface. The spacings were changed by hoisting the test surface and shrouding wall support bracket from the immersion bath and removing the installed spacer. The spacer corresponding to the next spacing desired was installed. The apparatus was then ready for a new set of tests.

D. DATA ANALYSIS

There is more than one vertical dimension involved in this study. Any one of these could be chosen as the characteristic length, L, for determining the nondimensional temperature, T, and the Modified Grashof number, Gr*. The 0.31 inch (7.874 mm) vertical height of the heater assembly was chosen since it characterizes the local region of the buoyant flow. The corresponding temperature scale was easily obtained by combining the convected energy from each component with the component height and fluid thermal conductivity. An alternative would be the local downstream distance from the channel bottom. However, the appropriate temperature scale for this choice was not clear. The properties of the water were evaluated at the ambient bath temperature, T_{INF}. These values, listed in Table II, were obtained by linearly interpolating a table of properties [Ref. 18].

In order to determine the net convected energy from each heater, the conduction losses, Q_{COND}, were required to be determined for each power input and channel width. These were calculated from a resistance network consisting of the foam rubber insulation and the plexiglas. The net conduction loss is given by

$$Q_{COND} = \frac{\Delta T}{R_A + R_B} = \frac{T_H - T_{INF}}{R_A + R_B} \qquad (1a)$$

with

$$R_A = \frac{\Delta X_{PG}}{k_{PG}\, A}$$

$$(1b)$$

$$R_B = \frac{\Delta X_R}{k_R\, A}$$

TABLE II

PROPERTIES OF WATER [REF. 18]

Run #	T_{INF} °C	Q_{IN} W	Spacing mm	Thermal Conductivity $k_f \cdot 10^3$ w/m·°C	Expansion Coefficient $\beta \cdot 10^4$ 1/°C	Kinematic Viscosity $\nu \cdot 10^6$ M^2/Sec
1	18.43	0.2	73.81	600.38	1.899	1.0453
2	18.32	0.5	73.81	600.35	1.897	1.0460
3	16.08	1.0	73.81	596.80	1.648	1.1030
4	16.20	2.0	73.81	596.96	1.662	1.0998
5	16.22	0.2	11.913	596.99	1.664	1.0992
6	16.25	0.5	11.913	597.04	1.668	1.0983
7	16.26	1.0	11.913	597.06	1.669	1.0981
8	16.27	2.0	11.913	597.07	1.670	1.0979
9	16.30	0.2	No wall	599.11	1.674	1.0970
10	16.30	0.5	No wall	597.11	1.674	1.0970
11	16.30	1.0	No wall	597.11	1.674	1.0970
12	16.31	2.0	No wall	597.14	1.675	1.0966

where A is the area normal to the direction of heat flow, and X_{PG} and X_R the thicknesses of plexiglas and foam rubber. See Table III.

TABLE III

PHYSICAL CONSTANTS

ITEM	VALUE
A	0.000188 m^2
ΔX_{PG}	0.006731 m
ΔX_R	0.003175 m

The thermal conductivity for each material was determined from a table of properties in Reference 19, and listed in Table IV.

TABLE IV

THERMAL CONDUCTIVITY OF MATERIALS

Material	k (w/m-°C)
Plexiglas	0.1421
rubber insulation	0.0389

The temperature difference, ΔT, was assumed to be the difference between the heater, T_H, and the ambient temperature, T_{INF}. The convective thermal resistance on the outside of the insulation was neglected here. This calculation of Q_{COND}, therefore, was a "worst case" estimate, using a one-dimensional model. Maximum estimated conduction losses in this study were only about 1.5% of the energy input.

After calculating Q_{COND} and knowing the energy into the system, Q_{IN}, a simple energy balance was used to determine the energy convected into the fluid, Q_{CONV}:

$$Q_{CONV} = Q_{IN} - Q_{COND} \tag{2a}$$

where

$$Q_{IN} = \left(\frac{V_T - V_H}{R}\right) V_H \tag{2b}$$

and:

V_T = input voltage

V_H = heater voltage

R = 2.02 ohms

The nondimensional temperature was next obtained as:

$$T = \frac{(T_{AVG} - T_{INF})\ A\ k_f}{Q_{CONV}\ L} \tag{3}$$

where T_{AVG} is the average of the temperatures measured on the five exposed surfaces of the heater assembly and L is the characteristic length.

The Modified Grashof number is defined as:

$$Gr^* = \frac{g \ \beta \ L^4 \ Q_{CONV}}{A \ k_f \ \nu^2} \tag{4}$$

A complete set of sample calculations is contained in Appendix A. Uncertainty calculations in the evaluation of the nondimensional parameters is presented in Appendix B.

IV. RESULTS

A. FLOW VISUALIZATIONS

Photographs of the natural convection flow in a plane passing through the geometric center of each component are presented in Figs. 25-27. Fig. 25 depicts flows with no shrouding wall in place. Figures 26 and 27 show flows with the shrouding wall 73.81 mm and 11.193 mm, respectively, in front of the test surface. Finally, Fig. 28 depicts one component power input without the shrouding wall in which the camera and laser positions were interchanged.

Observations for all the no wall case (Fig. 25), show the presence of a dual flow structure. Near the protruding heaters, the flow resembles flow past an obstruction. It is clearly visible that the flow follows the contour of the protrusions dipping nearer the test surface after passing over a block and rising before reaching the next block. Further away from the test surface a buoyant boundary layer structure is visible, as expected.

At the lowest power input setting, 0.2 watts, distinct particle traces are visible throughout the flow, indicating a strong two-dimensional behavior near the center of the block. As the power input is increased, these traces get shorter. This indicates more pronounced out-of-plane motion and hence a stronger three-dimensional flow.

It is also quite evident that as the power input is increased, the entrainment velocities also increase but the thickness of the buoyant layer remains vertically unchanged. This may again be due to larger three-dimensional effects.

It is of some interest to note that Fig. 25 shows no dead regions or vortices. Also, for these power levels, the particle traces indicate laminar flow. The effective origin for the outer boundary region flow is approximately one and a half heater spacings upstream of the lowest heater at the lowest power setting. It moves further upstream with increasing input power.

Observations with the shrouding wall 73.81 mm in front of the test surface (Fig. 26), are similar to the no wall case in many respects. However, the entrainment velocity is smaller, therefore the buoyant layer thickness is decreased. Also, the effective origin of the flow has moved to approximately one heater spacing upstream at the low power inputs. It is also apparent that for the 0.2 watt input power setting, quiescence was not achieved, prior to the start of the run.

For the closest spacing (Fig. 27) the flow still follows the contour of the test surface and there are no dead zones or eddy flow visible. Since the shrouding wall is so close to the test surface, the entire gap region participates in the transport, unlike for the two previous spacings, where the shrouding was either absent or was significantly far from the test surface. It is interesting to note that at this spacing, the shrouding was receiving thermal energy from within the channel. This caused a boundary layer flow to develop on the back of the shrouding wall.

Observation of the flow in Fig. 28 reveals the presence of entrainment from the left and right sides of the heater assemblies.

B. QUANTITATIVE

Graphs of block number vs. excess temperature are contained in Figs. 29-46. Note block 1 is the upper most block in the channel. It is also noted that thermocouple #1 corresponding to block 1 heater and thermocouple #31 corresponding to block 6 front face were broken and their data were not plotted. These figures allow a visual interpretation of the temperature across each block face at each spacing and power input. From these graphs and the data contained in Appendix C, no dramatic increase in temperature is apparent as the channel width is decreased.

Figure 47 is a comparison of the front surface temperature of the eight blocks at two watts with the self similar solution for a vertical uniform flux surface. The area of the flat plate is that formed by the eight blocks and the spacings between them. The uniform flux is then obtained by dividing the total convected energy with this area. The equation for the temperature excess at the surface is

$$(T_{SURF} - T_{INF}) = \left[\frac{Q_{CONV}}{1.172\ k_f A}\right]^{4/5}\left[\frac{4\nu^2 X}{g\beta}\right]^{1/5} \tag{5}$$

where the constant 1.172 has been evaluated at Prandtl number equal to 6.7 for water. The fluid property values used were those of the 2.0 watt run with no wall, run 12. From Fig. 47, near the bottom of the heated protrusion column, the measured excess temperatures agree well with the similarity prediction. However, as the flow progresses up the channel, the actual data and the theoretical prediction diverge. This may be due to the increased three-dimensionality of the flow leading to more cooling of the heated blocks.

Results of the data analysis are contained in Appendix E in tabular form. These are also plotted in Figs. 48-50 as the modified Grashof number versus a nondimensional temperature T. We note that T is the inverse of the Nusselt number. Each graph is for a single channel width.

In all the graphs, a general trend is that as the modified Grashof number increases, the nondimensional temperature decreases, indicating higher Nusselt numbers. It is also apparent that the data for various blocks show less of a variation with increasing modified Grashof numbers. This indicates that the temperature variation for the different blocks is not directly proportional to the change in component energy dissipation. The data have been plotted over approximately a ten-fold increase in Q_{CONV}.

However, the resulting component temperature increases are only by a factor of 3 to 4. This is evident for all channel widths.

Another important trend is observed from the nondimensional temperature variations in Figs. 48-50. For the lowest power input, resulting in the smallest modified Grashof number, the nondimensional temperatures decrease as the shrouding plate is moved further away from the test surface. At higher values of modified Grashof number, no significant difference is observed between the different channel widths. The difference at lower modified Grashof numbers presumably results from the greater entrainment as the channel width is increased. For larger modified Grashof numbers, conduction to the shrouding wall may become appreciable, making the temperature differences between the various spacings less significant.

V. CONCLUSIONS

The author has found no previous natural convection liquid immersion cooling studies of a simulated column of protruding electronic devices with or without a shrouding wall. A direct comparison with other studies has therefore not been possible.

Flow visualization provided the evidence of a dual flow structure. Near the test surface, the protrusions govern the flow structure, while further away from the test surface, the flow is similar to a natural convection boundary layer. There were no dead zones or vortices observed for the conditions examined. As the input power increased, the three-dimensional effects become more predominant and the effective origin moved further upstream. Entrainment velocities increased with increasing power input.

The surface temperatures increased with increasing power but no dramatic trend in temperature from spacing to spacing was apparent. The component temperatures near the bottom of the channel agreed with that of a flat plate with constant heat flux. Further downstream, the measured temperatures were below the uniform flux surface prediction. Nondimensional temperatures for each block decreased as the modified Grashof number increased.

VI. RECOMMENDATIONS

While performing the experimental runs a number of possible improvements to the apparatus were noted which would enable better flow visualization. Review of the obtained data showed that using the same configuration the data set should be enlarged to allow for better correlation of channel spacing and input power. These recommendations are stated below.

A. IMPROVEMENT TO EXPERIMENT

1. Apparatus

Both the test surface and the shrouding wall should be painted a dark, flat color, with only a thin slit remaining unpainted on the shrouding wall to allow passage of the plane of light.

A metal plate with a 12 inch long slit should be manufactured. It should have two leveling screws and hang from the top of the tank. This would allow for easier alignment of the plane of light with the test surface.

A similar device with an adjustable width slit should be manufactured to aid with the photographing of the flow.

The laboratory should be made lightproof, thus removing the need for experimentation at night only.

2. Data Acquisition

Data acquisition programs should be rewritten to include lines for the storage of acquired data. Also, the plotter should be interfaced with the system so that results could be directly plotted.

B. ADDITIONAL EXPERIMENTAL WORK

It is suggested that the following areas of study be experimentally explored:

1. Using the same test surface, several channel widths between 73.81 mm and 11.913 mm should be investigated to better understand the effects of card spacing. Note that at 11.913 mm thermal energy was conducted to the shrouding wall. It is recommended that the minimum channel spacing not be less than 11.913 mm, and that the minimum width where conduction to the shrouding wall is not present be found.

2. Using the same test surface, the input powers should be increased above 2.0 watts. Levels of 3.0, 4.0 and 5.0 watts are recommended. This will allow for a better power input to spacing correlation as well as seeing if the nondimensional temperature reaches a constant value.

3. Using the same test surface, only a selected number of blocks could be heated. This will allow an understanding of how the protrusion affects the flow.

4. A different test surface could be constructed and studied based on the above results. A 3 by 3 array of heater assemblies is recommended to begin with.

APPENDIX A

SAMPLE CALCULATIONS

A. DETERMINATION OF INPUT POWER

Using the data for block 2, run 1, Appendix C, the input power is calculated, using Equation (3b), to be:

$$Q_{IN} = \frac{(1.75 - 1.48)\ 1.48}{2.02} = 0.20 \text{ watts}$$

B. NONDIMENSIONAL TEMPERATURE

Using the same data as above, the heat loss via conduction through the test surface is calculated. Employing Equations (1b) and (1c), as well as the information in Tables II and III, and Appendix C, the resistances and area are calculated to be:

$$A = (0.0079)(0.0239) = 0.000188 \text{ m}^2$$

$$R_A = \frac{0.006731}{(0.1421)(0.000188)} = 251.96\ °C/W$$

$$R_B = \frac{0.003175}{(0.0389)(0.000188)} = 434.15\ °C/W$$

From Equation (1a), Q_{COND} is then calculated:

$$Q_{COND} = \frac{(20.63 - 18.32)}{251.96 + 434.15} = 0.003 \text{ watts}$$

From Equation (2a), Q_{CONV} is:

$$Q_{CONV} = 0.20 - 0.003 = 0.197 \text{ watts}$$

The average temperature of the convecting faces is:

$$T_{AVG} = \frac{(19.86 + 19.76 + 19.74 + 19.96 + 19.92)}{5.0} = 19.85°C$$

The ambient temperature, T_{INF}, is taken as the average at three tank temperatures.

$$T_{INF} = \frac{(18.36 + 18.33 + 18.78)}{3.0} = 18.32°C$$

From Equation (3) and Table II, the nondimensional temperature is found to be:

$$\bar{T} = \frac{(19.85 - 18.32)(0.000188)(0.60038)}{(0.197)(0.007874)} = 0.11$$

C. MODIFIED GRASHOF NUMBER

Using Table II and Equation (4), the Modified Grashof number is calculated to be:

$$Gr^* = \frac{(9.81)(1.897 \times 10^{-4})(0.197)(0.007874)^4}{(0.000188)(0.60035)(1.0460 \times 10^{-6})^2}$$

$$Gr^* = 1.14 \times 10^5$$

APPENDIX B

UNCERTAINTY ANALYSIS

TABLE V

UNCERTAINTY VARIABLES

Variable	Uncertainty	Basis
Voltmeter Resolution	0.026°C 1.0 μV	Manufacturer data
Ice Bath Temperature	0.05°C	Manufacturer Calibration data
Polynomial Temperature Conversion	0.00663°C RMS	Polynomial fit error calculation
R	1.0%	Manufacturer data
L	0.0000254 M	Resolution of measurement device
k_f	0.008 W/m·°C	[Ref. 18]
k_{pg}	5.0%	[Ref. 19]
k_r	7.0%	[Ref. 19]
β	0.0000535 1/°C	[Ref. 18]
ν	0.00012 m^2/sec	[Ref. 18]

$$\delta T_H = [(\delta VR)^2 + (\delta I.B.)^2]^{1/2} + \delta \text{ curve}$$

$$\delta T_H = [(0.025)^2 + (0.05)^2]^{1/2} + 0.00663$$

$$\delta T_H = 0.063$$

$$\frac{\delta Q_{IN}}{Q_{IN}} = [(\frac{\delta R}{R})^2 + (\frac{\delta V_H}{V_H})^2 + (\frac{\delta V_T}{V_T})^2]^{1/2}$$

$$= [(\frac{0.02}{2.02})^2 + (\frac{1 \times 10^{-6}}{2.32})^2 + (\frac{1 \times 10^{-6}}{2.75})^2]^{1/2}$$

$$= 0.010$$

$$\frac{\delta A}{A} = [(\frac{0.0000254}{0.007874})^2 + (\frac{0.0000254}{0.023876})^2]^{1/2}$$

$$= 0.0034$$

$$\frac{\delta R_A}{R_A} = [(\frac{\delta X_{pg}}{X_{pg}})^2 + (\frac{\delta A}{A})^2 + (\frac{\delta k_{pg}}{k_{pg}})^2]^{1/2}$$

$$= [(\frac{0.0000254}{0.006731})^2 + (0.0034)^2 + (0.05)^2]^{1/2}$$

$$= 0.050$$

$$\frac{\delta R_B}{R_B} = [(\frac{\delta X_r}{X_r})^2 + (\frac{\delta A}{A})^2 + (\frac{\delta k_r}{k_r})^2]^{1/2}$$

$$= [(\frac{0.0000254}{0.003175})^2 + (0.0034)^2 + (0.07)^2]^{1/2}$$

$$= 0.07$$

$$\frac{Q_{COND}}{Q_{COND}} = [(\frac{\delta R_A}{R_A})^2 + (\frac{\delta R_B}{R_B})^2 + (\frac{\delta T_H}{T_H})^2 + (\frac{\delta T_{INF}}{T_{inf}})^2]^{1/2}$$

$$= [(0.05)^2 + (0.07)^2 + (\frac{0.063}{20.63})^2 + (\frac{0.063}{18.32})^2]^{1/2}$$

$$= 0.0861$$

$$\frac{\delta Q_{CONV}}{Q_{CONV}} = [(\frac{\delta Q_{COND}}{Q_{COND}})^2 + (\frac{\delta Q_{IN}}{Q_{IN}})^2]^{1/2}$$

$$= [(0.086)^2 + (0.01)^2]^{1/2}$$

$$= 0.087$$

$$\frac{\delta T}{T} = [(\frac{\delta A}{A})^2 + (\frac{\delta k_f}{k_f})^2 + (\frac{\delta T_{AVG}}{T_{AVG}})^2 + (\frac{\delta T_{inf}}{T_{inf}})^2 + [\frac{\delta Q_{CONV}}{Q_{CONV}}] + (\frac{\delta L}{L})^2]^{1/2}$$

$$= [(0.0034)^2 + (\frac{0.0038}{0.60038})^2 + (\frac{0.063}{19.85})^2 + (\frac{0.063}{18.32})^2 + (0.087)^2$$

$$+ (\frac{0.0000254}{0.007874})^2]^{1/2}$$

$$= 0.0875$$

$$\frac{Gr^*}{Gr^*} = [(\frac{\delta B}{B})^2 + 4(\frac{\delta L}{L})^2 + (\frac{\delta Q_{CONV}}{Q_{CONV}})^2 + (\frac{\delta A}{A})^2 + (\frac{\delta k_f}{k_f})^2 + 2(\frac{\delta \nu}{\nu})^2]^{1/2}$$

$$= [(\frac{53.5 \times 10^{-6}}{0.1897 \times 10^{-3}})^2 + 4(\frac{0.0000254}{0.007874})^2 + (0.087)^2 - (0.0034)^2$$

$$+ (\frac{0.008}{0.60038})^2 + 2(\frac{0.00012}{0.1046 \times 10^{-5}})^2]^{1/2}$$

$$= 162.24$$

The above uncertainty calculations are intended to be a representative example of the overall uncertainty for this study.

APPENDIX C

TABULAR DATA

Run #1

Spacing: 73.81 mm

Power: 0.2 watts

Date: 11 November 1987

BLOCK #1

T. C.	# 1	Volts D.C.	.00079035	Temp. DEG. C	20.0243445765
T. C.	# 2	Volts D.C.	.00077911	Temp. DEG. C	19.7450658912
T. C.	# 3	Volts D.C.	.00077978	Temp. DEG. C	19.7617177375
T. C.	# 4	Volts D.C.	.00079212	Temp. DEG. C	20.0683090423
T. C.	# 5	Volts D.C.	.00079029	Temp. DEG. C	20.0228541966
T. C.	# 6	Volts D.C.	.0749417	Temp. DEG. C	253317.564556

BLOCK #2

T. C.	# 7	Volts D.C.	.00078393	Temp. DEG. C	19.8648471972
T. C.	# 8	Volts D.C.	.00077967	Temp. DEG. C	19.759983891
T. C.	# 9	Volts D.C.	.00077895	Temp. DEG. C	19.7410892474
T. C.	# 10	Volts D.C.	.00078759	Temp. DEG. C	19.9557819586
T. C.	# 11	Volts D.C.	.00078618	Temp. DEG. C	19.9207517085
T. C.	# 12	Volts D.C.	.00081496	Temp. DEG. C	20.8352713362

BLOCK #3

T. C.	# 13	Volts D.C.	.00078062	Temp. DEG. C	19.7825938819
T. C.	# 14	Volts D.C.	.00077524	Temp. DEG. C	19.6488717936
T. C.	# 15	Volts D.C.	.00077458	Temp. DEG. C	19.6324647191
T. C.	# 16	Volts D.C.	.00078948	Temp. DEG. C	20.0027334804
T. C.	# 17	Volts D.C.	.00078817	Temp. DEG. C	19.9701908396
T. C.	# 18	Volts D.C.	.00082402	Temp. DEG. C	20.8599881386

BLOCK #4

T. C.	# 19	Volts D.C.	.00078141	Temp. DEG. C	19.9022265892
T. C.	# 20	Volts D.C.	.00077783	Temp. DEG. C	19.7132518396
T. C.	# 21	Volts D.C.	.00077313	Temp. DEG. C	19.5964169503
T. C.	# 22	Volts D.C.	.00078624	Temp. DEG. C	19.9222424083
T. C.	# 23	Volts D.C.	.00078245	Temp. DEG. C	19.8280709822
T. C.	# 24	Volts D.C.	.00082316	Temp. DEG. C	20.8386618334

BLOCK #5

T. C.	# 25	Volts D.C.	.00077637	Temp. DEG. C	19.6769614222
T. C.	# 26	Volts D.C.	.00077434	Temp. DEG. C	19.6264983744
T. C.	# 27	Volts D.C.	.00077308	Temp. DEG. C	19.5951738766
T. C.	# 28	Volts D.C.	.00078541	Temp. DEG. C	19.9016206587
T. C.	# 29	Volts D.C.	.00077941	Temp. DEG. C	19.7525220116
T. C.	# 30	Volts D.C.	.00081266	Temp. DEG. C	20.5782076142

BLOCK #6

T. C.	# 31	Volts D.C.	.0271272	Temp. DEG. C	4348.10146544
T. C.	# 32	Volts D.C.	.00077167	Temp. DEG. C	19.5601179051
T. C.	# 33	Volts D.C.	.00077268	Temp. DEG. C	19.5852291742
T. C.	# 34	Volts D.C.	.00078155	Temp. DEG. C	19.8057057213
T. C.	# 35	Volts D.C.	.00077997	Temp. DEG. C	19.7664398002
T. C.	# 36	Volts D.C.	.00080983	Temp. DEG. C	20.5079853066

BLOCK #7

T. C.	# 37	Volts D.C.	.00076535	Temp. DEG. C	19.402958879
T. C.	# 38	Volts D.C.	.0007611	Temp. DEG. C	19.297242815
T. C.	# 39	Volts D.C.	.00076053	Temp. DEG. C	19.283062956
T. C.	# 40	Volts D.C.	.00077596	Temp. DEG. C	19.6667697958
T. C.	# 41	Volts D.C.	.00077246	Temp. DEG. C	19.5797595021
T. C.	# 42	Volts D.C.	.00080754	Temp. DEG. C	20.4511549433

BLOCK #8

T. C.	# 43	Volts D.C.	.0007653	Temp. DEG. C	19.4017133152
T. C.	# 44	Volts D.C.	.00075635	Temp. DEG. C	19.1790649214
T. C.	# 45	Volts D.C.	.00075687	Temp. DEG. C	19.192003674
T. C.	# 46	Volts D.C.	.00077204	Temp. DEG. C	19.5693172318
T. C.	# 47	Volts D.C.	.00076312	Temp. DEG. C	19.3474909198
T. C.	# 48	Volts D.C.	.00079523	Temp. DEG. C	20.1455478033

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00072357	TEMP. DEG. C	18.362739297
VOLTS D.C.	.00072241	TEMP. DEG. C	18.3338268635
VOLTS D.C.	.00072041	TEMP. DEG. C	18.2839738639

BLOCK # 1 HEATER VLOTS D.C. 1.474186

BLOCK # 2 HEATER VLOTS D.C. 1.482119

BLOCK # 3 HEATER VLOTS D.C. 1.475075

BLOCK # 4 HEATER VLOTS D.C. 1.475035

BLOCK # 5 HEATER VLOTS D.C. 1.47361

BLOCK # 6 HEATER VLOTS D.C. 1.47488

BLOCK # 7 HEATER VLOTS D.C. 1.475371

BLOCK # 8 HEATER VLOTS D.C. 1.478689

INPUT VLOTAGE D.C. VLOTS 1.756932

BLOCK # 1 HEATER POWER WATTS .205346631067
BLOCK # 2 HEATER POWER WATTS .201636420172
BLOCK # 3 HEATER POWER WATTS .205821888255
BLOCK # 4 HEATER POWER WATTS .205845515542
BLOCK # 5 HEATER POWER WATTS .206686204169
BLOCK # 6 HEATER POWER WATTS .205937056317
BLOCK # 7 HEATER POWER WATTS .205646997095
BLOCK # 8 HEATER POWER WATTS .203680625459

Run #2

Spacing: 73.81 mm

Power: 0.5 watts

Date: 11 November 1987

BLOCK #1

T. C. # 1	Volts D.C.	.00086618	Temp. DEG. C	21.7959413132
T. C. # 2	Volts D.C.	.00084356	Temp. DEG. C	21.3447868234
T. C. # 3	Volts D.C.	.00084743	Temp. DEG. C	21.4401533038
T. C. # 4	Volts D.C.	.00087354	Temp. DEG. C	22.0654206622
T. C. # 5	Volts D.C.	.00086713	Temp. DEG. C	21.9278413532
T. C. # 6	Volts D.C.	-.0111192	Temp. DEG. C	-204.164485618

BLOCK #2

T. C. # 7	Volts D.C.	.00085608	Temp. DEG. C	21.554350405
T. C. # 8	Volts D.C.	.00084051	Temp. DEG. C	21.2687280112
T. C. # 9	Volts D.C.	.00084449	Temp. DEG. C	21.3673296705
T. C. # 10	Volts D.C.	.00085387	Temp. DEG. C	21.5471712647
T. C. # 11	Volts D.C.	.00086159	Temp. DEG. C	21.7907437714
T. C. # 12	Volts D.C.	.00093125	Temp. DEG. C	23.5118106095

BLOCK #3

T. C. # 13	Volts D.C.	.00084844	Temp. DEG. C	21.465168443
T. C. # 14	Volts D.C.	.0008356	Temp. DEG. C	21.1470586682
T. C. # 15	Volts D.C.	.00083746	Temp. DEG. C	21.1931529503
T. C. # 16	Volts D.C.	.0008656	Temp. DEG. C	21.8899825115
T. C. # 17	Volts D.C.	.00086472	Temp. DEG. C	21.8682061615
T. C. # 18	Volts D.C.	.00095167	Temp. DEG. C	24.0151694159

BLOCK #4

T. C. # 19	Volts D.C.	.00084549	Temp. DEG. C	21.3921008313
T. C. # 20	Volts D.C.	.00083883	Temp. DEG. C	21.2271012422
T. C. # 21	Volts D.C.	.00083459	Temp. DEG. C	21.1220274501
T. C. # 22	Volts D.C.	.0008513	Temp. DEG. C	21.7835661229
T. C. # 23	Volts D.C.	.00085424	Temp. DEG. C	21.608794953
T. C. # 24	Volts D.C.	.00095168	Temp. DEG. C	24.015415791

BLOCK #5

T. C. # 25	Volts D.C. .00084001	Temp. DEG. C	21.2563394622
T. C. # 26	Volts D.C. .00083327	Temp. DEG. C	21.0893111906
T. C. # 27	Volts D.C. .00083464	Temp. DEG. C	21.1232666593
T. C. # 28	Volts D.C. .00086408	Temp. DEG. C	21.8523682058
T. C. # 29	Volts D.C. .00085179	Temp. DEG. C	21.5481302939
T. C. # 30	Volts D.C. .00093206	Temp. DEG. C	23.5317872731

BLOCK #6

T. C. # 31	Volts D.C. .0204947	Temp. DEG. C	1561.85597436
T. C. # 32	Volts D.C. .00082777	Temp. DEG. C	20.9529698935
T. C. # 33	Volts D.C. .00083079	Temp. DEG. C	21.0278383625
T. C. # 34	Volts D.C. .00085193	Temp. DEG. C	21.5515970394
T. C. # 35	Volts D.C. .00084676	Temp. DEG. C	21.4235583962
T. C. # 36	Volts D.C. .00092735	Temp. DEG. C	23.415615182

BLOCK #7

T. C. # 37	Volts D.C. .0008184	Temp. DEG. C	20.7206064139
T. C. # 38	Volts D.C. .00080663	Temp. DEG. C	20.4285698691
T. C. # 39	Volts D.C. .00081072	Temp. DEG. C	20.5300704385
T. C. # 40	Volts D.C. .00083772	Temp. DEG. C	21.1995958973
T. C. # 41	Volts D.C. .00083321	Temp. DEG. C	21.0878240359
T. C. # 42	Volts D.C. .00091659	Temp. DEG. C	23.1501157605

BLOCK #8

T. C. # 43	Volts D.C. .00081677	Temp. DEG. C	20.6801733318
T. C. # 44	Volts D.C. .00080155	Temp. DEG. C	20.3024714367
T. C. # 45	Volts D.C. .0008017	Temp. DEG. C	20.3061952802
T. C. # 46	Volts D.C. .00083331	Temp. DEG. C	21.0903026246
T. C. # 47	Volts D.C. .00081589	Temp. DEG. C	20.6583430413
T. C. # 48	Volts D.C. .00089782	Temp. DEG. C	22.6866252613

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00072415	TEMP. DEG. C	18.3771948788
VOLTS D.C.	.00072244	TEMP. DEG. C	18.3345746201
VOLTS D.C.	.00071894	TEMP. DEG. C	18.2473286999

BLOCK # 1 HEATER VLOTS D.C. 2.308692

BLOCK # 2 HEATER VLOTS D.C. 2.321047

BLOCK # 3 HEATER VLOTS D.C. 2.310025

BLOCK # 4 HEATER VLOTS D.C. 2.309965

BLOCK # 5 HEATER VLOTS D.C. 2.307129

BLOCK # 6 HEATER VLOTS D.C. 2.305733

BLOCK # 7 HEATER VLOTS D.C. 2.310471

BLOCK # 8 HEATER VLOTS D.C. 2.315697

INPUT VLOTAGE D.C. VLOTS 2.75119

BLOCK # 1 HEATER POWER WATTS .505738412186
BLOCK # 2 HEATER POWER WATTS .494248574119
BLOCK # 3 HEATER POWER WATTS .50450602927
BLOCK # 4 HEATER POWER WATTS .504561538181
BLOCK # 5 HEATER POWER WATTS .5071811935
BLOCK # 6 HEATER POWER WATTS .5047761391
BLOCK # 7 HEATER POWER WATTS .504093301311
BLOCK # 8 HEATER POWER WATTS .499242491892

Run #3

Spacing: 73.81 mm

Power: 1.0 watt

Date: 16 November 1987

BLOCK #1

T. C.	# 1	Volts D.C.	.00085264	Temp. DEG. C	21.5691780632
T. C.	# 2	Volts D.C.	.0008407	Temp. DEG. C	21.2734355776
T. C.	# 3	Volts D.C.	.00084341	Temp. DEG. C	21.340575407
T. C.	# 4	Volts D.C.	.00088203	Temp. DEG. C	22.2963785306
T. C.	# 5	Volts D.C.	.00086072	Temp. DEG. C	21.788210509
T. C.	# 6	Volts D.C.	.0718988	Temp. DEG. C	214249.697168

BLOCK #2

T. C.	# 7	Volts D.C.	.00084097	Temp. DEG. C	21.2801251992
T. C.	# 8	Volts D.C.	.00082733	Temp. DEG. C	20.9420609487
T. C.	# 9	Volts D.C.	.00083003	Temp. DEG. C	21.0089983693
T. C.	# 10	Volts D.C.	.00085922	Temp. DEG. C	21.7320819645
T. C.	# 11	Volts D.C.	.00085725	Temp. DEG. C	21.6833155213
T. C.	# 12	Volts D.C.	.00100509	Temp. DEG. C	25.3295237334

BLOCK #3

T. C.	# 13	Volts D.C.	.00084813	Temp. DEG. C	21.4574906652
T. C.	# 14	Volts D.C.	.00082149	Temp. DEG. C	20.797246471
T. C.	# 15	Volts D.C.	.00082354	Temp. DEG. C	20.8480851991
T. C.	# 16	Volts D.C.	.00087966	Temp. DEG. C	22.2377774762
T. C.	# 17	Volts D.C.	.0008622	Temp. DEG. C	21.8058412397
T. C.	# 18	Volts D.C.	.00104456	Temp. DEG. C	26.2983644288

BLOCK #4

T. C.	# 19	Volts D.C.	.0008555	Temp. DEG. C	21.6399909929
T. C.	# 20	Volts D.C.	.00081905	Temp. DEG. C	20.7367291048
T. C.	# 21	Volts D.C.	.000824	Temp. DEG. C	20.8594921586
T. C.	# 22	Volts D.C.	.00087162	Temp. DEG. C	22.0389264933
T. C.	# 23	Volts D.C.	.00086195	Temp. DEG. C	21.7996538091
T. C.	# 24	Volts D.C.	.00105802	Temp. DEG. C	26.6283139115

BLOCK #5

T. C.	# 25	Volts D.C.	.00083707	Temp. DEG. C	21.1834884457
T. C.	# 26	Volts D.C.	.00082369	Temp. DEG. C	20.8518048988
T. C.	# 27	Volts D.C.	.0008239	Temp. DEG. C	20.8570124309
T. C.	# 28	Volts D.C.	.00087763	Temp. DEG. C	22.187577725
T. C.	# 29	Volts D.C.	.0008539	Temp. DEG. C	21.6003766327
T. C.	# 30	Volts D.C.	.00102435	Temp. DEG. C	25.8025269276

BLOCK #6

T. C.	# 31	Volts D.C.	.0268306	Temp. DEG. C	4169.36370749
T. C.	# 32	Volts D.C.	.00080957	Temp. DEG. C	20.5015332825
T. C.	# 33	Volts D.C.	.00081653	Temp. DEG. C	20.6742197127
T. C.	# 34	Volts D.C.	.00085761	Temp. DEG. C	21.6922275192
T. C.	# 35	Volts D.C.	.00084015	Temp. DEG. C	21.2598082976
T. C.	# 36	Volts D.C.	.00102488	Temp. DEG. C	25.8155365789

BLOCK #7

T. C.	# 37	Volts D.C.	.00080817	Temp. DEG. C	20.4667901543
T. C.	# 38	Volts D.C.	.0007829	Temp. DEG. C	19.8392532308
T. C.	# 39	Volts D.C.	.00079324	Temp. DEG. C	20.0961263311
T. C.	# 40	Volts D.C.	.00084154	Temp. DEG. C	21.2942474331
T. C.	# 41	Volts D.C.	.00082862	Temp. DEG. C	20.9740433028
T. C.	# 42	Volts D.C.	.00100595	Temp. DEG. C	25.3506541914

BLOCK #8

T. C.	# 43	Volts D.C.	.0008016	Temp. DEG. C	20.303712721
T. C.	# 44	Volts D.C.	.00077564	Temp. DEG. C	19.6588152085
T. C.	# 45	Volts D.C.	.0007749	Temp. DEG. C	19.6404197327
T. C.	# 46	Volts D.C.	.00083422	Temp. DEG. C	21.1128572041
T. C.	# 47	Volts D.C.	.00079941	Temp. DEG. C	20.2493415233
T. C.	# 48	Volts D.C.	.0009841	Temp. DEG. C	24.8135071922

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063358	TEMP. DEG. C	16.114752114
VOLTS D.C.	.00063229	TEMP. DEG. C	16.082453277
VOLTS D.C.	.00063074	TEMP. DEG. C	16.0436418264

BLOCK # 1 HEATER VLOTS D.C. 3.2881

BLOCK # 2 HEATER VLOTS D.C. 3.30615

BLOCK # 3 HEATER VLOTS D.C. 3.28981

BLOCK # 4 HEATER VLOTS D.C. 3.28965

BLOCK # 5 HEATER VLOTS D.C. 3.28679

BLOCK # 6 HEATER VLOTS D.C. 3.28936

BLOCK # 7 HEATER VLOTS D.C. 3.2906

BLOCK # 8 HEATER VLOTS D.C. 3.29782

INPUT VLOTAGE D.C. VLOTS 3.91787

BLOCK # 1 HEATER POWER WATTS 1.02512214703
BLOCK # 2 HEATER POWER WATTS 1.00120596931
BLOCK # 3 HEATER POWER WATTS 1.02287033099
BLOCK # 4 HEATER POWER WATTS 1.02308115
BLOCK # 5 HEATER POWER WATTS 1.02684525396
BLOCK # 6 HEATER POWER WATTS 1.02346319485
BLOCK # 7 HEATER POWER WATTS 1.02182904059
BLOCK # 8 HEATER POWER WATTS 1.01228380743

Run #4

Spacing: 73.81 mm

Power: 2.0 watts

Date: 16 November 1987

BLOCK #1

T. C. # 1	Volts D.C. .00099999	Temp. DEG. C	25.1796184407
T. C. # 2	Volts D.C. .00098964	Temp. DEG. C	24.949755506
T. C. # 3	Volts D.C. .0009904	Temp. DEG. C	24.9684436235
T. C. # 4	Volts D.C. .00104159	Temp. DEG. C	25.225529513
T. C. # 5	Volts D.C. .00101351	Temp. DEG. C	25.5363959933
T. C. # 6	Volts D.C. -.0526181	Temp. DEG. C	54322.6553602

BLOCK #2

T. C. # 7	Volts D.C. .00098101	Temp. DEG. C	24.7374564584
T. C. # 8	Volts D.C. .00095578	Temp. DEG. C	24.1164190596
T. C. # 9	Volts D.C. .0009585	Temp. DEG. C	24.1834145146
T. C. # 10	Volts D.C. .00102363	Temp. DEG. C	25.7846528787
T. C. # 11	Volts D.C. .00101402	Temp. DEG. C	25.5488916062
T. C. # 12	Volts D.C. .00131394	Temp. DEG. C	32.8591971995

BLOCK #3

T. C. # 13	Volts D.C. .00098566	Temp. DEG. C	24.3597250041
T. C. # 14	Volts D.C. .00094913	Temp. DEG. C	23.9525860872
T. C. # 15	Volts D.C. .00093948	Temp. DEG. C	23.7147451812
T. C. # 16	Volts D.C. .00102837	Temp. DEG. C	25.9011951721
T. C. # 17	Volts D.C. .00098013	Temp. DEG. C	24.7158472085
T. C. # 18	Volts D.C. .0013708	Temp. DEG. C	34.2326913135

BLOCK #4

T. C. # 19	Volts D.C. .00096349	Temp. DEG. C	24.3062975819
T. C. # 20	Volts D.C. .00093199	Temp. DEG. C	23.5300609272
T. C. # 21	Volts D.C. .00093953	Temp. DEG. C	23.7159778176
T. C. # 22	Volts D.C. .00098074	Temp. DEG. C	24.7308541777
T. C. # 23	Volts D.C. .00099323	Temp. DEG. C	25.0380259348
T. C. # 24	Volts D.C. .00137817	Temp. DEG. C	34.4104326334

BLOCK #5

T. C.	# 25	Volts D.C.	.00097024	Temp. DEG. C	24.4724726756
T. C.	# 26	Volts D.C.	.00095663	Temp. DEG. C	24.1373561325
T. C.	# 27	Volts D.C.	.00095773	Temp. DEG. C	24.1644498276
T. C.	# 28	Volts D.C.	.00104532	Temp. DEG. C	26.317000557
T. C.	# 29	Volts D.C.	.0010185	Temp. DEG. C	25.6589065951
T. C.	# 30	Volts D.C.	.00135099	Temp. DEG. C	33.7546109452

BLOCK #6

T. C.	# 31	Volts D.C.	-.0831284	Temp. DEG. C	405992.00471
T. C.	# 32	Volts D.C.	.00093437	Temp. DEG. C	23.58875325
T. C.	# 33	Volts D.C.	.00095337	Temp. DEG. C	24.0570513909
T. C.	# 34	Volts D.C.	.00101723	Temp. DEG. C	25.6277218494
T. C.	# 35	Volts D.C.	.00099699	Temp. DEG. C	25.1304590652
T. C.	# 36	Volts D.C.	.00136077	Temp. DEG. C	33.9906937561

BLOCK #7

T. C.	# 37	Volts D.C.	.00094894	Temp. DEG. C	23.9479043329
T. C.	# 38	Volts D.C.	.0009049	Temp. DEG. C	22.8615046201
T. C.	# 39	Volts D.C.	.00092636	Temp. DEG. C	23.3911933139
T. C.	# 40	Volts D.C.	.00101444	Temp. DEG. C	25.5592065735
T. C.	# 41	Volts D.C.	.00098306	Temp. DEG. C	24.7879256219
T. C.	# 42	Volts D.C.	.0013394	Temp. DEG. C	33.4746860366

BLOCK #8

T. C.	# 43	Volts D.C.	.00092161	Temp. DEG. C	23.2740006238
T. C.	# 44	Volts D.C.	.00088689	Temp. DEG. C	22.4165257577
T. C.	# 45	Volts D.C.	.00088349	Temp. DEG. C	22.3324752532
T. C.	# 46	Volts D.C.	.00099579	Temp. DEG. C	25.1009610456
T. C.	# 47	Volts D.C.	.00092944	Temp. DEG. C	23.4671684316
T. C.	# 48	Volts D.C.	.00128954	Temp. DEG. C	32.2685944092

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063761	TEMP. DEG. C	16.2156411894
VOLTS D.C.	.00063615	TEMP. DEG. C	16.1790931662
VOLTS D.C.	.00063754	TEMP. DEG. C	16.2139889481

BLOCK # 1 HEATER VLOTS D.C. 4.62592

BLOCK # 2 HEATER VLOTS D.C. 4.65012

BLOCK # 3 HEATER VLOTS D.C. 4.62731

BLOCK # 4 HEATER VLOTS D.C. 4.62709

BLOCK # 5 HEATER VLOTS D.C. 4.62453

BLOCK # 6 HEATER VLOTS D.C. 4.62678

BLOCK # 7 HEATER VLOTS D.C. 4.62881

BLOCK # 8 HEATER VLOTS D.C. 4.63865

INPUT VLOTAGE D.C. VLOTS 5.50953

BLOCK # 1 HEATER POWER WATTS 2.02351939168
BLOCK # 2 HEATER POWER WATTS 1.97839585604
BLOCK # 3 HEATER POWER WATTS 2.02094328129
BLOCK # 4 HEATER POWER WATTS 2.02135113842
BLOCK # 5 HEATER POWER WATTS 2.02609358911
BLOCK # 6 HEATER POWER WATTS 2.02192576485
BLOCK # 7 HEATER POWER WATTS 2.01816116
BLOCK # 8 HEATER POWER WATTS 1.99985520396

Run #5

Spacing: 11.913

Power: 0.2 watts

Date: 17 November 1987

BLOCK #1

T. C. # 1	Volts D.C.	.00070914	Temp. DEG. C	18.0029581147
T. C. # 2	Volts D.C.	.00070222	Temp. DEG. C	17.8303297555
T. C. # 3	Volts D.C.	.00070959	Temp. DEG. C	18.0141818604
T. C. # 4	Volts D.C.	.00071276	Temp. DEG. C	18.093239593
T. C. # 5	Volts D.C.	.00071114	Temp. DEG. C	18.0528394784
T. C. # 6	Volts D.C.	.0651422	Temp. DEG. C	143771.001054

BLOCK #2

T. C. # 7	Volts D.C.	.00070498	Temp. DEG. C	17.8991887536
T. C. # 8	Volts D.C.	.0007008	Temp. DEG. C	17.7948985648
T. C. # 9	Volts D.C.	.00069983	Temp. DEG. C	17.7706941095
T. C. # 10	Volts D.C.	.00071178	Temp. DEG. C	18.0688004516
T. C. # 11	Volts D.C.	.0007084	Temp. DEG. C	17.9845007343
T. C. # 12	Volts D.C.	.00073574	Temp. DEG. C	18.6659685444

BLOCK #3

T. C. # 13	Volts D.C.	.00070403	Temp. DEG. C	17.8754893689
T. C. # 14	Volts D.C.	.0006988	Temp. DEG. C	17.7449911752
T. C. # 15	Volts D.C.	.00069779	Temp. DEG. C	17.7197860303
T. C. # 16	Volts D.C.	.00071117	Temp. DEG. C	18.0535876605
T. C. # 17	Volts D.C.	.00070769	Temp. DEG. C	17.9667909783
T. C. # 18	Volts D.C.	.00074196	Temp. DEG. C	18.8208748884

BLOCK #4

T. C. # 19	Volts D.C.	.00071244	Temp. DEG. C	18.0852596654
T. C. # 20	Volts D.C.	.00069556	Temp. DEG. C	17.6641305202
T. C. # 21	Volts D.C.	.00069395	Temp. DEG. C	17.6214487367
T. C. # 22	Volts D.C.	.00070627	Temp. DEG. C	17.931369563
T. C. # 23	Volts D.C.	.00070348	Temp. DEG. C	17.8617665744
T. C. # 24	Volts D.C.	.00074283	Temp. DEG. C	18.8425379729

BLOCK #5

T. C.	# 25	Volts D.C.	.00069733	Temp. DEG. C	17.7083060338
T. C.	# 26	Volts D.C.	.000693	Temp. DEG. C	17.6002312761
T. C.	# 27	Volts D.C.	.00069395	Temp. DEG. C	17.6239448487
T. C.	# 28	Volts D.C.	.00070453	Temp. DEG. C	17.8879623972
T. C.	# 29	Volts D.C.	.00070072	Temp. DEG. C	17.7929023659
T. C.	# 30	Volts D.C.	.00073311	Temp. DEG. C	18.6004549184

BLOCK #6

T. C.	# 31	Volts D.C.	.0632886	Temp. DEG. C	127933.131493
T. C.	# 32	Volts D.C.	.00068795	Temp. DEG. C	17.4741558483
T. C.	# 33	Volts D.C.	.00068902	Temp. DEG. C	17.5008715397
T. C.	# 34	Volts D.C.	.0006997	Temp. DEG. C	17.7674501235
T. C.	# 35	Volts D.C.	.00069678	Temp. DEG. C	17.6945796016
T. C.	# 36	Volts D.C.	.00072965	Temp. DEG. C	18.5145017952

BLOCK #7

T. C.	# 37	Volts D.C.	.0006945	Temp. DEG. C	17.63767324
T. C.	# 38	Volts D.C.	.00068188	Temp. DEG. C	17.3225733021
T. C.	# 39	Volts D.C.	.00068376	Temp. DEG. C	17.3695263267
T. C.	# 40	Volts D.C.	.00069482	Temp. DEG. C	17.6456604925
T. C.	# 41	Volts D.C.	.00069182	Temp. DEG. C	17.5707749411
T. C.	# 42	Volts D.C.	.00072565	Temp. DEG. C	18.4145780413

BLOCK #8

T. C.	# 43	Volts D.C.	.0006798	Temp. DEG. C	17.2706198805
T. C.	# 44	Volts D.C.	.00067404	Temp. DEG. C	17.1267207233
T. C.	# 45	Volts D.C.	.00067405	Temp. DEG. C	17.1269705844
T. C.	# 46	Volts D.C.	.00068794	Temp. DEG. C	17.4739061621
T. C.	# 47	Volts D.C.	.00068	Temp. DEG. C	17.2756156288
T. C.	# 48	Volts D.C.	.00071555	Temp. DEG. C	18.1628100985

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063946	TEMP. DEG. C	16.2619481867
VOLTS D.C.	.00063674	TEMP. DEG. C	16.1938628959
VOLTS D.C.	.00063796	TEMP. DEG. C	16.2244023031

BLOCK # 1 HEATER VLOTS D.C. 1.479227

BLOCK # 2 HEATER VLOTS D.C. 1.486967

BLOCK # 3 HEATER VLOTS D.C. 1.479592

BLOCK # 4 HEATER VLOTS D.C. 1.479553

BLOCK # 5 HEATER VLOTS D.C. 1.47892

BLOCK # 6 HEATER VLOTS D.C. 1.479432

BLOCK # 7 HEATER VLOTS D.C. 1.480182

BLOCK # 8 HEATER VLOTS D.C. 1.483219

INPUT VLOTAGE D.C. VLOTS 1.762348

BLOCK # 1 HEATER POWER WATTS .207326845281
BLOCK # 2 HEATER POWER WATTS .202714088825
BLOCK # 3 HEATER POWER WATTS .207110651253
BLOCK # 4 HEATER POWER WATTS .20713375774
BLOCK # 5 HEATER POWER WATTS .20750858305
BLOCK # 6 HEATER POWER WATTS .207205437481
BLOCK # 7 HEATER POWER WATTS .206760908026
BLOCK # 8 HEATER POWER WATTS .204955166461

Run #6

Spacing: 11.913 mm

Power: 0.5 watts

Date: 17 November 1987

BLOCK #1

T. C.	# 1	Volts D.C.	.0007757	Temp. DEG. C	19.6603067034
T. C.	# 2	Volts D.C.	.00075667	Temp. DEG. C	19.4357857992
T. C.	# 3	Volts D.C.	.0007762	Temp. DEG. C	19.6727356515
T. C.	# 4	Volts D.C.	.00078484	Temp. DEG. C	19.8874582327
T. C.	# 5	Volts D.C.	.00078316	Temp. DEG. C	19.8457139695
T. C.	# 6	Volts D.C.	.0567514	Temp. DEG. C	82326.501046

BLOCK #2

T. C.	# 7	Volts D.C.	.00077145	Temp. DEG. C	19.5546479536
T. C.	# 8	Volts D.C.	.00076157	Temp. DEG. C	19.3114222554
T. C.	# 9	Volts D.C.	.00076161	Temp. DEG. C	19.3099297019
T. C.	# 10	Volts D.C.	.00078706	Temp. DEG. C	19.9425148528
T. C.	# 11	Volts D.C.	.00077903	Temp. DEG. C	19.7430775733
T. C.	# 12	Volts D.C.	.0008491	Temp. DEG. C	2'.4815142779

BLOCK #3

T. C.	# 13	Volts D.C.	.00076889	Temp. DEG. C	19.4909931345
T. C.	# 14	Volts D.C.	.00075901	Temp. DEG. C	19.2452480378
T. C.	# 15	Volts D.C.	.00075925	Temp. DEG. C	19.2512190091
T. C.	# 16	Volts D.C.	.00078362	Temp. DEG. C	19.8571442991
T. C.	# 17	Volts D.C.	.00077795	Temp. DEG. C	19.7162344944
T. C.	# 18	Volts D.C.	.00086516	Temp. DEG. C	21.8790944579

BLOCK #4

T. C.	# 19	Volts D.C.	.00077507	Temp. DEG. C	19.6446457813
T. C.	# 20	Volts D.C.	.00075484	Temp. DEG. C	19.1414908466
T. C.	# 21	Volts D.C.	.0007536	Temp. DEG. C	19.1106331706
T. C.	# 22	Volts D.C.	.0007804	Temp. DEG. C	19.777126406
T. C.	# 23	Volts D.C.	.0007729	Temp. DEG. C	19.5906987854
T. C.	# 24	Volts D.C.	.00087154	Temp. DEG. C	22.0369474692

BLOCK #5

T. C.	# 25	Volts D.C.	.00075757	Temp. DEG. C	19.2094206886
T. C.	# 26	Volts D.C.	.00075131	Temp. DEG. C	19.053640927
T. C.	# 27	Volts D.C.	.00075303	Temp. DEG. C	19.0964479449
T. C.	# 28	Volts D.C.	.00077823	Temp. DEG. C	19.723193952
T. C.	# 29	Volts D.C.	.00076679	Temp. DEG. C	19.4387701379
T. C.	# 30	Volts D.C.	.00085011	Temp. DEG. C	21.5065273003

BLOCK #6

T. C.	# 31	Volts D.C.	.0622216	Temp. DEG. C	119433.511569
T. C.	# 32	Volts D.C.	.00074305	Temp. DEG. C	18.8480158435
T. C.	# 33	Volts D.C.	.00074401	Temp. DEG. C	18.871918566
T. C.	# 34	Volts D.C.	.00076745	Temp. DEG. C	19.4551836773
T. C.	# 35	Volts D.C.	.00075893	Temp. DEG. C	19.2432576979
T. C.	# 36	Volts D.C.	.00084297	Temp. DEG. C	21.3296751022

BLOCK #7

T. C.	# 37	Volts D.C.	.00074382	Temp. DEG. C	18.8671679109
T. C.	# 38	Volts D.C.	.00072871	Temp. DEG. C	18.4908309143
T. C.	# 39	Volts D.C.	.0007342	Temp. DEG. C	18.6276080094
T. C.	# 40	Volts D.C.	.00075992	Temp. DEG. C	19.2678875873
T. C.	# 41	Volts D.C.	.00075266	Temp. DEG. C	19.0872397726
T. C.	# 42	Volts D.C.	.00083567	Temp. DEG. C	21.1487936715

BLOCK #8

T. C.	# 43	Volts D.C.	.00072821	Temp. DEG. C	18.4783720998
T. C.	# 44	Volts D.C.	.00071818	Temp. DEG. C	18.2283818345
T. C.	# 45	Volts D.C.	.00071525	Temp. DEG. C	18.1553298798
T. C.	# 46	Volts D.C.	.0007481	Temp. DEG. C	18.9737411325
T. C.	# 47	Volts D.C.	.00072787	Temp. DEG. C	18.4698999262
T. C.	# 48	Volts D.C.	.00081746	Temp. DEG. C	20.6972895837

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063986	TEMP. DEG. C	16.271959944
VOLTS D.C.	.00063916	TEMP. DEG. C	16.2544392365
VOLTS D.C.	.00063874	TEMP. DEG. C	16.243926516

BLOCK # 1 HEATER VLOTS D.C. 2.31381

BLOCK # 2 HEATER VLOTS D.C. 2.325955

BLOCK # 3 HEATER VLOTS D.C. 2.314405

BLOCK # 4 HEATER VLOTS D.C. 2.314335

BLOCK # 5 HEATER VLOTS D.C. 2.313345

BLOCK # 6 HEATER VLOTS D.C. 2.314146

BLOCK # 7 HEATER VLOTS D.C. 2.315302

BLOCK # 8 HEATER VLOTS D.C. 2.32009

INPUT VLOTAGE D.C. VLOTS 2.756495

BLOCK # 1 HEATER POWER WATTS .507074897951
BLOCK # 2 HEATER POWER WATTS .495751976067
BLOCK # 3 HEATER POWER WATTS .506523574661
BLOCK # 4 HEATER POWER WATTS .506588454423
BLOCK # 5 HEATER POWER WATTS .507505519849
BLOCK # 6 HEATER POWER WATTS .506753605495
BLOCK # 7 HEATER POWER WATTS .505691757717
BLOCK # 8 HEATER POWER WATTS .501238216109

Run #7

Spacing: 11.913

Power: 1.0 watt

Date: 17 November 1987

		BLOCK #1		
T. C. # 1	Volts D.C.	.00086707	Temp. DEG. C	21.926356748
T. C. # 2	Volts D.C.	.00085117	Temp. DEG. C	21.5327772142
T. C. # 3	Volts D.C.	.0008672	Temp. DEG. C	21.9295733868
T. C. # 4	Volts D.C.	.0008699	Temp. DEG. C	21.9963757079
T. C. # 5	Volts D.C.	.00087838	Temp. DEG. C	22.2061250329
T. C. # 6	Volts D.C.	.0279265	Temp. DEG. C	4860.44901559
		BLOCK #2		
T. C. # 7	Volts D.C.	.00085135	Temp. DEG. C	21.7848036559
T. C. # 8	Volts D.C.	.00084486	Temp. DEG. C	21.3764951463
T. C. # 9	Volts D.C.	.00084905	Temp. DEG. C	21.4802759762
T. C. # 10	Volts D.C.	.00089124	Temp. DEG. C	22.5240398348
T. C. # 11	Volts D.C.	.00087403	Temp. DEG. C	22.0985408295
T. C. # 12	Volts D.C.	.00102538	Temp. DEG. C	25.8278095143
		BLOCK #3		
T. C. # 13	Volts D.C.	.00085993	Temp. DEG. C	21.7496564941
T. C. # 14	Volts D.C.	.00084233	Temp. DEG. C	21.3138196795
T. C. # 15	Volts D.C.	.00084307	Temp. DEG. C	21.3321524655
T. C. # 16	Volts D.C.	.000865	Temp. DEG. C	21.8751351055
T. C. # 17	Volts D.C.	.00087456	Temp. DEG. C	22.1116500592
T. C. # 18	Volts D.C.	.00105703	Temp. DEG. C	26.6040532895
		BLOCK #4		
T. C. # 19	Volts D.C.	.00086349	Temp. DEG. C	21.8377671353
T. C. # 20	Volts D.C.	.00083851	Temp. DEG. C	21.2191719321
T. C. # 21	Volts D.C.	.0008377	Temp. DEG. C	21.1991002913
T. C. # 22	Volts D.C.	.00088655	Temp. DEG. C	22.4081213593
T. C. # 23	Volts D.C.	.00087317	Temp. DEG. C	22.0772684996
T. C. # 24	Volts D.C.	.00107266	Temp. DEG. C	26.9869333575

BLOCK #5

T. C. # 25	Volts D.C. .00084506	Temp. DEG. C	21.381449386
T. C. # 26	Volts D.C. .00083412	Temp. DEG. C	21.1103787297
T. C. # 27	Volts D.C. .00083973	Temp. DEG. C	21.2494017377
T. C. # 28	Volts D.C. .00088712	Temp. DEG. C	22.4222110038
T. C. # 29	Volts D.C. .00086534	Temp. DEG. C	21.883548691
T. C. # 30	Volts D.C. .00103501	Temp. DEG. C	26.0641255333

BLOCK #6

T. C. # 31	Volts D.C. .0483189	Temp. DEG. C	42950.8457207
T. C. # 32	Volts D.C. .00082127	Temp. DEG. C	20.7917902939
T. C. # 33	Volts D.C. .00082191	Temp. DEG. C	20.8076626403
T. C. # 34	Volts D.C. .0008673	Temp. DEG. C	21.9320477099
T. C. # 35	Volts D.C. .0008495	Temp. DEG. C	21.4914205765
T. C. # 36	Volts D.C. .00102794	Temp. DEG. C	25.350642067

BLOCK #7

T. C. # 37	Volts D.C. .00082072	Temp. DEG. C	20.7781495851
T. C. # 38	Volts D.C. .00079664	Temp. DEG. C	20.1805620148
T. C. # 39	Volts D.C. .00080792	Temp. DEG. C	20.4605857652
T. C. # 40	Volts D.C. .00085499	Temp. DEG. C	21.6273642643
T. C. # 41	Volts D.C. .00084064	Temp. DEG. C	21.2719489826
T. C. # 42	Volts D.C. .0010133	Temp. DEG. C	25.5312082938

BLOCK #8

T. C. # 43	Volts D.C. .00079706	Temp. DEG. C	20.1909912969
T. C. # 44	Volts D.C. .0007804	Temp. DEG. C	19.777126406
T. C. # 45	Volts D.C. .00077589	Temp. DEG. C	19.6650297407
T. C. # 46	Volts D.C. .00083833	Temp. DEG. C	21.2147116387
T. C. # 47	Volts D.C. .00080045	Temp. DEG. C	20.275162387
T. C. # 48	Volts D.C. .00098359	Temp. DEG. C	24.8009625523

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063962	TEMP. DEG. C	16.2659529138
VOLTS D.C.	.00063902	TEMP. DEG. C	16.250935021
VOLTS D.C.	.00063946	TEMP. DEG. C	16.2619481867

BLOCK # 1 HEATER VLOTS D.C. 3.30153

BLOCK # 2 HEATER VLOTS D.C. 3.31896

BLOCK # 3 HEATER VLOTS D.C. 3.30248

BLOCK # 4 HEATER VLOTS D.C. 3.30231

BLOCK # 5 HEATER VLOTS D.C. 3.30105

BLOCK # 6 HEATER VLOTS D.C. 3.30192

BLOCK # 7 HEATER VLOTS D.C. 3.30351

BLOCK # 8 HEATER VLOTS D.C. 3.31045

INPUT VLOTAGE D.C. VLOTS 3.9327

BLOCK # 1 HEATER POWER WATTS 1.03159737134
BLOCK # 2 HEATER POWER WATTS 1.00840520317
BLOCK # 3 HEATER POWER WATTS 1.03034106218
BLOCK # 4 HEATER POWER WATTS 1.03056594104
BLOCK # 5 HEATER POWER WATTS 1.03223179627
BLOCK # 6 HEATER POWER WATTS 1.03108173149
BLOCK # 7 HEATER POWER WATTS 1.02897794896
BLOCK # 8 HEATER POWER WATTS 1.0197660953

Run #8

Spacing: 11.913 mm

Power: 2.0 watts

Date: 17 November 1987

BLOCK #1

T. C. # 1	Volts D.C.	.00098045	Temp. DEG. C	24.7237197749
T. C. # 2	Volts D.C.	.00097514	Temp. DEG. C	24.5930678391
T. C. # 3	Volts D.C.	.0009913	Temp. DEG. C	24.9905733571
T. C. # 4	Volts D.C.	.00098299	Temp. DEG. C	24.7862037369
T. C. # 5	Volts D.C.	.00100831	Temp. DEG. C	25.4086353635
T. C. # 6	Volts D.C.	-.0070743	Temp. DEG. C	-184.374127276

BLOCK #2

T. C. # 7	Volts D.C.	.00098243	Temp. DEG. C	24.7724284372
T. C. # 8	Volts D.C.	.0009667	Temp. DEG. C	24.3853301675
T. C. # 9	Volts D.C.	.00097125	Temp. DEG. C	24.497332499
T. C. # 10	Volts D.C.	.00102098	Temp. DEG. C	25.7197969998
T. C. # 11	Volts D.C.	.00101565	Temp. DEG. C	25.5889222746
T. C. # 12	Volts D.C.	.00132052	Temp. DEG. C	33.018342373

BLOCK #3

T. C. # 13	Volts D.C.	.00099028	Temp. DEG. C	24.965492916
T. C. # 14	Volts D.C.	.00096138	Temp. DEG. C	24.2543408025
T. C. # 15	Volts D.C.	.0009671	Temp. DEG. C	24.3951775629
T. C. # 16	Volts D.C.	.00098953	Temp. DEG. C	24.9470505872
T. C. # 17	Volts D.C.	.00101017	Temp. DEG. C	25.4543274978
T. C. # 18	Volts D.C.	.00138144	Temp. DEG. C	34.489273804

BLOCK #4

T. C. # 19	Volts D.C.	.00100216	Temp. DEG. C	25.2575258334
T. C. # 20	Volts D.C.	.00096484	Temp. DEG. C	24.3395371535
T. C. # 21	Volts D.C.	.00096499	Temp. DEG. C	24.3432302987
T. C. # 22	Volts D.C.	.00103215	Temp. DEG. C	25.9939544242
T. C. # 23	Volts D.C.	.00102539	Temp. DEG. C	25.8280549698
T. C. # 24	Volts D.C.	.00141873	Temp. DEG. C	35.3974418393

BLOCK #5

T. C.	# 25	Volts D.C.	.00098718	Temp. DEG. C	24.8892600791
T. C.	# 26	Volts D.C.	.0009658	Temp. DEG. C	24.3631727971
T. C.	# 27	Volts D.C.	.00097725	Temp. DEG. C	24.6449883594
T. C.	# 28	Volts D.C.	.00105606	Temp. DEG. C	26.5802816979
T. C.	# 29	Volts D.C.	.00102888	Temp. DEG. C	25.9137113471
T. C.	# 30	Volts D.C.	.0013606	Temp. DEG. C	33.9865910549

BLOCK #6

T. C.	# 31	Volts D.C.	-.0368589	Temp. DEG. C	14771.9525454
T. C.	# 32	Volts D.C.	.00094839	Temp. DEG. C	23.9343516318
T. C.	# 33	Volts D.C.	.00095853	Temp. DEG. C	24.1841533835
T. C.	# 34	Volts D.C.	.00103542	Temp. DEG. C	26.0741841938
T. C.	# 35	Volts D.C.	.00100336	Temp. DEG. C	25.2870143219
T. C.	# 36	Volts D.C.	.00135645	Temp. DEG. C	33.8864260423

BLOCK #7

T. C.	# 37	Volts D.C.	.00094947	Temp. DEG. C	23.9609638506
T. C.	# 38	Volts D.C.	.00090844	Temp. DEG. C	22.9489207544
T. C.	# 39	Volts D.C.	.00092711	Temp. DEG. C	23.4096948418
T. C.	# 40	Volts D.C.	.00101354	Temp. DEG. C	25.6598867592
T. C.	# 41	Volts D.C.	.00098967	Temp. DEG. C	24.9504932085
T. C.	# 42	Volts D.C.	.00133622	Temp. DEG. C	33.3978533444

BLOCK #8

T. C.	# 43	Volts D.C.	.00091492	Temp. DEG. C	23.1088960739
T. C.	# 44	Volts D.C.	.00088503	Temp. DEG. C	22.3705469628
T. C.	# 45	Volts D.C.	.00087504	Temp. DEG. C	22.1235222652
T. C.	# 46	Volts D.C.	.00099407	Temp. DEG. C	25.0586774191
T. C.	# 47	Volts D.C.	.00092318	Temp. DEG. C	23.3127390161
T. C.	# 48	Volts D.C.	.00128974	Temp. DEG. C	32.2734383616

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00063972	TEMP. DEG. C	16.2684558519
VOLTS D.C.	.00063946	TEMP. DEG. C	16.2619481867
VOLTS D.C.	.0006398	TEMP. DEG. C	16.2704581933

BLOCK # 1 HEATER VLOTS D.C. 4.63301

BLOCK # 2 HEATER VLOTS D.C. 4.65723

BLOCK # 3 HEATER VLOTS D.C. 4.63437

BLOCK # 4 HEATER VLOTS D.C. 4.63386

BLOCK # 5 HEATER VLOTS D.C. 4.6325

BLOCK # 6 HEATER VLOTS D.C. 4.63347

BLOCK # 7 HEATER VLOTS D.C. 4.63566

BLOCK # 8 HEATER VLOTS D.C. 4.64555

INPUT VLOTAGE D.C. VLOTS 5.5173

BLOCK # 1 HEATER POWER WATTS 2.02818040243
BLOCK # 2 HEATER POWER WATTS 1.98294247827
BLOCK # 3 HEATER POWER WATTS 2.02565559609
BLOCK # 4 HEATER POWER WATTS 2.02650251307
BLOCK # 5 HEATER POWER WATTS 2.02894119802
BLOCK # 6 HEATER POWER WATTS 2.02732582876
BLOCK # 7 HEATER POWER WATTS 2.02225905069
BLOCK # 8 HEATER POWER WATTS 2.00483079827

Run #9

Spacing: No Wall

Power: 0.2 watts

Date: 18 November 1987

BLOCK #1

T. C. # 1	Volts D.C.	.00070266	Temp. DEG. C	17.8413079193
T. C. # 2	Volts D.C.	.00069842	Temp. DEG. C	17.735506202
T. C. # 3	Volts D.C.	.00070024	Temp. DEG. C	17.7809250032
T. C. # 4	Volts D.C.	.0007085	Temp. DEG. C	17.9869950151
T. C. # 5	Volts D.C.	.0007047	Temp. DEG. C	17.9922034951
T. C. # 6	Volts D.C.	.0599001	Temp. DEG. C	101723.622549

BLOCK #2

T. C. # 7	Volts D.C.	.00070104	Temp. DEG. C	17.8008871133
T. C. # 8	Volts D.C.	.00069642	Temp. DEG. C	17.6855948216
T. C. # 9	Volts D.C.	.00069706	Temp. DEG. C	17.701567551
T. C. # 10	Volts D.C.	.0007076	Temp. DEG. C	17.9645460343
T. C. # 11	Volts D.C.	.0007043	Temp. DEG. C	17.8822243832
T. C. # 12	Volts D.C.	.00073297	Temp. DEG. C	18.5969672571

BLOCK #3

T. C. # 13	Volts D.C.	.00070065	Temp. DEG. C	17.7911556852
T. C. # 14	Volts D.C.	.00069458	Temp. DEG. C	17.6396700652
T. C. # 15	Volts D.C.	.00069496	Temp. DEG. C	17.6491548749
T. C. # 16	Volts D.C.	.00070667	Temp. DEG. C	17.9413476832
T. C. # 17	Volts D.C.	.00070201	Temp. DEG. C	17.8250900914
T. C. # 18	Volts D.C.	.00073986	Temp. DEG. C	18.7685807612

BLOCK #4

T. C. # 19	Volts D.C.	.0007092	Temp. DEG. C	18.0044546288
T. C. # 20	Volts D.C.	.00069264	Temp. DEG. C	17.5912447834
[illegible] # 21	Volts D.C.	.00069146	Temp. DEG. C	17.5617879137
[illegible] # 22	Volts D.C.	.00070405	Temp. DEG. C	17.875987336
[illegible] # 23	Volts D.C.	.00070015	Temp. DEG. C	17.7786792154
[illegible] # 24	Volts D.C.	.00074014	Temp. DEG. C	18.775553632

BLOCK #5

T. C.	# 25	Volts D.C.	.00069694	Temp. DEG. C	17.6985707846
T. C.	# 26	Volts D.C.	.00069151	Temp. DEG. C	17.5630361217
T. C.	# 27	Volts D.C.	.0006919	Temp. DEG. C	17.5727703361
T. C.	# 28	Volts D.C.	.00070297	Temp. DEG. C	17.8490417894
T. C.	# 29	Volts D.C.	.00069891	Temp. DEG. C	17.7477362124
T. C.	# 30	Volts D.C.	.00073208	Temp. DEG. C	18.5747551192

BLOCK #6

T. C.	# 31	Volts D.C.	.0684059	Temp. DEG. C	175187.227844
T. C.	# 32	Volts D.C.	.00068771	Temp. DEG. C	17.4681620458
T. C.	# 33	Volts D.C.	.00068907	Temp. DEG. C	17.5021189013
T. C.	# 34	Volts D.C.	.0006984	Temp. DEG. C	17.7352092931
T. C.	# 35	Volts D.C.	.00069629	Temp. DEG. C	17.6621026954
T. C.	# 36	Volts D.C.	.00073087	Temp. DEG. C	18.5446490732

BLOCK #7

T. C.	# 37	Volts D.C.	.00069103	Temp. DEG. C	17.551053195
T. C.	# 38	Volts D.C.	.00068235	Temp. DEG. C	17.3343119003
T. C.	# 39	Volts D.C.	.00068519	Temp. DEG. C	17.4052375826
T. C.	# 40	Volts D.C.	.00069503	Temp. DEG. C	17.6509022569
T. C.	# 41	Volts D.C.	.00069528	Temp. DEG. C	17.6571419421
T. C.	# 42	Volts D.C.	.0007268	Temp. DEG. C	18.4432235466

BLOCK #8

T. C.	# 43	Volts D.C.	.00068306	Temp. DEG. C	17.3520443201
T. C.	# 44	Volts D.C.	.00068003	Temp. DEG. C	17.2763649867
T. C.	# 45	Volts D.C.	.00067934	Temp. DEG. C	17.2591294683
T. C.	# 46	Volts D.C.	.00069069	Temp. DEG. C	17.5425651131
T. C.	# 47	Volts D.C.	.00068316	Temp. DEG. C	17.3545417703
T. C.	# 48	Volts D.C.	.00071856	Temp. DEG. C	18.237855358

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.00064216	TEMP. DEG. C	16.3295236403
VOLTS D.C.	.00064005	TEMP. DEG. C	16.2767154582
VOLTS D.C.	.00064024	TEMP. DEG. C	16.2814709269

BLOCK # 1 HEATER VOLTS D.C. 1.471185

BLOCK # 2 HEATER VOLTS D.C. 1.478995

BLOCK # 3 HEATER VOLTS D.C. 1.471518

BLOCK # 4 HEATER VOLTS D.C. 1.471441

BLOCK # 5 HEATER VOLTS D.C. 1.471044

BLOCK # 6 HEATER VOLTS D.C. [illegible]

BLOCK # 7 HEATER VOLTS D.C. [illegible]

BLOCK # [illegible] HEATER VOLTS D.C. [illegible]

INPUT VOLTAGE D.C. [illegible]

BLOCK # 1 HEATER POWER WATTS [illegible]
BLOCK # 2 HEATER POWER WATTS [illegible]
BLOCK # 3 HEATER POWER WATTS [illegible]
BLOCK # 4 HEATER POWER WATTS [illegible]
BLOCK # 5 HEATER POWER WATTS [illegible]
BLOCK # 6 HEATER POWER WATTS [illegible]
BLOCK # 7 HEATER POWER WATTS [illegible]
BLOCK # 8 HEATER POWER WATTS [illegible]

Run #10

Spacing: No Wall

Power: 0.5 watts

Date: 18 November 1987

BLOCK #1

T. C. # 1	Volts D.C.	.00077196	Temp. DEG. C	19.5673282028
T. C. # 2	Volts D.C.	.00076295	Temp. DEG. C	19.3432623166
T. C. # 3	Volts D.C.	.00076598	Temp. DEG. C	19.4166255001
T. C. # 4	Volts D.C.	.00078596	Temp. DEG. C	19.9406273344
T. C. # 5	Volts D.C.	.00077882	Temp. DEG. C	19.7378582006
T. C. # 6	Volts D.C.	.050299	Temp. DEG. C	50549.0271583

BLOCK #2

T. C. # 7	Volts D.C.	.0007687	Temp. DEG. C	19.4862684249
T. C. # 8	Volts D.C.	.0007578	Temp. DEG. C	19.2151432974
T. C. # 9	Volts D.C.	.00075724	Temp. DEG. C	19.1962335771
T. C. # 10	Volts D.C.	.0007866	Temp. DEG. C	19.9311685124
T. C. # [illegible]	Volts D.C.	.00077723	Temp. DEG. C	19.6949584012
T. C. # [illegible]	Volts D.C.	.00086297	Temp. DEG. C	21.5278245282

BLOCK #3

[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]

BLOCK #4

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

		BLOCK #5			
T. C.	# 25	Volts D.C.	.00075665	Temp. DEG. C	19.1865296279
T. C.	# 26	Volts D.C.	.0007481	Temp. DEG. C	18.9737411325
T. C.	# 27	Volts D.C.	.00074975	Temp. DEG. C	19.0148127392
T. C.	# 28	Volts D.C.	.00077707	Temp. DEG. C	19.6943612718
T. C.	# 29	Volts D.C.	.00076375	Temp. DEG. C	19.3631613086
T. C.	# 30	Volts D.C.	.00084926	Temp. DEG. C	21.4854768222
		BLOCK #6			
T. C.	# 31	Volts D.C.	.0785367	Temp. DEG. C	306107.842144
T. C.	# 32	Volts D.C.	.00073939	Temp. DEG. C	18.7568760777
T. C.	# 33	Volts D.C.	.00074344	Temp. DEG. C	18.8577264643
T. C.	# 34	Volts D.C.	.00076531	Temp. DEG. C	19.401962028
T. C.	# 35	Volts D.C.	.00075892	Temp. DEG. C	19.2430089049
T. C.	# 36	Volts D.C.	.00084826	Temp. DEG. C	21.4607103931
		BLOCK #7			
T. C.	# 37	Volts D.C.	.00074454	Temp. DEG. C	[illegible]
T. C.	# 38	Volts D.C.	.00072862	Temp. DEG. C	[illegible]
T. C.	# 39	Volts D.C.	.00073538	Temp. DEG. C	[illegible]
T. C.	# 40	Volts D.C.	.00075767	Temp. DEG. C	[illegible]
T. C.	# 41	Volts D.C.	.00075462	Temp. DEG. C	[illegible]
T. C.	# 42	Volts D.C.	.00082778	Temp. DEG. C	[illegible]
		BLOCK #8			
T. C.	# 43	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]
T. C.	# 44	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]
T. C.	# 45	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]
T. C.	# 46	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]
T. C.	# 47	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]
T. C.	# 48	Volts D.C.	[illegible]	Temp. DEG. C	[illegible]

BLOCK # 1 HEATER VLOTS D.C. 2.318752

BLOCK # 2 HEATER VLOTS D.C. 2.330904

BLOCK # 3 HEATER VLOTS D.C. 2.3193

BLOCK # 4 HEATER VLOTS D.C. 2.319161

BLOCK # 5 HEATER VLOTS D.C. 2.318535

BLOCK # 6 HEATER VLOTS D.C. 2.318915

BLOCK # 7 HEATER VLOTS D.C. 2.320086

BLOCK # 8 HEATER VLOTS D.C. 2.324893

INPUT [illegible]

BLOCK # [illegible]
BLOCK # [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Run #11

Spacing: No Wall

Power: 1.0 watt

Date: 18 November 1987

BLOCK #5

T. C.	# 25	Volts D.C.	.00084304	Temp. DEG. C	21.3314092579
T. C.	# 26	Volts D.C.	.00082799	Temp. DEG. C	20.9584242747
T. C.	# 27	Volts D.C.	.0009304	Temp. DEG. C	21.0181705619
T. C.	# 28	Volts D.C.	.00088298	Temp. DEG. C	22.3196664278
T. C.	# 29	Volts D.C.	.00085725	Temp. DEG. C	21.6833155213
T. C.	# 30	Volts D.C.	.00103041	Temp. DEG. C	25.9512579238

BLOCK #6

[illegible]	# [illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	# [illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	# [illegible]	[illegible]	[illegible]	Temp. DEG. C	[illegible]
[illegible]	# [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	# [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	# [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

BLOCK # 1 HEATER VLOTS D.C. 3.28433

BLOCK # 2 HEATER VLOTS D.C. 3.30169

BLOCK # 3 HEATER VLOTS D.C. 3.28511

BLOCK # 4 HEATER VLOTS D.C. 3.28502

BLOCK # 5 HEATER VLOTS D.C. 3.28425

BLOCK # 6 HEATER VLOTS D.C. 3.28458

BLOCK # 7 HEATER VLOTS D.C. 3.2862[illegible]

BLOCK # [illegible] HEATER VLOTS D.C. 3.28305

[illegible]

[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	#	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]
[illegible]	:	[illegible]	[illegible]	[illegible]

Run #12

Spacing: No Wall

Power: 2.0 watts

Date: 18 November 1987

BLOCK #1				
T. C. # 1	Volts D.C.	.00100754	Temp. DEG. C	25.3921753126
T. C. # 2	Volts D.C.	.00099476	Temp. DEG. C	25.0756404799
T. C. # 3	Volts D.C.	.00100176	Temp. DEG. C	25.2476959383
T. C. # 4	Volts D.C.	.00104886	Temp. DEG. C	26.4037952168
T. C. # 5	Volts D.C.	.00102275	Temp. DEG. C	25.7632503868
T. C. # 6	Volts D.C.	.00580521	Temp. DEG. C	134.673569863
BLOCK #2				
T. C. # 7	Volts D.C.	.00099672	Temp. DEG. C	24.3779470882
T. C. # 8	Volts D.C.	.00096131	Temp. DEG. C	24.2526170225
T. C. # 9	Volts D.C.	.0009554	Temp. DEG. C	24.1070536644
T. C. # 10	Volts D.C.	.00102935	Temp. DEG. C	25.9014405904
T. C. # 11	Volts D.C.	.00102373	Temp. DEG. C	25.7573076463
T. C. # 12	Volts D.C.	.0013287	Temp. DEG. C	33.2161121574
BLOCK #3				
T. C. # 13	Volts D.C.	.00097605	Temp. DEG. C	24.6154607831
T. C. # 14	Volts D.C.	.00094861	Temp. DEG. C	23.9397727576
T. C. # 15	Volts D.C.	.00094154	Temp. DEG. C	23.7655272123
T. C. # 16	Volts D.C.	.00102941	Temp. DEG. C	25.9257180096
T. C. # 17	Volts D.C.	.00098165	Temp. DEG. C	24.7532407604
T. C. # 18	Volts D.C.	.0013812	Temp. DEG. C	34.4834877346
BLOCK #4				
T. C. # 19	Volts D.C.	.00097153	Temp. DEG. C	24.5042241058
T. C. # 20	Volts D.C.	.00093507	Temp. DEG. C	23.6060143493
T. C. # 21	Volts D.C.	.00093541	Temp. DEG. C	23.6143980907
T. C. # 22	Volts D.C.	.00098113	Temp. DEG. C	24.740448554
T. C. # 23	Volts D.C.	.00099116	Temp. DEG. C	24.9871310205
T. C. # 24	Volts D.C.	.00138586	Temp. DEG. C	34.5958214998

BLOCK #5

T. C. # 25	Volts D.C. .00097727	Temp. DEG. C	24.6454804705
T. C. # 26	Volts D.C. .00096117	Temp. DEG. C	24.2491694442
T. C. # 27	Volts D.C. .00095846	Temp. DEG. C	24.1824293543
T. C. # 28	Volts D.C. .00104858	Temp. DEG. C	26.3969315908
T. C. # 29	Volts D.C. .00101464	Temp. DEG. C	25.5641183855
T. C. # 30	Volts D.C. .00135813	Temp. DEG. C	33.926977279

BLOCK #6

T. C. # 31	Volts D.C. .0184661	Temp. DEG. C	1104.75486434
T. C. # 32	Volts D.C. .00093562	Temp. DEG. C	23.6195762117
T. C. # 33	Volts D.C. .00095092	Temp. DEG. C	23.9966909256
T. C. # 34	Volts D.C. .00102525	Temp. DEG. C	25.824618581
T. C. # 35	Volts D.C. .00100942	Temp. DEG. C	25.4359037688
T. C. # 36	Volts D.C. .00136326	Temp. DEG. C	34.1955430547

BLOCK #7

T. C. # 37	Volts D.C. .00095197	Temp. DEG. C	24.0225608151
T. C. # 38	Volts D.C. .00090534	Temp. DEG. C	22.8723707565
T. C. # 39	Volts D.C. .00093074	Temp. DEG. C	23.499222299
T. C. # 40	Volts D.C. .00101609	Temp. DEG. C	25.5994819606
T. C. # 41	Volts D.C. .0009884	Temp. DEG. C	24.9192828199
T. C. # 42	Volts D.C. .00133658	Temp. DEG. C	33.4065520005

BLOCK #8

T. C. # 43	Volts D.C. .00092359	Temp. DEG. C	23.3228549035
T. C. # 44	Volts D.C. .00090358	Temp. DEG. C	22.8289047559
T. C. # 45	Volts D.C. .00088635	Temp. DEG. C	22.4031775278
T. C. # 46	Volts D.C. .00100126	Temp. DEG. C	25.2354082889
T. C. # 47	Volts D.C. .00093101	Temp. DEG. C	23.5058914404
T. C. # 48	Volts D.C. .0012997	Temp. DEG. C	32.5146055682

BATH TEMPERATURES (TOP TO BOTTOM)

VOLTS D.C.	.0006428	TEMP. DEG. C	16.3455401802
VOLTS D.C.	.00064058	TEMP. DEG. C	16.2899805997
VOLTS D.C.	.00064043	TEMP. DEG. C	16.2862263502

BLOCK # 1 HEATER VLOTS D.C. 4.64237

BLOCK # 2 HEATER VLOTS D.C. 4.66686

BLOCK # 3 HEATER VLOTS D.C. 4.64344

BLOCK # 4 HEATER VLOTS D.C. 4.64304

BLOCK # 5 HEATER VLOTS D.C. 4.64245

BLOCK # 6 HEATER VLOTS D.C. 4.64253

BLOCK # 7 HEATER VLOTS D.C. 4.64473

BLOCK # 8 HEATER VLOTS D.C. 4.65456

INPUT VLOTAGE D.C. VLOTS 5.52795

BLOCK # 1 HEATER POWER WATTS 2.03524258644
BLOCK # 2 HEATER POWER WATTS 1.98939924624
BLOCK # 3 HEATER POWER WATTS 2.03325203683
BLOCK # 4 HEATER POWER WATTS 2.0339963002
BLOCK # 5 HEATER POWER WATTS 2.0350937995
BLOCK # 6 HEATER POWER WATTS 2.03494500624
BLOCK # 7 HEATER POWER WATTS 2.03085070822
BLOCK # 8 HEATER POWER WATTS 2.01249809822

APPENDIX D

SOFTWARE

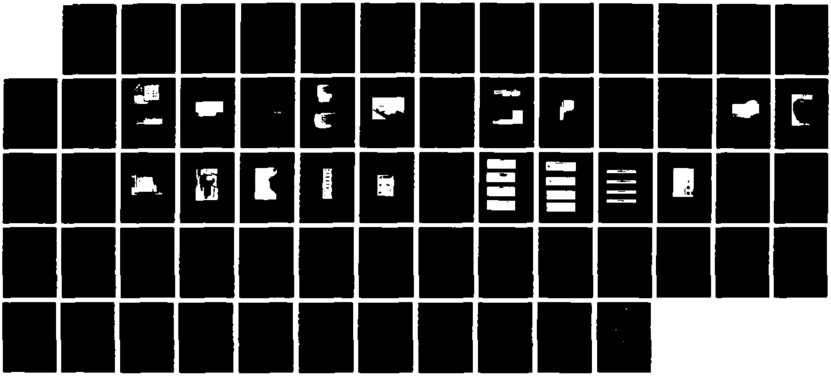
TEMPERATURE MEASUREMENT ACQUISITION PROGRAM

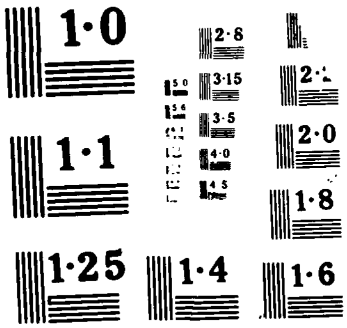
```
10    REAL Volts(60)
20    REAL Temp(59)
40    PRINT "                              BLOCK #1"
50    PRINT " "
51    OUTPUT 709:"CONFMEAS DCV,100,USE 0"
52    ENTER 709:Volts(60)
60    OUTPUT 709:"CONFMEAS DCV,100-105,USE 0"
70    FOR I=0 TO 5
80    ENTER 709:Volts(I)
90    Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
100   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C ";Temp(I)
110   NEXT I
120   PRINT " "
130   PRINT "                              BLOCK #2"
140   PRINT " "
150   OUTPUT 709:"CONFMEAS DCV,106-111,USE 0"
160   FOR I=6 TO 11
170   ENTER 709:Volts(I)
180   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
190   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C ";Temp(I)
200   NEXT I
210   PRINT " "
220   PRINT "                              BLOCK #3"
230   PRINT " "
240   OUTPUT 709:"CONFMEAS DCV,112-117,USE 0"
250   FOR I=12 TO 17
260   ENTER 709:Volts(I)
270   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
280   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C ";Temp(I)
290   NEXT I
300   PRINT " "
310   PRINT "                              BLOCK #4"
320   PRINT " "
330   OUTPUT 709:"CONFMEAS DCV,118-119,USE 0"
340   FOR I=18 TO 19
350   ENTER 709:Volts(I)
360   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
370   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C ";Temp(I)
380   NEXT I
```

```
390   OUTPUT 709;"CONFMEAS DCV,200-203,USE 0"
400   FOR I=20 TO 23
410   ENTER 709;Volts(I)
420   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))+(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
430   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C  ";Temp(I)
440   NEXT I
450   PRINT " "
460   PRINT "                              BLOCK #5"
470   PRINT " "
480   OUTPUT 709;"CONFMEAS DCV,204-209,USE 0"
490   FOR I=24 TO 29
500   ENTER 709;Volts(I)
510   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))+(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
520   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C  ";Temp(I)
530   NEXT I
540   PRINT " "
550   PRINT "                              BLOCK #6"
560   PRINT " "
570   OUTPUT 709;"CONFMEAS DCV,210-215,USE 0"
580   FOR I=30 TO 35
590   ENTER 709;Volts(I)
600   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))+(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
610   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C  ";Temp(I)
620   NEXT I
630   FOR J=1 TO 14
640   PRINT " "
650   NEXT J
660   PRINT "                              BLOCK #7"
670   PRINT " "
680   OUTPUT 709;"CONFMEAS DCV,216-219,USE 0"
690   FOR I=36 TO 39
700   ENTER 709;Volts(I)
710   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))+(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
720   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C  ";Temp(I)
730   NEXT I
740   OUTPUT 709;"CONFMEAS DCV,300-301,USE 0"
750   FOR I=40 TO 41
760   ENTER 709;Volts(I)
770   Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))+(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
780   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C  ";Temp(I)
790   NEXT I
```

AD-A191 224 SINGLE PHASE LIQUID IMMERSION COOLING OF DISCRETE HEAT SOURCES IN A VERTICAL CHANNEL(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S J HAZARD DEC 87 2/2

UNCLASSIFIED F/G 9/1 NL




1·0
2·8
3·15
2·0
3·5
4·0
1·1
1·8
1·25
1·4
1·6

```
800   PRINT " "
810   PRINT "                              BLOCK #8"
820   PRINT " "
830   OUTPUT 709;"CONFMEAS DCV,302-307,USE 0"
840   FOR I=42 TO 47
850   ENTER 709;Volts(I)
860   Temp(I)=.0006797+(25825.1328*Volts(I))-(507789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
870   PRINT "T. C.  #";I+1,"  Volts D.C.  ";Volts(I),"Temp. DEG. C ";Temp(I)
880   NEXT I
890   PRINT " "
1130  PRINT " "
1140  PRINT "                  BATH TEMPERATURES (TOP TO BOTTOM)"
1150  PRINT " "
1160  OUTPUT 709;"CONFMEAS DCV,317-319,USE 0"
1170  FOR I=57 TO 59
1180  ENTER 709;Volts(I)
1190  Temp(I)=.0006797+(25825.1328*Volts(I))-(507789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
1200  PRINT "VOLTS D.C.  ";Volts(I),"TEMP. DEG. C ";Temp(I)
1210  NEXT I
1220  END
```

SINGLE THERMOCOUPLE TEMPERATURE VARIATION PROGRAM

```
10     REAL Volts(101)
20     REAL Temp(101)
30     PRINTER IS 1
40     PRINT " INPUT THE NUMBER OF CONSECUTIVE READINGS YOU WANT."
50     PRINT " "
60     PRINT " THIS PROGRAM WILL READ ONLY THE THERMOCOUPLE SHOWN IN THE"
70     PRINT " SOURCE CODE.  IF YOU WISH TO WORK WITH A DIFFERENT ONE YOU "
80     PRINT " MUST ENTER THAT T.C. ON THE CONFMEAS LINE OF THE CODE!!!"
90     INPUT N
100    PRINT " "
110    PRINT " "
120    PRINT " INPUT THE NUMBER OF THE T.C. YOU WANT TO MEASURE."
130    INPUT M
131    PRINTER IS 701
140    PRINT " THESE ARE ";N,"CONSECUTIVE READINGS FOR THERMOCOUPLE # ";M
150    PRINT " "
160    PRINT " "
170    FOR I=50 TO N+50
180    OUTPUT 709;"CONFMEAS DCV,115,USE 0"
190    ENTER 709;Volts(I)
200    Temp(I)=.0006797+(25825.1328*Volts(I))-(607789.2467*(Volts(I)*Volts(I)))-(
21952034.3364*(Volts(I)^3))+(8370810996.1874*(Volts(I)^4))
210    PRINT "VOLTS D.C. ";Volts(I),"TEMP. DEG. C ";Temp(I)
220    NEXT I
230    Evolts=0.
240    Etemp=0.
250    FOR J=50 TO N+50
260    Evolts=Evolts+Volts(J)
270    Etemp=Etemp+Temp(J)
280    NEXT J
290    Avolts=Evolts/(N+1)
300    Atemp=Etemp/(N+1)
310    PRINT " "
320    PRINT "AVERAGE VOLTAGE D.C. IS ";Avolts
330    PRINT " "
340    PRINT "AVERAGE TEMPERATURE DEG. C IS ";Atemp
350    PRINTER IS 1
360    END
```

HEATER VOLTAGE ACQUISION AND POWER CALCULATION PROGRAM

```
10    REAL Volts(59)
920   OUTPUT 709;"CONFMEAS DCV,308-315,USE 0"
930   FOR I=48 TO 55
940   ENTER 709;Volts(I)
950   PRINT " "
960   PRINT "BLOCK #";I-47,"HEATER VLOTS D.C.";Volts(I)
970   NEXT I
980   PRINT " "
990   PRINT " "
1000  PRINT " "
1010  OUTPUT 709;"CONFMEAS DCV,316,USE 0"
1020  ENTER 709;Volts(56)
1030  PRINT " "
1040  PRINT " "
1050  PRINT "INPUT VLOTAGE D.C. VLOTS";Volts(56)
1060  PRINT " "
1070  PRINT " "
1080  Resist=2.02
1090  FOR I=48 TO 55
1100  Pow=((Volts(56)-Volts(I))/Resist)*Volts(I)
1110  PRINT "BLOCK #";I-47,"HEATER POWER WATTS";Pow
1120  NEXT I
1220  END
```

```
*********************************************
*                                           *
*  DATA REDUCING PROGRAM WRITTEN IN FORTRAN  *
*                                           *
*********************************************

      DOUBLE PRECISION T(48),TT(48),Q(8),QCONV(8),GR(8),TTT(8),AT(8)
      DOUBLE PRECISION TINF,KH2O,BETA,NU,DXPG,DXR,KPG,KR,A,G,R1,R2,LEN
      DOUBLE PRECISION POWER,SPACE
      CHARACTER NAME*8, FNAME*8, EPNAME*8,GRNAME*8
      INTEGER RUN

      DXPG = 0.006731D0
      DXR = 0.003175D0
      KPG = 0.1421D0
      KR = 0.0389D0
      A = 0.000188D0
      G = 9.81D0
      LEN = 0.007874D0

      R1 = DXPG/(KPG*A)
      R2 = DXR/(KR*A)

      PRINT*,'INPUT RUN #, INTEGER ONLY'
      READ*,RUN
      PRINT*,'INPUT POWER VALUE IN WATTS'
      READ*,POWER
      PRINT*,'INPUT SPACING IN MM'
      READ*, SPACE
      PRINT*,'INPUT TEMPERATURE @ INFINITY, DEG. C'
      READ*,TINF
      PRINT*,'INPUT THE THERMAL CONDUCTIVITY OF H2O, K'
      READ*,KH2O
      PRINT*,'INPUT THE EXPANSION COEFFICIENT, B'
      READ*,BETA
      PRINT*,'INPUT THE VISCOSITY, NU'
      READ*, NU

******************************
*  READ IN TEMPERATURE DATA  *
******************************

      PRINT*,'INPUT THE NAME CORRESPONDING TO THE FILE TYPE OF DATA.'
      READ (5,'(A)') NAME
      REWIND 9
      OPEN (UNIT=9, FILE=NAME)

      DO 100 I=1,48,1
         READ(9,*) T(I)
  100 CONTINUE

************************
*  CALCULATE T - TINF  *
************************

      DO 200 I=1,48,1
         TT(I) = T(I)-TINF
  200 CONTINUE

**********************************************************
*  CALCULATE CONDUCTION LOSSES THROUGH THE TEST SURFACE  *
**********************************************************

      L=6
      DO 300 I=1,8,1
         Q(I) = TT(L)*(1.0/(R1+R2))
         L=L+6
  300 CONTINUE
```

```
**********************************
*  CALCULATE CONVECTED HEAT FLUX  *
**********************************

      DO 400 I=1,8,1
         QCONV(I) = POWER - Q(I)
  400 CONTINUE

*******************************************
*  CALCULATE AVERAGE SURFACE TEMPERATURES  *
*******************************************

      J = 1
      DO 105 I=1,8,1
         AT(I)=(T(J)+T(J+1)+T(J+2)+T(J+3)+T(J+4))/5.0
         J = J+6
  105 CONTINUE

*****************************************
*  CALCULATE NONDIMENSIONAL TEMPERATURE  *
*****************************************

      DO 205 I=1,8,1
         TTT(I)=(AT(I)-TINF)/((QCONV(I)*LEN)/(A*KH2O))
  205 CONTINUE



**************************************
*  CALCULATE MODIFIED GRASHOF NUMBER  *
**************************************

      DO 500 I=1,8,1
         GR(I) = ((G*BETA*(QCONV(I)/A))*(LEN**4))/(KH2O*(NU**2))
  500 CONTINUE

*******************************
*  GENERATE OUTPUT DATA FILES  *
*******************************

      PRINT*,'INPUT THE FILETYPE FOR THE OUTPUT FILE'
      READ (5,'(A)') FNAME
      REWIND 11
      OPEN (UNIT=11, FILE=FNAME)

      WRITE (11,1100) RUN,POWER,SPACE,TINF,KH2O,BETA,NU
 1100 FORMAT(1X,'RUN NUMBER',2X,I2,/,
     C1X,'POWER IN WATTS',2X,F5.3,/,
     C1X,'SPACING IN MM.',2X,F6.3,/,
     C1X,'AMBIENT TEMP. DEG. C',2X,F6.3,/,
     C1X,'THERMAL CONDUCTIVITY OF H2O',2X,E11.5,/,
     C1X,'EXPANSION COEFFICIENT,B',2X,E11.5,/,
     C1X,'VISCOSITY,NU',2X,E11.5,/)

      WRITE (11,1101)
 1101 FORMAT(1X,/1X,/1X,'BLOCK #',3X,'QCOND',5X,'QCONV',5X,'GRASHOF #',4
     CX,'NON-DIMEN. TEMP.')

      DO 600 J=1,8,1
         WRITE (11,1102) J,Q(J),QCONV(J),GR(J),TTT(J)
  600 CONTINUE

 1102 FORMAT(1X,3X,I2,5X,F5.3,5X,F5.3,5X,E9.3,8X,F6.3)

      WRITE(11,1103)
 1103 FORMAT(1X,/,1X,/,1X,/,5X,'B#',4X,'TF',6X,'TR',6X,'TL',6X,'TT',6X,'
     CTB',6X,'TH')

      K = 1
      DO 601 N=1,8,1
         WRITE(11,12)N,TT(K),TT(K+1),TT(K+2),TT(K+3),TT(K+4),TT(K+5)
         K = K+6
```

```
  601 CONTINUE

      WRITE(11,1104)
 1104 FORMAT(1X,/,1X,/,1X,'B# = BLOCK NUMBER',
     C3X,'TF = FRONT TEMP.',/,
     C1X,'TR = RIGHT TEMP.',
     C4X,'TL = LEFT TEMP.',/,
     C1X,'TT = TOP TEMP.',
     C6X,'TB = BOTTOM TEMP.',/,
     C1X,'TH = HEATER TEMP.')
      PRINT*,'ENTER THE FILETYPE FOR EASYPLOT DATA FILE.'
      READ (5,'(A)') EPNAME
      REWIND 12
      OPEN (UNIT=12, FILE =EPNAME)

      K=1

      DO 700 M=1,8,1
       WRITE(12,12)M,TT(K),TT(K+1),TT(K+2),TT(K+3),TT(K+4),TT(K+5)
       K=K+6
  700 CONTINUE

   12 FORMAT (4X,I2,2X,F6.3,2X,F6.3,2X,F6.3,2X,F6.3,2X,F6.3,2X,F6.3)

      PRINT*,'ENTER THE FILETYPE FOR GR# EASYPLOT.'
      READ(5,'(A)') GRNAME
      REWIND 15
      OPEN(UNIT=15, FILE=GRNAME)
      DO 800 M=1,8,1
         WRITE(15,1300) TTT(M),GR(M)
  800 CONTINUE
 1300 FORMAT(3X,F6.3,2X,E10.3)

      STOP
      END
```

APPENDIX E

TABULAR RESULTS

RUN NUMBER 1
POWER IN WATTS 0.200
SPACING IN MM. 73.810
AMBIENT TEMP. DEG. C 18.430
THERMAL CONDUCTIVITY OF H2O 0.60038E+00
EXPANSION COEFFICIENT,B 0.18994E-03
VISCOSITY,NU 0.10453E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.003	0.197	0.114E+05	0.108
2	0.003	0.197	0.114E+05	0.104
3	0.003	0.197	0.114E+05	0.100
4	0.004	0.196	0.114E+05	0.098
5	0.003	0.197	0.114E+05	0.092
6	0.003	0.197	0.114E+05	0.088
7	0.003	0.197	0.114E+05	0.074
8	0.003	0.197	0.115E+05	0.068

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	1.560	1.330	1.310	1.630	1.570	-----
2	1.450	1.320	1.340	1.530	1.485	2.200
3	1.350	1.200	1.220	1.560	1.530	2.400
4	1.350	1.260	1.190	1.500	1.400	2.420
5	1.240	1.150	1.170	1.460	1.330	2.160
6	-----	1.110	1.150	1.380	1.330	2.080
7	0.960	0.840	0.890	1.220	1.150	2.030
8	1.000	0.800	0.790	1.120	0.940	1.730

B# = BLOCK NUMBER
DTF = TF - TINF
DTR = TR - TINF
DTL = TL - TINF
DTT = TT - TINF
DTB = TB - TINF
DTH = TH - TINF

RUN NUMBER 2
POWER IN WATTS 0.500
SPACING IN MM. 73.810
AMBIENT TEMP. DEG. C 18.320
THERMAL CONDUCTIVITY OF H2O 0.60035E+00
EXPANSION COEFFICIENT,B 0.18970E-03
VISCOSITY,NU 0.10460E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.007	0.493	0.285E+05	0.099
2	0.008	0.492	0.285E+05	0.095
3	0.008	0.492	0.285E+05	0.093
4	0.008	0.492	0.285E+05	0.091
5	0.008	0.492	0.285E+05	0.089
6	0.007	0.493	0.285E+05	0.095
7	0.007	0.493	0.286E+05	0.072
8	0.006	0.494	0.286E+05	0.066

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	3.480	3.020	3.120	3.770	3.610	-----
2	3.330	2.950	3.060	3.530	3.470	5.190
3	3.140	2.830	2.870	3.570	3.550	5.690
4	3.070	2.910	2.800	3.460	3.290	5.690
5	2.940	2.770	2.800	3.530	3.230	5.210
6	-----	2.630	2.710	3.230	3.100	5.100
7	2.400	2.110	2.210	2.880	2.770	4.830
8	2.360	1.980	1.990	2.770	2.340	4.370

RUN NUMBER 3
POWER IN WATTS 1.000
SPACING IN MM. 73.810
AMBIENT TEMP. DEG. C 16.080
THERMAL CONDUCTIVITY OF H2O 0.59680E+00
EXPANSION COEFFICIENT,B 0.16480E-03
VISCOSITY,NU 0.11030E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.014	0.986	0.449E+05	0.080
2	0.013	0.987	0.449E+05	0.076
3	0.015	0.985	0.448E+05	0.078
4	0.015	0.985	0.448E+05	0.077
5	0.014	0.986	0.449E+05	0.076
6	0.014	0.986	0.449E+05	0.072
7	0.014	0.986	0.449E+05	0.064
8	0.013	0.987	0.449E+05	0.059

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	5.490	5.190	5.260	6.220	5.690	-----
2	5.200	4.860	4.930	5.650	5.610	9.250
3	5.380	4.720	4.770	6.260	5.730	10.220
4	5.560	4.660	4.780	5.960	5.720	10.550
5	5.100	4.770	4.780	6.110	5.520	9.720
6	-----	4.420	4.590	5.610	5.181	9.740
7	4.390	3.760	4.020	5.210	4.890	9.270
8	4.220	3.580	3.560	5.030	4.170	8.730

RUN NUMBER 4
POWER IN WATTS 2.000
SPACING IN MM. 73.810
AMBIENT TEMP. DEG. C 16.200
THERMAL CONDUCTIVITY OF H2O 0.59696E+00
EXPANSION COEFFICIENT,B 0.16621E-03
VISCOSITY,NU 0.10998E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.025	1.975	0.912E+05	0.066
2	0.024	1.976	0.912E+05	0.063
3	0.026	1.974	0.911E+05	0.060
4	0.027	1.973	0.911E+05	0.058
5	0.026	1.974	0.912E+05	0.063
6	0.026	1.974	0.911E+05	0.060
7	0.025	1.975	0.912E+05	0.057
8	0.023	1.977	0.913E+05	0.051

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	8.980	8.750	8.770	10.030	9.340	------
2	8.540	7.920	7.980	9.580	9.350	16.660
3	8.160	7.750	7.510	9.700	8.520	18.030
4	8.110	7.330	7.520	8.530	8.840	18.210
5	8.270	7.940	7.960	10.120	9.460	17.550
6	-----	7.390	7.860	9.430	8.930	17.790
7	7.750	6.660	7.190	9.360	8.590	17.270
8	7.070	6.220	6.130	8.900	7.270	16.070

RUN NUMBER 5
POWER IN WATTS 0.200
SPACING IN MM. 11.913
AMBIENT TEMP. DEG. C 16.220
THERMAL CONDUCTIVITY OF H2O 0.59699E+00
EXPANSION COEFFICIENT,B 0.16645E-03
VISCOSITY,NU 0.10992E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.003	0.197	0.910E+04	0.129
2	0.004	0.196	0.909E+04	0.122
3	0.004	0.196	0.908E+04	0.120
4	0.004	0.196	0.908E+04	0.117
5	0.003	0.197	0.910E+04	0.109
6	0.003	0.197	0.910E+04	0.100
7	0.003	0.197	0.911E+04	0.093
8	0.003	0.197	0.913E+04	0.075

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	1.780	1.610	1.790	1.870	1.830	-----
2	1.680	1.570	1.550	1.850	1.760	2.450
3	1.650	1.520	1.500	1.830	1.750	2.600
4	1.860	1.440	1.400	1.710	1.640	2.620
5	1.490	1.380	1.400	1.670	1.570	2.380
6	-----	1.250	1.280	1.550	1.470	2.290
7	1.420	1.100	1.150	1.430	1.350	2.190
8	1.050	0.910	0.910	1.250	1.060	1.940

RUN NUMBER 6
POWER IN WATTS 0.500
SPACING IN MM. 11.913
AMBIENT TEMP. DEG. C 16.250
THERMAL CONDUCTIVITY OF H2O 0.59705E+00
EXPANSION COEFFICIENT,B 0.16685E-03
VISCOSITY,NU 0.10983E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.008	0.492	0.229E+05	0.100
2	0.008	0.492	0.229E+05	0.096
3	0.008	0.492	0.229E+05	0.095
4	0.008	0.492	0.228E+05	0.093
5	0.008	0.492	0.229E+05	0.088
6	0.007	0.493	0.229E+05	0.082
7	0.007	0.493	0.229E+05	0.076
8	0.006	0.494	0.229E+05	0.064

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	3.410	3.190	3.420	3.640	3.600	-----
2	3.300	3.060	3.060	3.690	3.490	5.230
3	3.240	2.990	3.000	3.610	3.470	5.630
4	3.390	2.890	2.860	3.530	3.340	5.790
5	2.960	2.800	2.850	3.470	3.190	5.260
6	-----	2.600	2.620	3.210	2.990	5.080
7	2.620	2.240	2.380	3.020	2.840	4.900
8	2.230	1.980	1.900	2.720	2.220	4.450

RUN NUMBER 7
POWER IN WATTS 1.000
SPACING IN MM. 11.913
AMBIENT TEMP. DEG. C 16.260
THERMAL CONDUCTIVITY OF H2O 0.59706E+00
EXPANSION COEFFICIENT,B 0.16693E-03
VISCOSITY,NU 0.10981E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.013	0.987	0.459E+05	0.082
2	0.014	0.986	0.459E+05	0.081
3	0.015	0.985	0.458E+05	0.078
4	0.016	0.984	0.458E+05	0.080
5	0.014	0.986	0.458E+05	0.077
6	0.014	0.986	0.459E+05	0.072
7	0.014	0.986	0.459E+05	0.067
8	0.012	0.988	0.459E+05	0.057

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	5.670	5.270	5.670	5.740	5.950	-----
2	5.520	5.120	5.220	6.260	5.840	9.570
3	5.490	5.050	5.070	5.610	5.850	10.340
4	5.580	4.960	4.940	6.150	5.820	10.730
5	5.120	4.850	4.990	6.160	5.620	9.800
6	-----	4.530	4.550	5.670	5.230	9.630
7	4.520	3.920	4.200	5.370	5.010	9.270
8	3.930	3.520	3.400	4.950	4.010	8.540

RUN NUMBER 8
POWER IN WATTS 2.000
SPACING IN MM. 11.913
AMBIENT TEMP. DEG. C 16.270
THERMAL CONDUCTIVITY OF H2O 0.59707E+00
EXPANSION COEFFICIENT,B 0.16702E-03
VISCOSITY,NU 0.10979E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.024	1.976	0.920E+05	0.062
2	0.024	1.976	0.920E+05	0.063
3	0.027	1.973	0.919E+05	0.062
4	0.028	1.972	0.918E+05	0.064
5	0.026	1.974	0.919E+05	0.065
6	0.026	1.974	0.919E+05	0.062
7	0.025	1.975	0.919E+05	0.057
8	0.023	1.977	0.920E+05	0.050

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	8.450	8.320	8.720	8.520	9.140	------
2	8.500	8.110	8.230	9.450	9.320	16.750
3	8.690	7.980	8.120	8.680	9.180	18.220
4	8.990	8.070	8.070	9.720	9.560	19.120
5	8.620	8.090	8.370	10.310	9.640	17.720
6	-----	7.660	7.910	9.800	9.020	17.620
7	7.690	6.680	7.140	9.390	8.680	17.130
8	6.840	6.100	5.850	8.790	7.040	16.000

RUN NUMBER 9
POWER IN WATTS 0.200
SPACING IN MM. NO SHROUDING WALL
AMBIENT TEMP. DEG. C 16.300
THERMAL CONDUCTIVITY OF H2O 0.59712E+00
EXPANSION COEFFICIENT,B 0.16737E-03
VISCOSITY,NU 0.10970E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.003	0.197	0.918E+04	0.112
2	0.003	0.197	0.919E+04	0.109
3	0.004	0.196	0.918E+04	0.107
4	0.004	0.196	0.918E+04	0.106
5	0.003	0.197	0.919E+04	0.100
6	0.003	0.197	0.919E+04	0.094
7	0.003	0.197	0.920E+04	0.088
8	0.003	0.197	0.921E+04	0.076

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	1.540	1.440	1.480	1.690	1.590	-----
2	1.500	1.390	1.400	1.660	1.580	2.300
3	1.490	1.340	1.350	1.640	1.520	2.470
4	1.700	1.290	1.260	1.580	1.480	2.430
5	1.400	1.260	1.270	1.550	1.450	2.270
6	-----	1.170	1.200	1.430	1.380	2.240
7	1.250	1.030	1.100	1.350	1.360	2.140
8	1.050	0.980	0.960	1.240	1.050	1.940

RUN NUMBER 10
POWER IN WATTS 0.500
SPACING IN MM. NO SHROUDING WALL
AMBIENT TEMP. DEG. C 16.300
THERMAL CONDUCTIVITY OF H2O 0.59712E+00
EXPANSION COEFFICIENT,B 0.16737E-03
VISCOSITY,NU 0.10970E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.008	0.492	0.230E+05	0.096
2	0.008	0.492	0.230E+05	0.093
3	0.008	0.492	0.230E+05	0.091
4	0.008	0.492	0.230E+05	0.088
5	0.008	0.492	0.230E+05	0.085
6	0.008	0.492	0.230E+05	0.080
7	0.007	0.493	0.230E+05	0.074
8	0.007	0.493	0.231E+05	0.066

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	3.270	3.040	3.120	3.640	3.440	-----
2	3.190	2.910	2.900	3.630	3.390	5.230
3	3.130	2.840	2.830	3.550	3.270	5.600
4	3.250	2.710	2.700	3.410	3.180	5.640
5	2.890	2.670	2.710	3.390	3.060	5.180
6	-----	2.460	2.560	3.100	2.940	5.160
7	2.550	2.190	2.360	2.920	2.840	4.900
8	2.270	2.110	1.990	2.750	2.310	4.540

RUN NUMBER 11
POWER IN WATTS 1.000
SPACING IN MM. NO SHROUDING WALL
AMBIENT TEMP. DEG. C 16.300
THERMAL CONDUCTIVITY OF H2O 0.59712E+00
EXPANSION COEFFICIENT,B 0.16737E-03
VISCOSITY,NU 0.10970E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.014	0.986	0.461E+05	0.080
2	0.014	0.986	0.461E+05	0.075
3	0.015	0.985	0.460E+05	0.077
4	0.015	0.985	0.460E+05	0.076
5	0.014	0.986	0.461E+05	0.075
6	0.014	0.986	0.461E+05	0.070
7	0.013	0.987	0.461E+05	0.065
8	0.013	0.987	0.461E+05	0.059

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	5.410	5.160	5.270	6.190	5.650	-----
2	5.150	4.750	4.760	5.770	5.650	9.340
3	5.300	4.850	4.740	6.050	5.630	10.250
4	5.490	4.670	4.700	5.890	5.570	10.480
5	5.030	4.660	4.720	6.020	5.380	9.650
6	-----	4.280	4.480	5.500	5.210	9.690
7	4.470	3.810	4.150	5.240	4.940	9.180
8	4.030	3.750	3.500	4.980	4.110	8.650

RUN NUMBER 12
POWER IN WATTS 2.000
SPACING IN MM. NO SHROUDING WALL
AMBIENT TEMP. DEG. C 16.310
THERMAL CONDUCTIVITY OF H2O 0.59714E+00
EXPANSION COEFFICIENT,B 0.16753E-03
VISCOSITY,NU 0.10966E-05

BLOCK #	QCOND	QCONV	GRASHOF #	NON-DIMEN. TEMP.
1	0.025	1.975	0.924E+05	0.067
2	0.025	1.975	0.924E+05	0.063
3	0.026	1.974	0.923E+05	0.060
4	0.027	1.973	0.923E+05	0.058
5	0.026	1.974	0.924E+05	0.063
6	0.026	1.974	0.924E+05	0.060
7	0.025	1.975	0.924E+05	0.057
8	0.024	1.976	0.925E+05	0.052

B#	DTF	DTR	DTL	DTT	DTB	DTH
1	9.080	8.770	8.940	10.090	9.450	------
2	8.570	7.940	7.800	9.590	9.480	16.910
3	8.300	7.630	7.460	9.620	8.440	18.170
4	8.190	7.300	7.300	8.430	8.680	18.290
5	8.330	7.940	7.870	10.090	9.250	17.620
6	-----	7.310	7.690	9.510	9.130	17.890
7	7.710	6.560	7.190	9.290	8.610	17.100
8	7.010	6.520	6.090	8.920	7.200	16.200

APPENDIX F

FIGURES

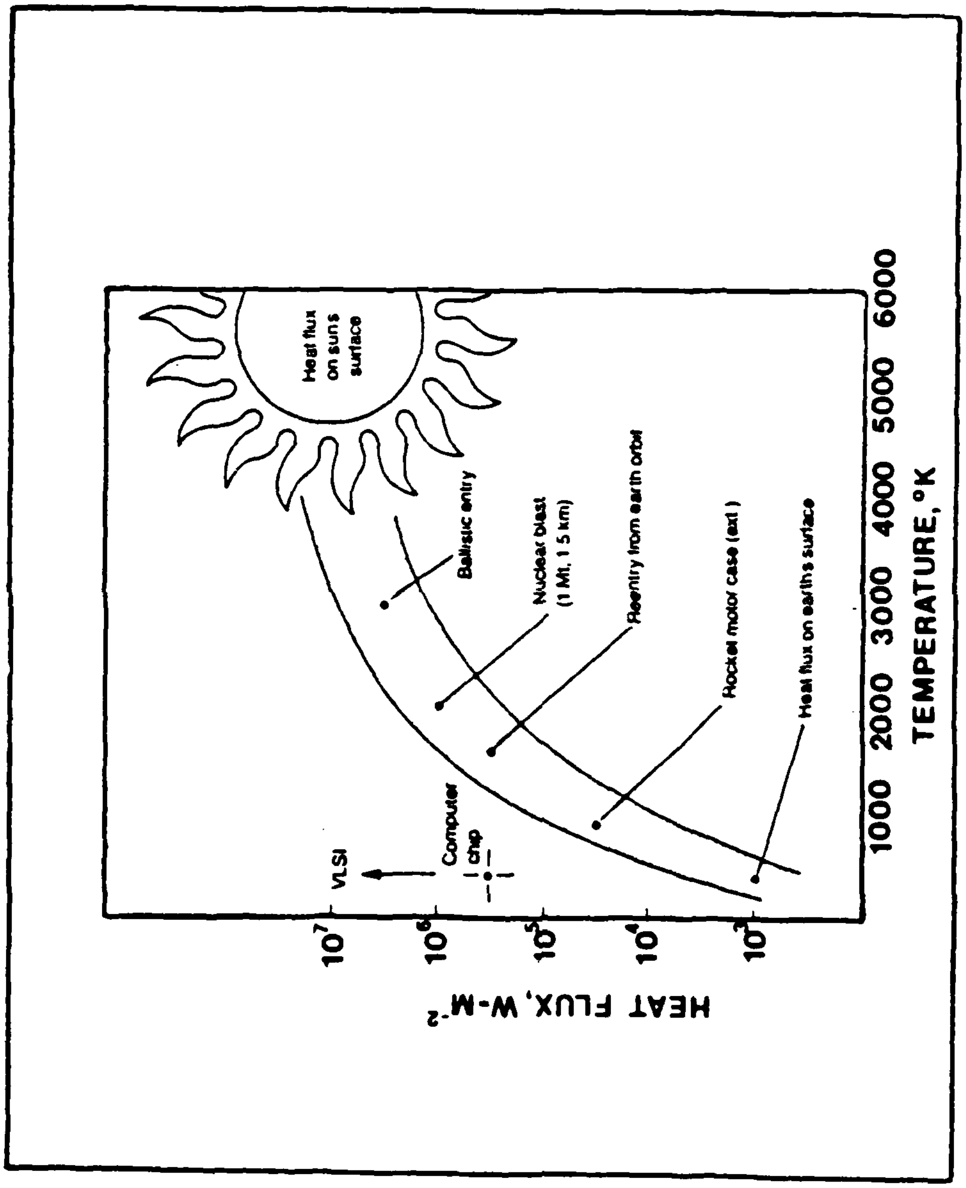


Figure 1. Temperature versus Heat Flux for Various Phenomena [Ref. 5]

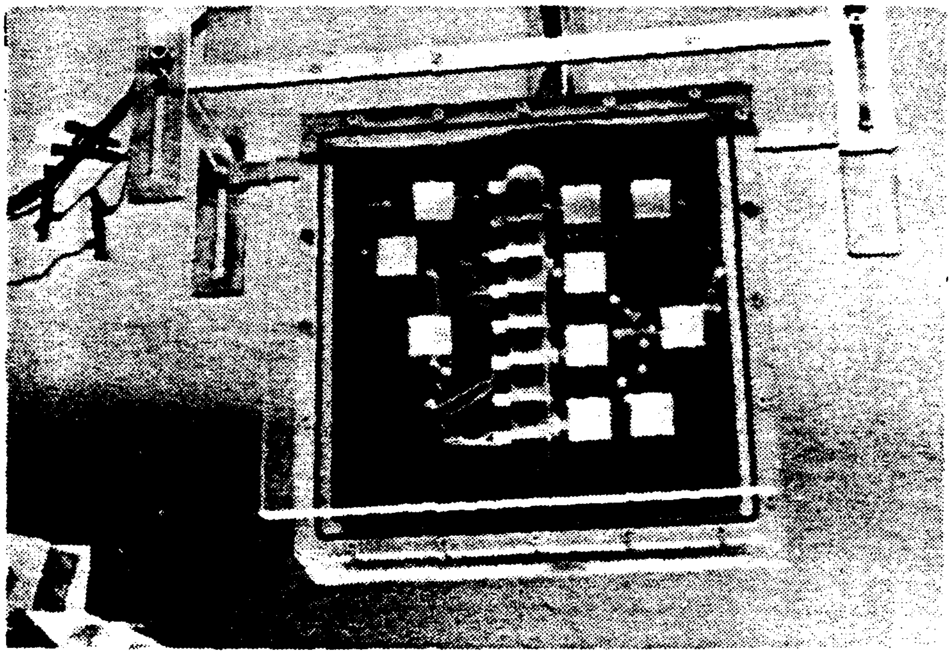


Figure 2. Assembled Test Surface and Shrouding Wall

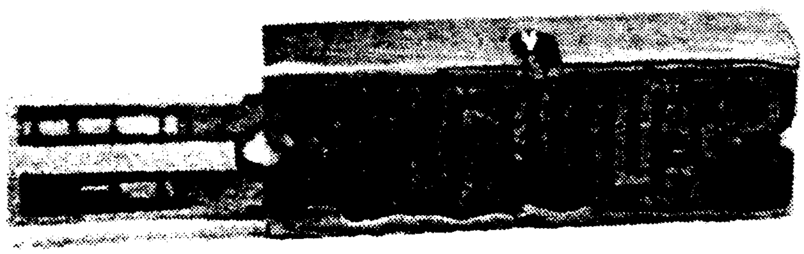


Figure 3. Mounted Foil Heater

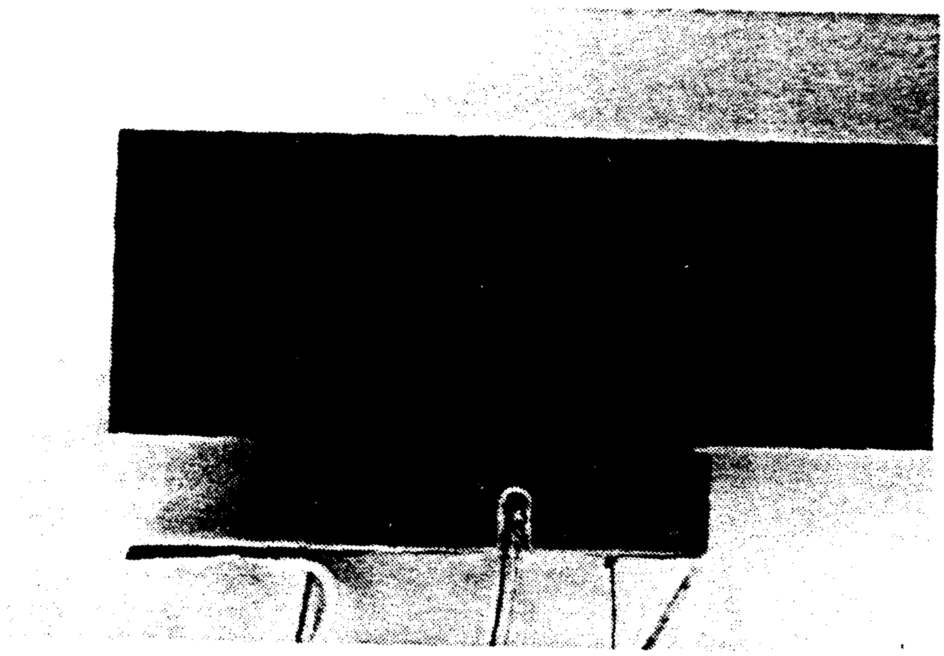


Figure 4. Mounted Thermocouple

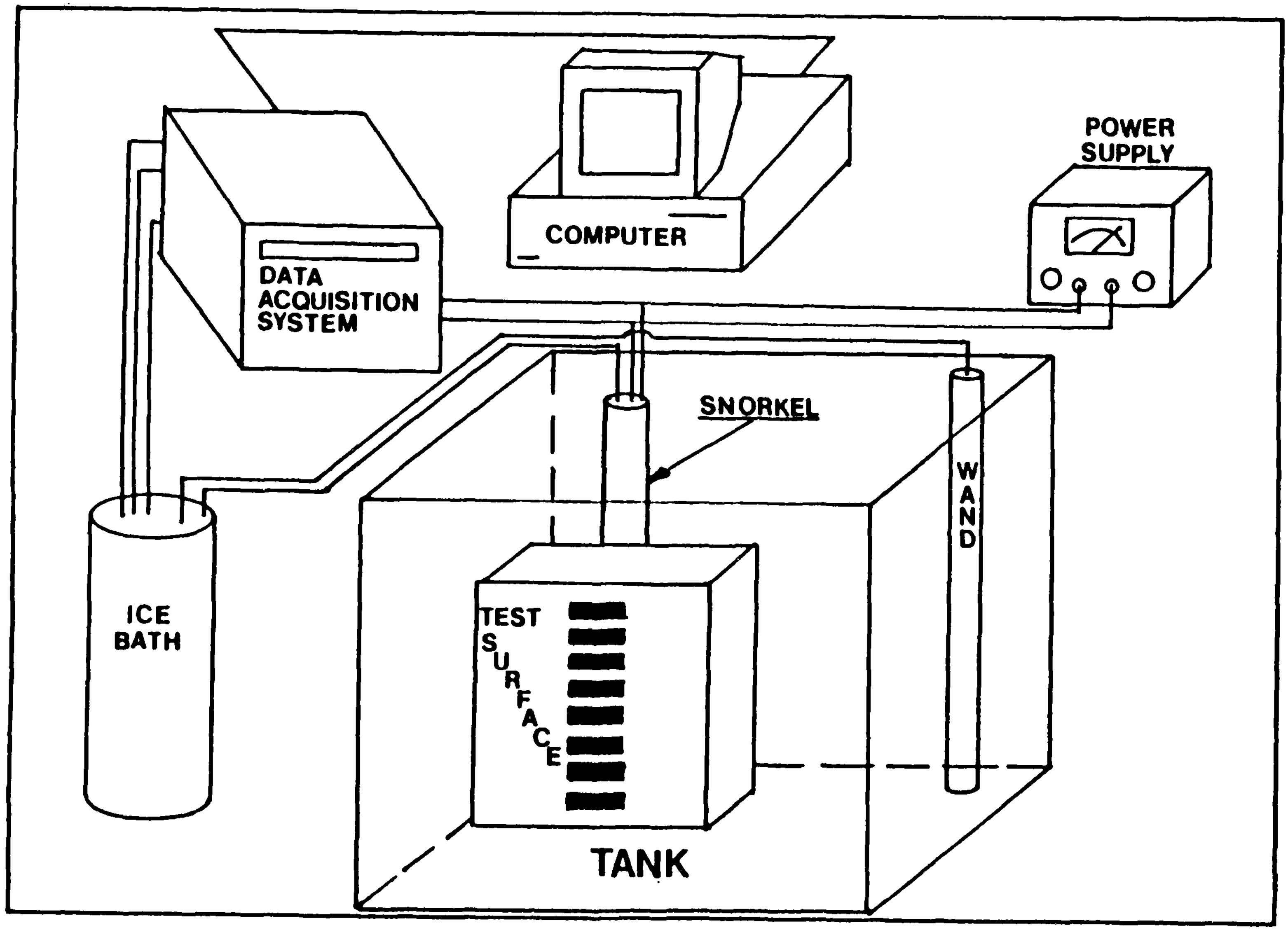


Figure 5. System Configuration

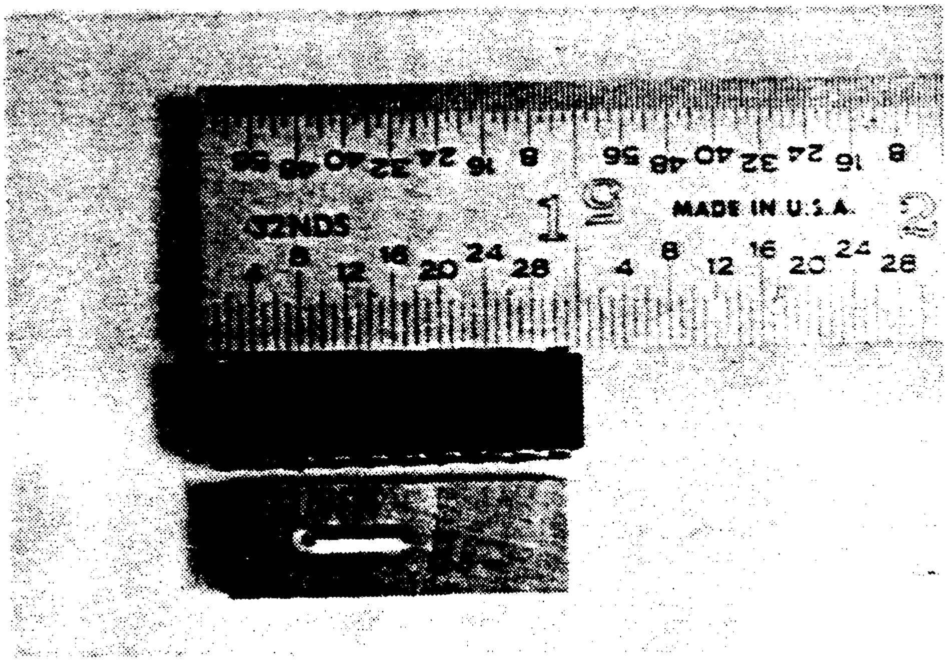


Figure 6. 20 Pin DIP and Chip Comparison, Too View

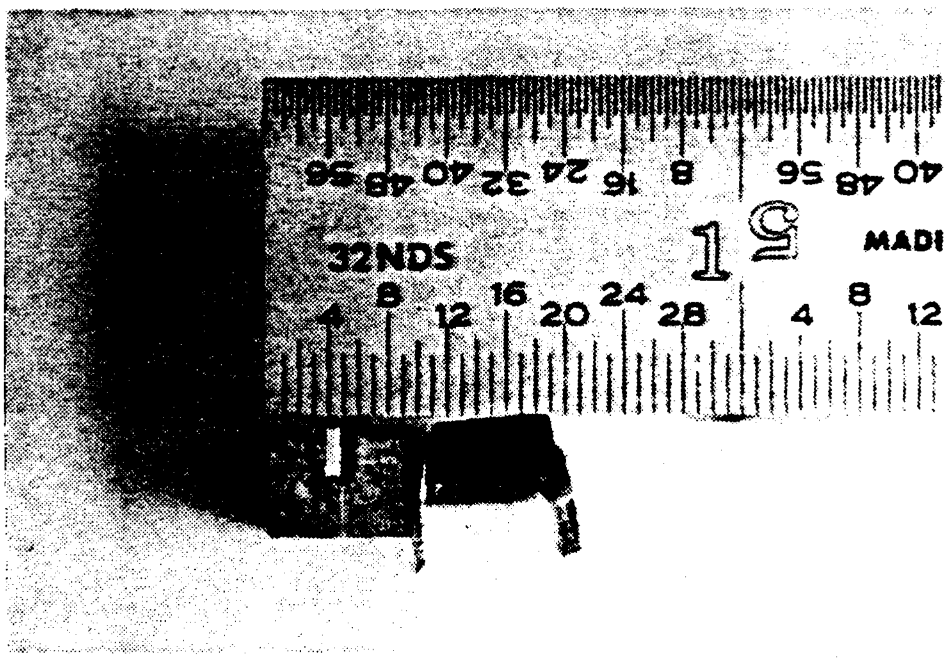


Figure 7. 20 Pin DIP and Chip Comparison, End View

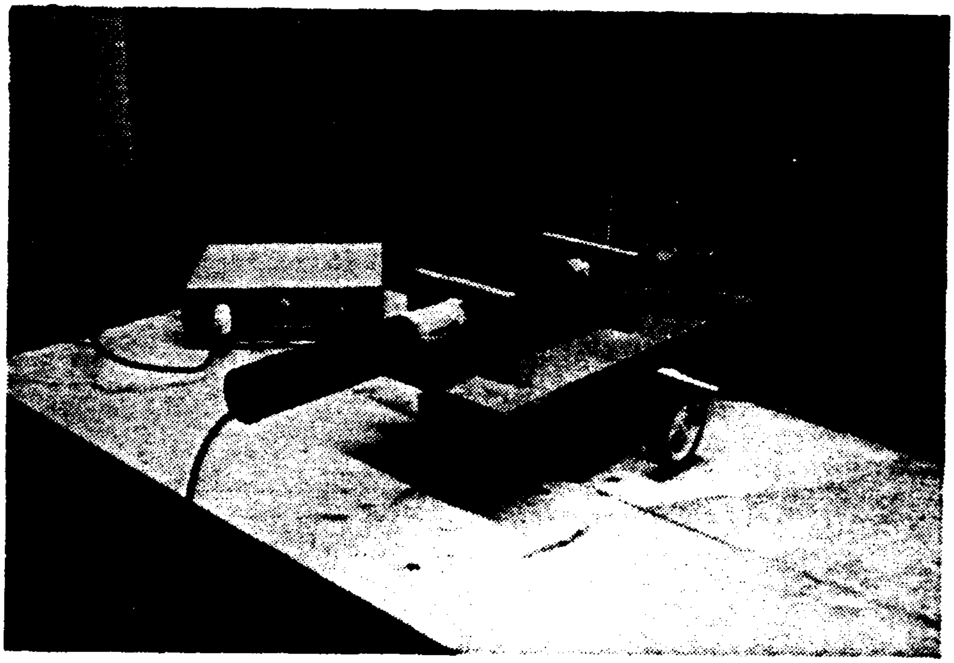


Figure 8. Laser and Cylindrical Lens

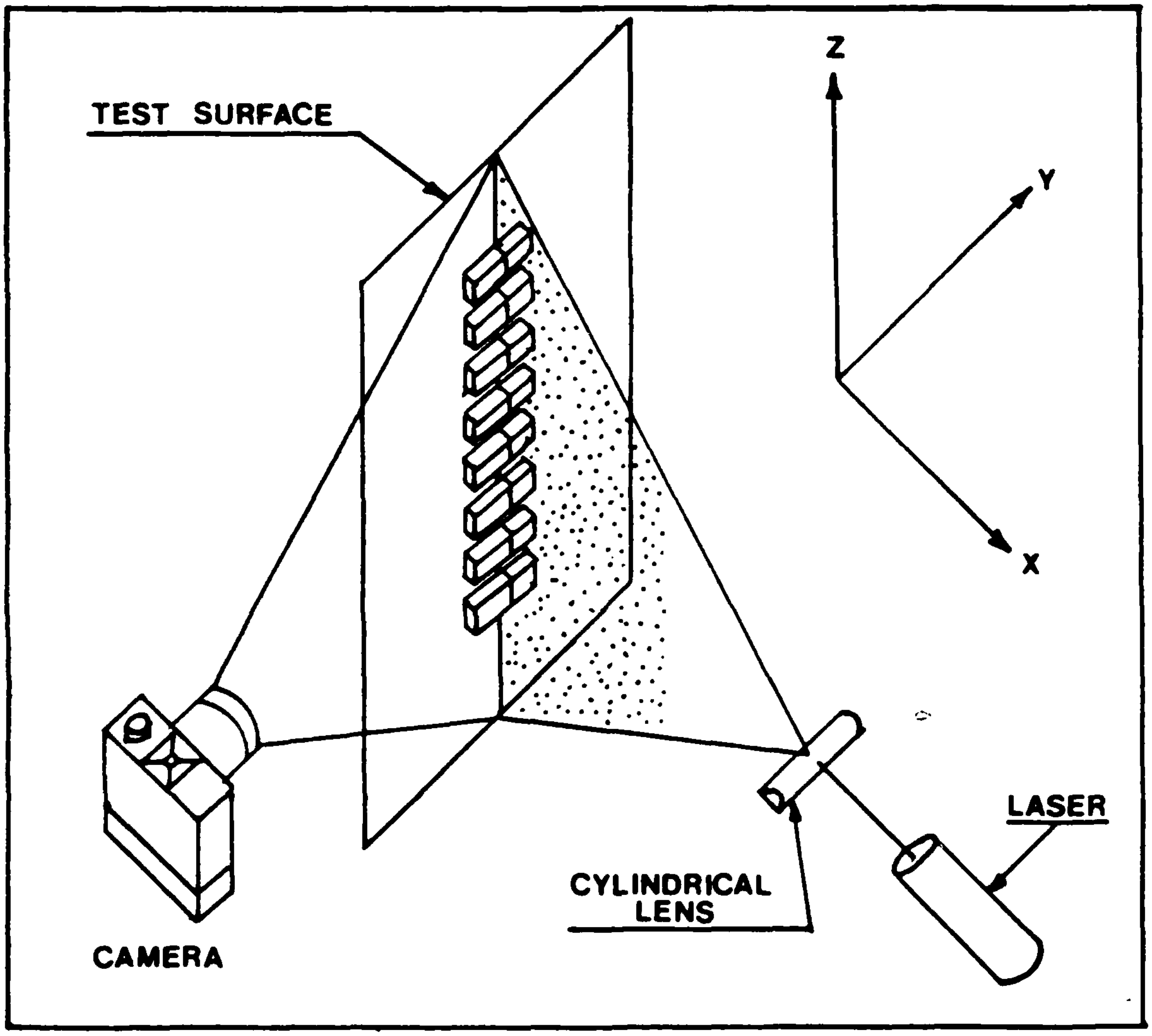


Figure 9. Laser and Camera Orientation

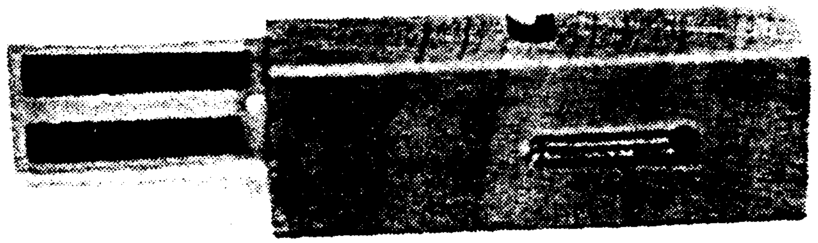


Figure 10. Block with Grooves

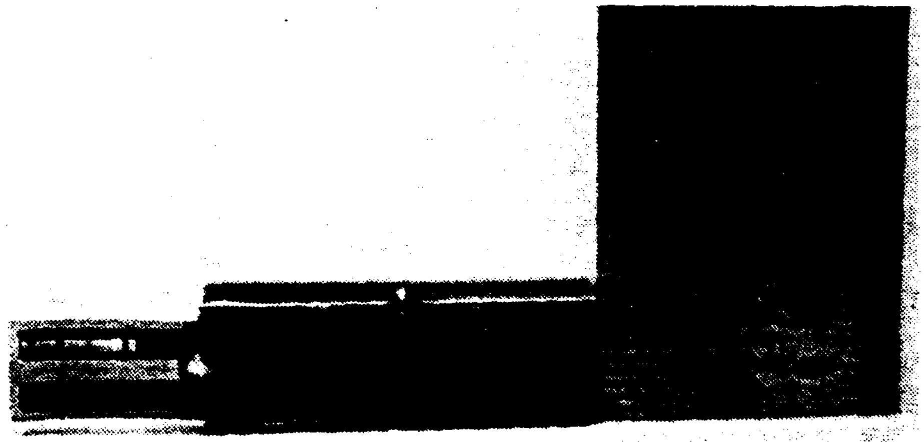


Figure 11. Mounted Foil Heater, End Measured

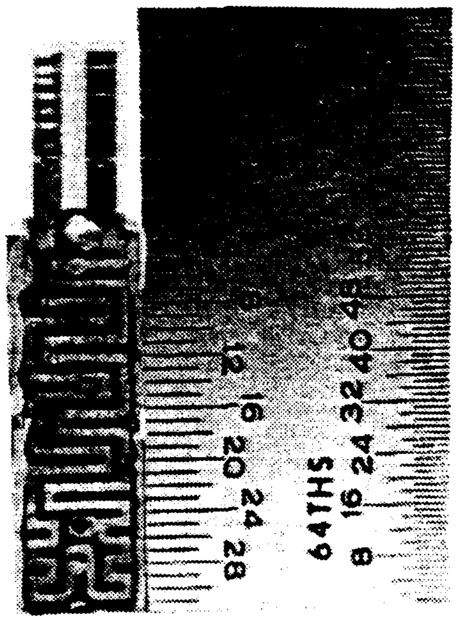


Figure 12. Mounted Foil Heater, Length Measured

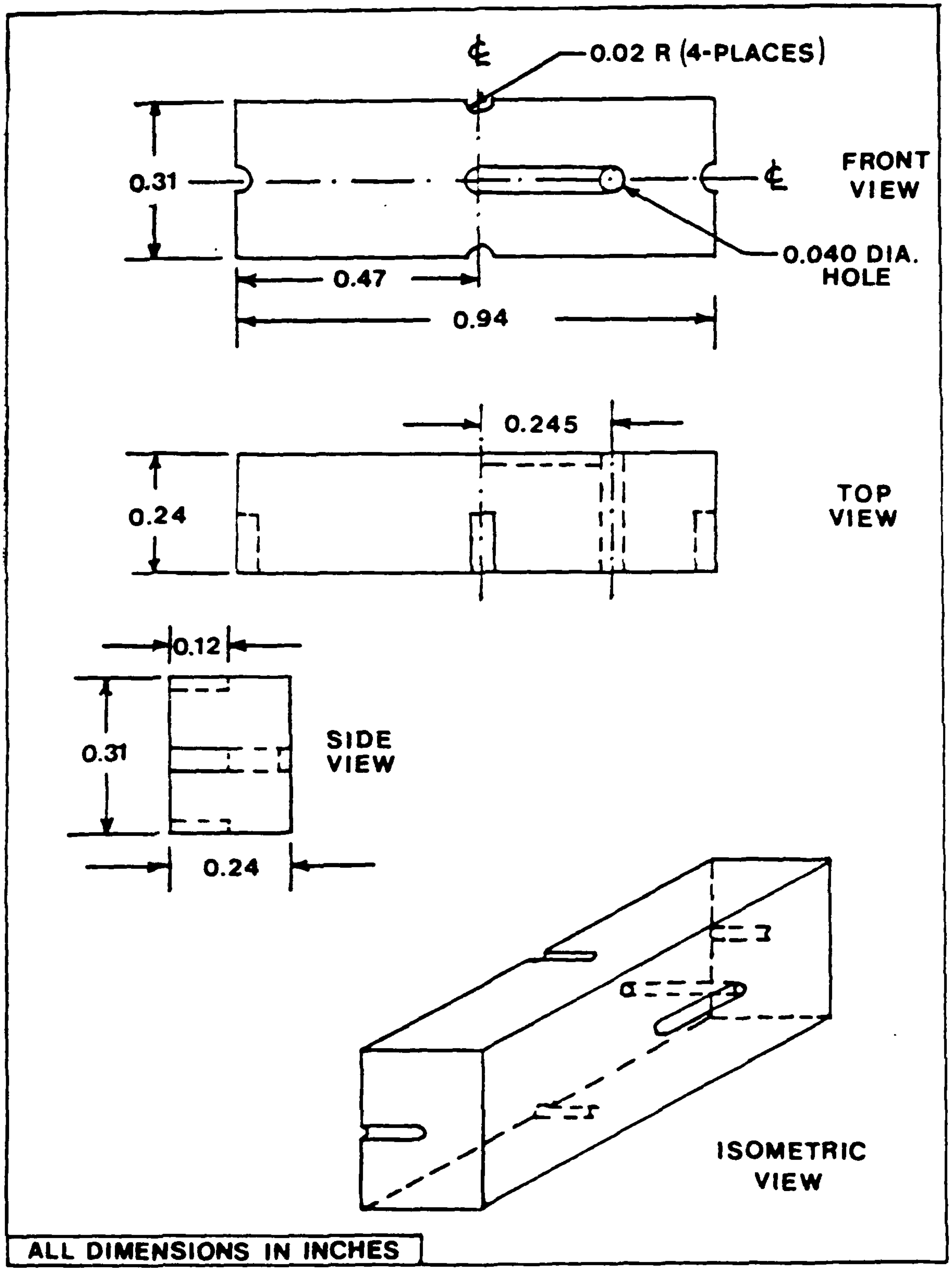


Figure 13. Heater Block Schematic

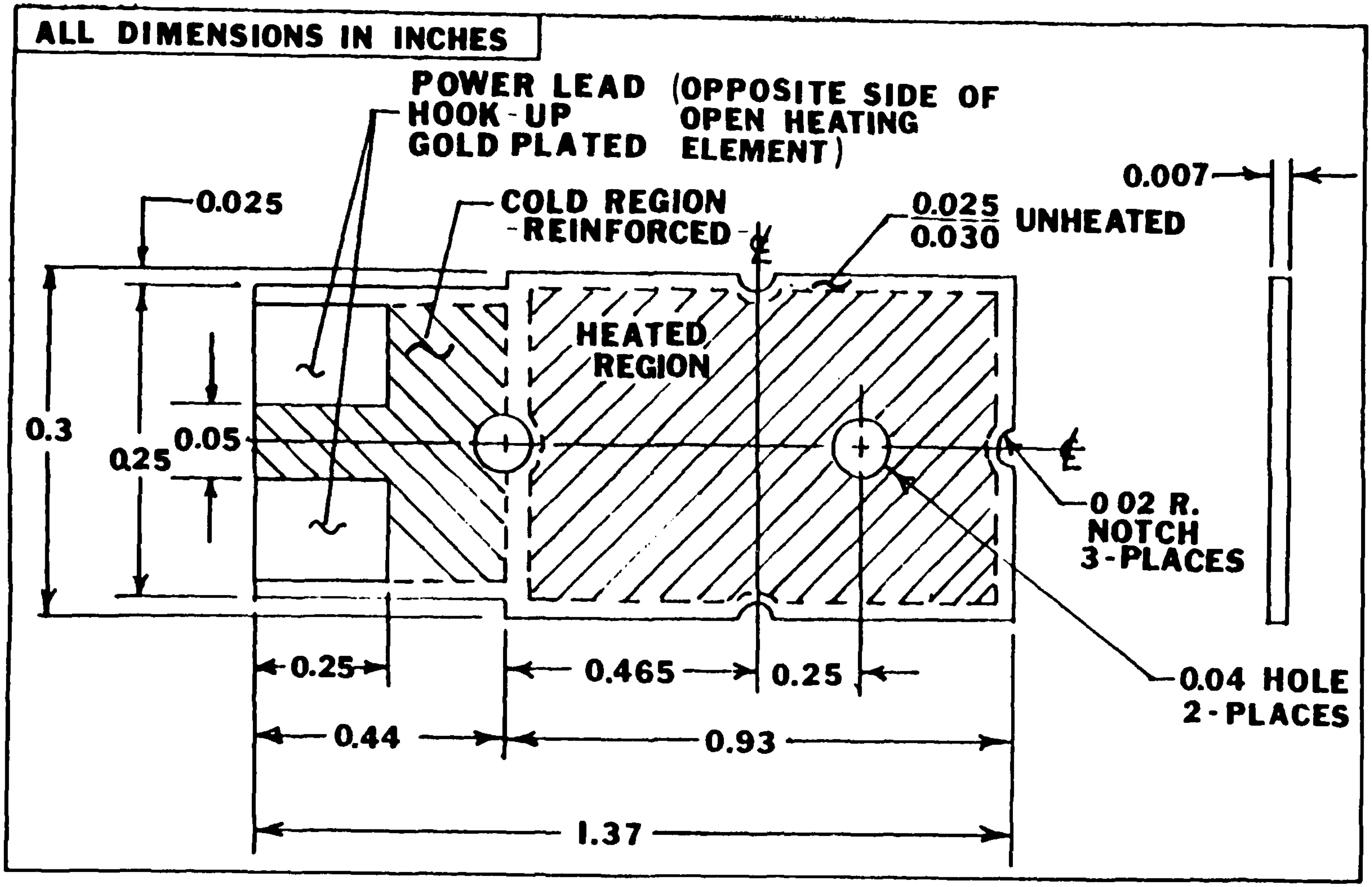


Figure 14. Foil Heater Schematic

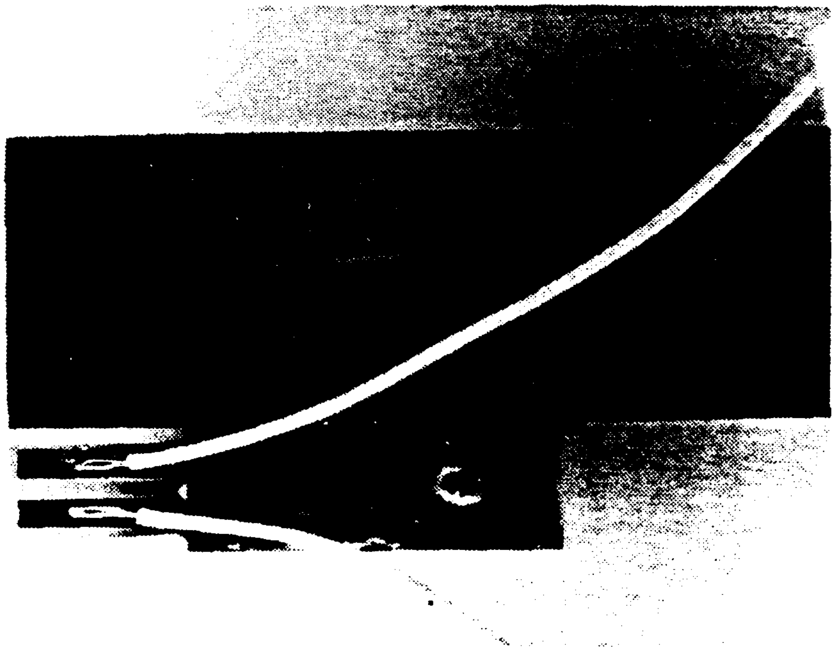


Figure 15. Power Lead Attachment

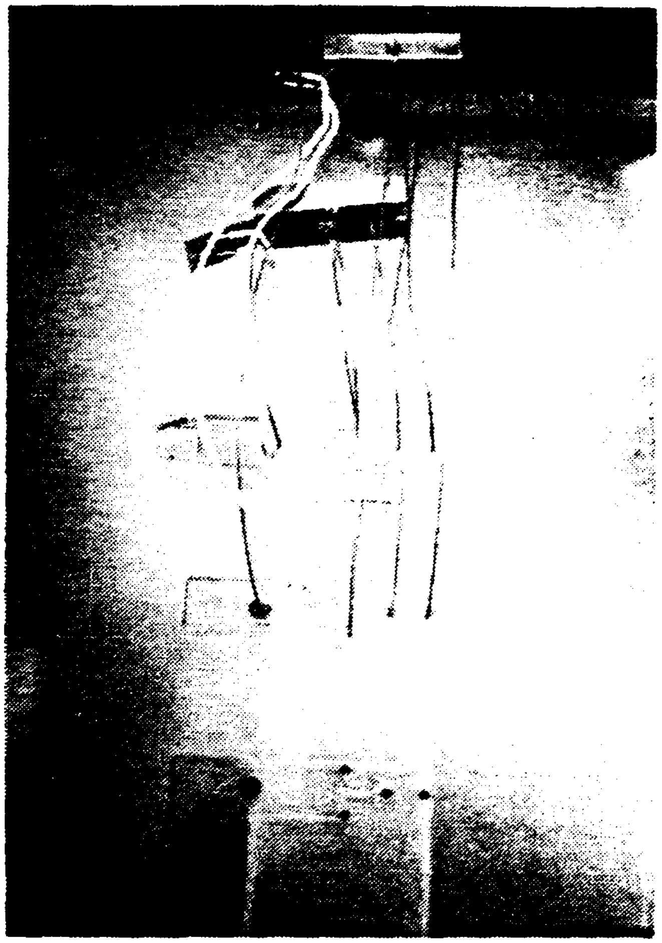


Figure 16. Slot and Holes in Test Surface

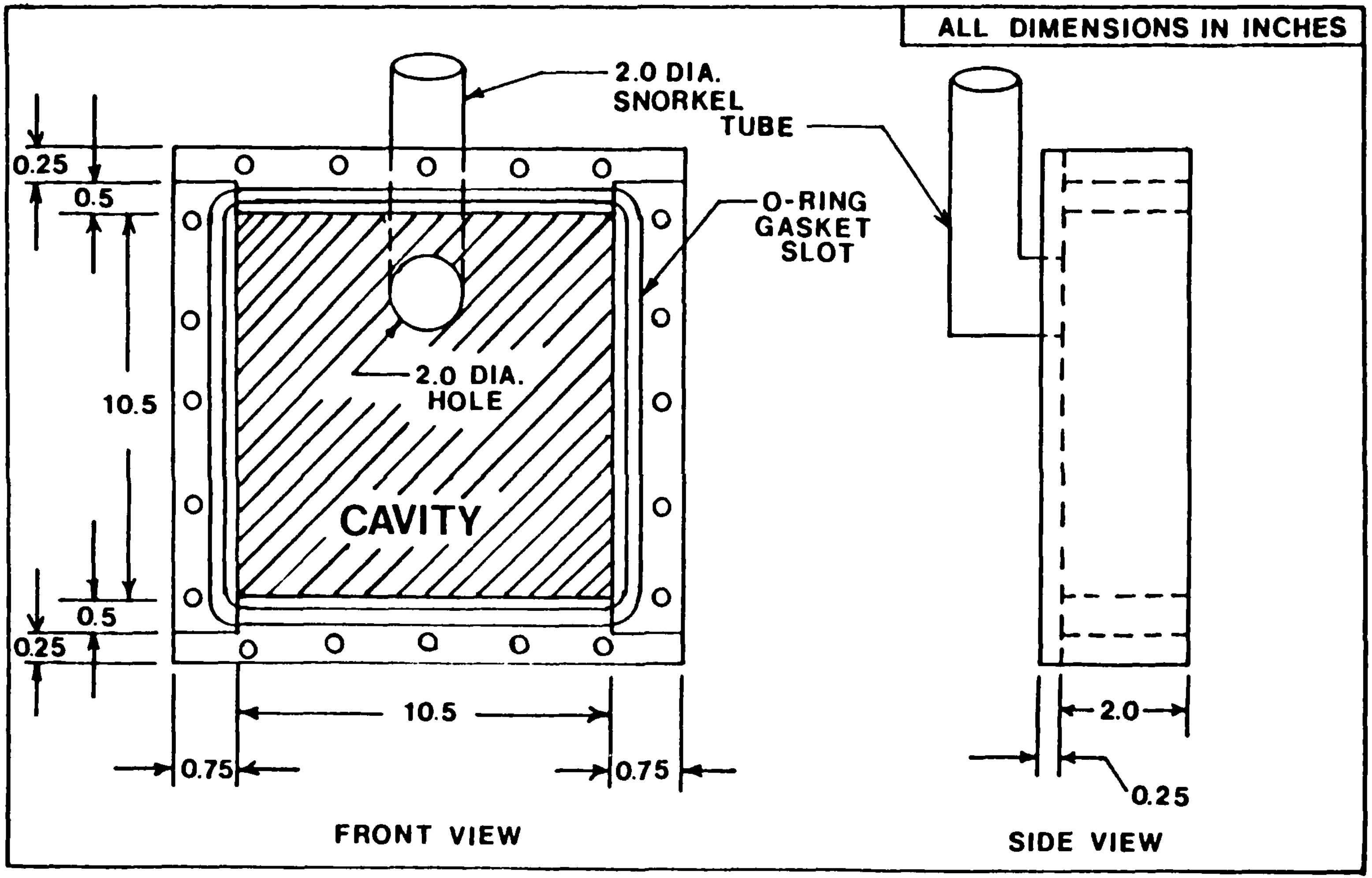


Figure 17. Containment Back Schematic

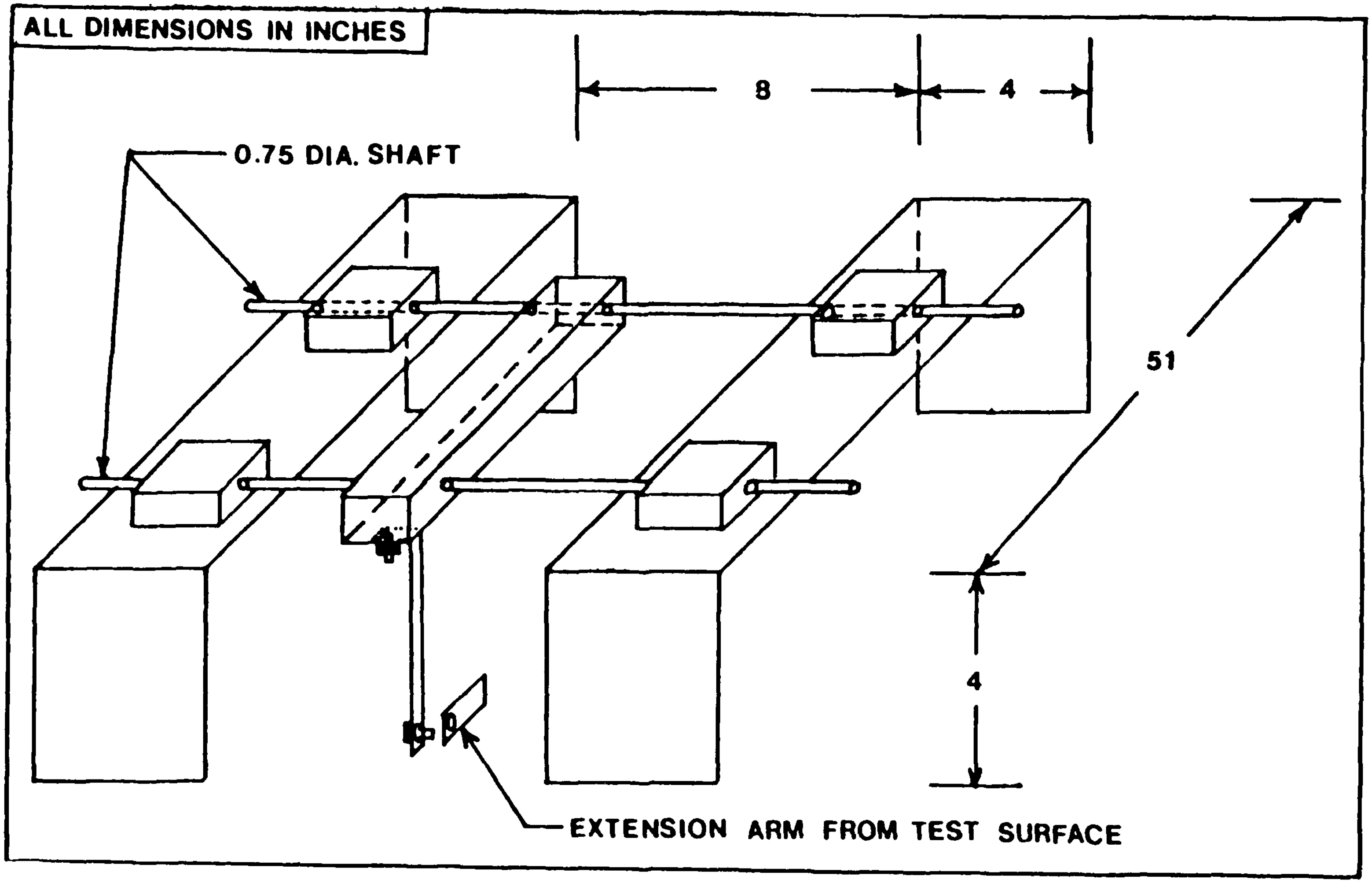


Figure 18. Test Surface and Shrouding Wall Support Bracket

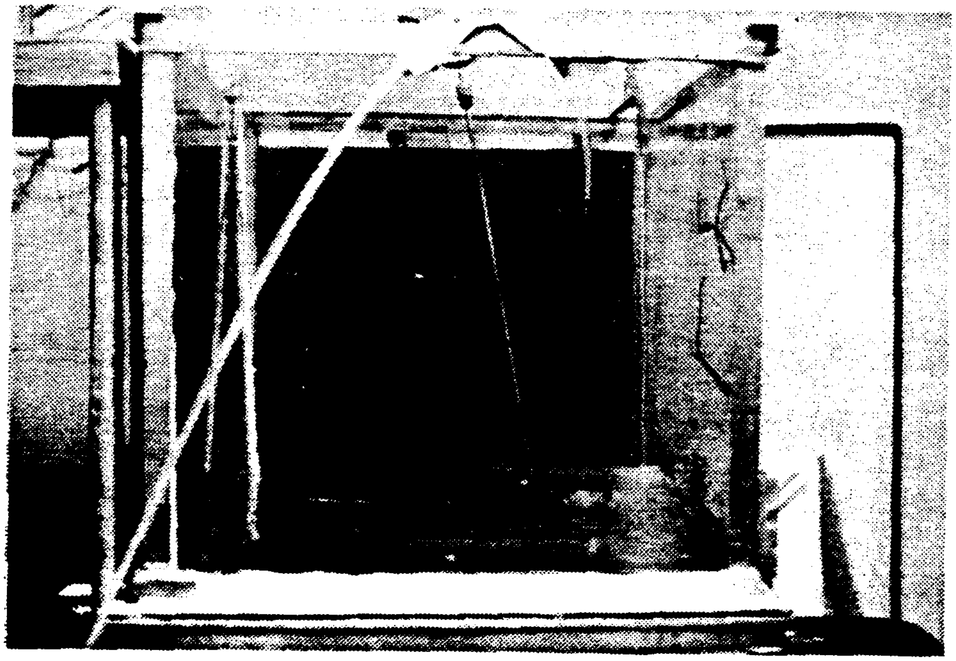


Figure 19. Immersion Tank

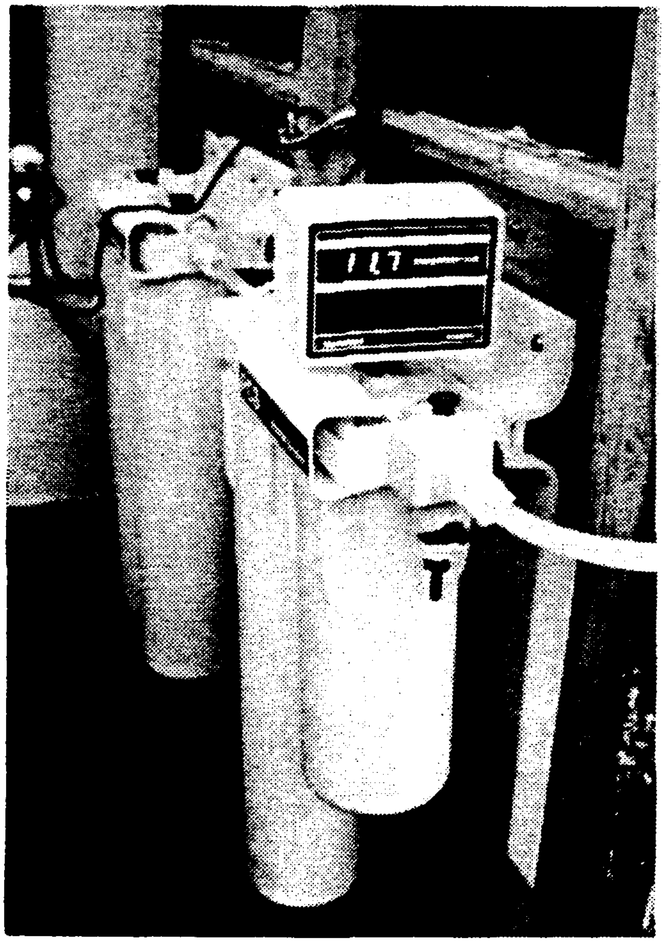


Figure 20. Filtration and Purification System

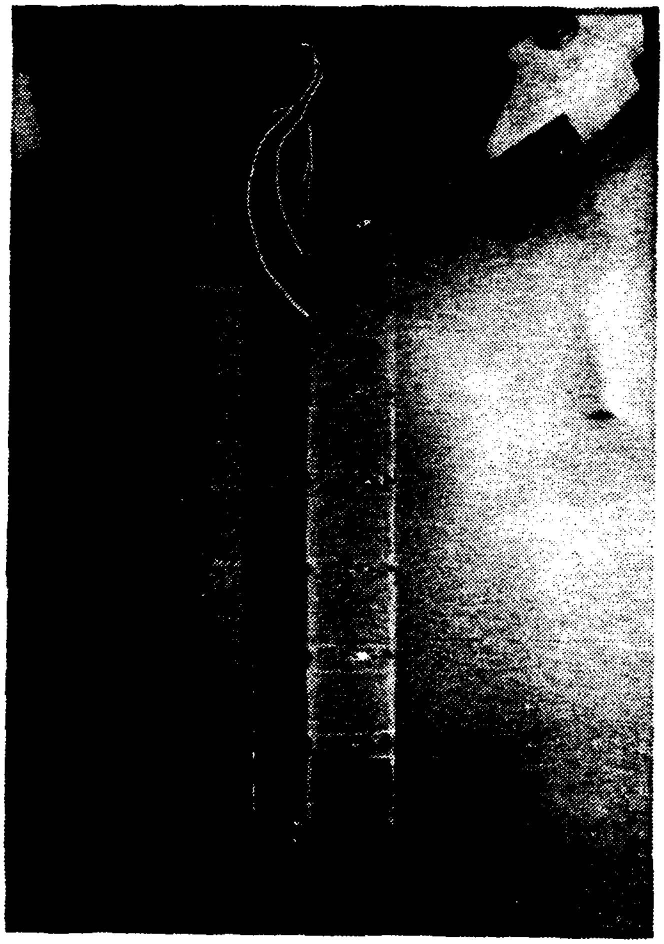


Figure 21. Mounting the Heater Assemblies

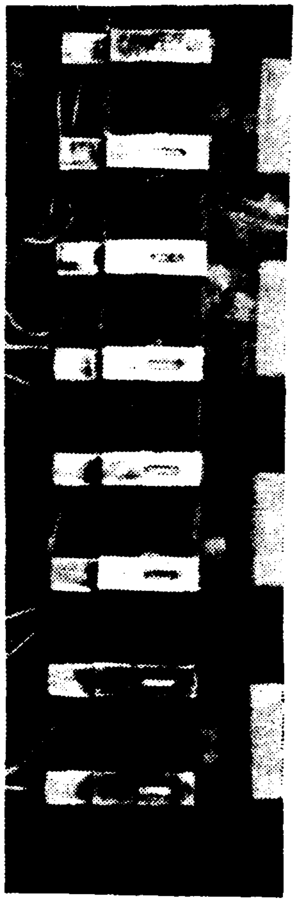


Figure 22. Mounted Heater Assemblies

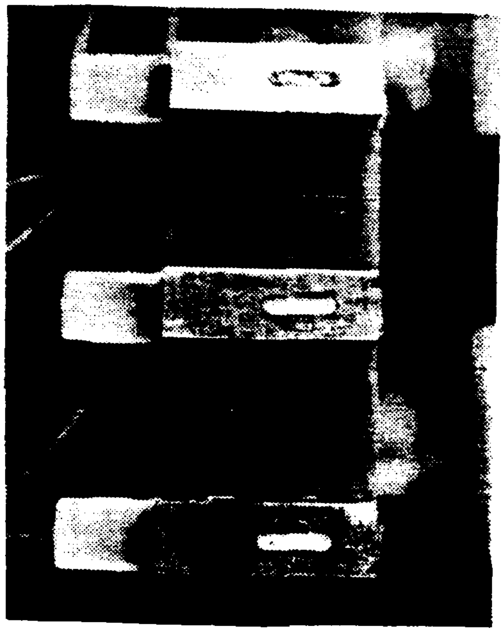


Figure 23. Close-Up of Mounted Heater Assemblies

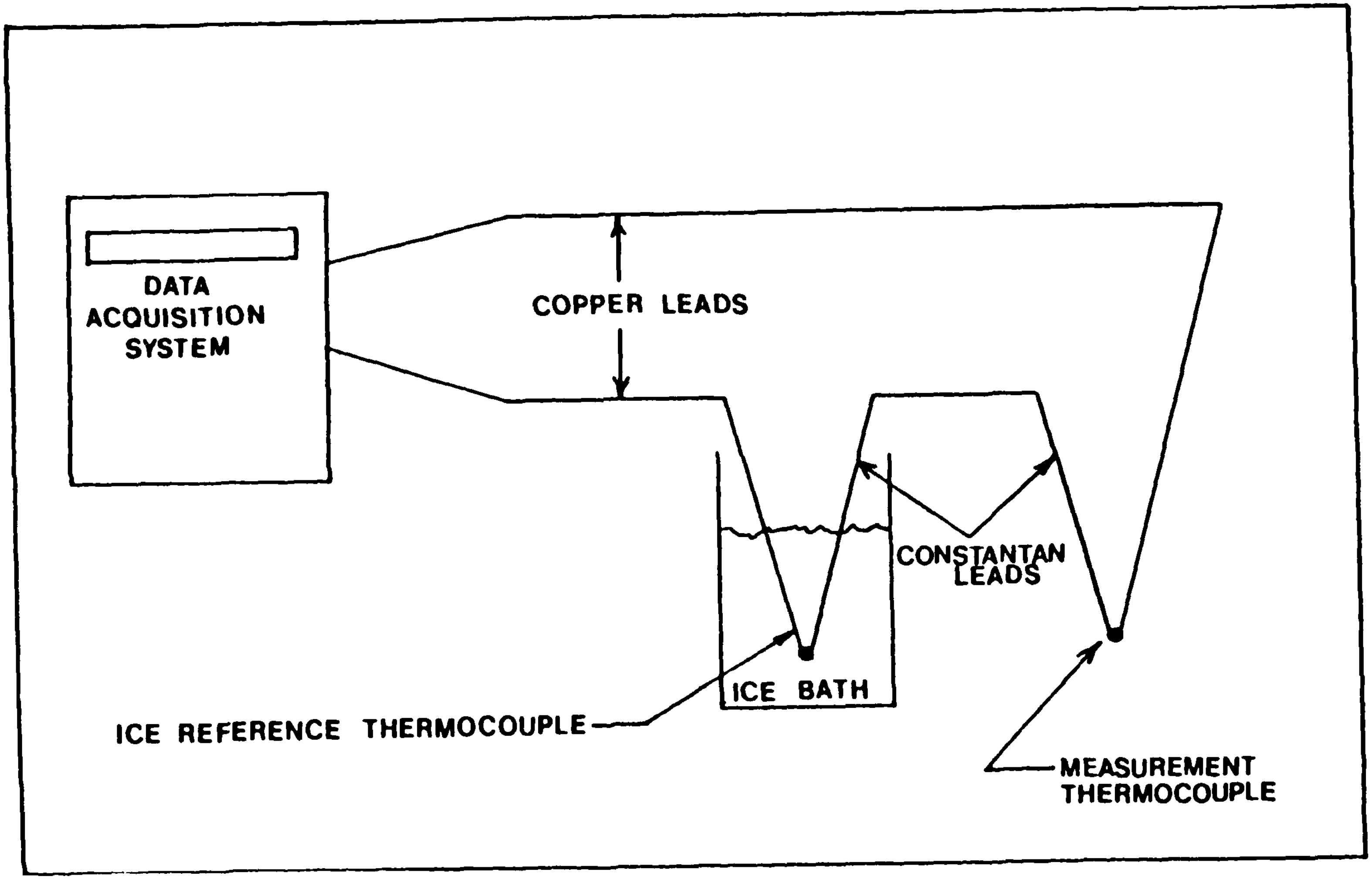
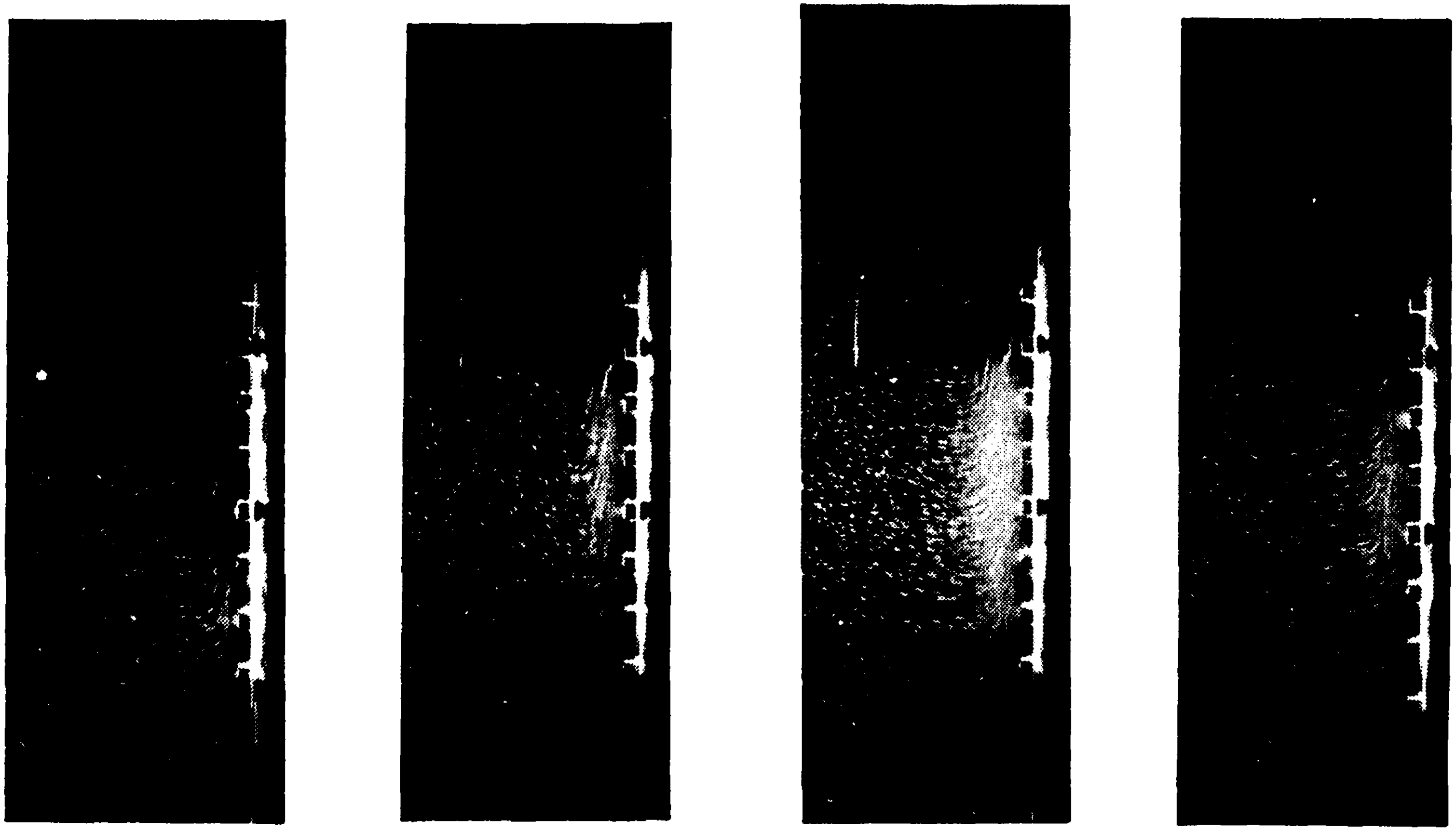


Figure 24. Thermocouple Connection Schematic



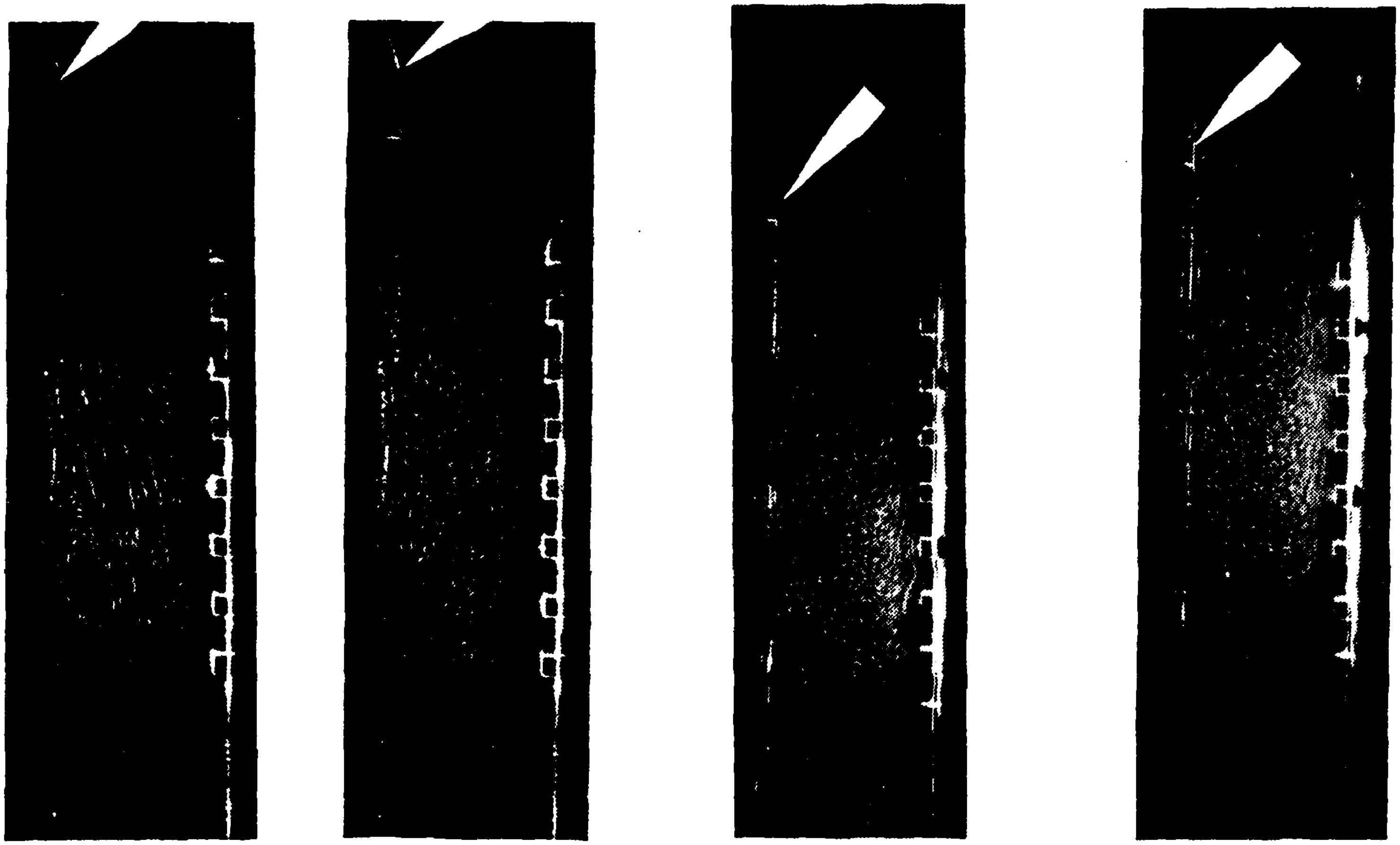
Run 9
0.2 watts

Run 10
0.5 watts

Run 11
1.0 watt

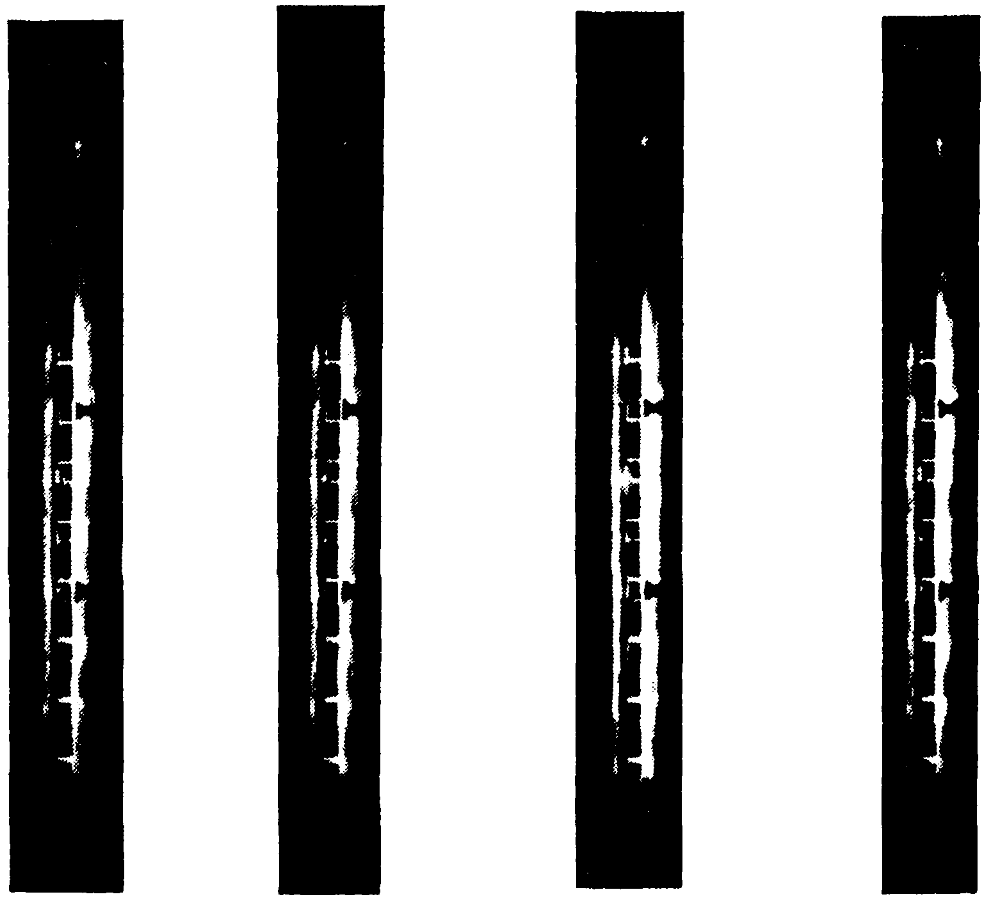
Run 12
2.0 watts

Figure 25. Flow Visualization Photographs for the No Wall Spacing



Run 1 0.2 watts | Run 2 0.5 watts | Run 3 1.0 watt | Run 4 2.0 watts

Figure 26. Flow Visualization Photographs for the 73.81 mm Spacing



Run 5 0.5 watts | Run 6 0.5 watts | Run 7 1.0 watt | Run 8 2.0 watts

Figure 27. Flow Visualization Photographs for the 11.913 mm Spacing

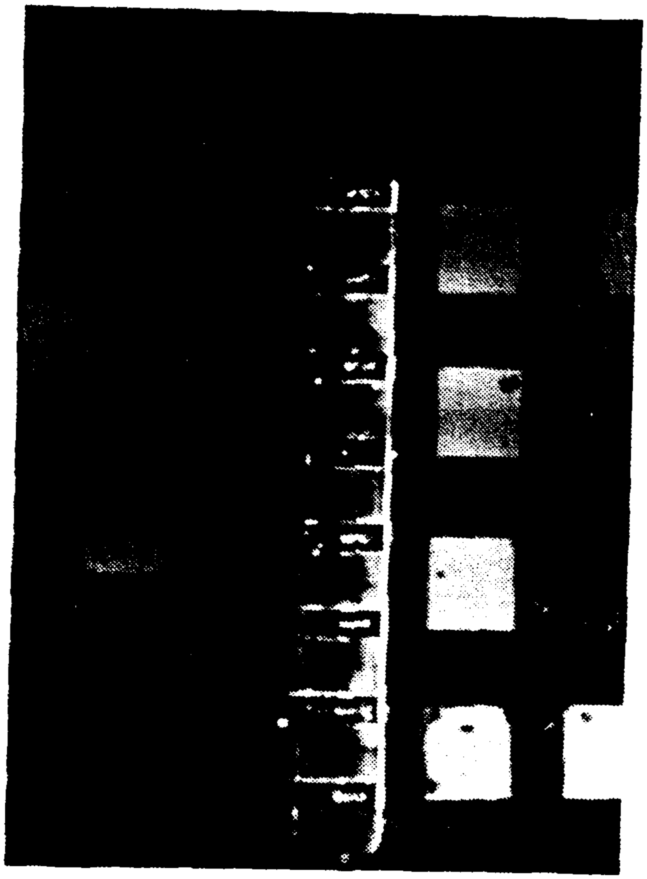


Figure 28. Across Test Surface Flow Visualization Photograph

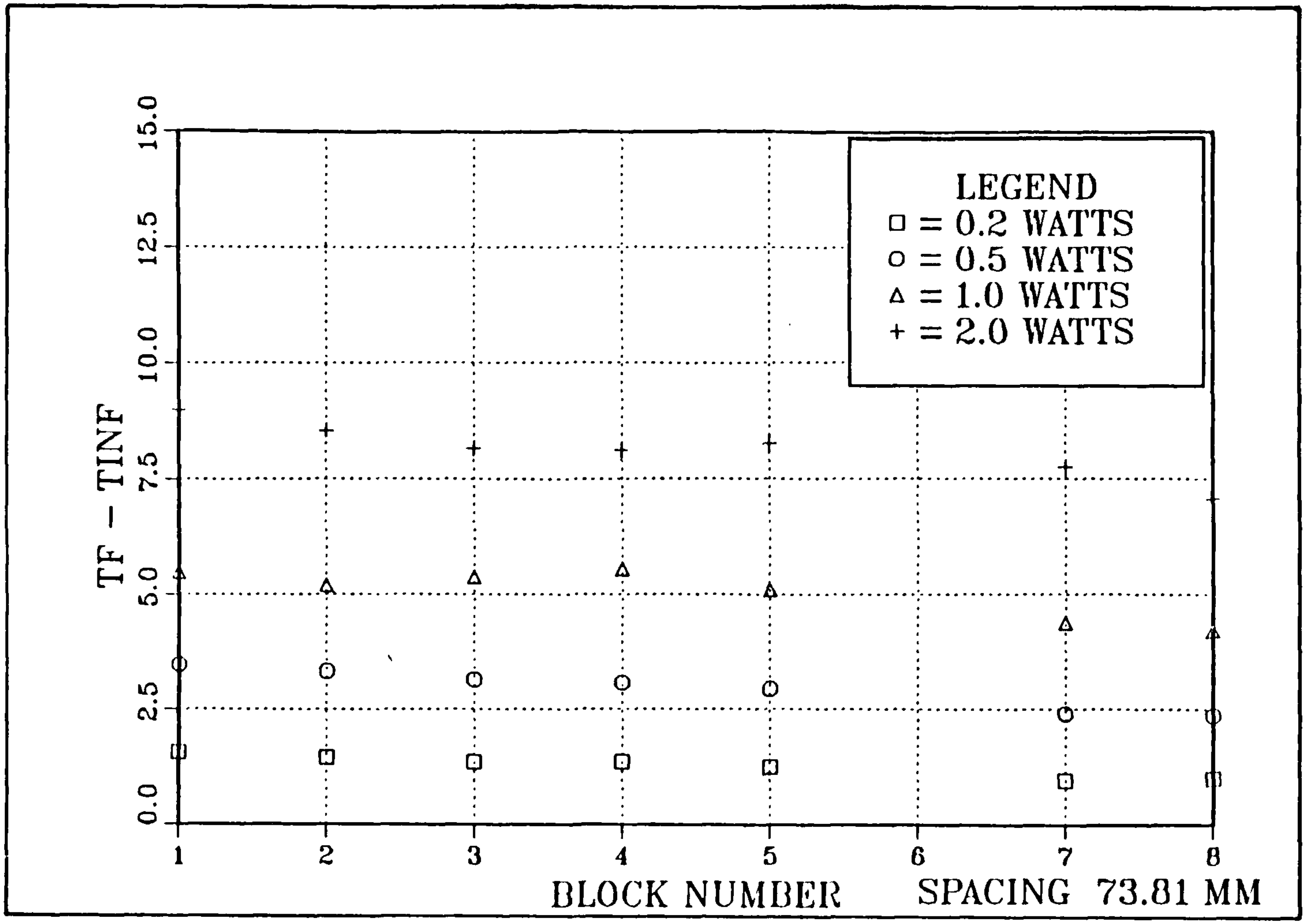


Figure 29. Block Number vs. Excess Temperature (Front Face) Runs 1-4

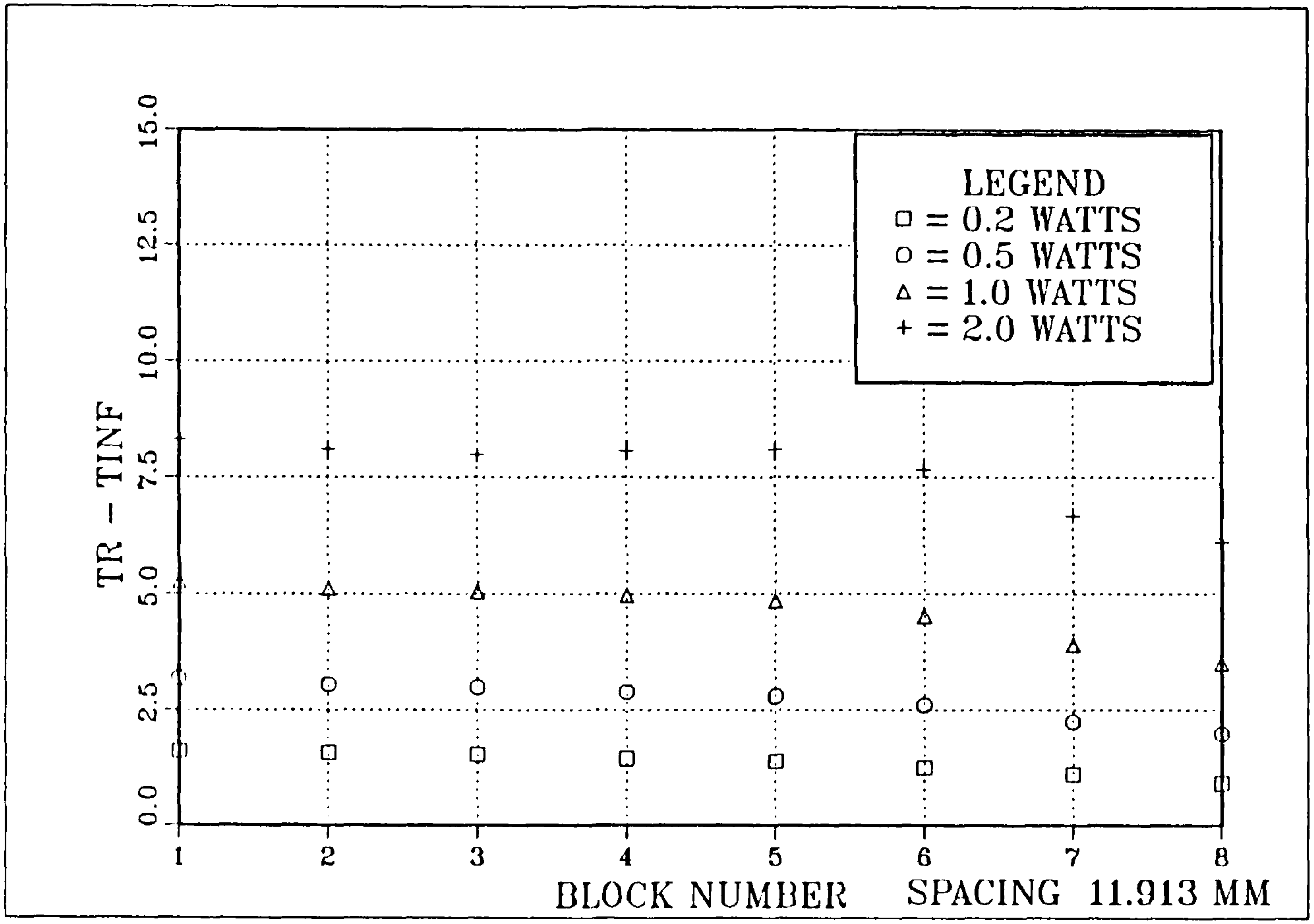


Figure 30. Block Number vs. Excess Temperature (Front Face) Runs 5-8

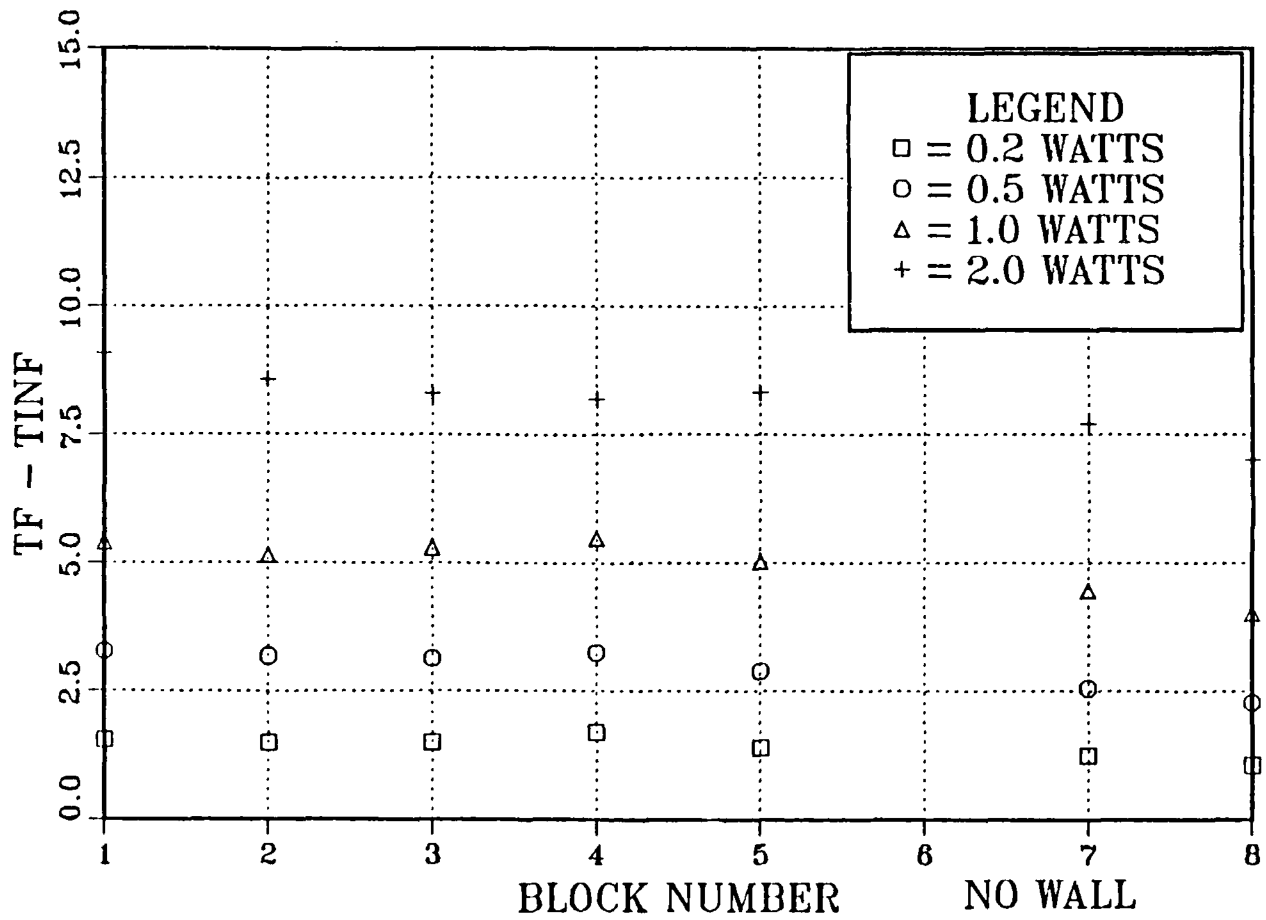


Figure 31. Block Number vs. Excess Temperature (Front Face) Runs 9-12

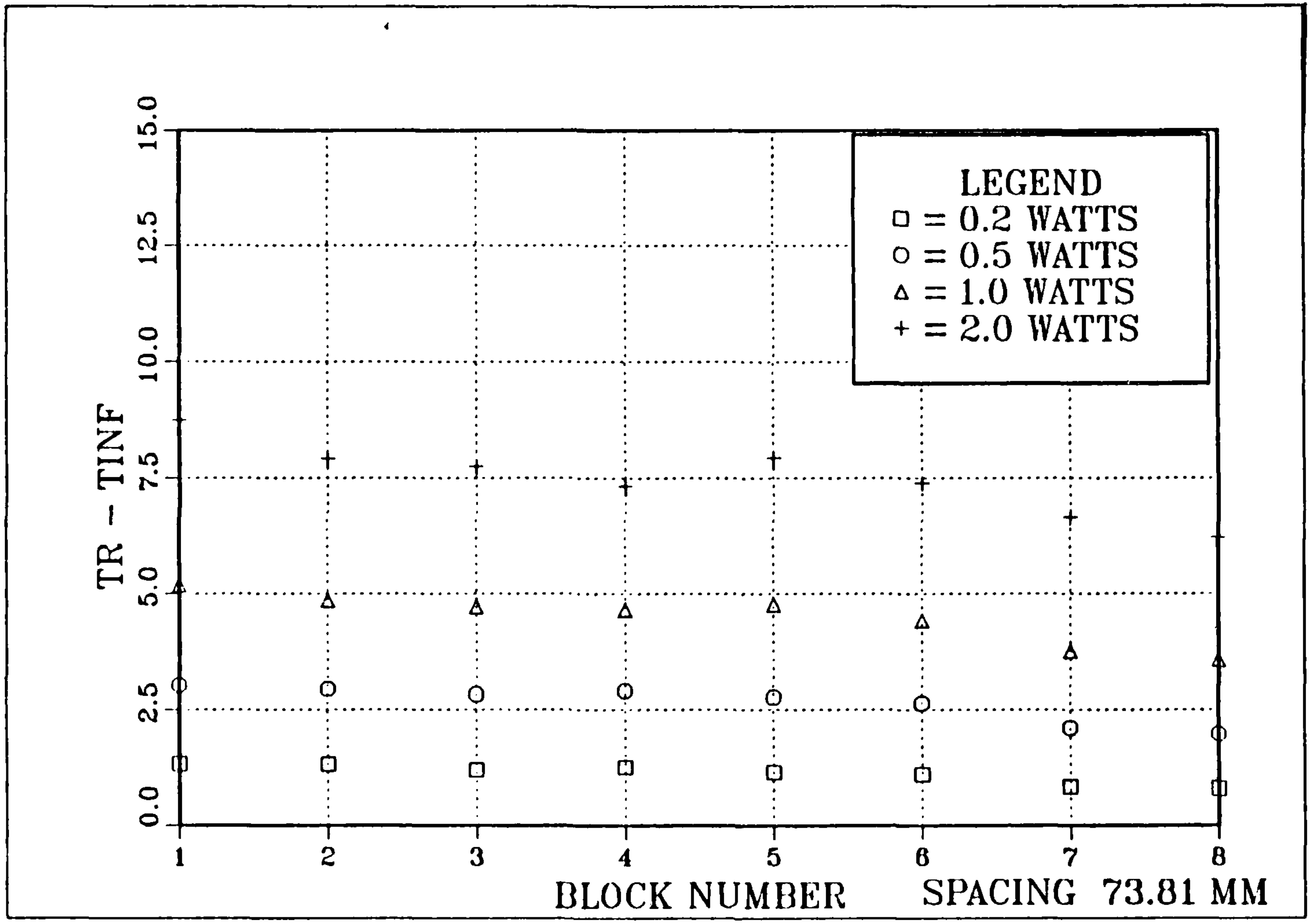


Figure 32. Block Number vs. Excess Temperature (Right Face) Runs 1-4

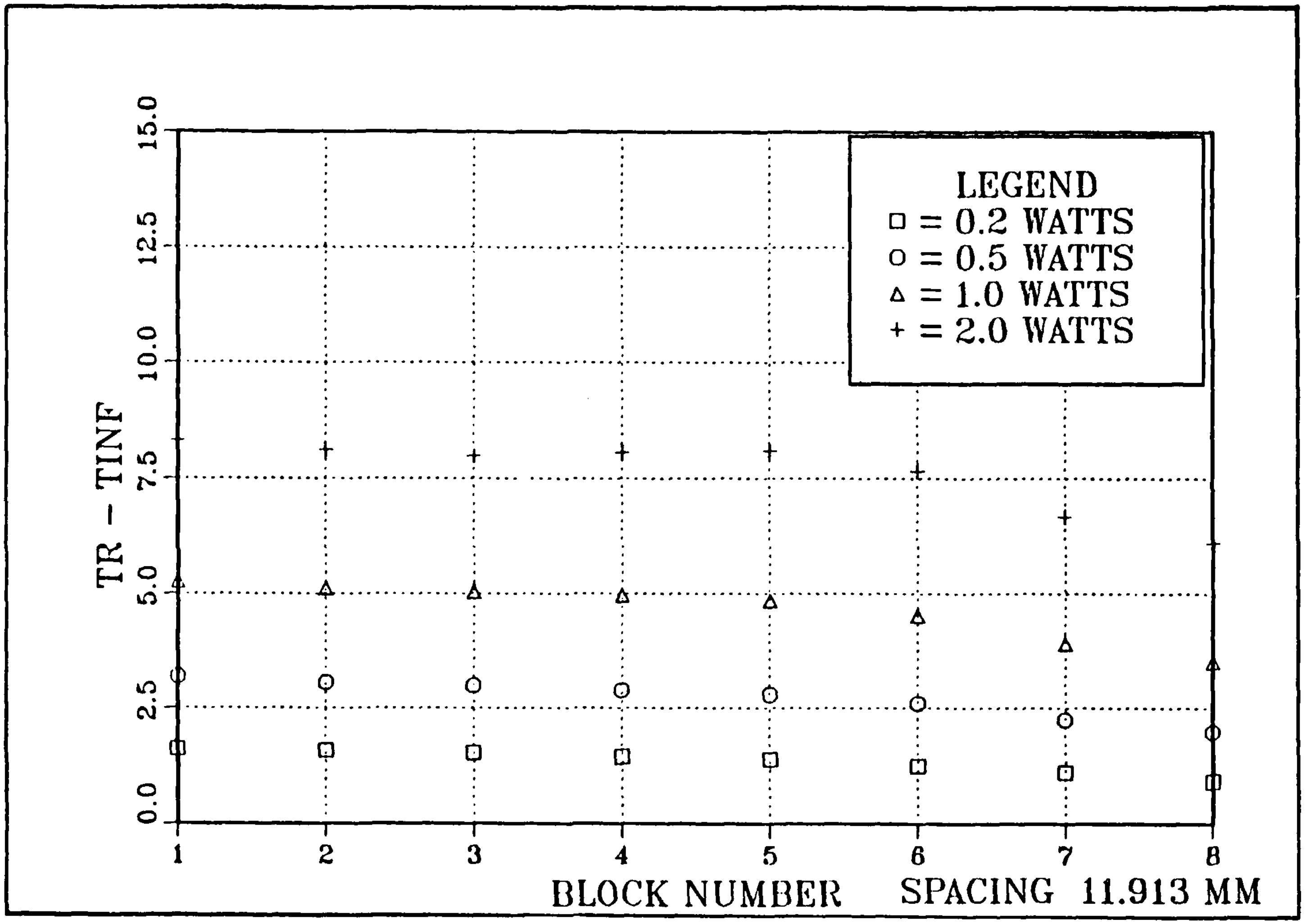


Figure 33. Block Number vs. Excess Temperature (Right Face) Runs 5-8

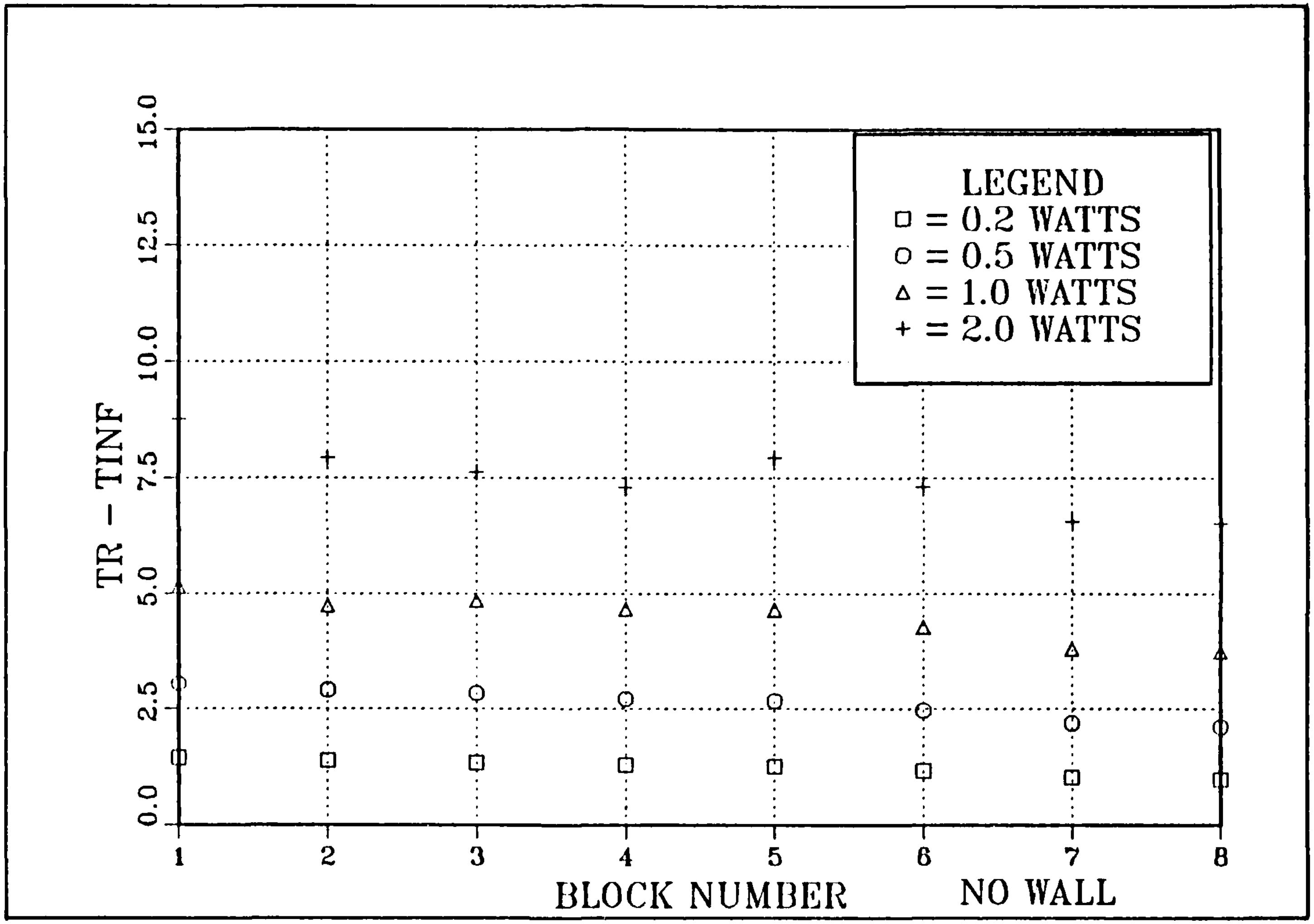


Figure 34. Block Number vs. Excess Temperature (Right Face) Runs 9-12

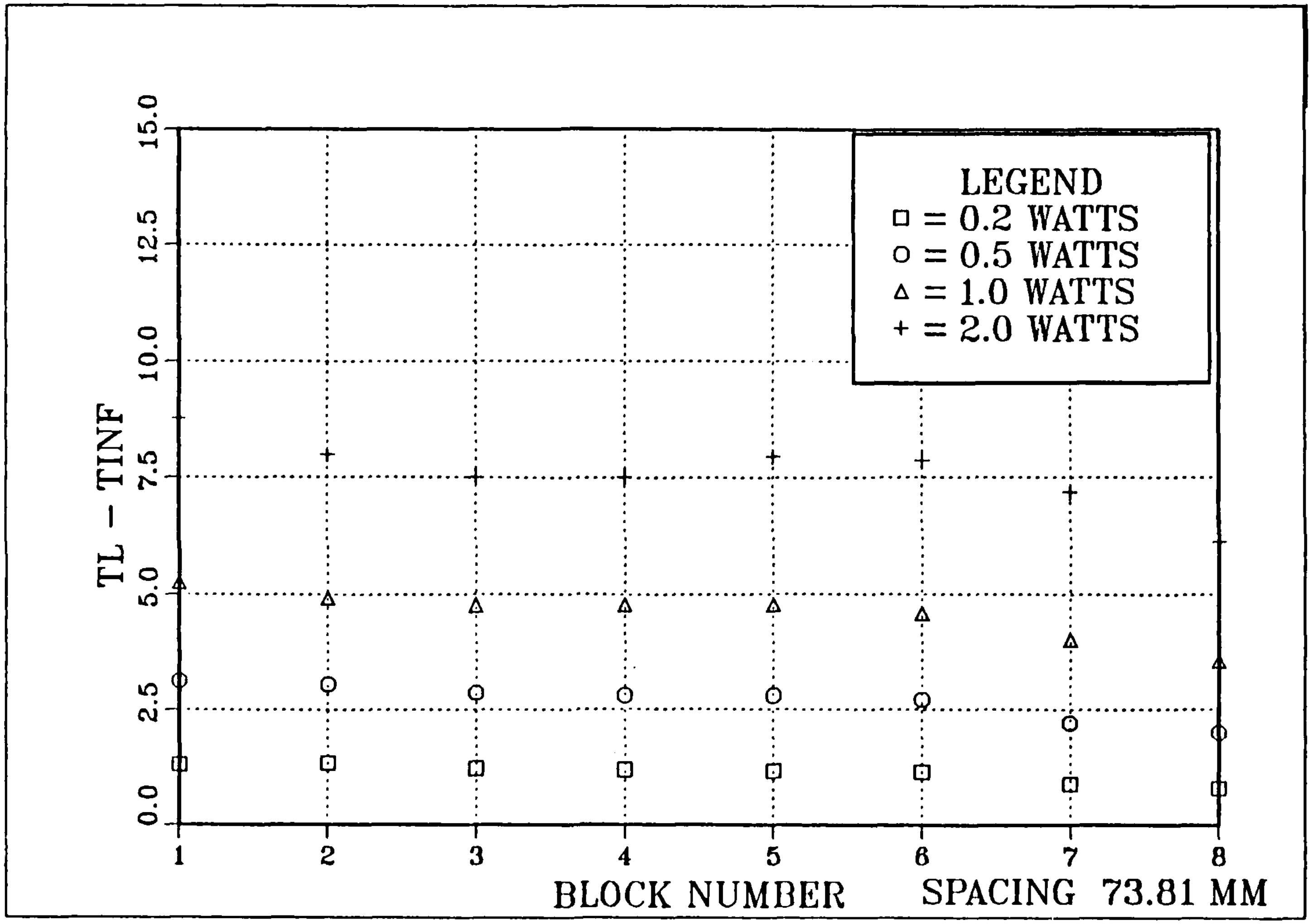


Figure 35. Block Number vs. Excess Temperature (Left Face) Runs 1-4

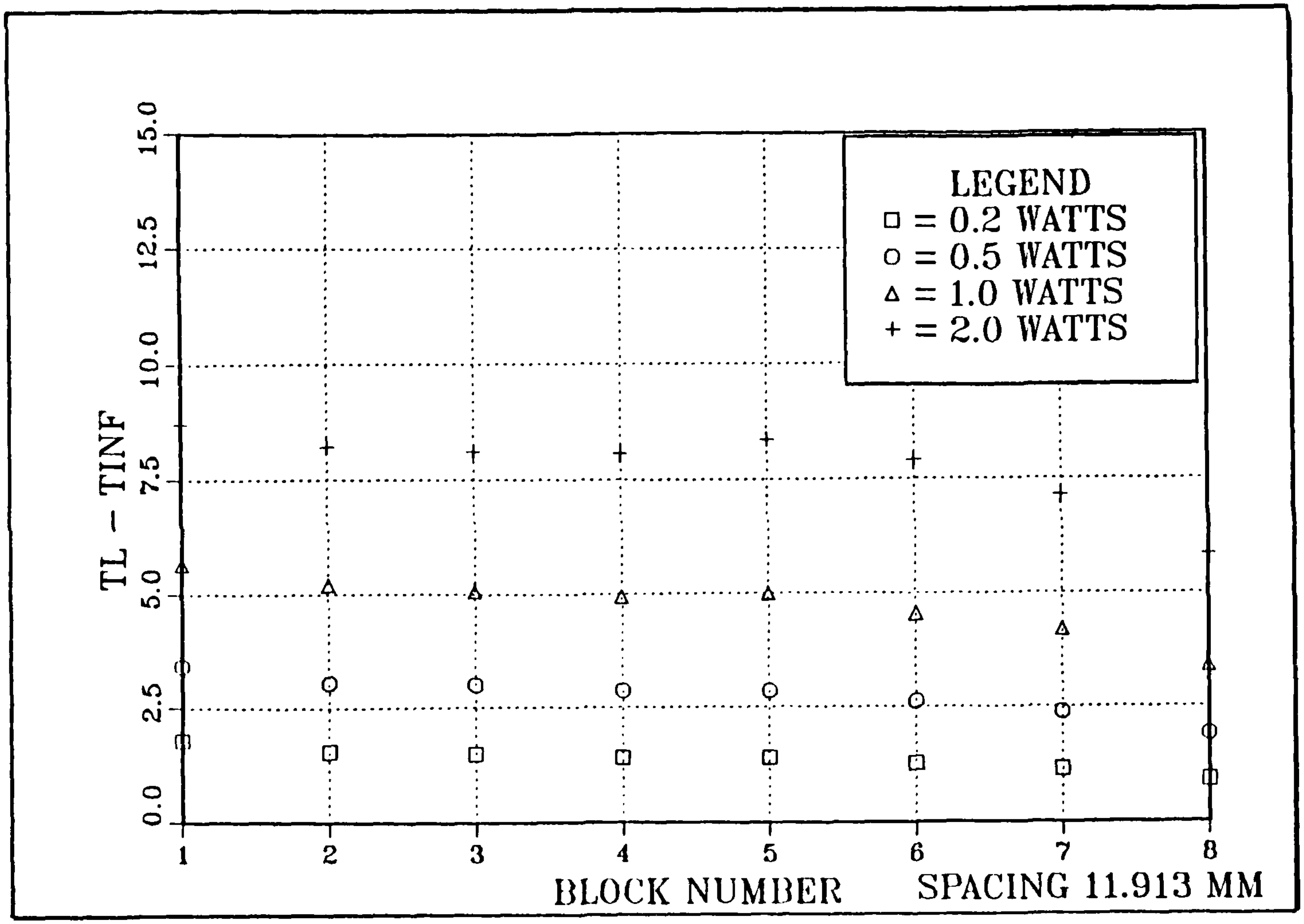


Figure 36. Block Number vs. Excess Temperature (Left Face) Runs 5-8

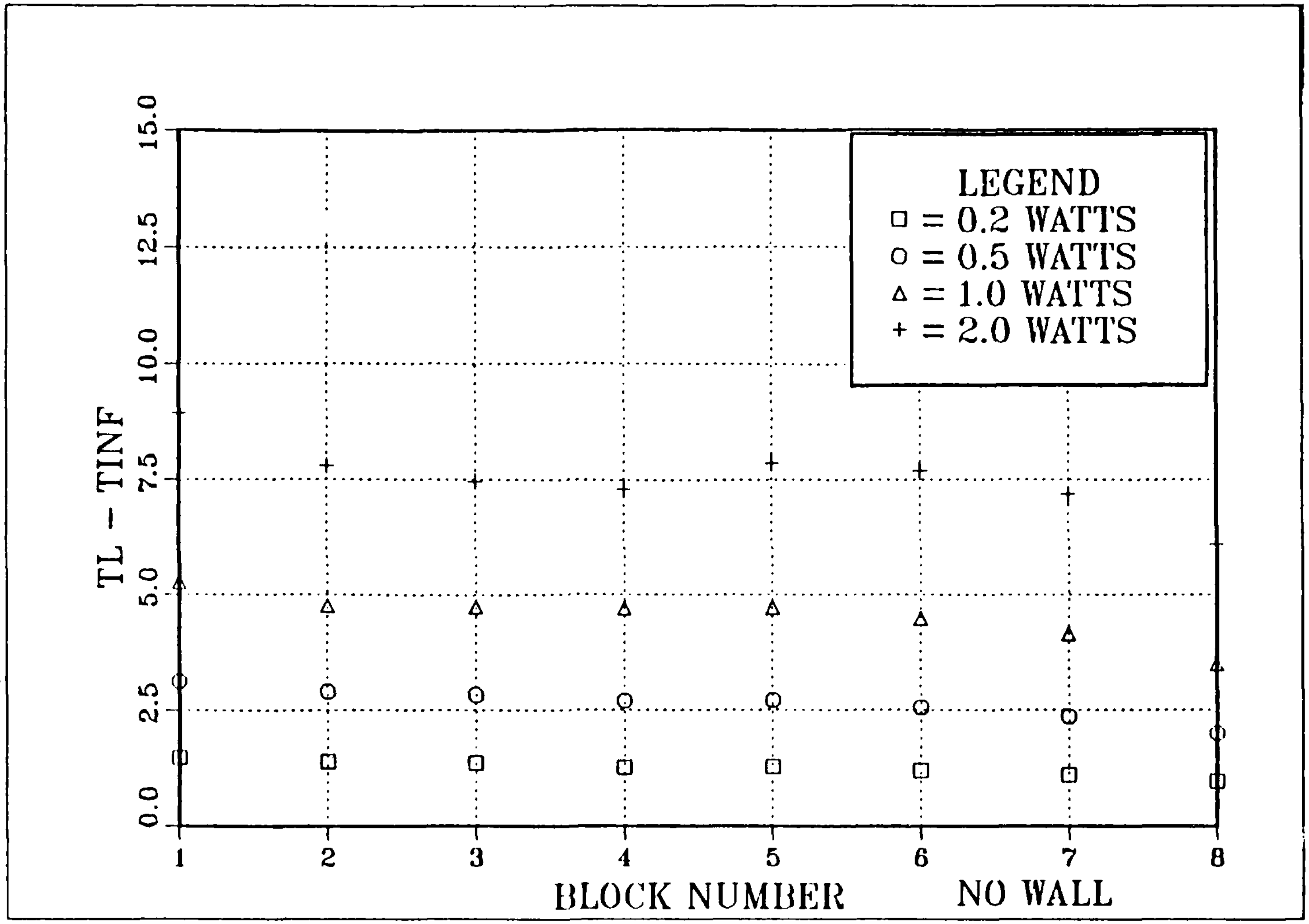


Figure 37. Block Number vs. Excess Temperature (Left Face) Runs 9-12

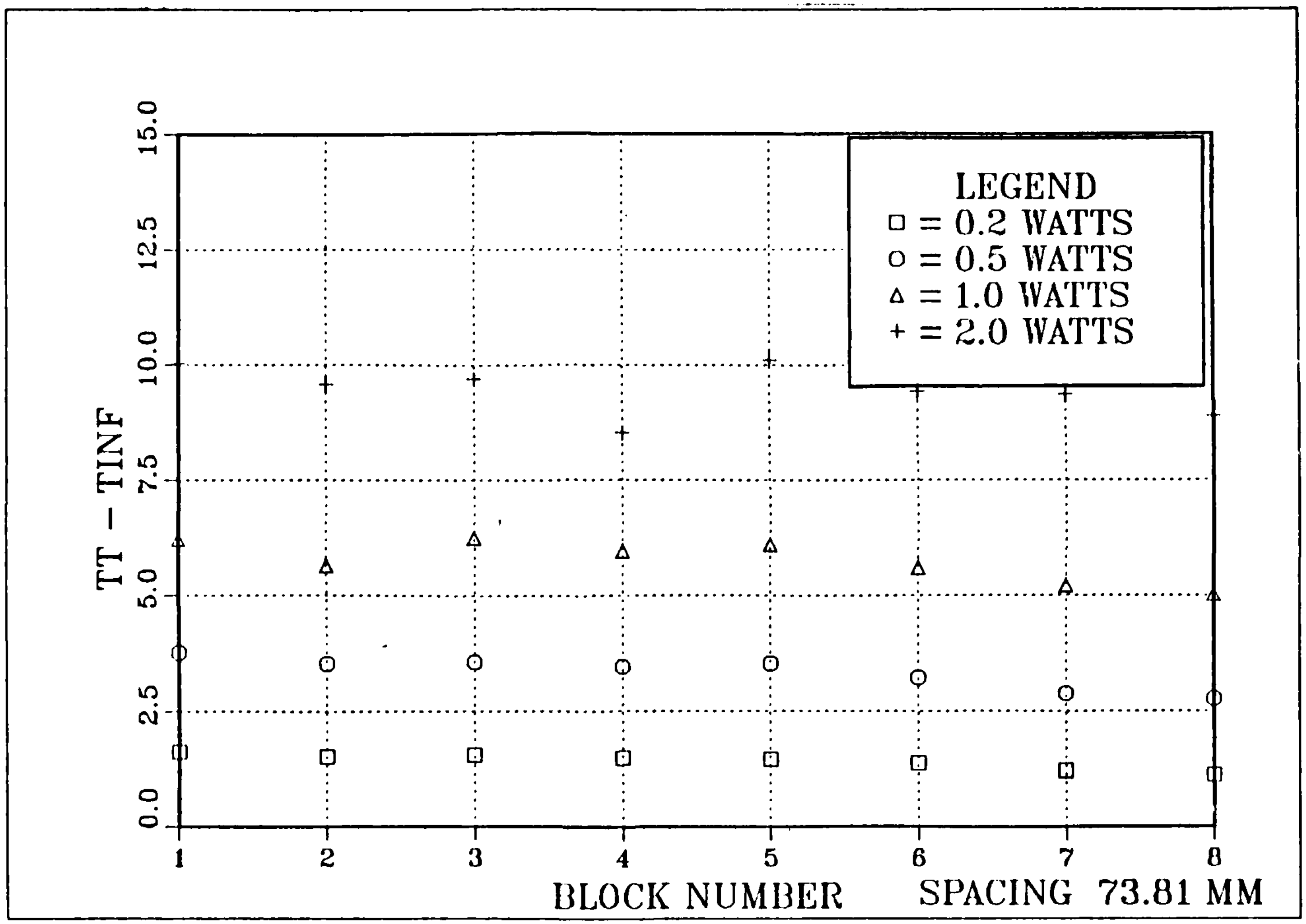


Figure 38. Block Number vs. Excess Temperature (Top Face) Runs 1-4

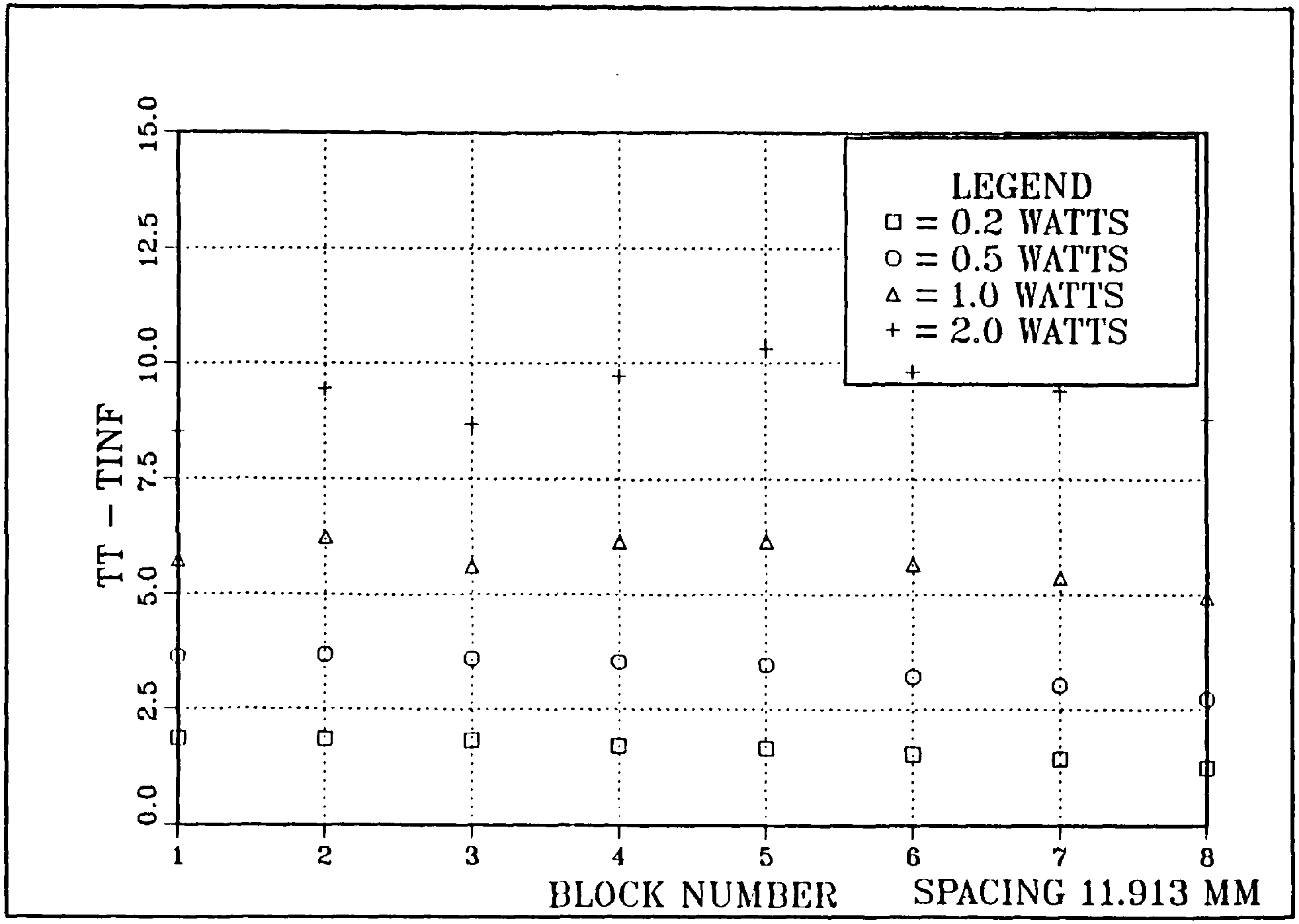


Figure 39. Block Number vs. Excess Temperature (Top Face) Runs 5-8

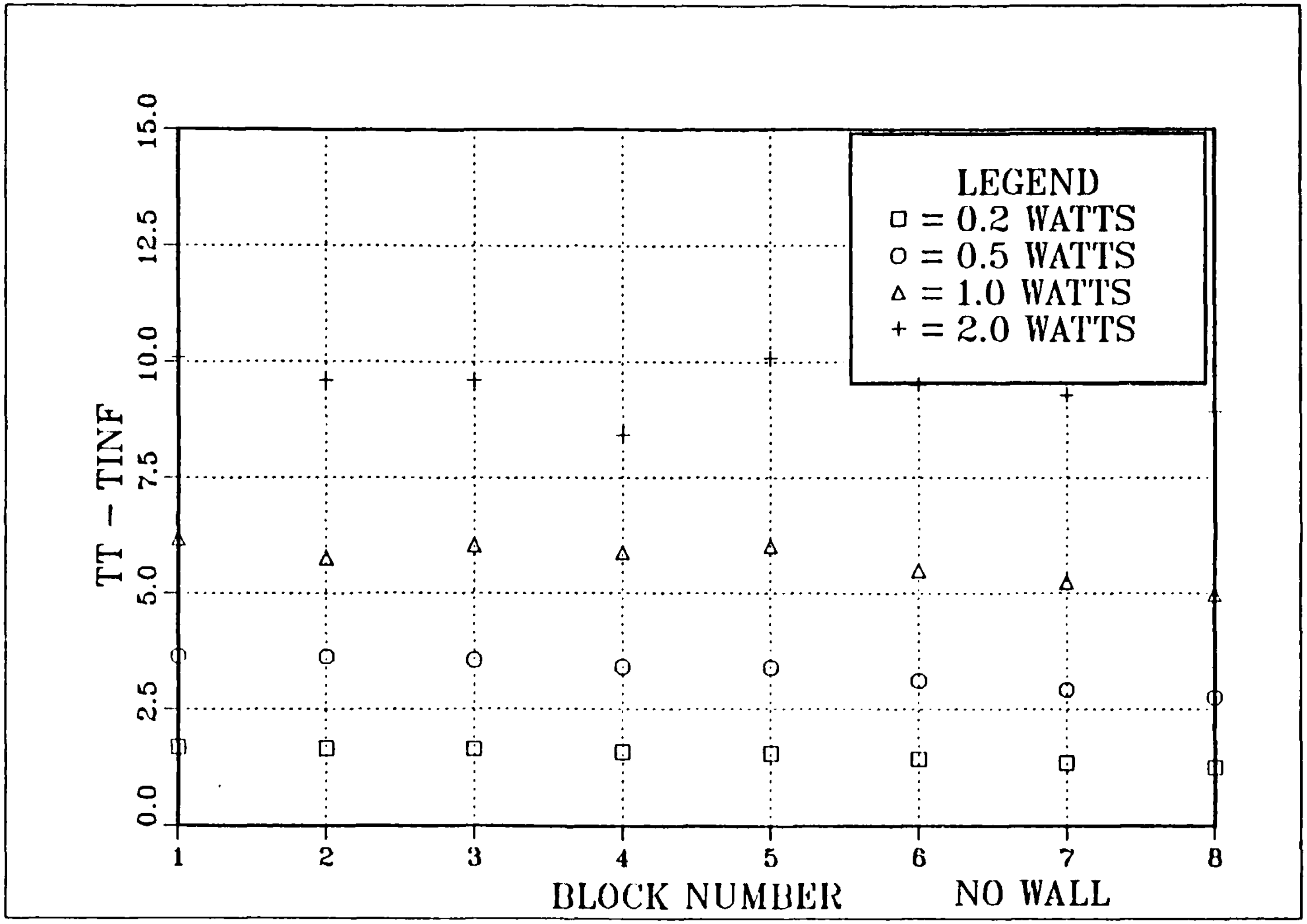


Figure 40. Block Number vs. Excess Temperature (Top Face) Runs 9-12

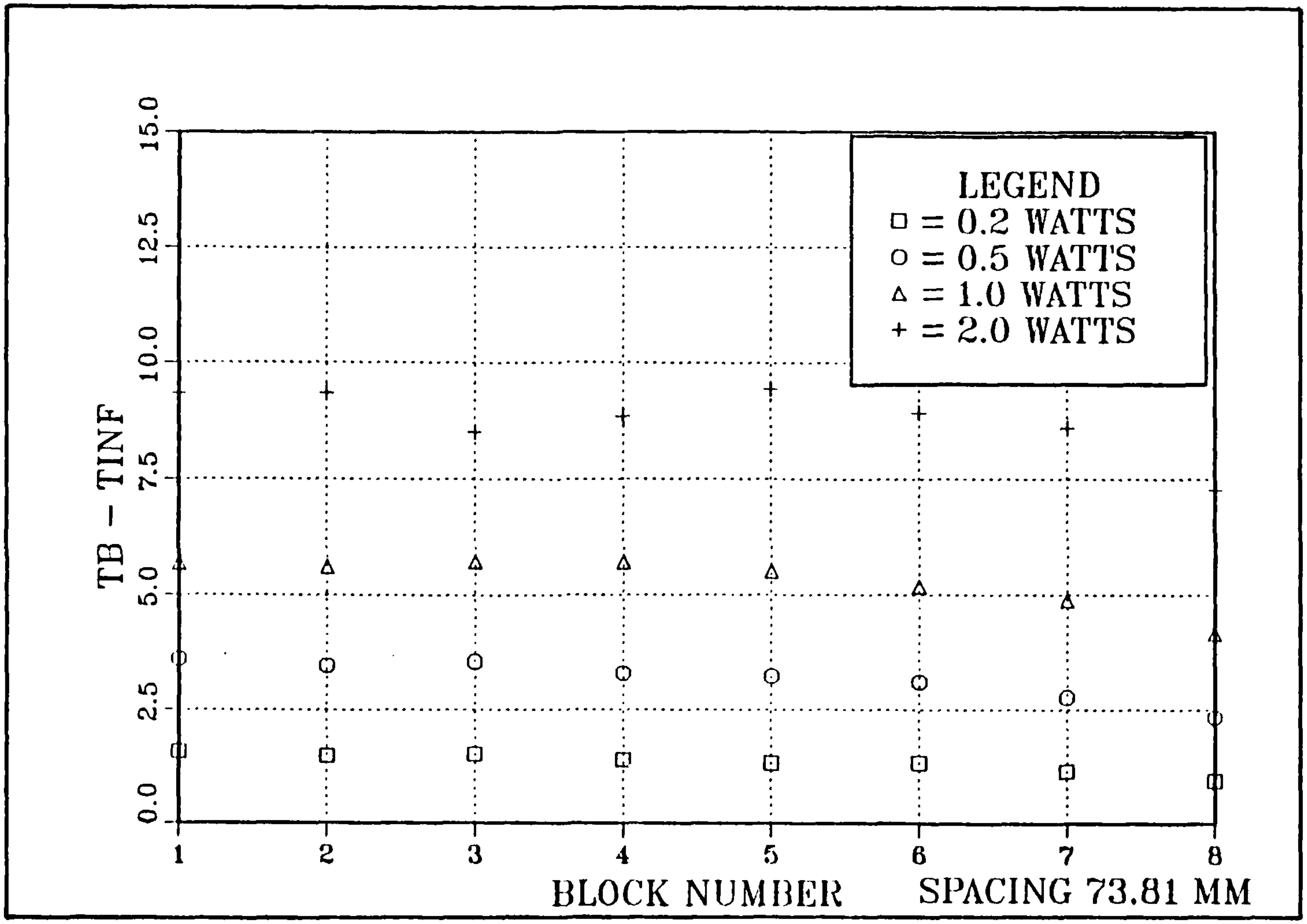


Figure 41. Block Number vs. Excess Temperature (Bottom Face) Runs 1-4

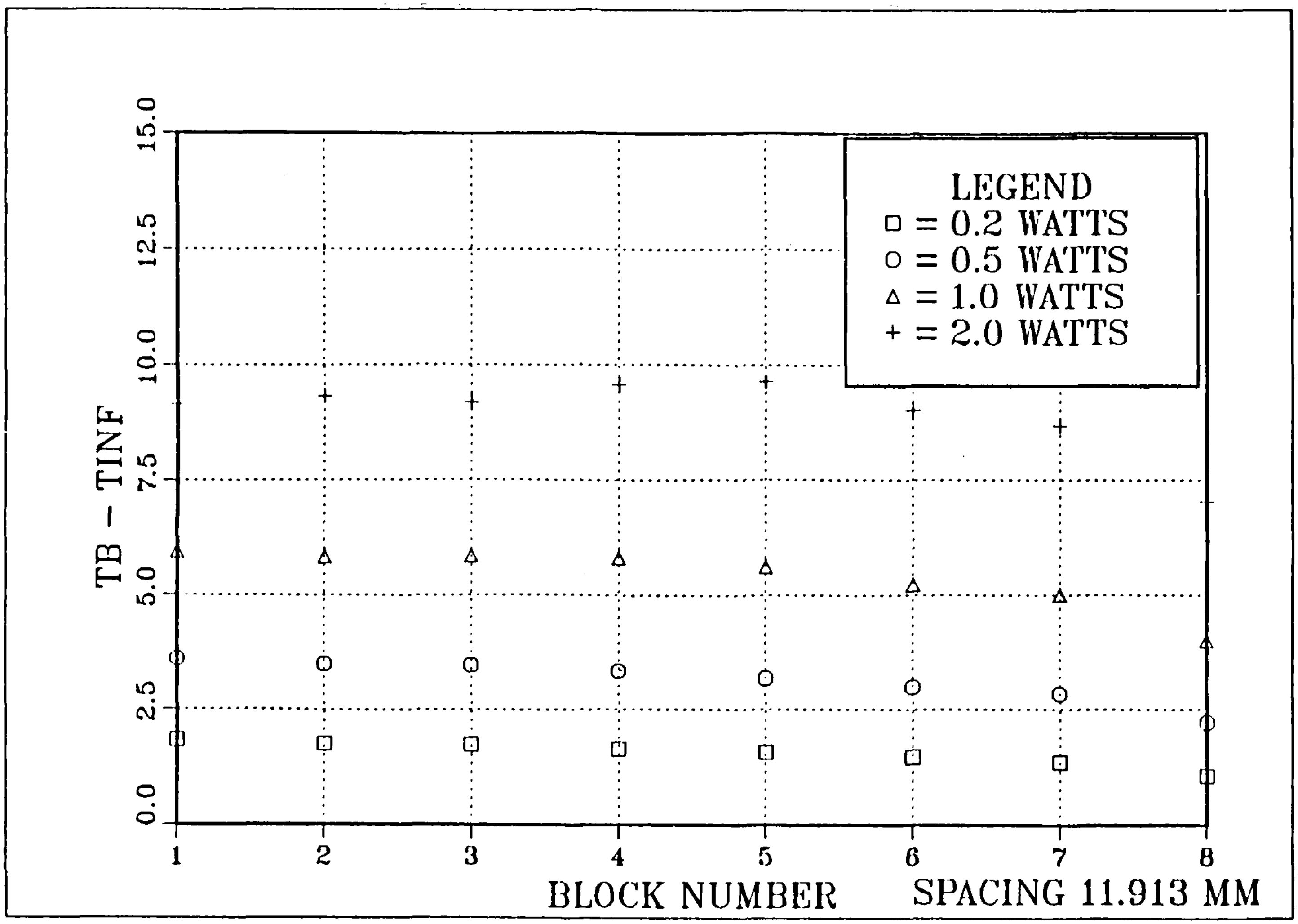


Figure 42. Block Number vs. Excess Temperature (Bottom Face) Runs 5-8

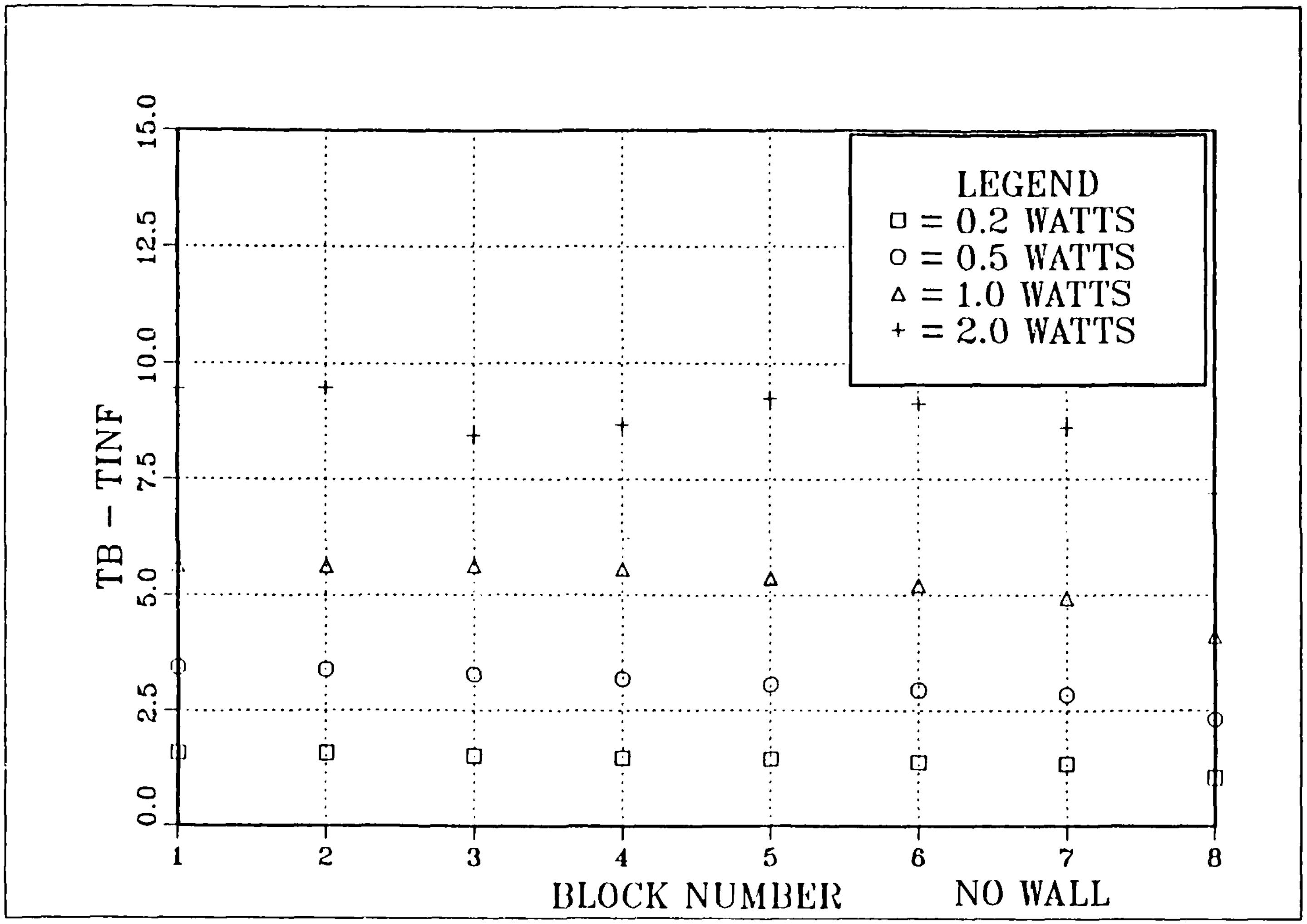


Figure 43. Block Number vs. Excess Temperature (Bottom Face) Runs 9-12

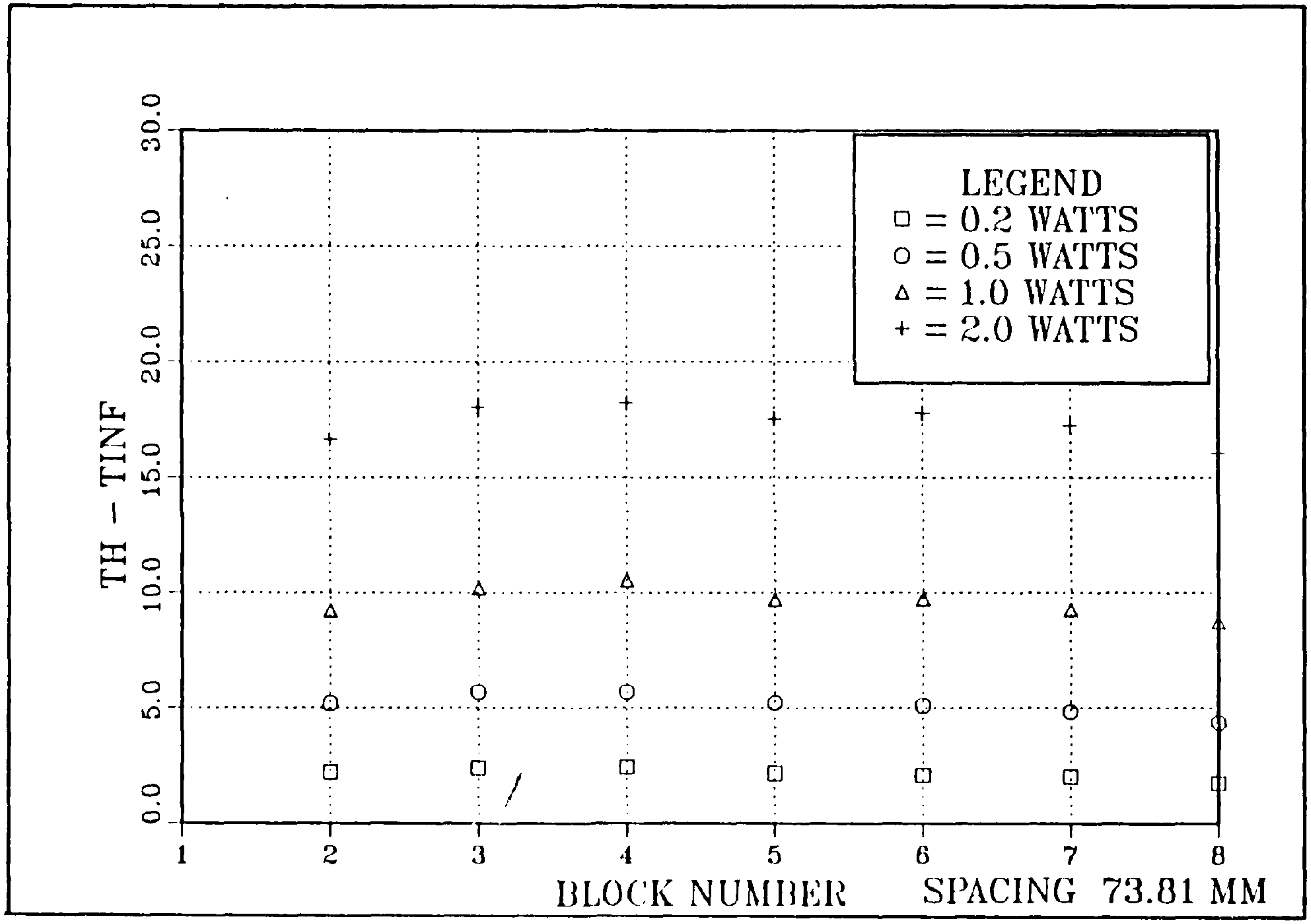


Figure 44. Block Number vs. Excess Temperature (Heater) Runs 1-4

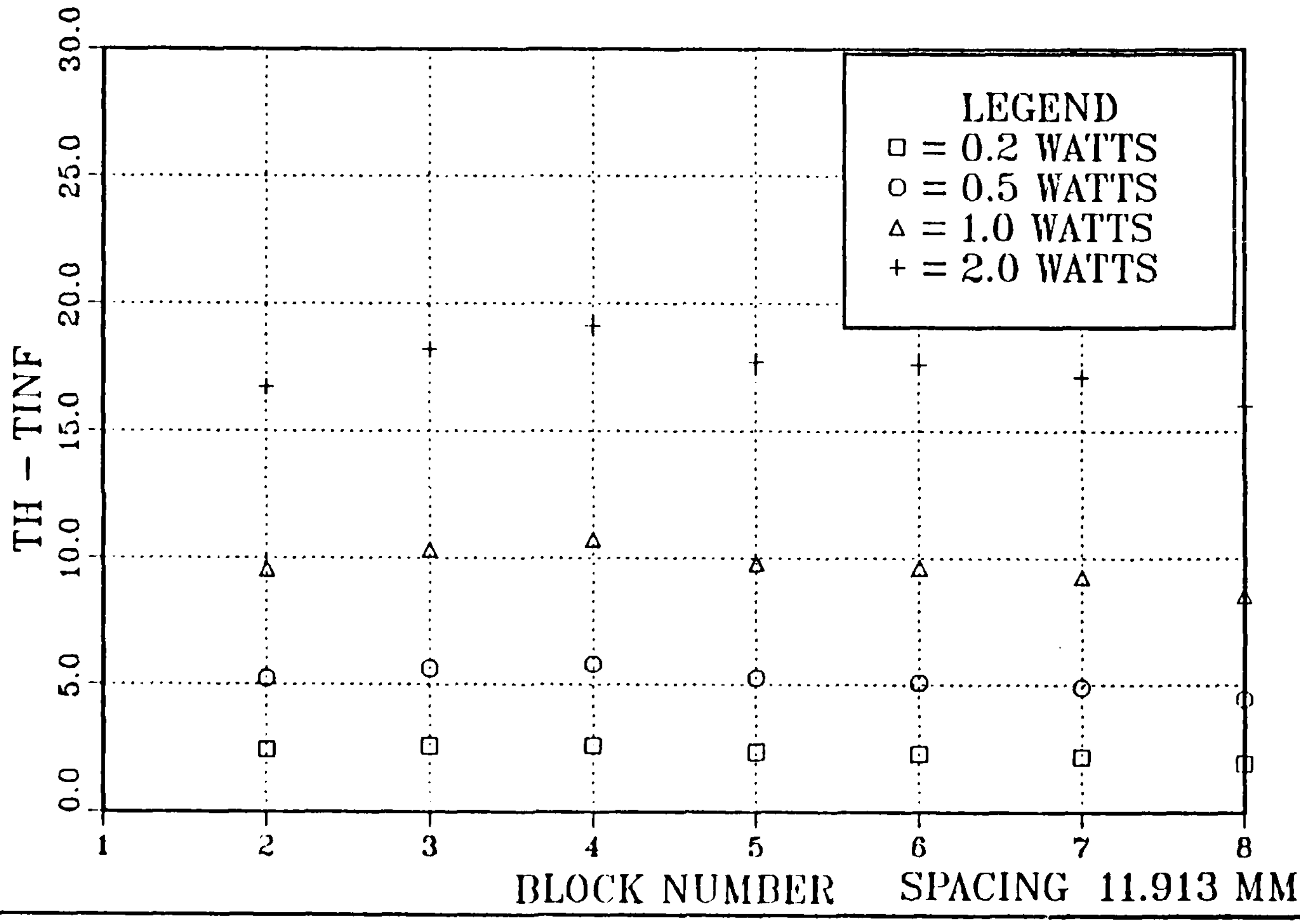


Figure 45. Block Number vs. Excess Temperature (Heater) Runs 5-8

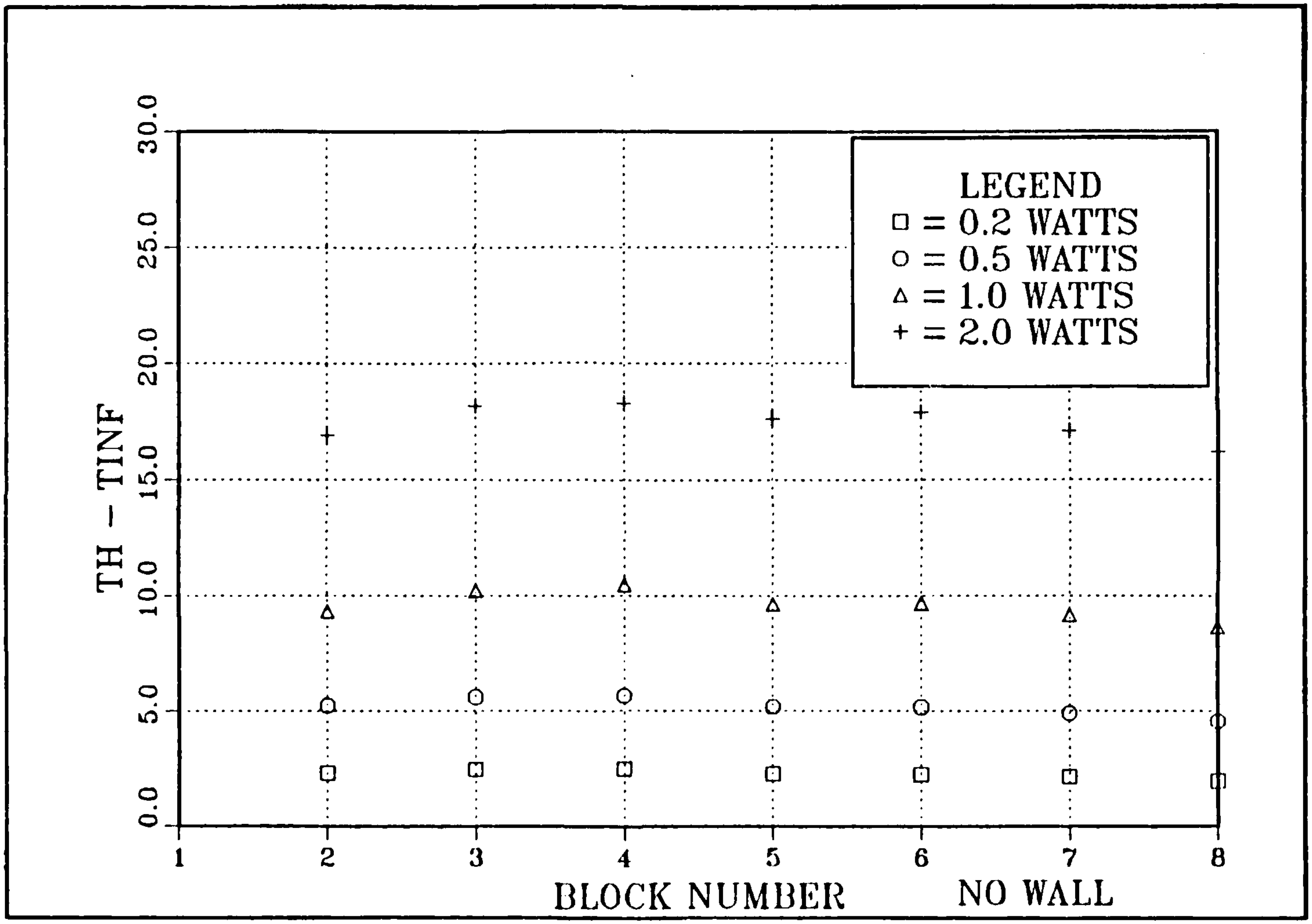


Figure 46. Block Number vs. Excess Temperature (Heater) Runs 9-12

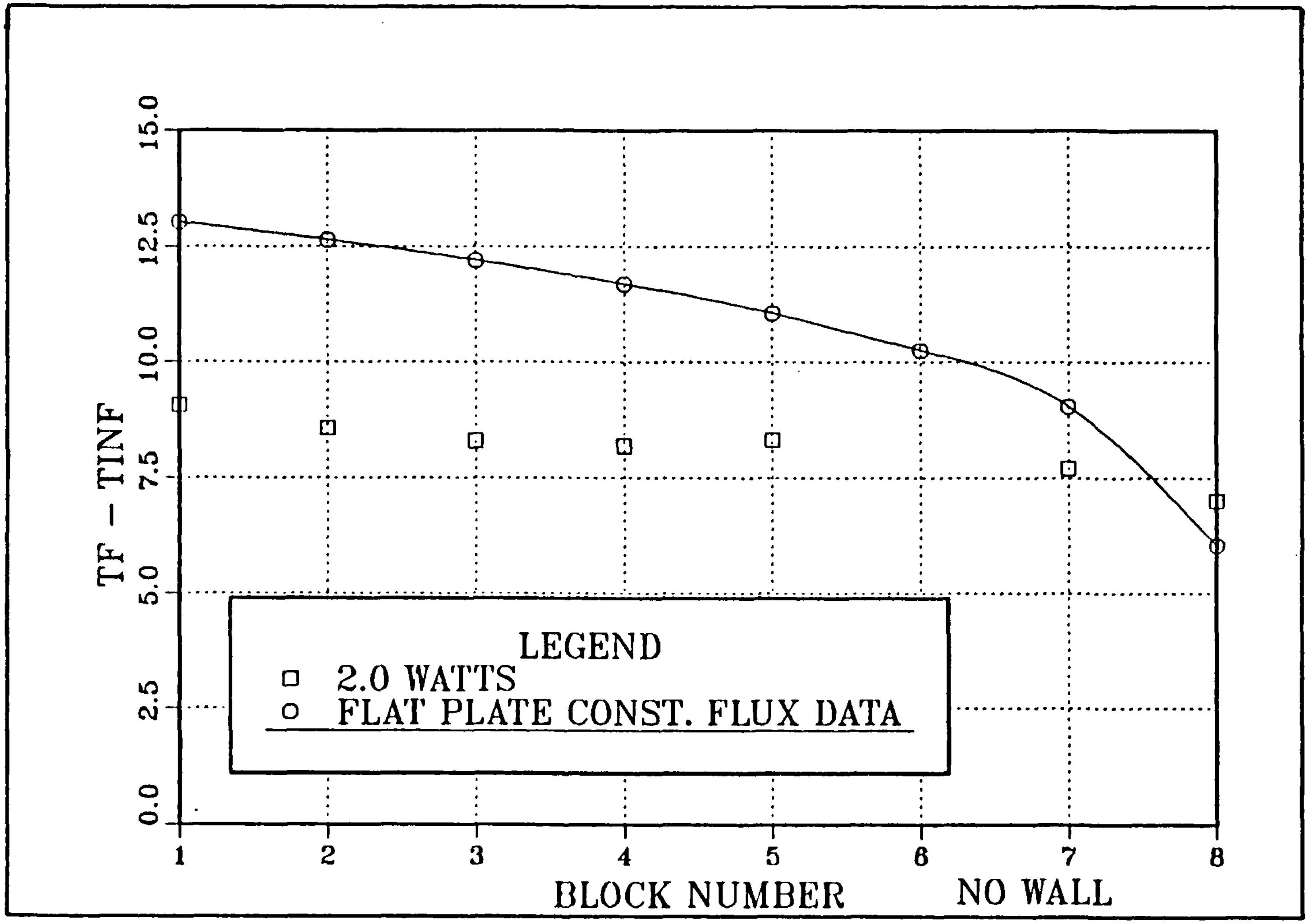


Figure 47. Block Number vs. Excess Temperature (Comparison of Front Face and a Flat Plate with Constant Heat Flux)

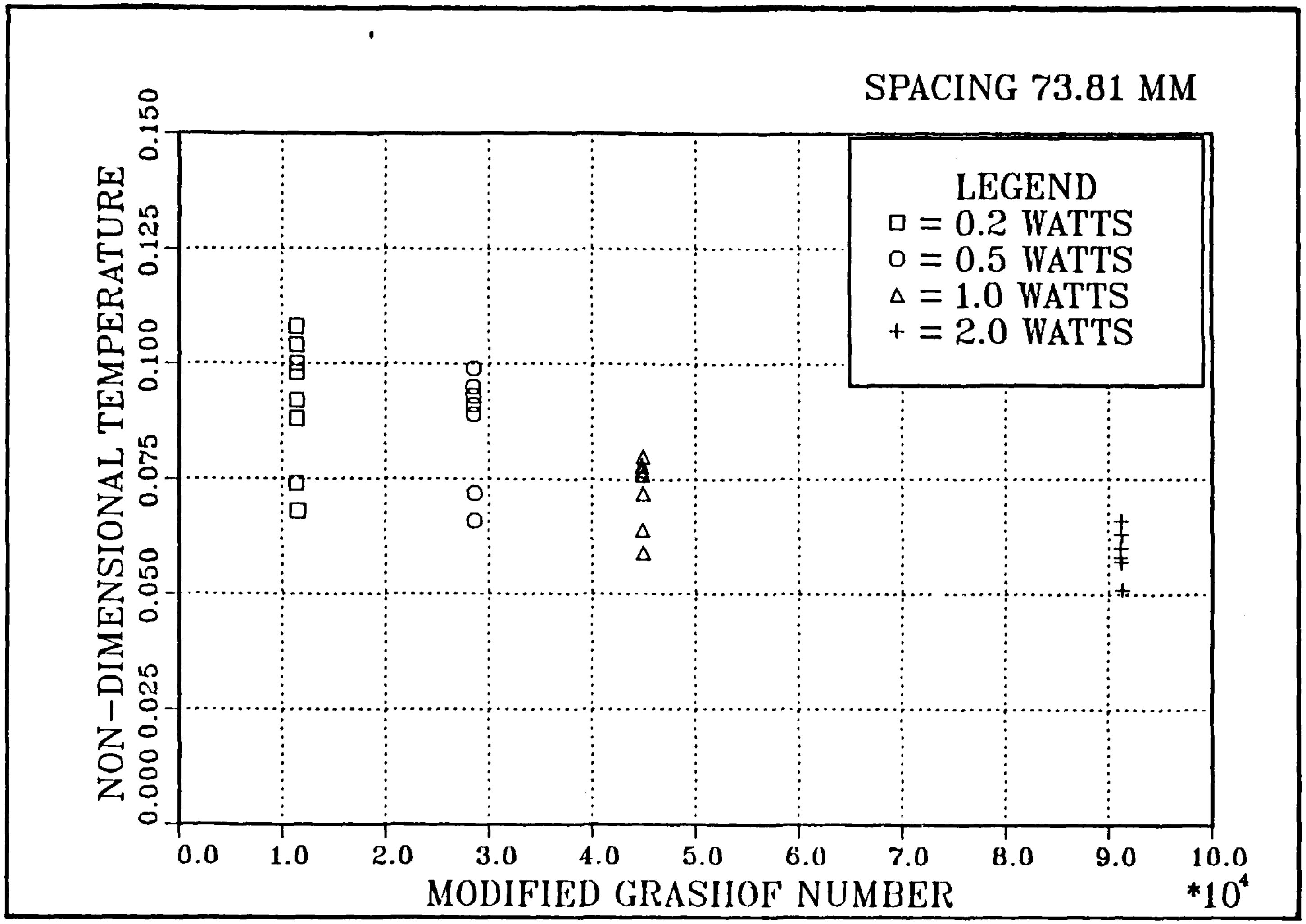


Figure 48. Modified Grashof Number vs. Nondimensional Temperature Runs 1-4

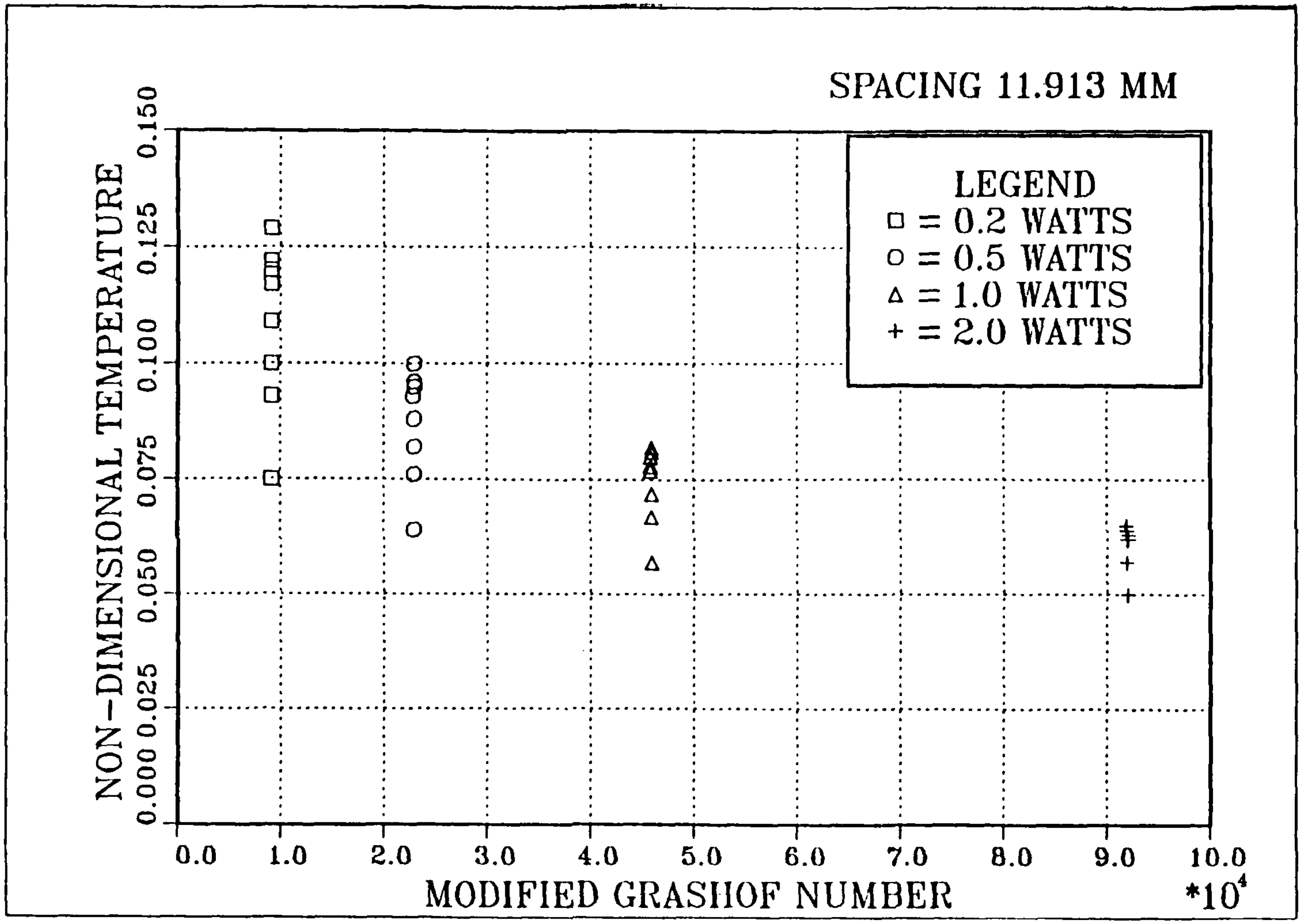


Figure 49. Modified Grashof Number vs. Nondimensional Temperature Runs 5-8

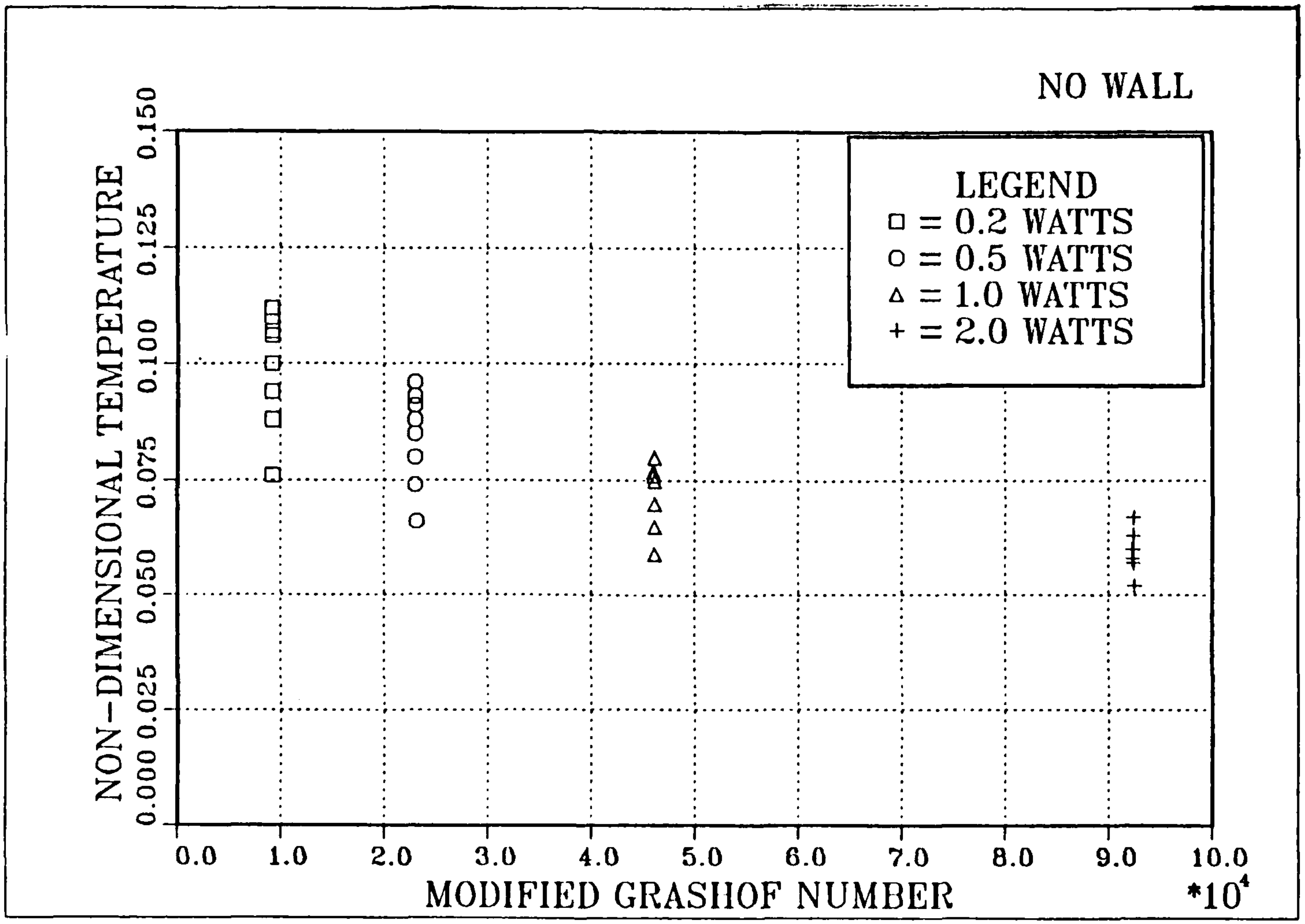


Figure 50. Modified Grashof Number vs. Nondimensional Temperature Runs 9-12

LIST OF REFERENCES

1. Hanson, D., The New Alchemists, pp. 57-61, Avon Books, New York, 1987.

2. Bashe, C.J., "The Architecture of IBM's Early Computers," IBM J. Res. Dev., Vol. 26, No. 5, pp. 363-365, 1981.

3. Chu, R.C., "Heat Transfer in Electronic Systems," The Eight International Heat Transfer Conference, Vol. 1, pp. 293-305, 1986.

4. Solomon, S., "The Idaho Chip," Science Digest, Vol. 91, No. 7, p. 16, July 1983.

5. Oktay, S., "High Heat from A Small Package," Mechanical Engineering, Vol. 108, No. 3, ASME Publication, pp. 36-42, March 1986.

6. Oktay, S., Electronic Package Cooling, Second Annual International Electronics Packaging Conference, San Diego, California, November 15-17, 1982.

7. Bar-Cohen, A., Thermal Management of Air- and Liquid-cooled Multichip Modules, 23rd ASME/AIChE Heat Transfer Conference, Denver, Colorado, August 4-7, 1985.

8. Simons, R.E., and Moran, K.P., "Immersion Cooling Systems for High Density Electronic Packages," National Electronic Packaging and Production Conference (NEPCONN) Proceedings, pp. 396-409, February 1977.

9. Bar-Cohen, A., "Thermal Design of Immersion Cooling Modules for Electronic Components," Heat Transfer Engineering, Vol. 4, Nos. 3-4, 1983.

10. Simons, R.E., and Chu, R.C., "Direct Immersion Cooling Techniques for High Density Electronic Packages and Systems," Proceedings of the 1985 International Symposium on Microelectronics, pp. 314-321, Anaheim, California, November 1985.

11. Yang, K.T., Liu, K.V., Wu, Y.W., and Kelleher, M.D., Local Oscillatory Surface Temperature Responses in Immersion Cooling of a Chip Array by Natural Convection in an Enclosure, 1987.

12. Baker, E., "Liquid Cooling of Microelectronic Devices by Free and Forced Convection," Microelectronic and Reliability, Vol. 11, pp. 213-221, 1972.

13. Baker, E., "Liquid Immersion Cooling of Small Electronic Devices," Microelectronics and Reliability, Vol. 12, pp. 163-173, 1973.

14. Park, K.A., and Bergles, A.E., "Natural Convection Heat Transfer Characteristics of Simulated Microelectric Chips," Heat Transfer in Electronic Equipment--1985, ASME Publication, pp. 29-37, 1985.

15. Knock, R.H., Flow Visualization Study of Natural Convection from a Heated Protrusion in a Liquid Filled Rectangular Enclosure, M.S.M.E. Thesis, Naval Postgraduate School, Monterey, California, December 1983.

16. Lin, Y-S, and Akins, R.G., "An Experimental Study of Flow Patterns and Heat Transfer by Natural Convection Inside Cubical Enclosures," Natural Convections in Enclosures--1983, HTD-Vol. 26, ASME Publication, pp. 35-42, 1983.

17. Chu, H. H-S, Churchill, S.W. and Patterson, C.V.S., "The Effect of Heater Size, Location, Aspect Ratio, and Boundary Conditions on Two-Dimensional, Laminar, Natural Convection in Rectangular Channels," Journal of Heat Transfer, pp. 194-201, May 1976.

18. Incropera, F.P., and DeWitt, D.P., Fundamentals of Heat and Mass Transfer, p. 774, John Wiley & Sons, 1981.

19. Touloukian, Y.S., and others, Thermophysical Properties of Matter, Vols. 1 and 2, IFI/Plenum, 1970.

20. Vliet, G.C., "Natural Convection Local Heat Transfer on Constant Heat Flux Inclined Surfaces," Journal of Heat Transfer, Vol. 91, p. 511, 1969.

21. Vliet, G.C. and Lin, C.K., "An Experimental Study of Turbulent Natural Convection Boundary Layers," Journal of Heat Transfer, Vol. 91, p. 517, 1969.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Mr. Howard Stevens Head, Electrical Research Center David Taylor Research Center Annapolis, Maryland 21402	2
4.	Professor Y. Joshi, Code 69Ji Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5004	5
5.	Professor M.D. Kelleher, Code 69Kk Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5004	1
6.	Professor A.D. Kraus, Code 62Ks Department of Electrical and Computer Engineering Naval Postgraduate School Monterey, California 93943-5004	2
7.	LCDR Thomas Wilson, USN SMC #1089 Naval Postgraduate School Monterey, California 93943-5000	1
8.	LT Dan Knight, USN SMC #2681 Naval Postgraduate School Monterey, California 93943-5000	1
9.	LT Terry Benidict, USN SMC #1238 Naval Postgraduate School Monterey, California 93943-5000	1

10. LT Sherrill John Hazard, III 4
1017 Wood Crest Drive
Appleton, Wisconsin 54915

END
DATE
FILMED
5-88
DTIC