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AFATL-TR-75-24

OPTIMIZATION OF FLAME FUEL DISSEMINATION PATTERNS ASSOCIATED WITH FIREBOMBS

BOMBS AND WARHEADS BRANCH
MUNITIONS DIVISION

FEBRUARY 1975

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FINAL REPORT: FEBRUARY 1974 - OCTOBER 1974

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up and dissemination pattern. The parameters characterizing this pattern were defined, and an optimum model was constructed. Although the experimental results of this model are unique to the physical conditions of the experiments and cannot be applied directly to dynamic situations, the technique and results offer excellent relative data for the screening of possible dissemination patterns and firebomb effectiveness studies.

FOREWORD

This report covers research conducted during the period February 1974 to October 1974 by the Flame Fuel Laboratory, Air Force Armament Laboratory (AFATL/DLJW) in support of Project 10820302. This project was managed by Dr. Harry L. Wolfgang (DLJW).

The research was carried out at the AFATL Flame Fuel Laboratory and Burn Facility by 1st Lt Jerry D. Abrams and Capt Robert D. Epperson with assistance from D. A. Davis, Thomas G. Floyd, Andrew J. Bilbo, and Gregory A. Brinson.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

William F Brockman

WILLIAM F. BROCKMAN, Colonel, USAF
Chief, Munitions Division

ABSTRACT

This report describes a research effort to find the optimum dissemination of flame agent from a firebomb. The basic approach taken was to experimentally model under laboratory conditions static dissemination patterns. This involved controlling the physical environment of the experiments and representative collection of data. A computer program was used to reduce and analyze the data. The measuring criteria for optimization were calculated in the computer analysis. These criteria were optimized to give the most effective fuel break-up and dissemination pattern. The parameters characterizing this pattern were defined, and an optimum model was constructed. Although the experimental results of this model are unique to the physical conditions of the experiments and cannot be applied directly to dynamic situations, the technique and results offer excellent relative data for the screening of possible dissemination patterns and firebomb effectiveness studies.

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SECTION I

INTRODUCTION

A major problem realized in the use of firebombs was the control of fuel breakup. The current operational environment requires flame agents that are suitable for use in a high-speed delivery mode. The requirement for an improved fuel initiated an extensive research program to develop a flame agent exhibiting physical properties which could be varied to control the breakup characteristics.[1,2] Before a new fuel could be tailored to meet these requirements, the optimum breakup had to be determined. This report describes the results of a program developed to optimize the particle size distribution resulting from the fuel breakup.[3]

DISCUSSION OF THE PROBLEM

The effectiveness of a firebomb is dependent on three variables: area coverage, temperature over the area, and the duration of burn.[4] The optimum breakup of any candidate flame agent would be that which maximizes these three variables. Each of the three variables is functionally dependent on the density (grams of fuel per square foot) and particle separation (distance between fires).

In order to find the best combination of these variables, an experimental model had to be designed such that the density and separation distance could be varied over the range of interest. The variations in the physical conditions affecting the kinetics of the fuel combustion had to be minimized.

OBJECTIVES

The principal objective of this research was to find the fuel breakup that would give the most effective temperature distribution from a firebomb. The optimum should be independent of the flame agent and environmental conditions. The results of this study will also indicate the effectiveness of a firebomb weapon. The accomplishment of these objectives required the selection of a flame agent to be burned and a number of fire array configurations to be analyzed. The fuel was selected on the basis of the research conducted by the Flame Fuel Laboratory, Air Force Armament Laboratory, Eglin Air Force Base, Florida. A blend of styrene-butadiene rubbers dissolved in benzene and gasoline (SBR) was selected. This fuel was under development as a candidate to replace the napalm B presently used in the firebomb in inventory and as a fuel for a new proximity fuzed, high speed delivery bomb.

SUMMARY OF RESULTS

An optimum dissemination pattern of the flame fuel from a 100-gallon firebomb was found based on the following criteria: area coverage, mean effective temperature, and duration of the effective temperature. An experimentally determined matrix consisting of seven densities and five separation distances for each density was analyzed with each of the above mentioned dependent variables maximized. The findings of these efforts were:

> The optimum area coverage from a 100-gallon firebomb with SBR fuel is 1.32 x 10^4 square feet with a density of 0.053 lb/ft^2 ($24 g/ft^2$).
>
> The optimum separation distance is 16.5 inches with a particle size of 0.088 lb (40 g).
>
> The mean temperature above a minimum effective temperature of 150°C was predicted to be 300°C with a duration time of 200 seconds.

The predicted optimum particle size distribution was experimentally modeled with the following results: mean effective temperature of 299°C for a duration of 194 seconds. Although the results are unique to the physical conditions of these experiments and cannot be applied directly to dynamic situations, the technique and results offer excellent relative data for the screening of possible dissemination patterns and firebomb effectiveness studies.

SECTION II

SYSTEM MODELING

The dissemination pattern of the fuel from a firebomb was modeled under laboratory conditions. The model had to be representative of the particle size distribution and the separation distance of the particles. Symmetrical arrays were found with variable parameters covering the range under investigation.

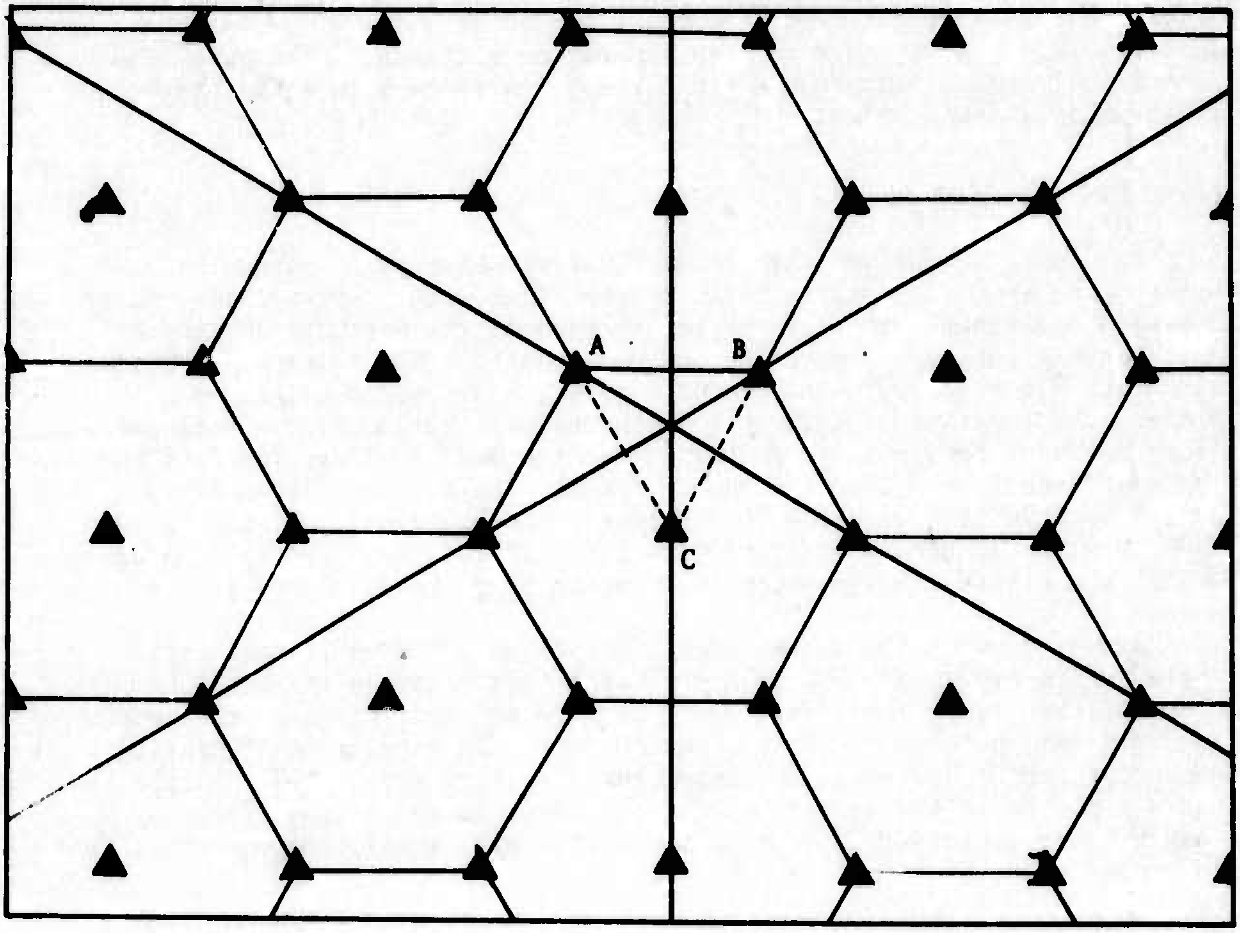
ARRAY CONFIGURATION

Five arrays of fires with geometrical symmetry were found with the distance between fires characterizing the array. Each array consisted of a grid of hexagons with fires placed at each of the vertices and centers, which gave a constant separation between samples. The hexagon was chosen since it is a good approximation of a circle that can be packed on a plane. The separation distance and density were varied over a reasonable range based on preliminary studies around the mean fuel density from the lay-down mode of a BLU-27 firebomb. The fire separation distance was varied between 12 inches and 30 inches for several densities ranging from 0.02 lb/sq ft (9 grams/sq ft) to 0.08 lb/sq ft (36 grams/sq ft). An example of the fire configuration of an array is given in Figure 1.

Symmetry was achieved by varying the size of the equilateral triangle ABC in Figure 1. The triangle was always centered on the centerpoint of the array; therefore, lines of fire 60° apart through the center occurred for each array. This technique achieved similar configurations about the center for the five separation distances considered. A fire was not placed at the center because of the fixed thermocouple placement. This will be discussed in Section III. The array configurations are given in Appendix A.

PARAMETER VARIATIONS

The primary concern of this study was to optimize the fuel dissemination of a firebomb. The variables affecting the criteria to be optimized were reduced to two by controlling the experiments in a burn chamber. The two variables were density and separation distance. The functional dependence of each of the parameters on the mean effective burn time and mean effective temperature had to be determined experimentally. A two-dimensional matrix over the range discussed in the previous section was constructed from the experimental results of Table 1 for each of the functions. Table 1 gives the sample size in grams for each of the experiments.



▲ Fire Location

Figure 1. Sample Fire Configuration

TABLE 1. SAMPLE SIZE IN GRAMS
FOR EACH EXPERIMENT

No. Samples	25	32	53	63	96
Separation (Inches)	30	24	18	15	12
Density $\frac{(\mathrm{lb/ft}^2)}{(\mathrm{g/ft}^2)}$					
$\frac{0.02}{9.0}$	49	31	18	12	8
$\frac{0.03}{13.6}$	74	47	27	18	12
$\frac{0.04}{18.0}$	98	63	35	25	16
$\frac{0.05}{27.6}$	123	79	44	31	20
$\frac{0.06}{27.0}$	147	94	53	37	24
$\frac{0.07}{31.7}$	172	110	62	43	27
$\frac{0.08}{36.0}$	196	126	71	49	31

Every element in the matrix represents an experiment. It was feasible to run all 35 experiments required for the completion of the matrix; therefore, no statistical design of the experiments was necessary.

Once the matrix was completed, the functional dependence of the mean effective burn time and the mean effective temperature on the density and separation could be analyzed. The effects of each variable could be isolated. The area coverage was strictly a function of density and could be expressed analytically. With these interrelationships of the parameters known, the model could be optimized according to the definition of the optimum dissemination (maximum area coverage, maximum effective temperature, and maximum effective time).

SECTION III

EXPERIMENTAL DESIGN AND EQUIPMENT

A simple experimental model of an ideal fuel breakup pattern was developed in Section II. This section explains how the model was adapted to laboratory conditions and instrumented. The equipment used for data collection and the procedural techniques are also discussed.

DATA COLLECTION

The ultimate goal of the instrumentation was to monitor the temperature or heat over a representative area of the fire array during the entire burn time. An overall mean temperature or heat flux should be obtainable from the raw data received from selective placement of sensing devices. Physical constraints which were considered included the limited size of the chamber and the practical number of sensing devices. Relative effectiveness could be obtained from heat or temperature data. Calorimeters and radiometers were considered as possible heat sensors but were discarded due to their directional limitations. Dosimeter-type instruments measure only the total heat sensed without respect to time. Therefore, temperature measurements with thermocouples were selected as the simplest and most reproducible method of monitoring the effectiveness of the fire arrays. Since the thermocouple gives a point source temperature, it is necessary to selectively place a number of thermocouples over the area in order to obtain a representative mean temperature.

Thermocouple Configuration. The electronic data acquisition systems available had a total of 44 channels as possible inputs. This limitation necessitated a search for the most representative placement of the thermocouples to get meaningful data. The 44 channels were divided into three groups: grid, fire, and room. The grid was defined as the group of thermocouples selectively placed to monitor the temperature over the entire fire array. This group utilized 37 of the channels. Four channels were used to monitor the room temperature of the burn chamber. Two thermocouples in series were placed in each corner of the chamber, one at the top and one at the bottom of the room. The thermocouples in each corner were then connected to one of the four channels used for room temperature measurement. Three thermocouples were used to monitor fire temperatures. These were placed in the three centermost fires of each array.

Since it was desired to measure the temperature over a simulated infinite area, it was necessary to locate the thermocouples far enough away from the edge of the fire array to eliminate any possible edge effects. The fire arrays and thermocouple grid were selected such that there were always at least two rows of fires on the outside of the thermocouple grid. These configurations are shown in Appendix A.

The placement of the grid thermocouples presented a more complex problem. Since the wiring of the thermocouple grid involved a considerable amount of effort, it was desirable to have a fixed configuration that would give an excellent sampling of all the fire arrays. The complexity of the heat transfer mechanisms in the burn chamber made mathematical modeling of the temperature distribution impractical. Therefore, it was determined that the best method of sampling would be from a random placement of the thermocouples over the entire area. Several different grids were considered and evaluated by an empirical trial and error method until a grid was selected which appeared to give a satisfactory sampling of the area.

Since the fire arrays used are symmetrical, many points within each array are theoretically equivalent. The hexagons in the arrays can be divided into six equilateral triangles with fires at each of the vertices as shown in Figure 2. The area of triangle ABC in this figure is equivalent to the area inside any triangle connecting any three fires in an array. This triangle can be further subdivided into the six triangles numbered 1 through 6, as shown in the figure. Each of these triangles is a truly unique area, that is, no two points within the triangle are equivalent and every point within the triangle is equivalent to a corresponding point within any of the other congruent triangles. If the position of each thermocouple is considered with respect to the nearest fire, the location of every thermocouple can be represented by a point in triangle 1 (or similarly any of the triangles numbered 1 through 6). The thermocouple grids considered were evaluated by locating each thermocouple in triangle 1 to determine if the sampling was random and representative of the entire area.

The thermocouple grid selected is shown in Figure 3. This configuration gave an excellent coverage of the unique area for each of the fire arrays without having to move the thermocouples. The sampling for each of the arrays is shown in Figure 4. The dots in the triangle represent single thermocouples while the circled dots and slashed dots represent two and three thermocouples, respectively. One thermocouple was placed at the unique point where the six triangles in triangle ABC of Figure 2 intersect. The thermocouple and fire configurations are given in Appendix A.

Monitoring Equipment and Burn Facility. A specially equipped burn chamber was electronically instrumented to carry out the experiments necessary for this study. Equipment readily available was adapted to the needs dictated by these experiments. A chamber designed for the purpose of studying flame agents and incendiaries was modified to accommodate the tests.

Two data acquisition systems were available for use in the monitoring of the temperature distribution over the fire arrays. System I was a 24-channel data collection unit with a variable sampling rate and controlled by a Nova 1210 computer. System II was a 20-channel unit with 100-

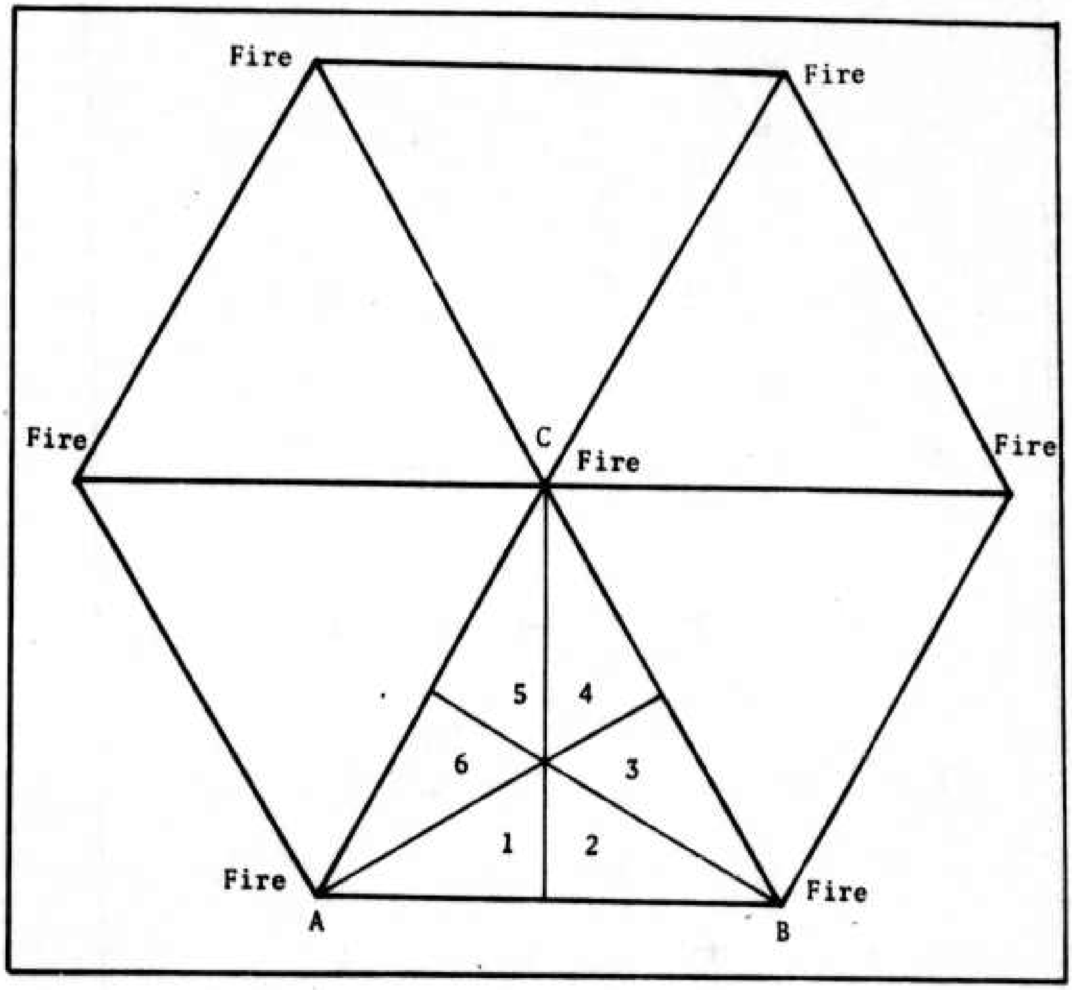


Figure 2. Divided Hexagon

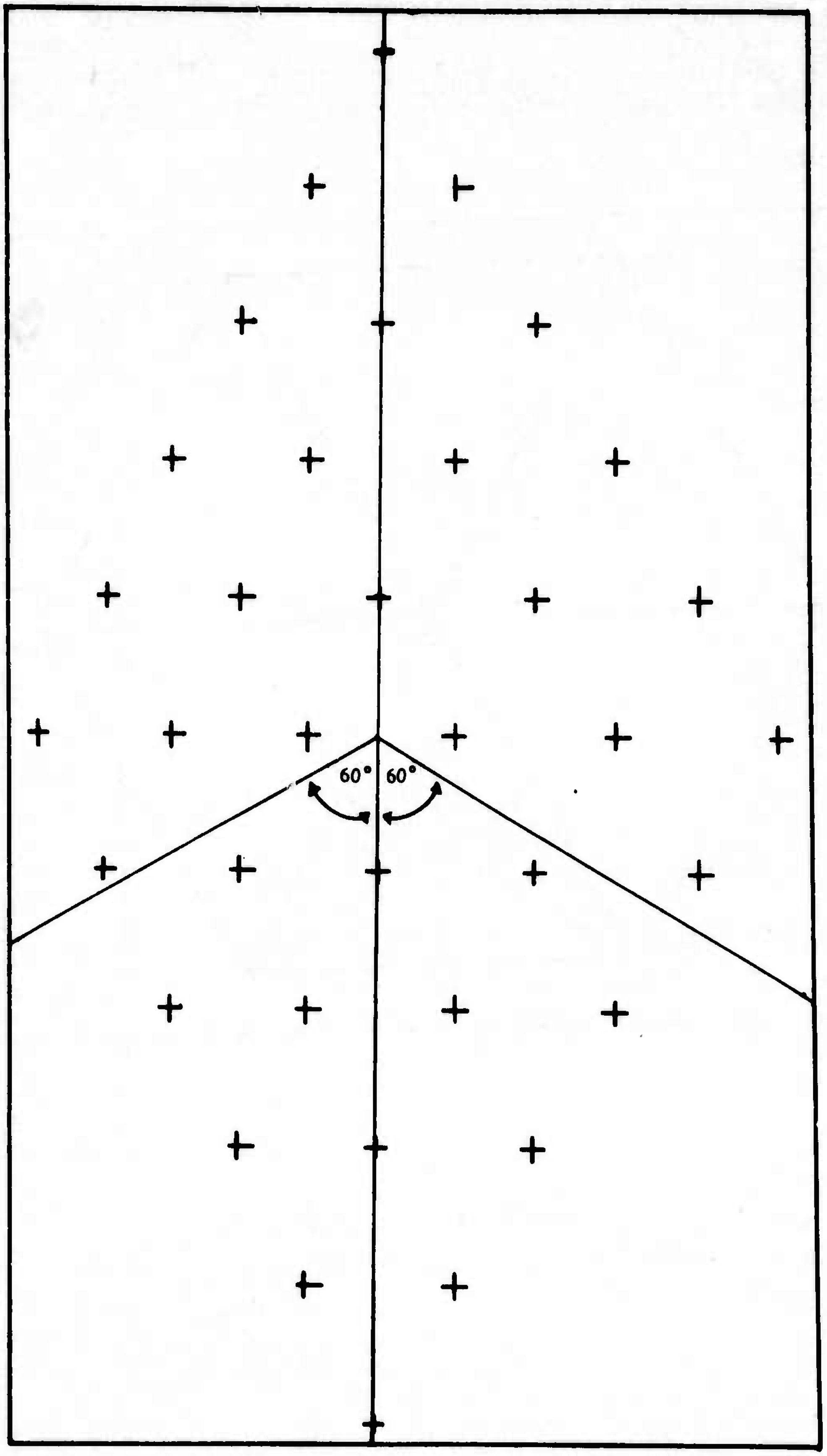
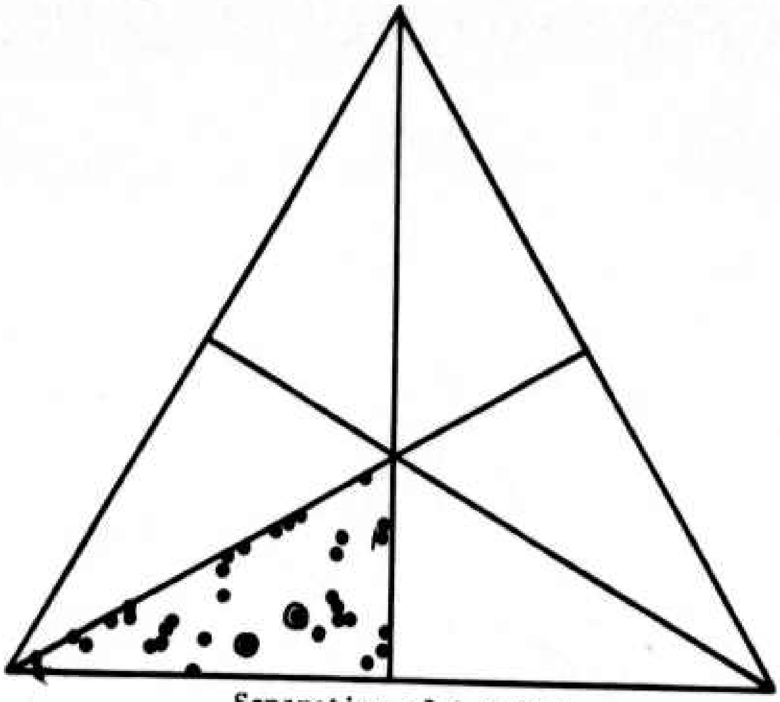
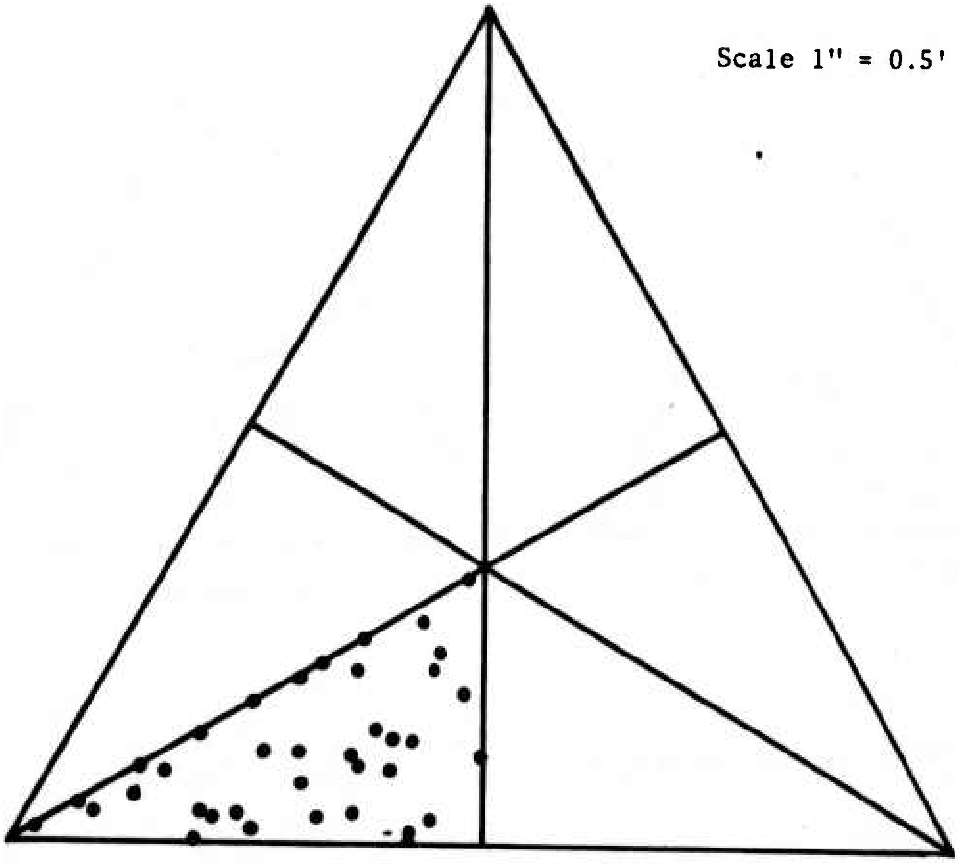


Figure 3. Thermocouple Grid



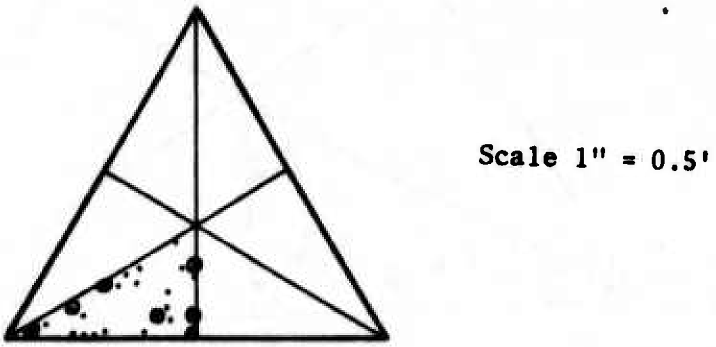
Separation of 2.0 Feet

Scale 1" = 0.5'

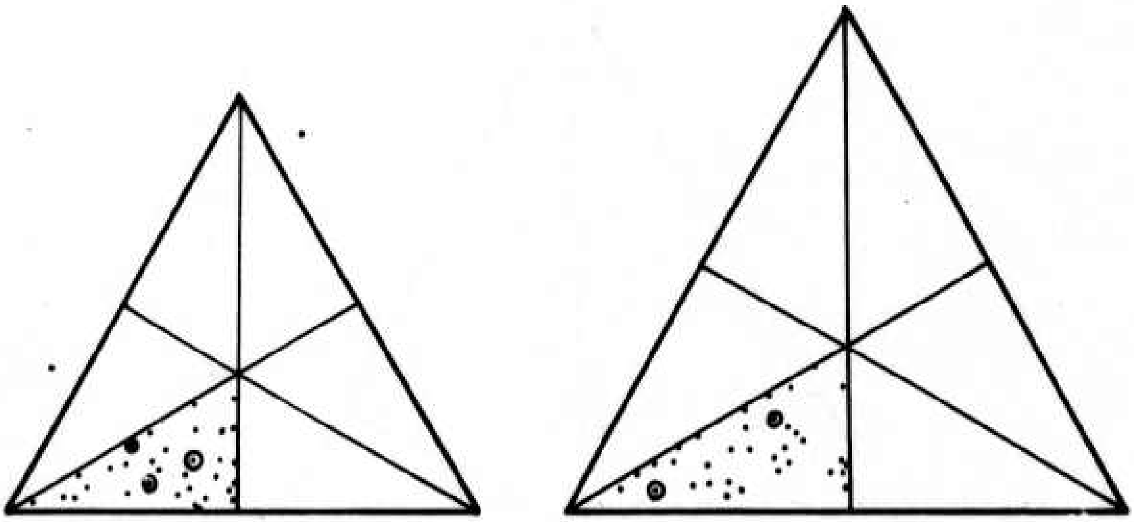


Separation of 2.5 Feet

Figure 4. Thermocouple Sampling Patterns



Separation of 1 Foot



Separation of 1.5 Feet

Separation of 1.5 Feet

Figure 4. Thermocouple Sampling Patterns (Concluded)

millisecond sampling rate. Both systems were built by Scientific Instruments Research. Seven-track Kennedy Recorders were used to record the data on magnetic tape. The two collection systems were synchronized by a common on-off switch located near the burn chamber. The combined 44 channels were wired to Chromel-Alumel thermocouples selectively placed in the chamber. The data acquisition systems are shown in Figures 5 and 6.

A 19 x 19-foot burn chamber with insulated walls was used as a controlled environment to carry out the experiments. A Dexon floor was installed with all the wiring beneath the floor and the thermocouples fixed in position on the surface. An asbestos covering was placed on top of the flooring with the thermocouple junctions three to four inches above the surface. The chamber was equipped with a refrigeration unit capable of maintaining temperatures as low as -30°C. An air circulation system consisting of an inlet and exhaust fan prevented oxygen starvation by displacing the by-products of the combustion with fresh air. Figure 7 shows the chamber immediately before a burn with the samples in position. The fixed thermocouple grid can also be seen in Figure 7.

The combined effect of the errors occurring from the equipment was well within the accuracy of the experimental procedure. An estimated accuracy within ± 5 percent from combined equipment and experimental error was determined. This was well within a set allowable error of ± 10 percent.

EXPERIMENTAL PROCEDURES

All experiments were basically the same, therefore, a general procedure was outlined for the preparation and running of the two types of experiments (ambient and cold weather). The initial sample handling was the same for all tests.

Sample Preparation. The flame agent selected for the study was a blend of Styrene-butadiene Rubber (29 percent), benzene (27.3 percent), and gasoline (43.7 percent). The selection was based on the results of a screening program by the Air Force Armament Laboratory. This fuel was readily available since it was the primary agent being considered for a high-speed, proximity fuzed firebomb and was prepared in-house. The fuel blend was held constant throughout the program; therefore, the results should be relative to each experiment and independent of the fuel.

The fuel samples ranged in size from 8 to 200 grams. Polyethylene zip-top bags were used to contain the samples. The bags were filled by two techniques depending on the size of the fuel sample. Samples between 100 and 200 grams were filled directly from a 5-gallon Jerry can with a 1-inch ball valve for control. The accuracy was ± 1 gram. The smaller samples were filled with syringes, and the accuracy was ± 0.5 gram. Two different size bags were used: 4 x 4-inch bags were used for the smaller samples, and 6 x 6-inch bags were used for the larger samples. The time

Figure 5. Data Acquisition System I

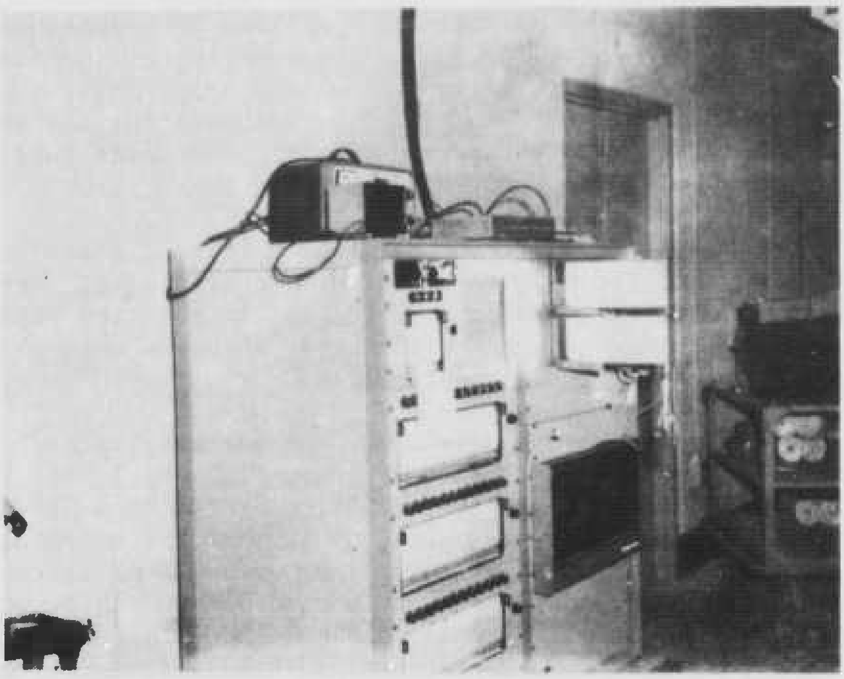


Figure 6. Data Acquisition System II

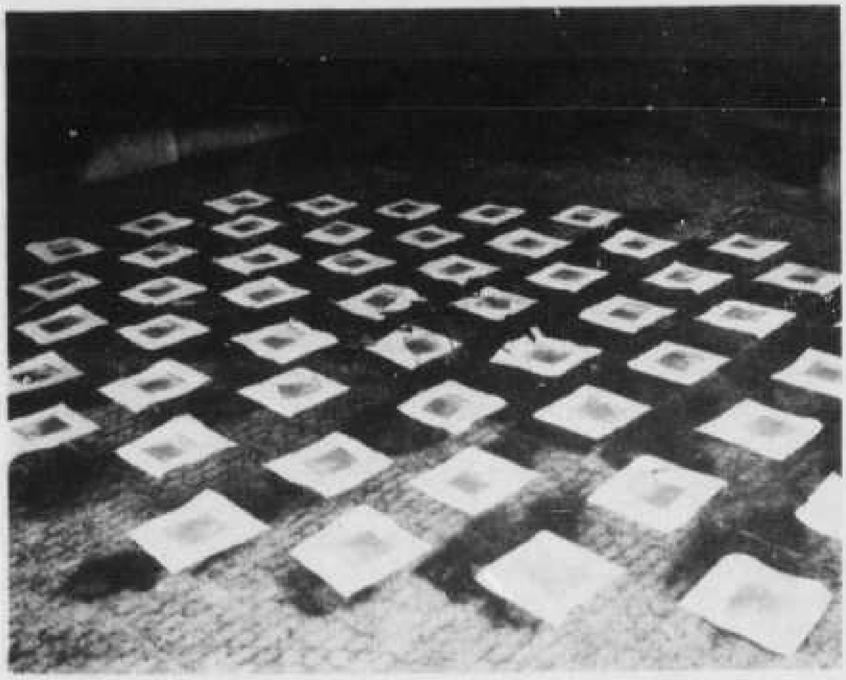


Figure 7. Burn Chamber

required to prepare the samples was held at a minimum to reduce possible errors resulting from lost volatiles during the handling of the fuel. The prepared samples were stored in air-tight ammunition cans until they were burned. The storage time was held to less than 24 hours for the ambient experiments. The samples used in the cold weather study were cold soaked for at least 24 hours below the temperature under investigation.

Ambient Burns (25°C to 30°C). The complete matrix of experiments was run with the initial conditions in the burn chamber held at ambient (25°C to 30°C). The fire positions were identified, and an asbestos paper square was placed on each location. The three fire thermocouples were placed over the respective fires for the array being burned.

The two data collection systems were checked and calibrated before each experiment. Each system was loaded with magnetic tapes, and the control was switched to a common on-off switch located next to a view port near the burn chamber. A sample was placed on each of the asbestos papers. At this time the inlet and exhaust fans for the burn chamber were turned on. Five personnel were needed to start each experiment. Three persons were used to light the fires with propane torches, one stayed outside the chamber for safety purposes, and the fifth controlled and monitored the data acquisition. Electronic timers were used to measure the ignition time and burn times.

The data collection systems and the timers were started when the first fire was ignited. The ignition time ranged between 20 and 40 seconds depending on the number of fires. This variation was negligible since the total burn time was always over 10 minutes. The times the first and last fires burned out were recorded. Good reproducibility of these times indicated the burning mechanism did not vary enough to affect the results.

At the end of each burn the chamber was allowed to cool while the data was unpacked, and the equipment was prepared for the next experiment. The data was stored on two magnetic tapes until it could be reduced on the CDC 6600 computer.

Cold Weather (0°C and -30°C). The cold weather experiments were carried out by procedures similar to the ambient runs. The only variations occurred in the chamber preparation and the fire ignition. The temperature in the burn chamber was stabilized at the temperature being investigated. The refrigeration unit was turned on at least 24 hours before a scheduled experiment. This allowed time for the walls to reach a stable temperature so that the cooling unit could hold the chamber temperature close to the set value with minimum fluctuation. The only changes in the ignition procedure were the time the fans were turned on and the duties of the person located outside the burn chamber. The cooling unit was turned off after all the samples had been placed in the chamber. The exhaust and inlet fans were turned on when the first fire was ignited. The outside man opened the vent for the exhaust fan and the door for the inlet fan when the personnel entered the chamber to begin igniting the fires. The procedure was the same as the ambient procedure for the remaining portion of the experiment. At the end of the burn the inlet and exhaust vents were closed, and the cooling unit was turned back on. The chamber was lowered to the temperature being studied and allowed to stabilize. This time varied according to the amount of temperature difference between the set value and the maximum temperature resulting from the burn.

SECTION IV

ANALYSIS OF DATA

The data collected had to be converted to a form that could be analyzed thoroughly. A computer program was written in Fortran IV and used with a CDC 6600 computer to reduce the data. Once the data had been reduced to a workable form, the optimum combination of parameters was found. This section discusses the computer reduction of the data and the techniques used to optimize the variables.

COMPUTER REDUCTION OF DATA

The raw data consisted of millivolt readings taken from each thermocouple at 0.1-second intervals. This information was stored on two magnetic tapes in binary for each experiment. Tape I from system I was a recording of the first 24 thermocouples, and Tape II from system II contained the data from the remaining 20 thermocouples. The information was placed on the tapes in 5-second records with each record representing 50 scans of each thermocouple. All experiments contained at least 120 records.

A computer program was written in Fortran IV to unpack the data from the tapes and reduce it to a meaningful form. The program is given in Appendix B. A step-by-step summary of the operations carried out by the program follows:

> The millivolt readings from the thermocouples were converted to degrees centigrade by the conversion factors: 1 millivolt = 24.6°C and 1 millivolt = 10.24 in binary coded digits.
>
> All channels were averaged over each 5-second record with the average treated as the reading at the beginning of the time interval. This smoothed the curves and reduced the data points to 120 for each point monitored.
>
> The 37 values for the grid thermocouples were averaged for each of the 120 time steps. The same operation was carried out for the three fire values and the four room values. A fourth average combined the grid and fire values. These averages along with the averages of the 44 channels were stored in a 120 x 48 matrix. The first 44 columns represent the actual thermocouples monitored. Columns 45, 46, 47 and 48 represent the average of the grid, grid plus the fire, fire and room, respectively.
>
> A minimum effective temperature of 150°C was selected. This baseline was picked as the minimum since very little target destruction would be expected below this temperature.

A numerical integration of all 48 curves was carried out over the 120 time steps. The trapezoidal method was used. The results gave a relative heat measurement which could be used for comparison.

A search was conducted for the maximum temperature of each thermocouple and the time this maximum occurred. The same values were determined for the four averages also.

The baseline of 150°C was established, and the portion of each curve above this baseline was identified.[2] This part of the curve was numerically integrated for each of the 48 curves.

A time-averaged temperature was calculated for the entire curve and the effective region of each curve.

Each of the 48 curves was plotted by the computer. These plots were used for fast validity checks on the data.

A map of the thermocouple grid was also plotted by the computer at various time intervals. The temperature distribution could easily be seen from these maps.

The computer program had many checks incorporated in the logic. Errors encountered in the handling of magnetic tape were routed through specific subroutines for special treatment in order to salvage data. The option of throwing out bad data resulting from thermocouple or electronic equipment failure was included in the program. This minimized the rerunning of experiments where only an insignificant fraction of the data was bad. A complete listing of the program named Particle Size Distribution Study (PSDS) is given in Appendix B.

EXPERIMENTAL RESULTS

Each experiment was run at least three times to assure the validity of the data. Each bit of information from the reduction of the data was tabulated by the computer for each experiment. An example of this table is given in Table 2. The three tables from each like experiment showed excellent reproduction and were combined to give a fourth table of averages. The data needed for optimization was then extracted from the averaged results.

The criteria defined earlier for an optimum dissemination pattern were maximum mean effective temperature, maximum mean time above the minimum effective temperature and the maximum area coverage. The data describing these criteria were taken from the average tables and tabulated in Tables 3 and 4. Table 3 is the mean effective temperature for the thermocouple grid, and Table 4 is the mean time above the mimimum effective temperature for the grid thermocouples. Graphs were constructed

TABLE 2. SAMPLE OUTPUT OF COMPUTER PROGRAM

```
           TOTAL HEAT OUTPUT           MAXIMUM         HEAT      OUTPUT              MAXIMUM        TIME AT
             AREA    AVE TEMP      AREA     AVE TEMP   START END  DELTA TIME      TEMPERATURE      MAX TEMP
CHANNEL  DEG-SEC     DEG C       DEG-SEC    DEG C      SEC   SEC   SECONDS           DEG C          SECONDS
   1      95656.      159.       79460.     344.       35.   240.   205.             544.            105.
   2      72049.      120.       47906.     282.       25.   195.   170.             475.             40.
   3     104821.      175.       82608.     330.       25.   275.   250.             627.             70.
   4      95443.      159.       70337.     343.       35.   240.   205.             545.            105.
   5     107803.      180.       83734.     361.       30.   250.   220.             684.             85.
   6      74447.      124.       51234.     285.       15.   195.   180.             521.             40.
   7      96633.      161.       74413.     413.       30.   210.   180.             695.             75.
   8      65396.      109.       40243.     287.       30.   170.   140.             505.             60.
   9      72761.      121.       47804.     290.       25.   190.   165.             516.             60.
  10      99595.      151.       65215.     343.       20.   210.   190.             526.             70.
  11      79003.      132.       54258.     310.       10.   185.   175.             538.             35.
  12      64634.      108.       39153.     245.       20.   180.   160.             332.             40.
  13      90797.      151.       63316.     344.       20.   210.   190.             524.             70.
  14     108654.      181.       86996.     328.       25.   290.   265.             624.            105.
  15      80095.      133.       56554.     314.       15.   195.   180.             498.             30.
  16      66061.      110.       41591.     268.       30.   185.   155.             430.             50.
  17      79907.      133.       56462.     314.       30.   210.   180.             505.             65.
  18      72355.      121.       46635.     283.       30.   195.   165.             509.             45.
  19      93529.      155.       68152.     349.       25.   220.   195.             554.             55.
  20      63674.      106.       36538.     252.       20.   165.   145.             389.             55.
  21      78004.      130.       50588.     281.       30.   210.   180.             410.             80.
  22      73692.      123.       47248.     305.       35.   190.   155.             512.             85.
  23      85846.      143.       61489.     307.       20.   220.   200.             462.             80.
  24      84514.      141.       62408.     290.       20.   235.   215.             550.             65.
  25      69472.      116.       47626.     307.       20.   175.   155.             450.             95.
  26     112683.      188.       91277.     445.       20.   225.   205.             757.             70.
  27      67869.      113.       46008.     307.       20.   170.   150.             565.             65.
  28      98788.      165.       74306.     391.       20.   210.   190.             577.             75.
  29      68829.      115.       43844.     274.       20.   180.   160.             471.             45.
  30      62695.      104.       40719.     271.       20.   170.   150.             381.             60.
  31      70731.      118.       47468.     288.       20.   185.   165.             438.             50.
  32      72717.      121.       50206.     295.       20.   190.   170.             429.             35.
  33      66607.      111.       42906.     266.       15.   165.   150.             440.             30.
  34      66508.      111.       45862.     296.       20.   175.   155.             401.             75.
  35     105060.      175.       83300.     438.       20.   210.   190.             689.             85.
  36      74789.      125.       52637.     310.       15.   185.   170.             419.             45.
  37      58836.       98.       34962.     259.       30.   165.   135.             372.             50.
  38     104704.      175.       79205.     348.       25.   250.   225.             561.             50.
  39      93000.      155.       66435.     324.       35.   240.   205.             420.            120.
  40      93886.      156.       71692.     326.       10.   230.   220.             718.             35.
  41      27295.       45.           0.       0.        0.     0.     0.             126.            120.
  42      25507.       43.           0.       0.        0.     0.     0.              97.            105.
  43      23092.       38.           0.       0.        0.     0.     0.              81.            185.
  44          0.        0.           0.       0.        0.     0.     0.               0.            600.
  45      80864.      135.       57173.     309.       20.   205.   185.             450.             70.
  46      82089.      137.       57820.     313.       20.   205.   185.             451.             70.
  47      97197.      162.       71904.     327.       20.   240.   220.             485.             50.
  48      25298.       42.           0.       0.        0.     0.     0.              98.            120.

AVE OF ALL TC'S                  56986.     319.       23.   202.   179.
AVE FOR TC'S ABOVE
MAX TEMP                         56986.     319.       23.   202.   179.
```

TABLE 3. MEAN EFFECTIVE GRID TEMPERATURES VERSUS DENSITY

Mean Grid Temperature = Average of 37 Thermocouples in the Grid (°C)

	Separation Distance (Inches)				
Density (Grams/ft^2)	12	15	18	24	30
9.0	233	218	198	182	172
13.6	283	250	227	207	186
18.0	301	288	260	225	211
22.6	340	319	271	254	250
27.0	364	341	295	269	268
31.7	382	355	327	291	316
36.0	406	370	341	320	319

TABLE 4. AVERAGE TIME GRID TEMPERATURE WAS ABOVE 150°C

Δt(sec) = Time above 150°C

	Separation Distance (Inches)				
Density (Grams/ft^2)	12	15	18	24	30
9.0	78	83	88	92	108
13.6	107	125	140	172	188
18.0	137	160	178	218	263
22.6	160	178	210	252	262
27.0	178	192	233	273	275
31.7	182	202	258	260	293
36.0	183	233	275	278	305

from these tables to illustrate the functional dependence of the criteria on density and sample separation. Figure 8 graphically illustrates the relationships of the mean effective temperature over the thermocouple grid with the density and sample separation. Figure 9 is a similar plot for the mean time above the minimum effective temperature. These figures can be used to describe the effectiveness of an actual SBR firebomb behavior by correlating the experimentally determined density and particle size with the corresponding combination from this study. The SBR fuel should be the same blend as that used in this program for the best correlation, but other thicknesses and hydrocarbon fuels should yield similar results.

A representative sample of the experiments was run at lowered temperatures. The results of these experiments indicated the behavior of the fuel at cold weather conditions. Table 5 compares these results with the ambient runs. The trends are the same with the only difference being an offset of the baseline approximately equivalent to the temperature differential between the ambient temperature and the lowered temperature. The ignition time was increased slightly which was to be expected since the samples had been cold-soaked.

OPTIMIZATION OF THE PARAMETERS

The general objective in any optimization is to choose a set of values of the independent variables, subject to various restrictions, which will produce the desired optimum response for the particular problem under examination. The purpose of this section is to explain the methods used to accomplish this objective from the experimental results given in the previous section. Tables 3 and 4 are matrices representing black box models of the system to be optimized. A black box model is defined as a model constructed by varying controlling parameters of a physical process and recording the results experimentally.[5]

The criteria on which the optimum is based was divided into two systems with competing influences. The area coverage is a decreasing function of density; that is, the area coverage decreases as the density increases. The mean effective temperature over the grid thermocouples increases as the density increases, therefore a system was considered for these opposing influences. An optimum density was found that would give the best combination of these criteria. The area coverage is independent of the sample separation. The functional relationship of the area coverage and the density is given by Table 6 and Figure 10. The second system consisted of the mean effective temperature and the mean time above the minimum effective temperature as the conflicting influences. This system was expressed as a function of sample separation for each density. The separation giving the best combination of these criteria was found for the optimum density.

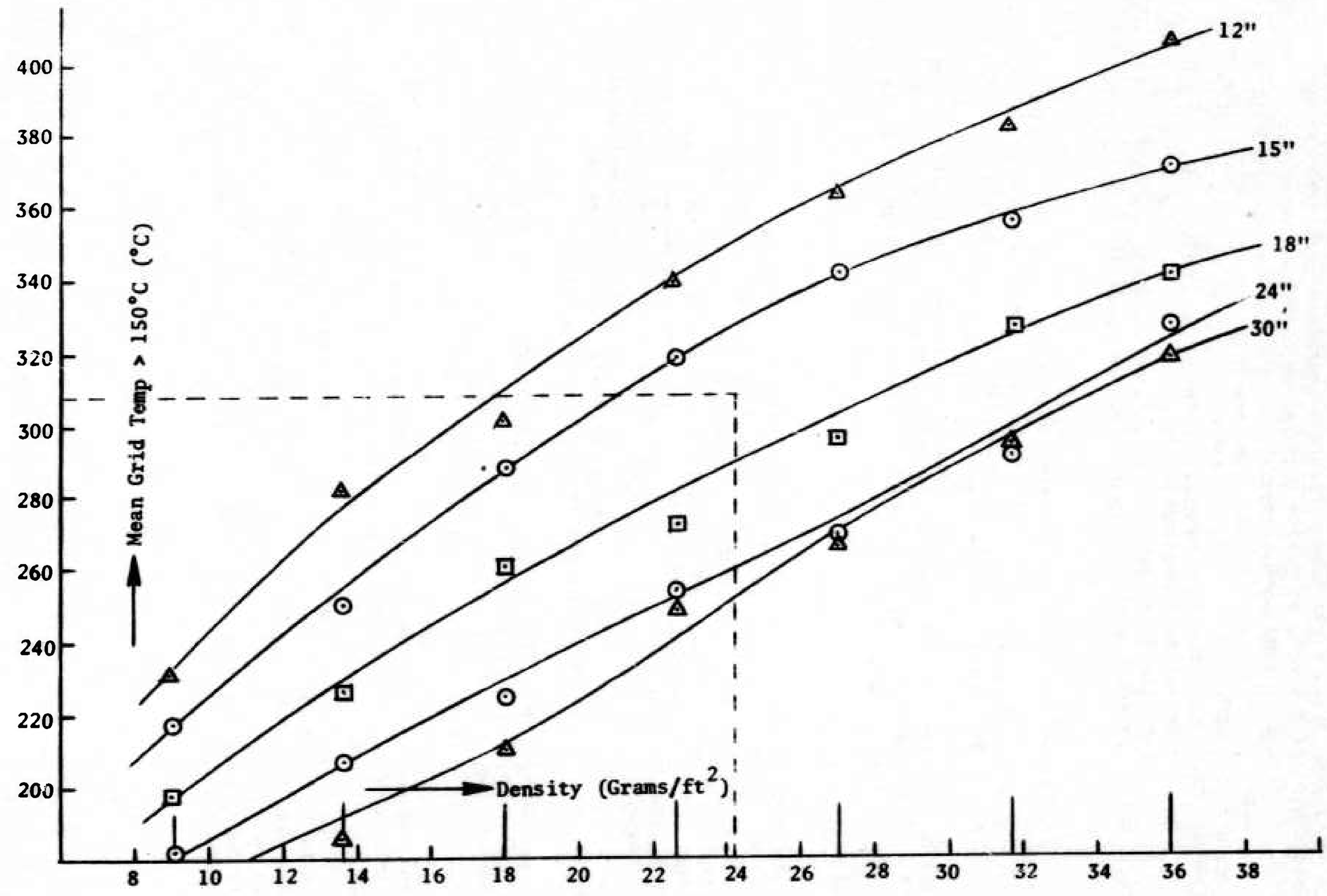


Figure 8. Mean Grid Temperature Above 150°C Versus Density

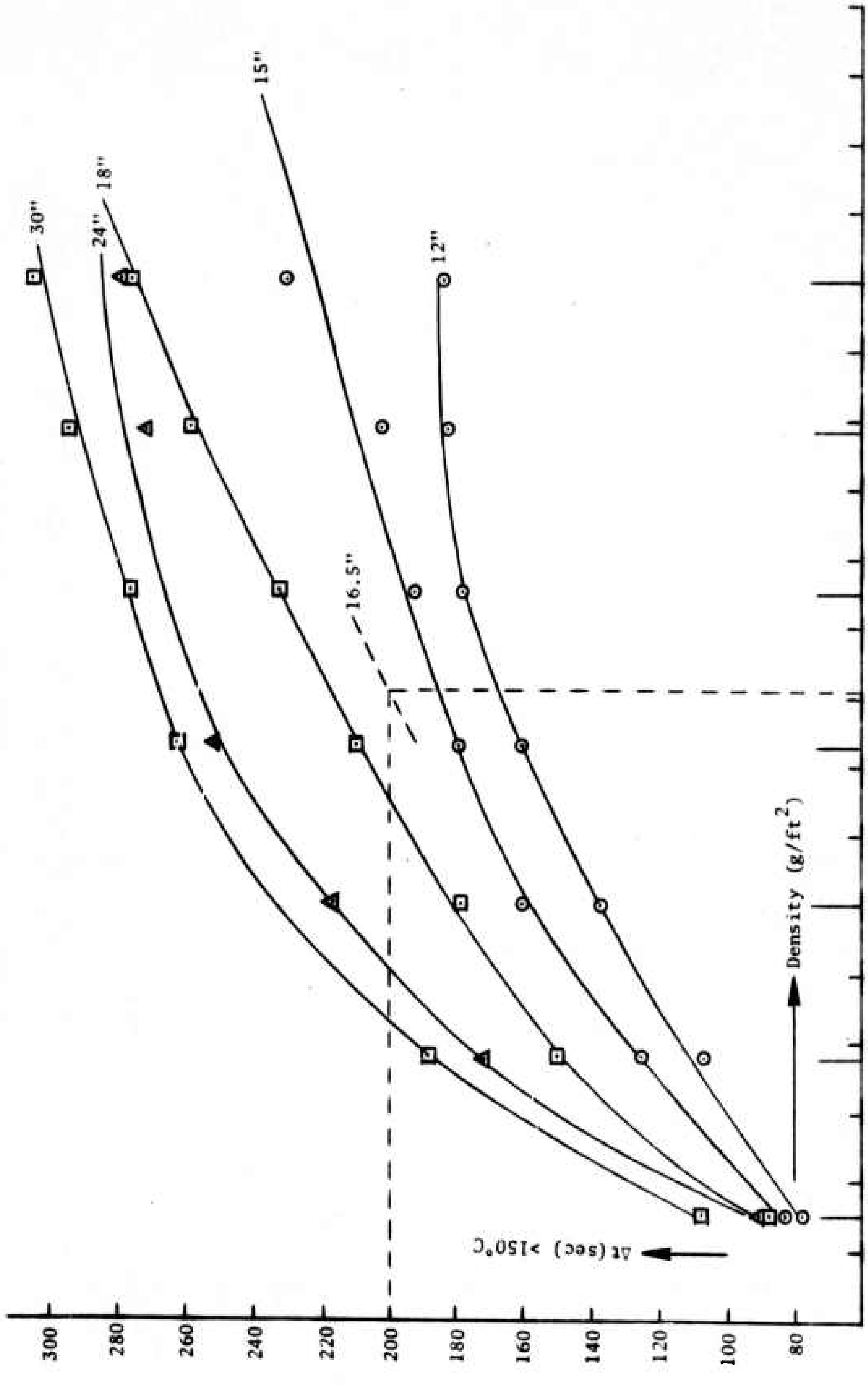


Figure 9. Mean Time Grid Above 150°C Versus Density

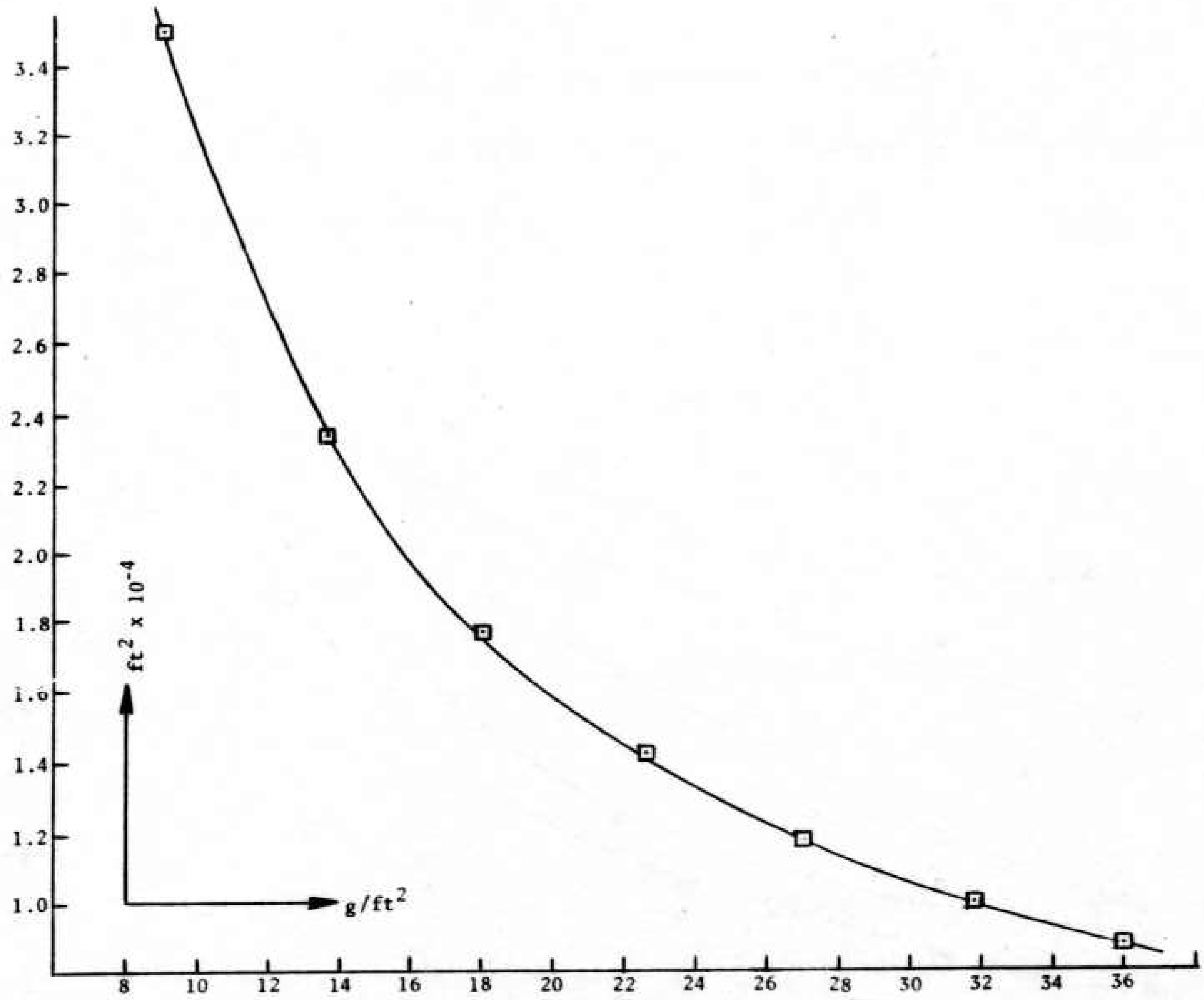


Figure 10. Area Coverage Versus Den

TABLE 5. COMPARISON OF LOWERED TEMPERATURES
TO AMBIENT FOR SPECIFIED
DENSITIES AND SEPARATION DISTANCES

Density	Separation Distance (Inches)			
	18	18	24	24
	Mean Grid Temp > 150°C	Mean Time > 150°C	Mean Grid Temp > 150°C	Mean Time > 150°C
22.6				
Ambient	271	210	247	252
0°C	256	222	214	282
27.0				
Ambient	295	233	245	293
0°C	248	272	205	323
31.7				
Ambient	326	256	343	230
0°C	280	300	249	268

TABLE 6. AREA COVERAGE VERSUS DENSITY (100-GALLON BOMB)

Density (Grams/ft^2)	Area Coverage (Ft^2)
9.0	3.5×10^4
13.6	2.34×10^4
18.0	1.77×10^4
22.6	1.41×10^4
27.0	1.18×10^4
31.7	1.00×10^4
36.0	0.883×10^4

The approach used to optimize the system of conflicting influences consisted of converting the data such that the two influences are measured on similar scales. This was accomplished by basing the criteria on the minimum and expressing the results graphically as the ratio of the minimum to the particular experimental results versus the independent variable.

The first system to be optimized was the area coverage and mean effective temperature versus density. The system was analyzed for several sample separations, and the final result was taken to be the average. Tables 7 and 8 express this system as two matrices with the indicators measured on similar scales. Each column represents the results for a particular separation distance. The same column of each matrix is plotted versus density on a common graph in Figures 11 and 12. The point of intersection should give the optimum density. This point represents the minimum ratio of the lowest experimental value of the mean effective temperature and also the mimimum ratio of the smallest area coverage to the area coverage. Therefore, the density at the particular point will give the maximum area coverage and the maximum mean effective temperature. The average over the various sample separations gave an optimum density of 24 grams per square foot (0.053 lb/ft^2).

The second system was used to optimize the sample separation. The competing influences were mean effective temperature and mean time above a minimum effective temperature. A matrix of each of the conflicting influences was constructed with the indicators based on the ratio of the minimum to the particular measurement. The matrices are given by Tables 9 and 10. These matrices were treated in the same manner as those of system 1. Common rows of each matrix were plotted versus sample separation on the same graphs. These graphs are given in Figures 13 to 18. The intersection of the curves occurred at the separation distance which gave the maximum mean effective temperature and maximum mean time above a minimum effective temperature. The average of the results obtained for the different densities was concluded to be the optimum sample separation. This result was 16.5 inches.

The optimum dissemination of a flame agent with physical properties similar to the SBR blend used in this study (or Napalm B) would give a mean density of 24 grams/ft^2 (0.053 lb/ft^2) over an area of 13,300 ft^2 with fuel particle separation averaging 16.5 inches. The mean particle size for this dissemination was found from Figure 19 to be 40 grams (0.088 lb). A theoretical relative effectiveness of this dissemination can be extracted from Figures 8 and 9 based on these parameters. This predicted effectiveness criteria for the experimental conditions of this study were a mean effective temperature of 300°C for a mean time of 200 seconds.

TABLE 7. MEAN EFFECTIVE TEMPERATURE BASED ON THE MINIMUM EXPERIMENTAL VALUE FOR EACH SEPARATION DISTANCE

	Separation (Inches)				
Density (Grams/ft^2)	30	24	18	15	12
9.0	1.0	1.0	1.0	1.0	1.0
13.6	0.92	0.88	0.87	0.87	0.82
18.0	0.81	0.81	0.76	0.76	0.77
22.6	0.69	0.72	0.73	0.68	0.68
27.0	0.60	0.68	0.67	0.69	0.64
31.7	0.54	0.55	0.61	0.61	0.61
36.0	0.54		0.58	0.60	

TABLE 8. AREA COVERAGE BASED ON THE MINIMUM AREA COVERED

Density (Grams/ft^2)	Minimum Area/Area
9.0	0.25
13.6	0.38
18.0	0.50
22.6	0.63
27.0	0.75
31.7	0.88
36.0	1.00

TABLE 9. MEAN EFFECTIVE TEMPERATURE BASED ON THE MINIMUM EXPERIMENTAL VALUE FOR EACH DENSITY

	Density (Grams/ft^2)						
Separation (Inches)	9	13.6	18	22.6	27	31.7	36
30	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	0.95	0.90	0.94	1.01	1.09	0.92	0.98
18	0.87	0.81	0.81	0.92	0.96	0.97	0.94
15	0.79	0.74	0.73	0.78	0.84	0.89	0.86
12	0.74	0.66	0.70	0.74	0.78	0.83	0.88

TABLE 10. MEAN TIME ABOVE 150°C BASED ON THE MINIMUM EXPERIMENTAL VALUE FOR EACH DENSITY

	Density (Grams/ft^2)						
Separation (Inches)	9	13.6	18	22.6	27	31.7	36
30	0.72	0.57	0.52	0.61	0.65	0.62	0.62
24	0.85	0.62	0.63	0.63	0.61	0.79	0.68
18	0.89	0.71	0.77	0.76	0.76	0.71	0.69
15	0.94	0.86	0.86	0.90	0.93	0.90	0.82
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00

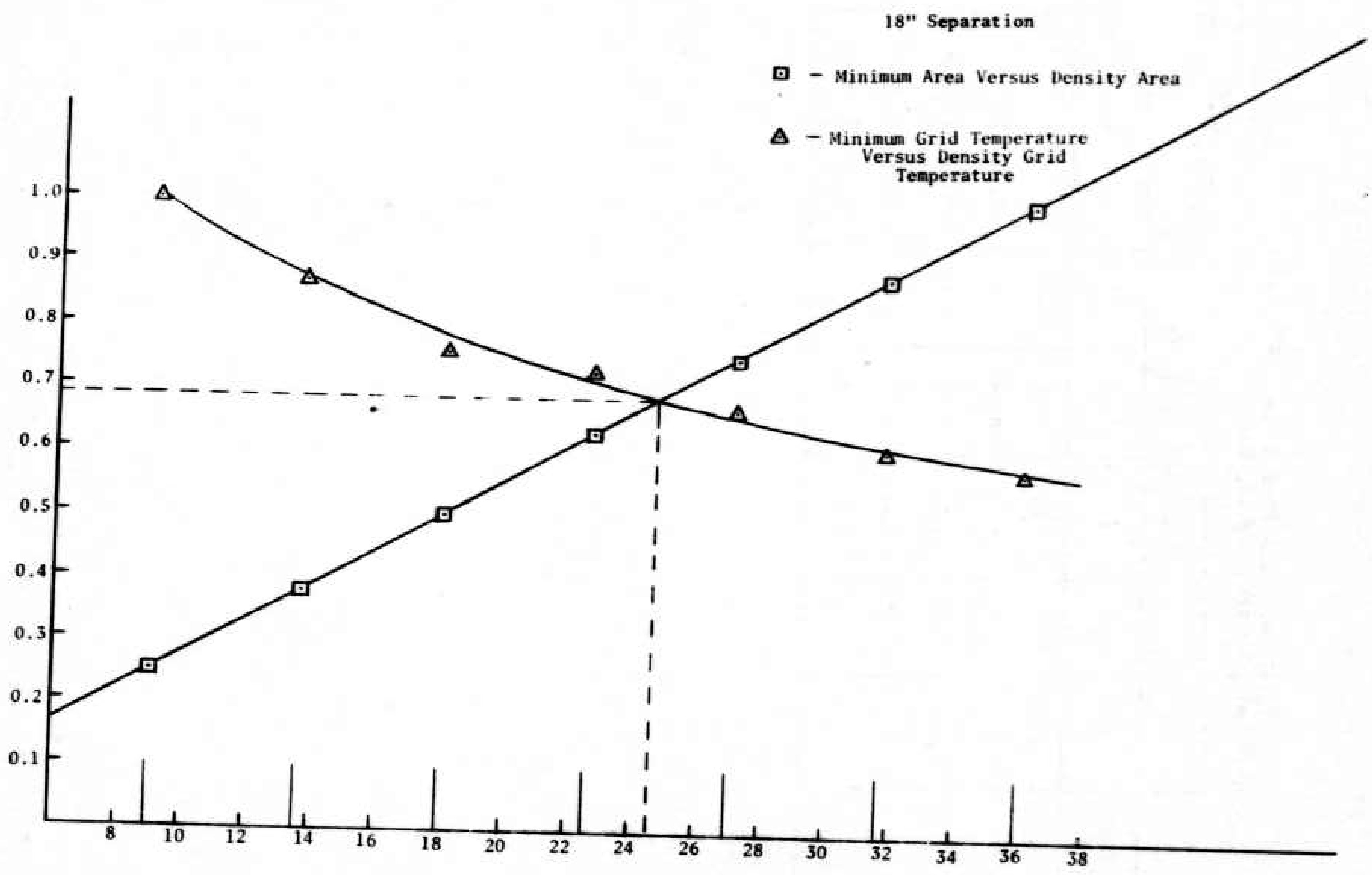


Figure 11. 18-Inch Separation With Area Coverage and Mean Effective Grid Temperature as the Competing Influences

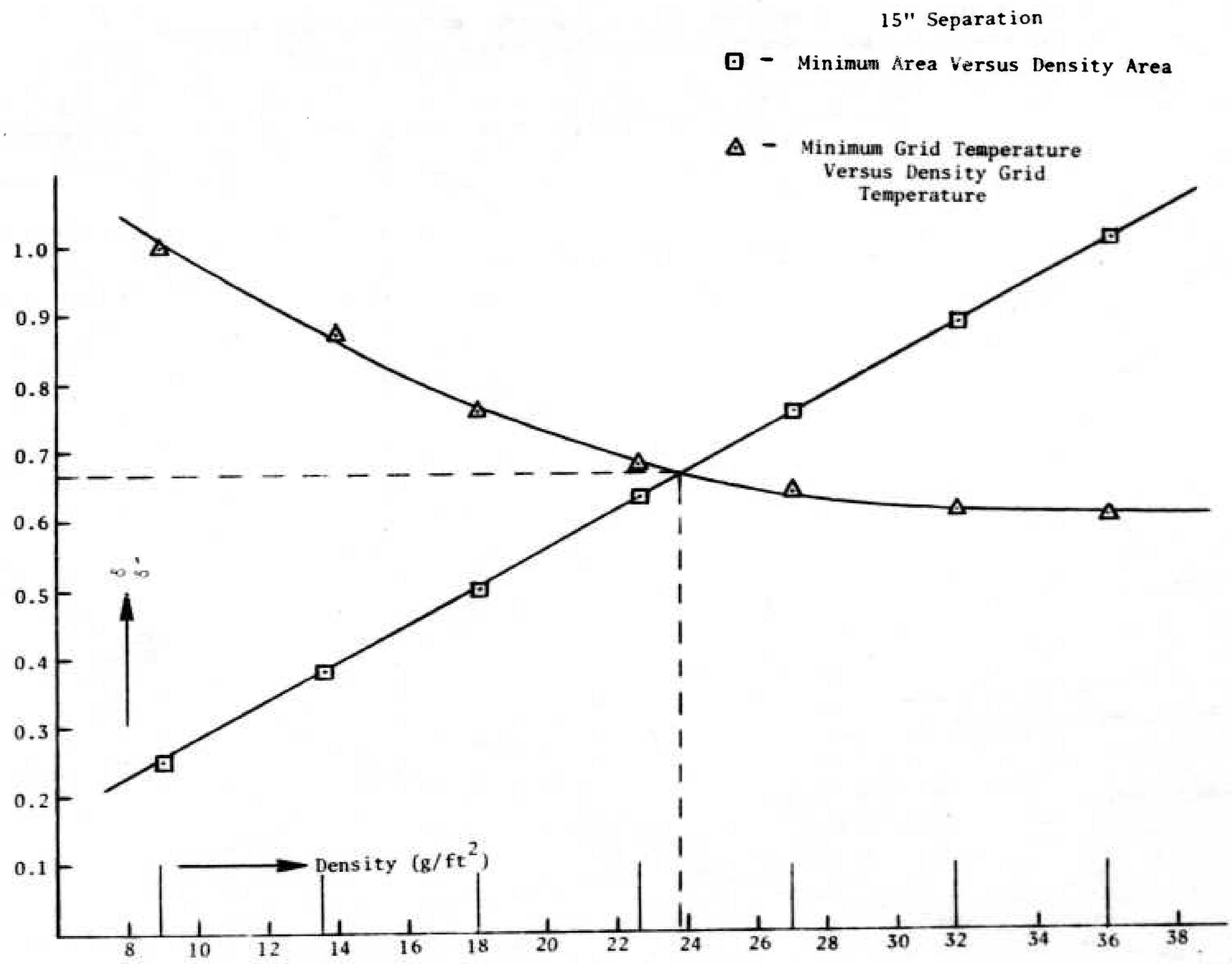


Figure 12. 15-Inch Separation With Area Coverage and Mean Effective Grid Temperature as the Competing Influences

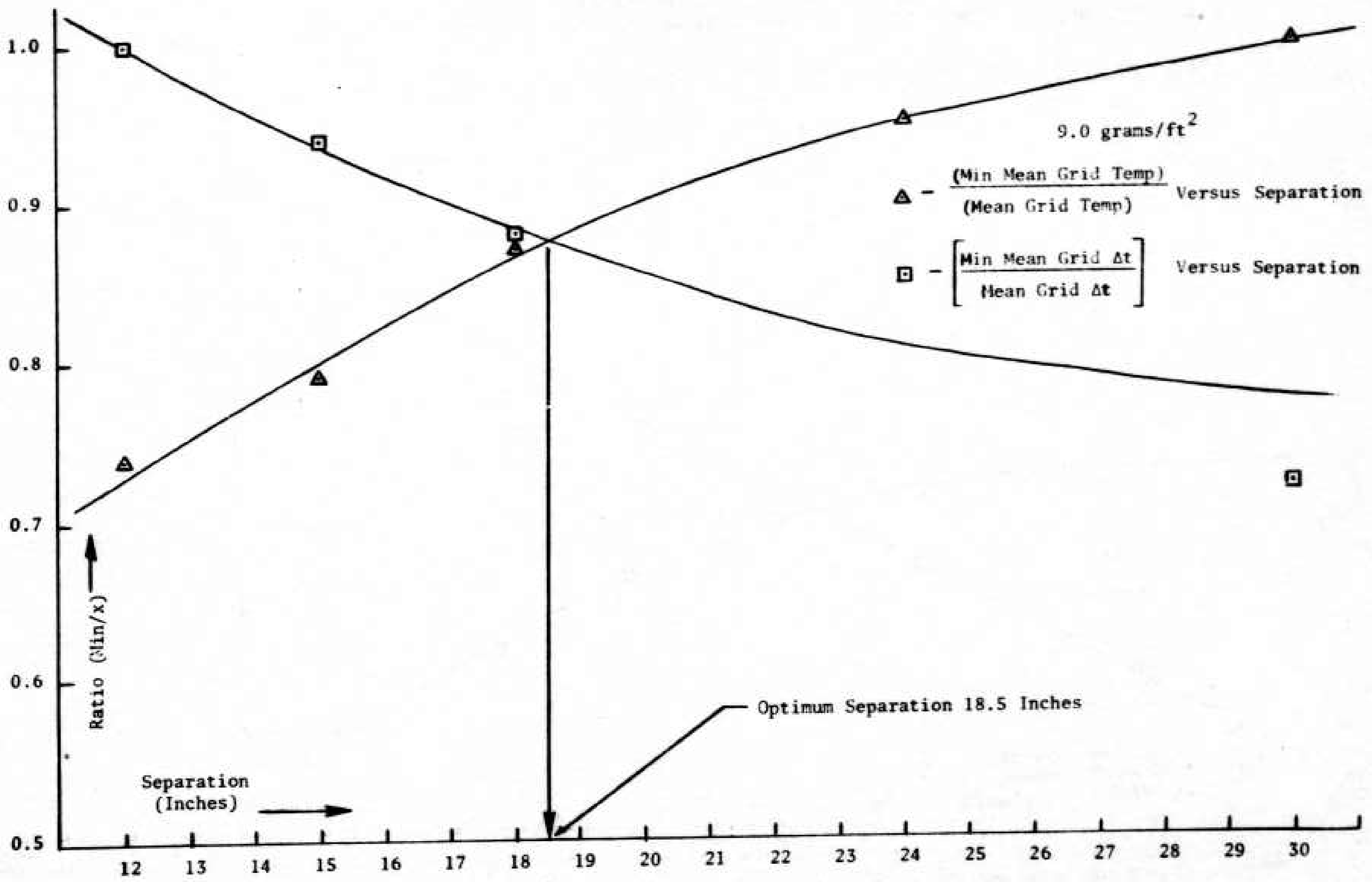


Figure 13. 9 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

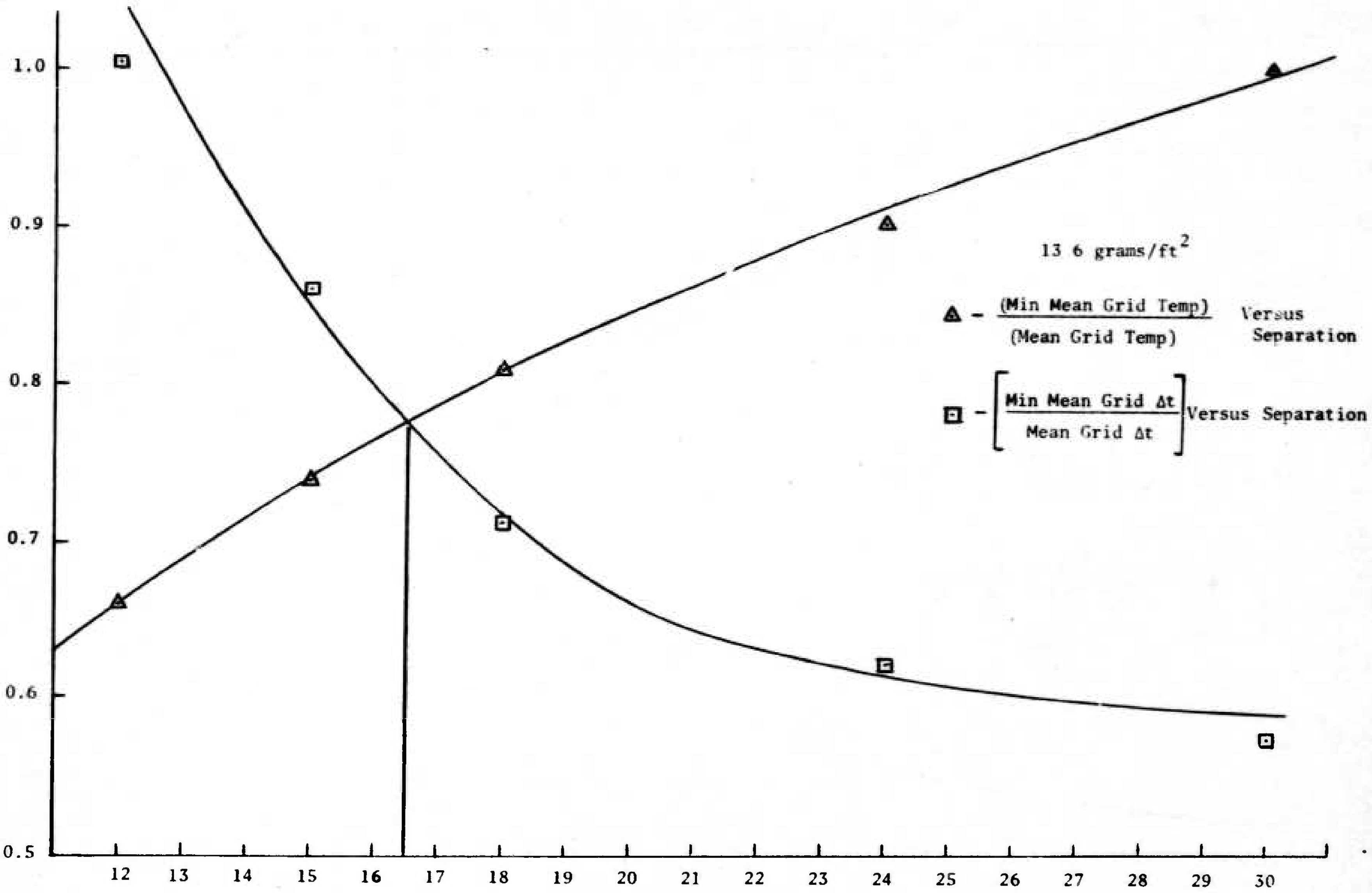


Figure 14. 13.6 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

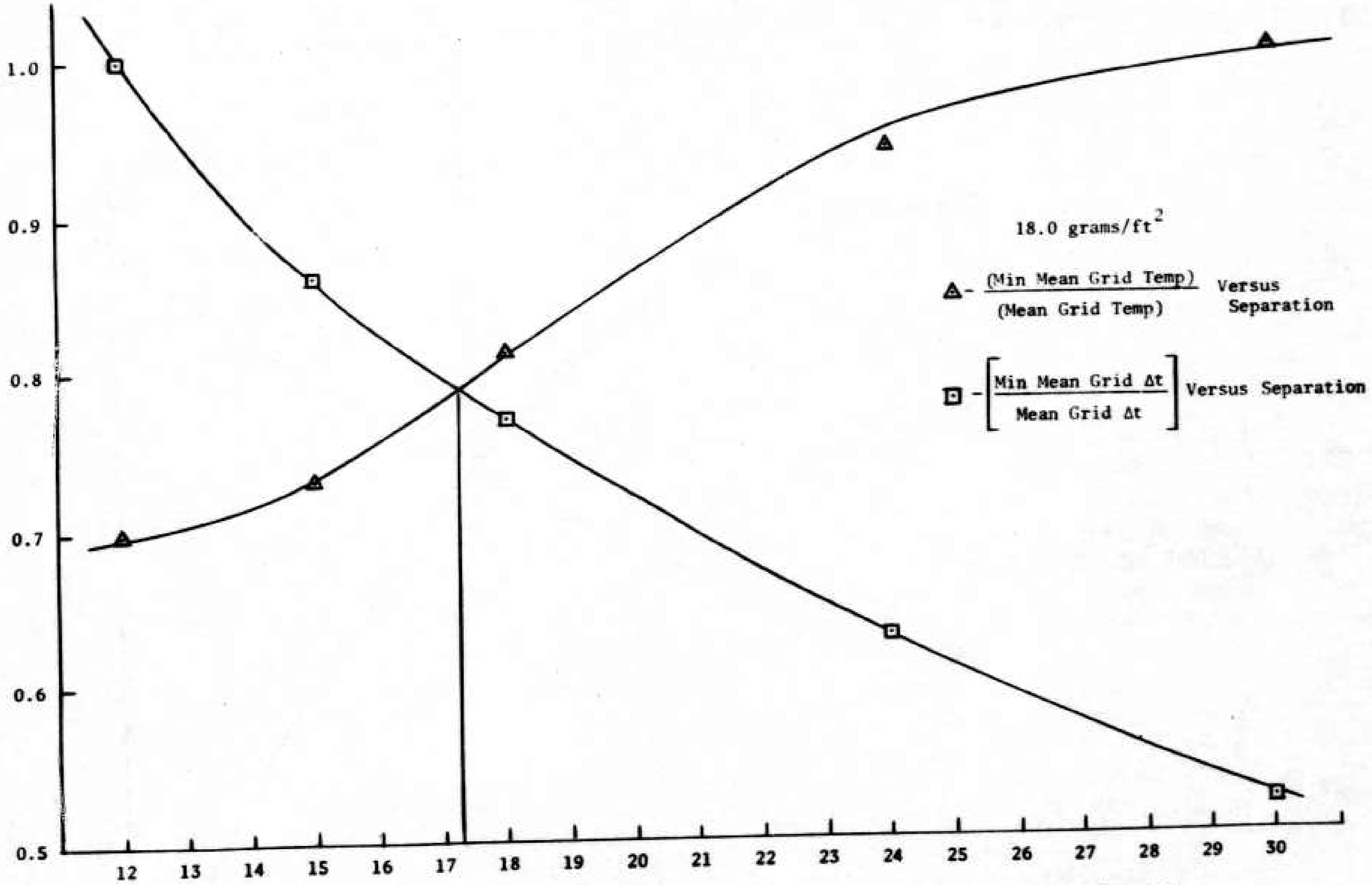


Figure 15. 18.0 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

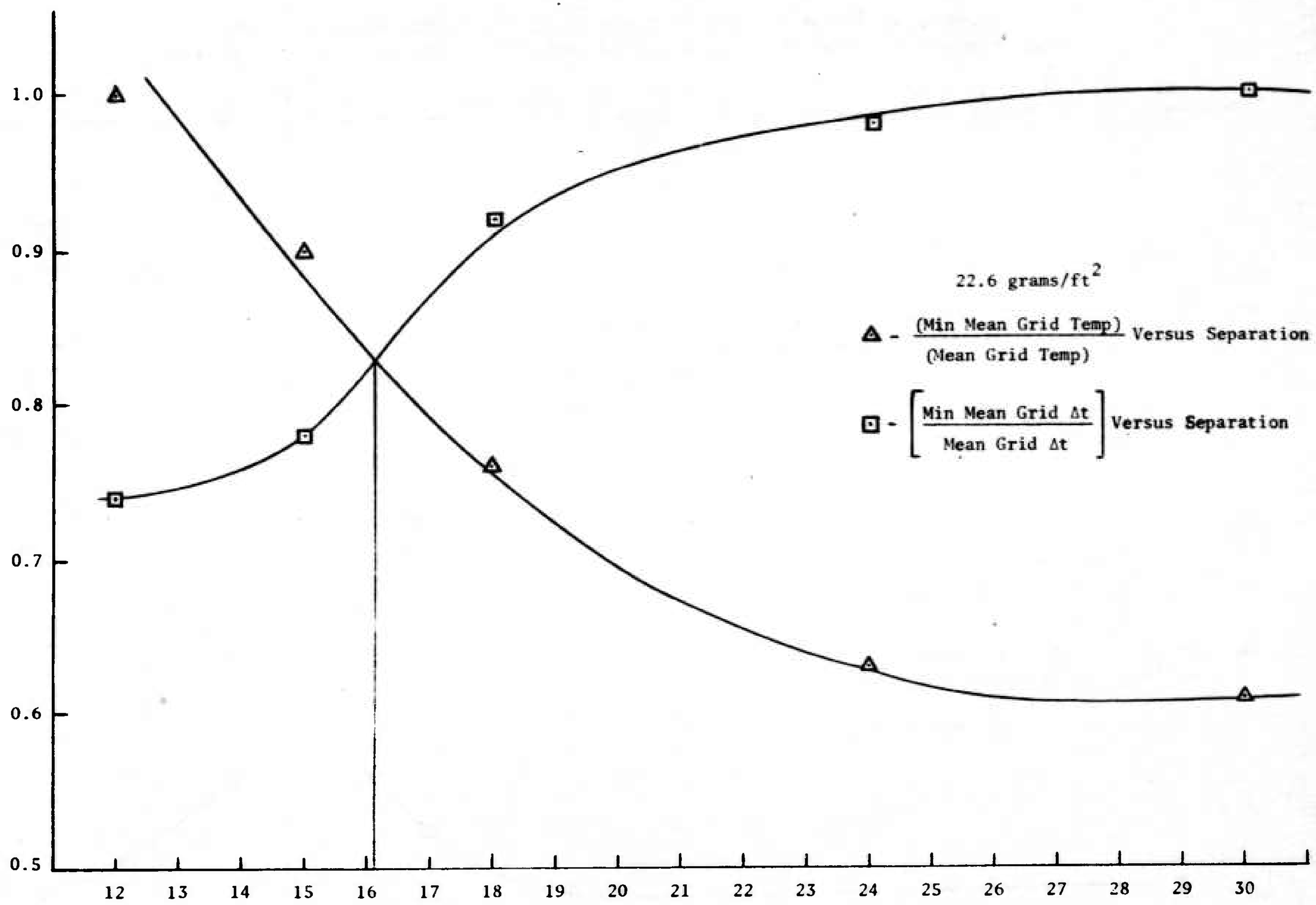


Figure 16. 22.6 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

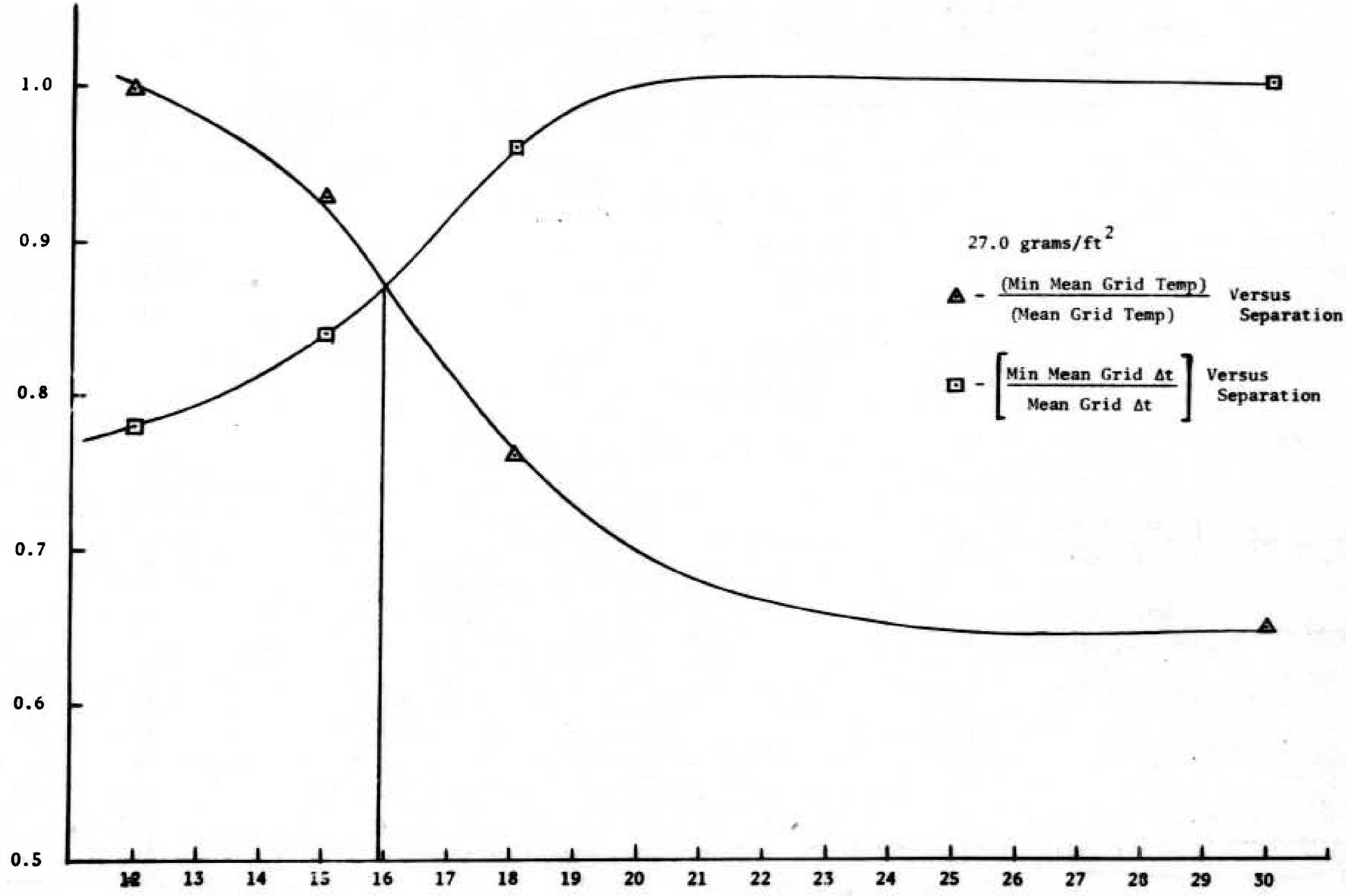


Figure 17. 27.0 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

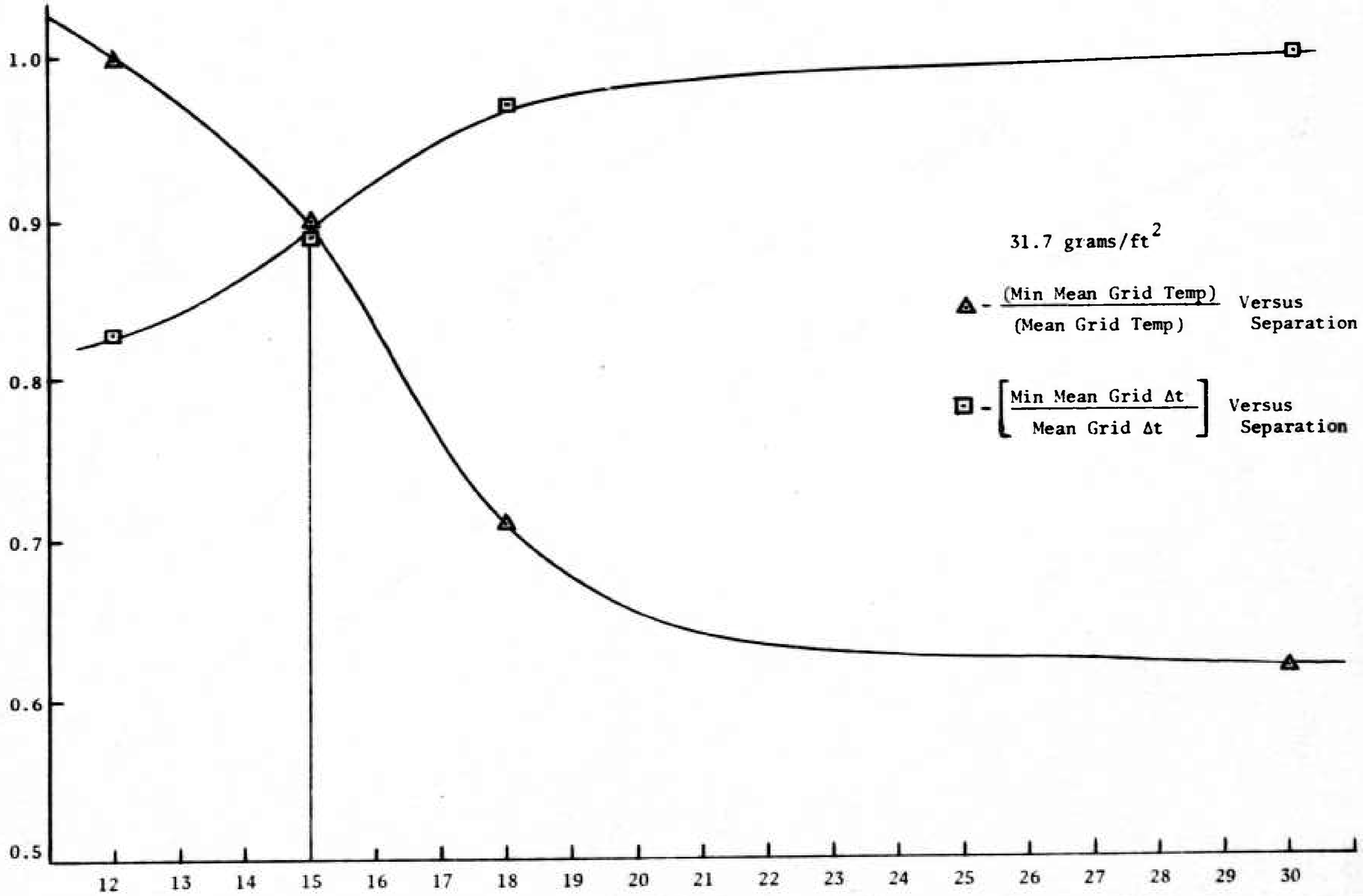


Figure 18. 31.7 Grams/Ft^2 With Mean Effective Grid Temperature and Mean Time the Grid Temperature was Above 150°C as the Competing Influences

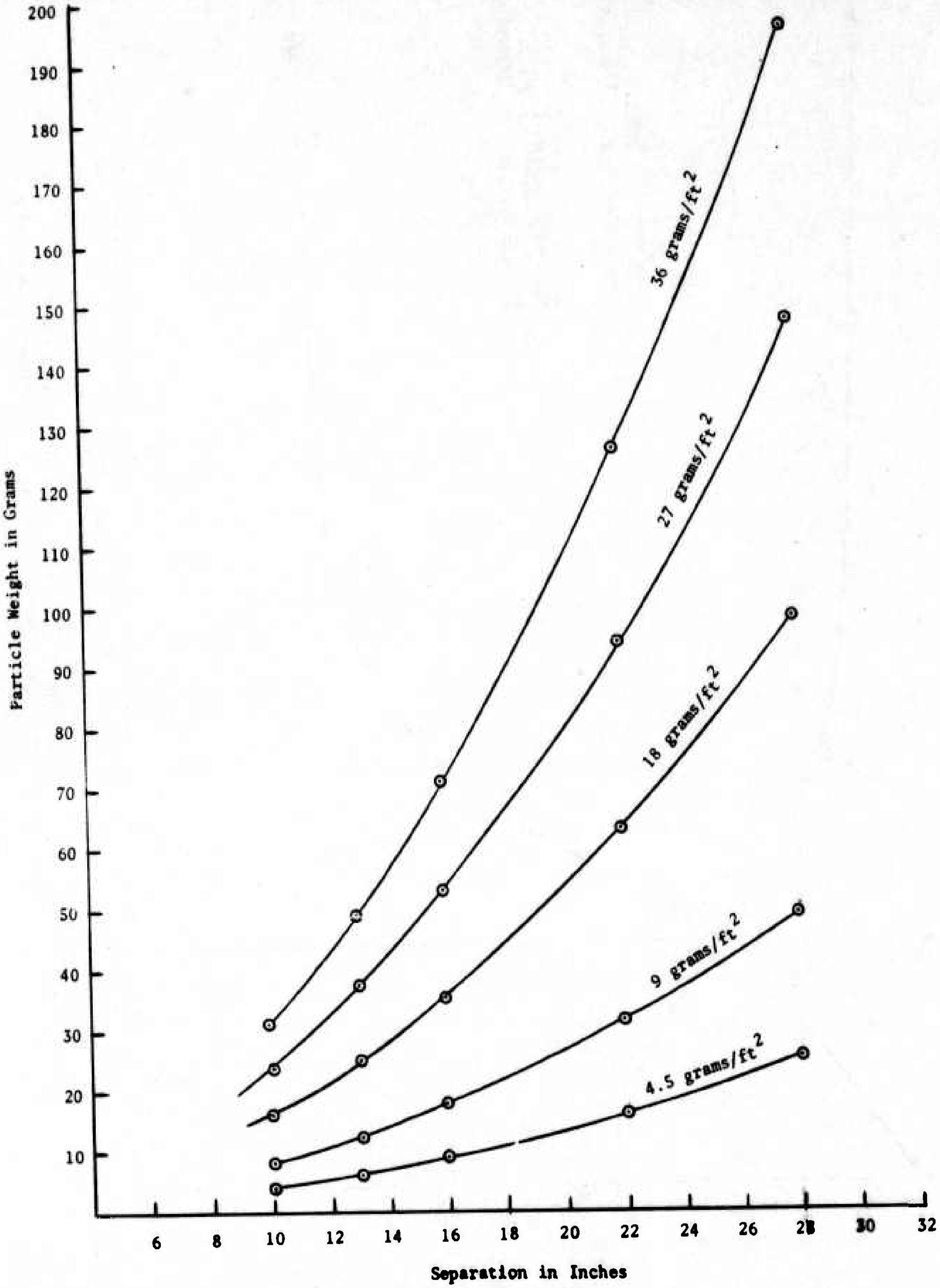


Figure 19. Particle Weight in Grams Versus Separation in Inches for all Densities

SECTION V

EXPERIMENTAL STUDY OF THE OPTIMIZED DISSEMINATION

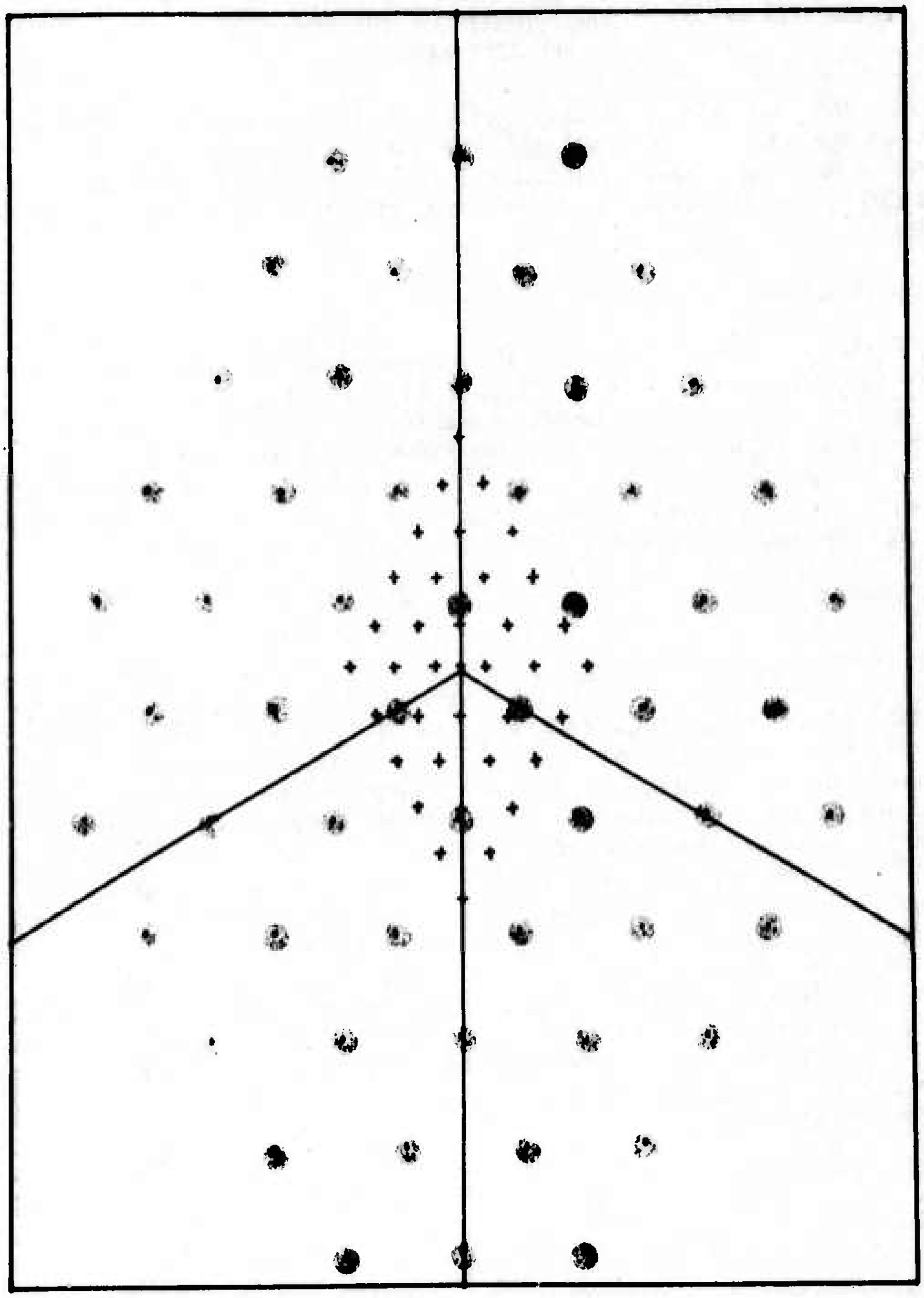
The theoretically predicted optimum dissemination was experimentally studied at the same conditions the data had been collected. This study served as a check on the model and the accuracy of the prediction. This section describes the study and discusses the overall results of this program.

ARRAY CONFIGURATION

Once the parameters defining the proposed optimum fire distribution had been determined an array of fires exhibiting these characteristics had to be constructed. The sample separation distance of 16.5 inches defined the size of the hexagon and the number of fires was based on the placement of the array on the thermocouple grid. The configuration of the hexagons was constructed according to Section II. The array representing the optimum fire distribution is given by Figure 20.

EXPERIMENTAL RESULTS

The theoretical optimum was experimentally checked at ambient and two lower temperatures. The ambient results were compared to the predicted ambient effectiveness from the model. Table 11 gives the averaged results of three experimental runs at each temperature and the theoretical ambient values. Figure 21 compares the results of the three temperatures. The predicted values were almost the same as the actual results of the experiments. The mean effective temperature predicted by the model was 300°C, and the average of three experimental runs was 299°C. The mean time above the minimum effective temperature predicted was 200 seconds, and the actual value obtained from the three runs was 194 seconds. The closeness of these values indicated that the model was well represented by the data collected. While these results are unique to the physical conditions of these experiments and cannot be applied directly to dynamic situations, the technique and results give excellent relative data for the screening of possible dissemination patterns and firebomb effectiveness studies.



+ Thermocouples

● Fires

Scale 1" = 2'

Figure 20. Optimum Fire Array Geometry

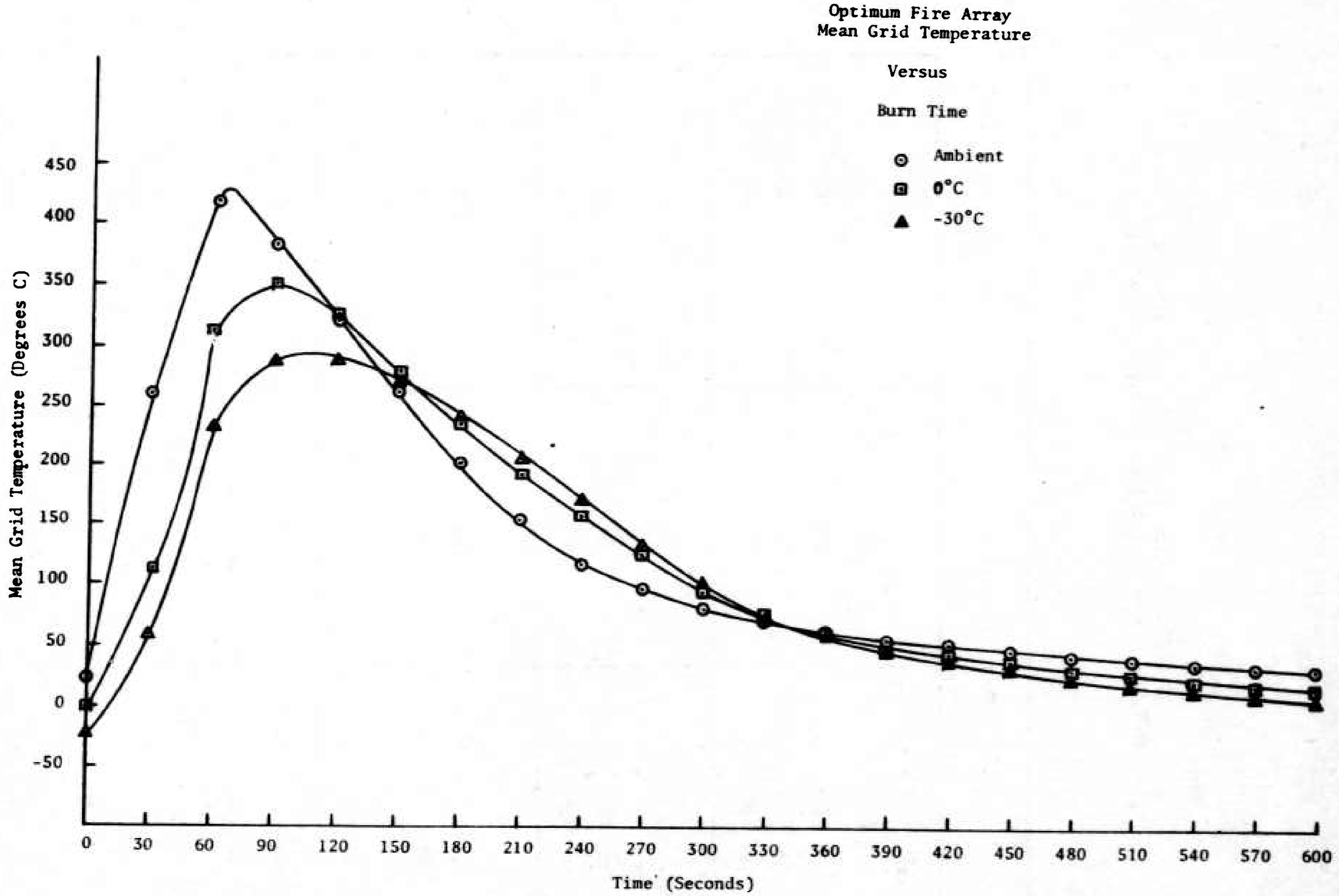


Figure 21. Optimum Fire Array Experimental Results

TABLE 11. EXPERIMENTAL RESULTS OF THE OPTIMUM ARRAY AT THREE DIFFERENT TEMPERATURES

	Mean Temperature Above 150°C (Degrees C)	Mean Time Above 150°C (Seconds)
Ambient		
Run #1	309	186
Run #2	298	210
Run #3	291	186
Average	299	194
0°C		
Run #1	261	210
Run #2	274	210
Average	268	210
-30°C		
Run #1	231	210
Run #2	251	215
Run #3	247	210
Average	243	212
Predicted Ambient	300	200

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1. Long, R. L., Flame Agents for High Velocity/Low Temperature Use, Air Force Armament Laboratory Technical Report AFATL-TR-71-55, Monsanto Research Corporation, May 1971.

2. Long, R. L., Improved Flame Agents, Air Force Armament Laboratory Technical Report AFATL-TR-72-177, Monsanto Research Corporation, September 1972.

3. Rigdon, V. B. Jr., Interim Report on Dynamic Test of Dissemination/Ignition Devices and Flame Agents for Firebombs, Armament Development and Test Center Technical Report ADTC-TR-73-107, December 1973.

4. Nickel, J. A., and Palmer, J. D., Criteria for Casualty Production and Preliminary Flame Pattern Analysis, TM-1454-1-1, University of Oklahoma Research Institute, September 1964.

5. Beveridge, G.S.G., and Schechter, R. S., Optimization: Theory and Practice, McGraw-Hill, 1970.

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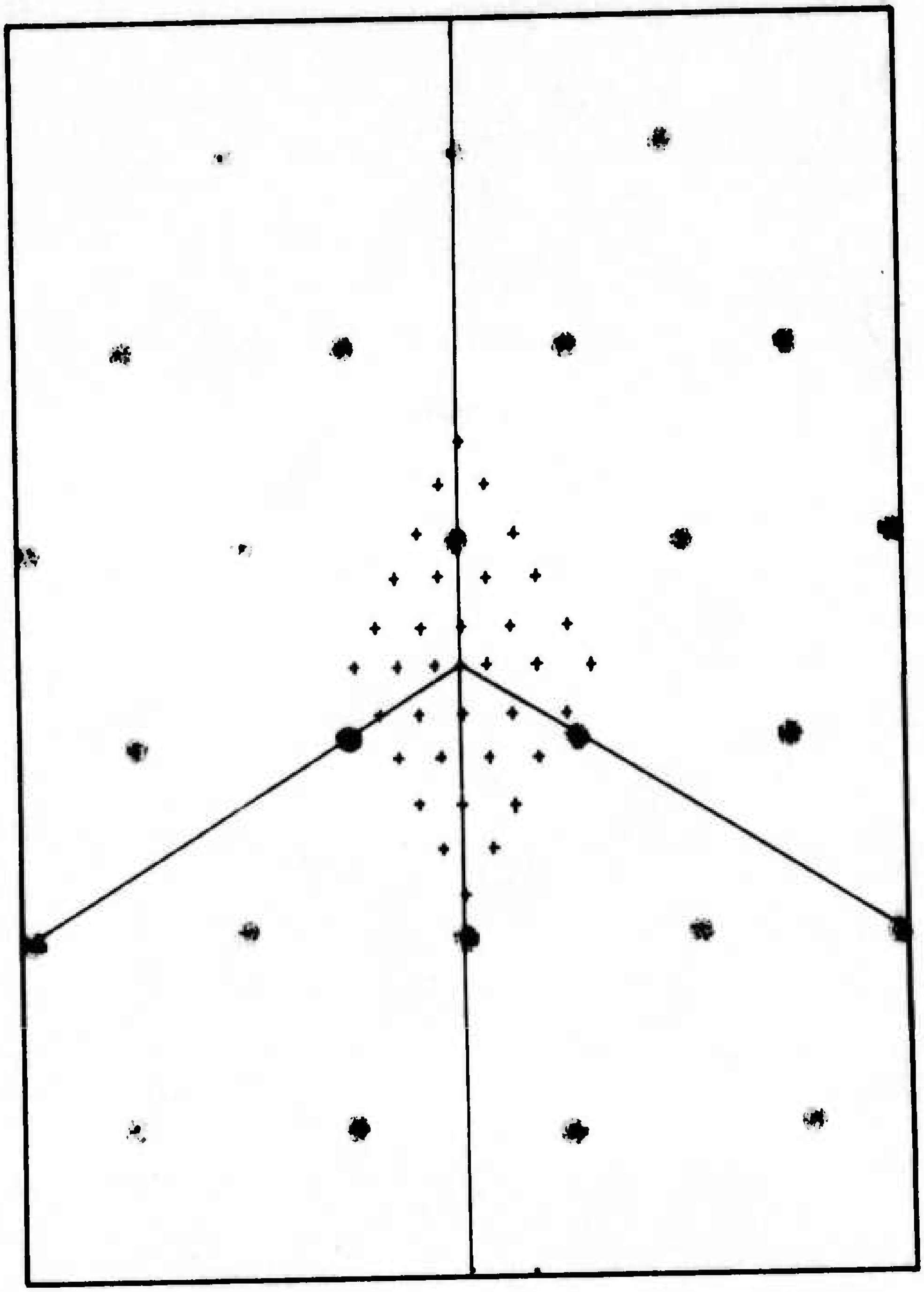
APPENDIX A

FIRE ARRAYS

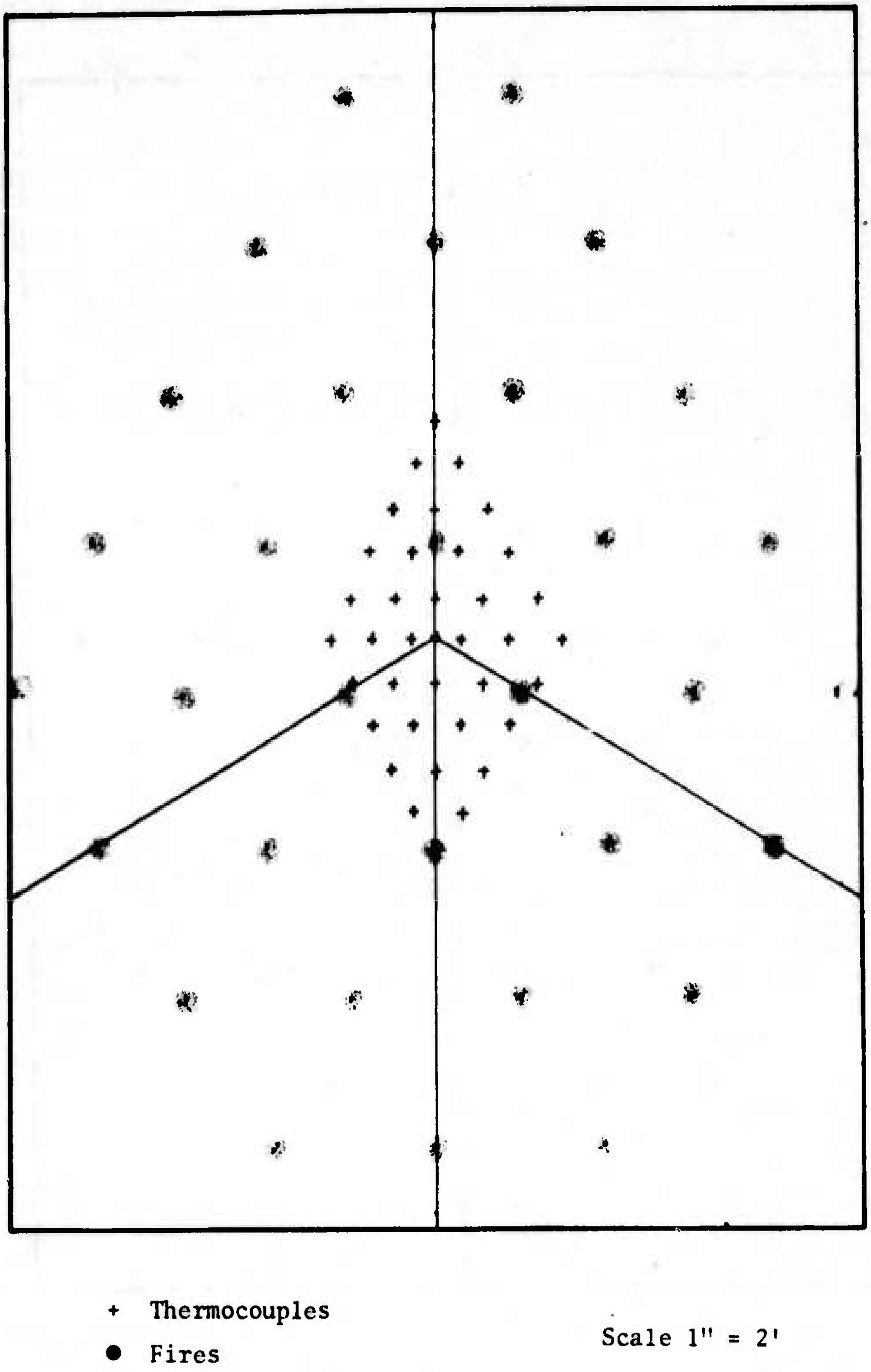


\+ Thermocouples

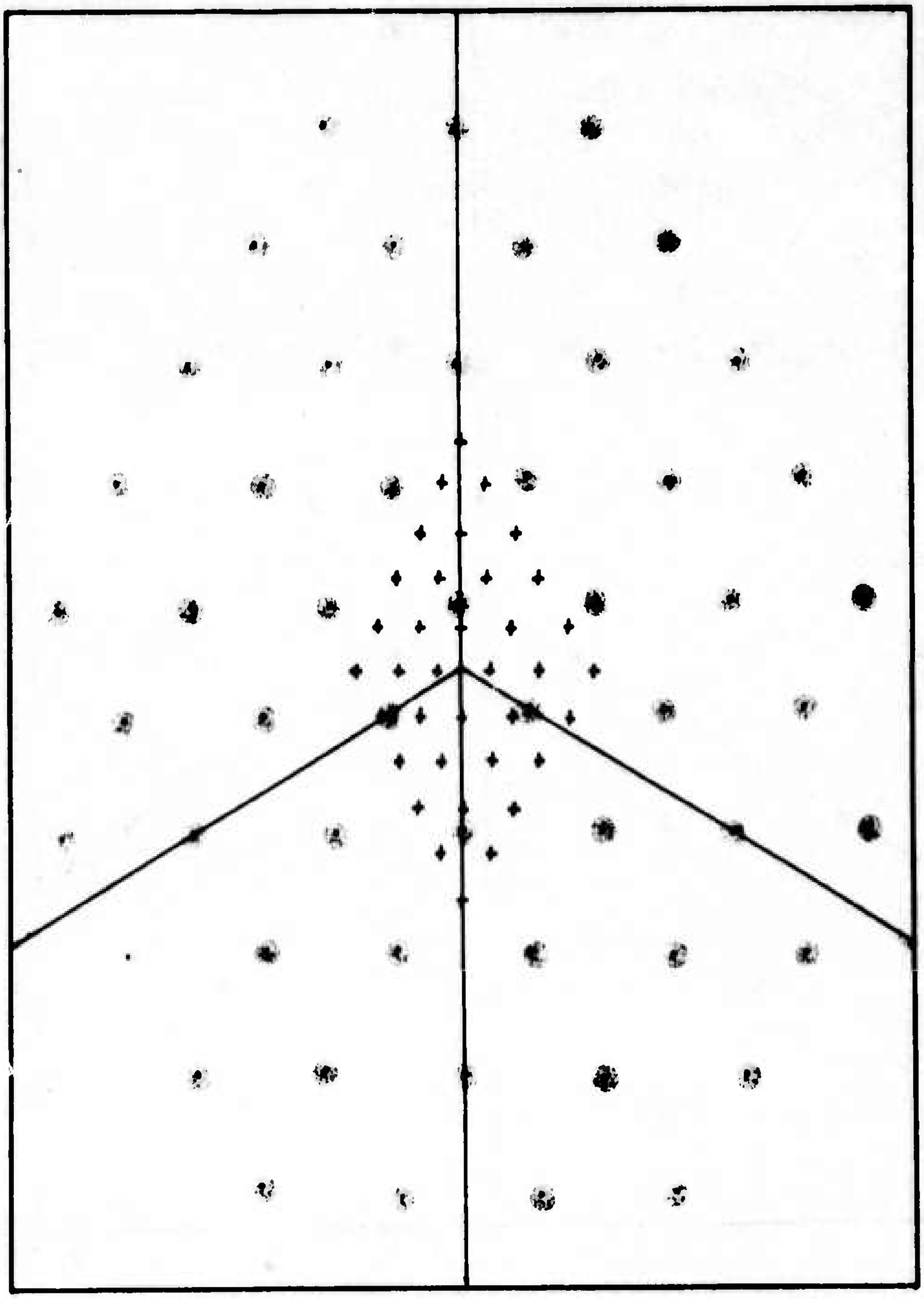
● Fires

Scale 1" = 2'

Separation Distance 2.5 Feet With 25 Fires



Separation Distance 2.0 Feet With 32 Fires

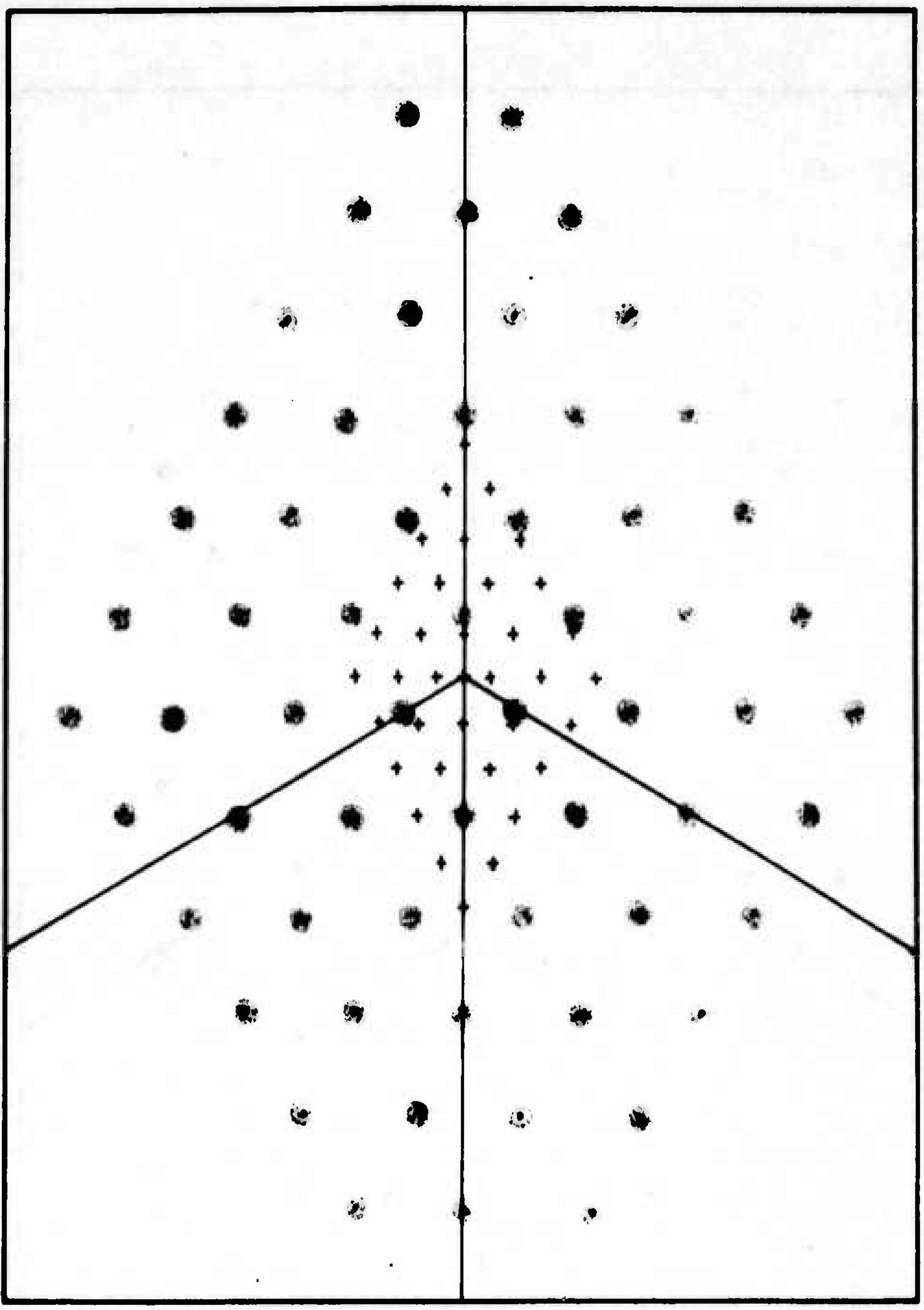


+ Thermocouples

● Fires

Scale 1" = 2'

Separation Distance 1.5 Feet With 53 Fires

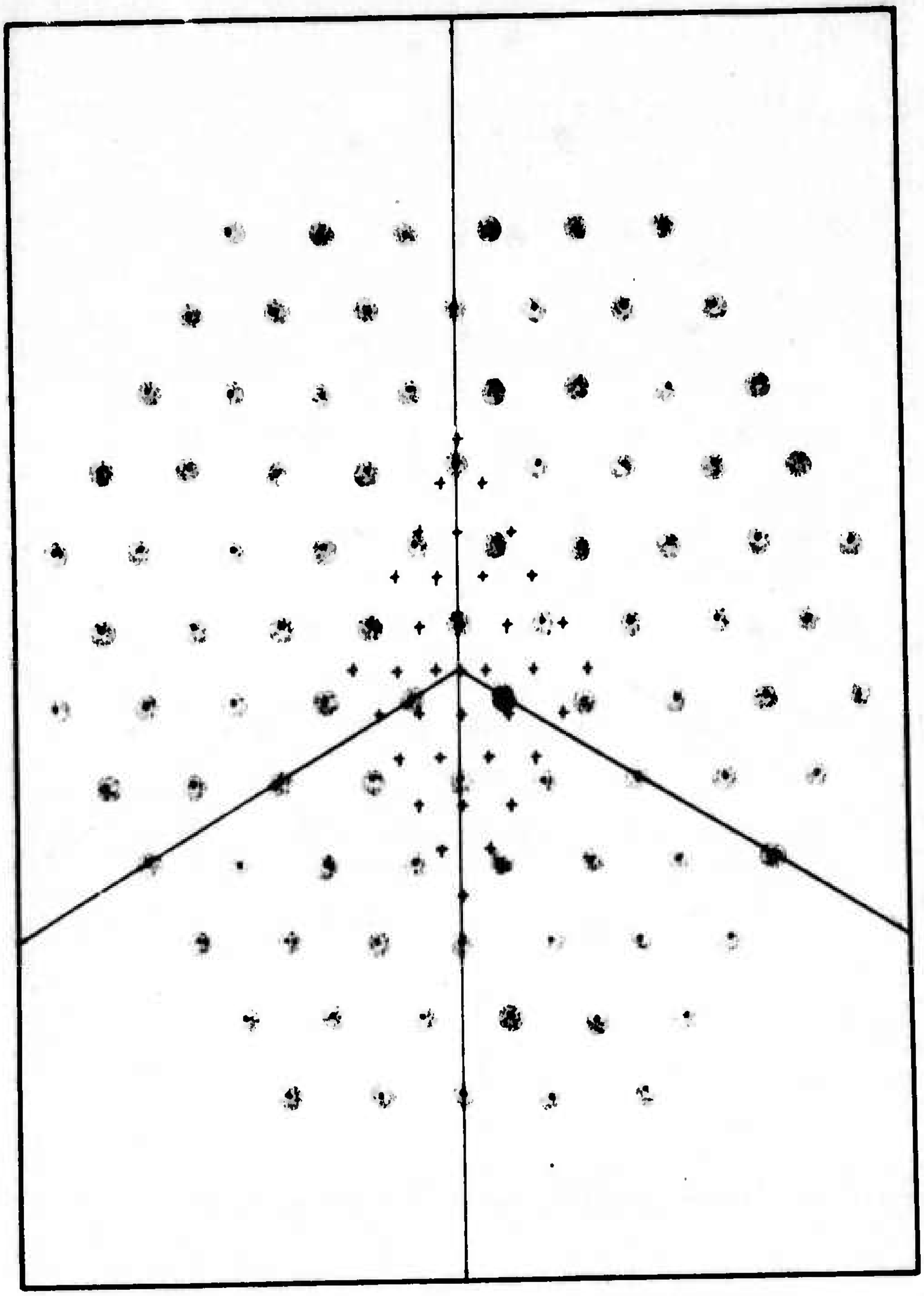


+ Thermocouples

● Fires

Scale 1" = 2'

Separation Distance 1.25 Feet With 63 Fires



+ Thermocouples
● Fires

Scale 1" = 2'

Separation Distance 1.0 Feet With 96 Fires

APPENDIX B

COMPUTER PROGRAM FOR REDUCTION OF DATA

```
      PROGRAM PSDS(INPUT=129,OUTPUT=129,TAPE1,TAPE2,TAPE5=INPUT,TAPE6=OU
     1TPUT)
      COMMON RAW(240),IARRAY(24,50),ARRAY(120,48),NARR(80),GRAPH(852)
      DIMENSION JARRAY(20,50),MTAB(2401),NSCALE(5),TIME(120),NNBG(6)
      EQUIVALENCE(IARRAY(1,1),JARRAY(1,1))
      DATA MTAB/1200*(-2,10),0/,NSCALE/1,4*0/
C
C NUTAP3 IS A CODE INDICATING WHETHER A NEW TAPE IS TO BE USED FOR WRITING OUT
C DATA TO BE SAVED.  IF A NEW TAPE IS USED A NUMBER MUST BE PUNCHED IN THE FIRST
C TWO COLUMNS OF THE FIRST CARD.  IF AN OLD TAPE IS USED, THE FIRST CARD SHOULD
C BE BLANK OR HAVE A ZERO IN THE SECOND COLUMN.  THIS WILL INITIATE A SEARCH FOR
C A DOUBLE END OF FILE INDICATING THE END OF PREVIOUS DATA.  ONCE FOUND IT BACK-
C SPACES TO REMOVE ONE EOF AND IS READY TO WRITE.
C
      READ(5,9000) NUTAP3
 9000 FORMAT(I2)
      IF(NUTAP3.NE.0) GO TO 975
  900 ASSIGN 910 TO MEOF
      CALL EOF(MEOF)
      DO 950 M=1,95
      READ(3,9010)DUMMY
 9010 FORMAT(A10)
      GO TO 950
  910 ASSIGN 920 TO MEOF
      READ(3,9010) DUMMY
      GO TO 900
  920 BACKSPACE 3
      GO TO 975
  950 CONTINUE
C
C THE SECOND CARD READ CONTAINS THE TEMPERATURE COEFFICIENT, TCOEF, FOR
C CONVERSION OF MILLIVOLTS TO DEGREES C AND THE LENGTH OF THE NARRATIVE,NARR.
C ANY THERMOCOUPLE WIRE AND ITS COEFFICIENT MAY BE USED, BUT ALL 44 CHANNELS
C MUST USE THE SAME WIRE.  LENGTH IS THE NUMBER OF CARDS USED FOR NARR TIMES
C EIGHT.  UP TO TEN CARDS MAY BE USED.
C
```

```
  975 READ(5,9020) TCOEF,LENGTH
 9020 FORMAT(F4.2,I3)
      READ(5,9025) (NARR(I),I=1,LENGTH)
 9025 FORMAT(8A10)
C
C WRITE THE NARRATIVE ON BOTH THE PRINTER AND TAPE3 FOR FUTURE REFERENCE.
C
 9029 FORMAT(I3)
      WRITE(6,9999)
 9999 FORMAT(1H1,A10)
      WRITE(6,9030)(NARR(I),I=1,LENGTH)
 9030 FORMAT(1X,8A10)
 9035 FORMAT(13A10)
C
C CALL THE TAPERR FUNCTION TO WATCH FOR PARITY ERRORS AND ASSIGN CONTROL TO
C STATEMENT NUMBER 1110.
C
      ASSIGN 1110 TO ITAPE
      CALL TAPERR(ITAPE)
      ASSIGN 1390 TO MEOF
      CALL EOF(MEOF)
C
C INITIALIZE THE NUMBER OF CHANNELS, NUM, TO BE READ FROM TAPE AS 24, AND THE
C NUMBER OF WORDS, NNUM, TO BE READ AS 240.  NOW READY TO READ PYRO LAB TAPE.
C
      NUM=24
      NNUM=240
C
C READ DATA FROM TWO TAPES.
C
      DO 1400 L=1,2
C
C READ 120 RECORDS FROM EACH TAPE.  EACH RECORD CONTAINS A FIVE SECOND INTERVAL.
C
      DO 1300 ITIME=1,120
      ICT=0
```

```
C
C REESTABLISH THE COUNT AS 24 CHANNELS ALREADY READ WHEN READING TAPE2.
C
      IF(L.NE.1) ICT=24
C
C READ THE TAPE USING THE CORRECT NUMBER, NNUM, OF WORDS IN RAW AND UNPACK TAPE.
C
      READ(L) (RAW(K),K=1,NNUM)
      CALL UNPACK(RAW,MTAB,IARRAY(1,1))
C
C AVERAGE EACH CHANNEL CVER THE ENTIRE RECORD(5 SECONDS) AND CONVERT TO DEGREES
C C. THIS VALUE IS TREATED AS THE TEMPERATURE AT THE BEGINNING OF THE INTERVAL.
C
      DO 1100 IM=1,NUM
      ICT=ICT+1
      HOLD=0.0
      DO 1000 J=1,50
      IF(L.NE.1) GO TO 990
      HOLD=HOLD+(FLOAT(IARRAY(IM,J)))/10.24
      GO TO 1000
  990 HOLD=HOLD+(FLOAT(JARRAY(IM,J)))/10.24
 1000 CONTINUE
      ARRAY(ITIME,ICT)=(HOLD/50.0)*TCOEF
      IF(ICT.GT.40) APRAY(ITIME,ICT)=ARRAY(ITIME,ICT)/2.0
 1100 CONTINUE
      GO TO 1300
C
C IF A PARITY ERROR IS ENCOUNTERED THE VALUE CF EACH CHANNEL IS SET EQUAL TO ITS
C VALUE IN THE PRECEEDING TIME INTERVAL.  IF THE ERROR OCCURS IN THE FIRST
C RECORD, THAT RECORD IS GIVEN THE VALUE 0.0.
C
 1110 WRITE(6,9040)
 9040 FORMAT(1X)
      ASSIGN 1115 TO ITAPE
      KOUNT=0
 1115 DO 1200 IN=1,NUM
```

```
      ICT=ICT+1
      IF(ITIME.NE.1) GO TO 1120
      ARRAY(ITIME,ICT)=0.0
      GO TO 1200
 1120 II=ITIME-1
      ARRAY(ITIME,ICT)=ARRAY(II,ICT)
 1200 CONTINUE
C
C THE NUMBER OF PARITY ERRORS ARE COUNTED, AND THE TIME INTERVAL IN WHICH AN
C ERROR OCCURS IS PRINTED OUT.
C
      KOUNT=KOUNT+1
      WRITE(6,9045) ITIME
 9045 FORMAT(1X,19HPARITY ERROR IN THE,I4,16HTH TIME INTERVAL)
 1300 CONTINUE
C
C NUM, NNUM, AND MTAB(2001) ARE REINITIALIZED TO READ THE SECOND TAPE CONTAINING
C ONLY TWENTY CHANNELS.
C
      NUM=20
      NNUM=200
      MTAB(2001)=0
 1390 WRITE(6,9199) L,ITIME
 9199 FORMAT(1H0,17HEOF FOUND ON TAPE,I3,10HRECORD NO.,I4)
 1400 CONTINUE
      READ(5,9200) NBG,NBF,NBR
 9200 FORMAT(3I2)
      IF(NBG.EQ.0) GO TO 1405
      READ(5,9210) (NNBG(I),I=1,NBG)
 9210 FORMAT(40I2)
      DO 1404 KLUX=1,NBG
      KLAN=NNBG(KLUX)
      DO 1403 KLU=1,120
      ARRAY(KLU,KLAN)=0.0
 1403 CONTINUE
 1404 CONTINUE
 1405 FNTC=37.0-FLOAT(NBG)
```

```
      IF(NBF.EQ.0) GO TO 1410
      READ(5,9210) (NNBG(I),I=1,NBF)
      DO 1409 KLAX=1,NBF
      KLIX=NNBG(KLAX)
      DO 1408 KLOX=1,120
      ARRAY(KLOX,KLIX)=0.0
 1408 CONTINUE
 1409 CONTINUE
 1410 FNTCF=3.0-NBF
      IF(NBR.EQ.0) GO TO 1420
      READ(5,9210) (NNBG(I),I=1,NBR)
      DO 1415 KLANG=1,NBR
      KLONG=NNBG(KLANG)
      DO 1414 KLING=1,120
      ARRAY(KLING,KLONG)=0.0
 1414 CONTINUE
 1415 CONTINUE
 1420 FNTCR=4.0-NBR
      IF(FNTCR.EQ.0.0) FNTCR=1.0
C
C AVERAGE ARE CALCULATED FOR EACH OF 120 TIME INTERVALS AND STORED IN AN ARRAY
C 120 BY 48 CHANNELS.
C
      DO 1500 JJ=1,120
C
C CALCULATE THE AVERAGE OF ALL 37 THERMOCOUPLES IN THE GRID
C
      RETAIN=0.0
      DO 1425 KK=1,37
      RETAIN=RETAIN+ARRAY(JJ,KK)
 1425 CONTINUE
      ARRAY(JJ,45)=RETAIN/FNTC
C
C CALCULATE THE AVERAGE THREE THERMOCOUPLES IN FIRES AND THEIR AVERAGE WITH THE
C 37 PRECEEDING THERMOCOUPLES.
C
      RETAIN=0.0
      DO 1450 KK=38,40
      RETAIN=RETAIN+ARRAY(JJ,KK)
```

```
 1450 CONTINUE
      ARRAY(JJ,46)=(FNTC*ARRAY(JJ,45)+RETAIN)/(FNTC+FNTCF)
      IF(FNTCF.EQ.0.0) FNTCF=1.0
      ARRAY(JJ,47)=RETAIN/FNTCF
C
C CALCULATE THE AVERAGE OF FOUR SETS OF THERMOCOUPLES MONITORING ROOM TEMP.
C
      RETAIN=0.0
      DO 1475 KK=41,44
      RETAIN=RETAIN+ARRAY(JJ,KK)
 1475 CONTINUE
      ARRAY(JJ,48)=RETAIN/FNTCR
 1500 CONTINUE
C
C WRITE OUT THE ENTIRE ARRAY FOR REFERENCE WITH THE PRINTED DATA.
C ON TAPE3 WRITE THE ENTIRE ARRAY, 17 VALUES PER RECORD, FOLLOWED BY THE NUMBER
C OF PARITY ERRORS.  WRITE END OF FILE MARK TO INDICATE END OF DATA TO BE SAVED.
C
      WRITE(6,9999) NARR(1)
      WRITE(6,9046)
 9046 FORMAT(1H ,133HCHANNEL      1         2         3         4         5
     1 6         7         8         9        10        11        12        13        14
     2        15      16)
      WRITE(6,9044)
 9044 FORMAT(1H0,3X,3HSEC)
      ISNT=0
      DO 1505 IS=1,60
      ISNT=ISNT+5
      WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=1,16)
 9047 FORMAT(3X,I3,3X,16F8.1)
 1505 CONTINUE
      WRITE(6,9999) NARR(1)
      WRITE(6,9046)
      WRITE(6,9044)
      DO 1510 IS=61,120
      ISNT=ISNT+5
      WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=1,16)
```

```
1510 CONTINUE
     WRITE(6,9999) NARR(1)
     WRITE(6,9048)
9048 FORMAT(1H ,133HCHANNEL     17       18       19       20       21
    122       23       24       25       26       27       28       29       30
    2       31       32)
     WRITE(6,9044)
     ISNT=0
     DO 1515 IS=1,60
     ISNT=ISNT+5
     WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=17,32)
1515 CONTINUE
     WRITE(6,9999) NARR(1)
     WRITE(6,9048)
     WRITE(6,9044)
     DO 1520 IS=61,120
     ISNT=ISNT+5
     WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=17,32)
1520 CONTINUE
     WRITE(6,9999) NARR(1)
     WRITE(6,9049)
9049 FORMAT(1H ,133HCHANNEL     33       34       35       36       37
    138       39       40       41       42       43       44       45       46
    2       47       48)
     WRITE(6,9044)
     ISNT=0
     DO 1525 IS=1,60
     ISNT=ISNT+5
     WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=33,48)
1525 CONTINUE
     WRITE(6,9999) NARR(1)
     WRITE(6,9049)
     WRITE(6,9044)
     DO 1530 IS=61,120
     ISNT=ISNT+5
     WRITE(6,9047) ISNT,(ARRAY(IS,NOT),NOT=33,48)
1530 CONTINUE
9050 FORMAT(17F8.1)
9051 FORMAT(I3)
```

```
C
C READ THE LIMITING TEMPERATURE FOR CALCULATING THE INTERVAL OF MAXIMUM HEAT
C OUTPUT.
C
      READ(5,9055) TMIN
 9055 FORMAT(F4.0)
      WRITE(6,9999) NARR(1)
      WRITE(6,9060)
 9060 FORMAT(1H ,8X,17HTOTAL HEAT OUTPUT,7X,29HMAXIMUM      HEAT      OU
     1TPUT,10X,7HMAXIMUM,5X,7HTIME AT)
      WRITE(6,9061)
 9061 FORMAT(11X,81HAREA   AVE TEMP    AREA   AVE TEMP  START END  DELTA
     1 TIME  TEMPERATURE   MAX TEMP)
      WRITE(6,9062)
 9062 FORMAT(1X,90HCHANNEL DEG-SEC   DEG C    DEG-SEC   DEG C     SEC
     1SEC   SECCNDS       DEG C      SECONDS)
C
C INITIALIZE VALUES FOR DETERMINING THE AVERAGES FOR THERMOCOUPLES ABOVE THE
C LIMITING TEMPERATURES.
C
      SUM3=0.0
      COUNT=0.0
      TSTYM=0.0
      TFTYM=0.0
      TTYM=0.0
C
C INTEGRATE UNDER CURVE FOR ALL 48 CHANNELS.  DETERMINE MAXIMUM TEMPERATURE, ETC
C BOTH INTEGRATIONS ARE CARRIED OUT SIMULTANEOUSLY.
C
      DO 1700 NN=1,48
C
C INITIALIZE VALUES USED IN INTEGRATIONS.
C
      ICOUNT=0
      SUM1=0.0
      SUM2=0.0
      TMAX=ARRAY(120,NN)
      TYMX=600.0
      NTIME=1
```

```
C
C INTEGRATION IS CARRIED OUT ASSUMING THE FIRST AND LAST TEMPERATURES ARE BELOW
C TMIN, THE LIMITING TEMPERATURE.
C
      DO 1600 MM=1,120
C
C SUM TOTAL AREA UNDER THE CURVE, THEN SEARCH FOR THE MAXIMUM TEMPERATURE AND
C WHEN IT APPEARS.
C
      SUM1=ARRAY(MM,NN)+SUM1
      IF(ARRAY(MM,NN).LT.TMAX) GO TO 1550
      TMAX=ARRAY(MM,NN)
      TYMX=(FLOAT(MM))*5.0
C
C SUM AREA UNDER THE CURVE WITH THE TEMPERATURE ABOVE THE LIMITING TEMPERATURE.
C
 1550 IF(ARRAY(MM,NN).LT.TMIN) GO TO 1600
      ICOUNT=ICOUNT+1
 1580 SUM2=SUM2+ARRAY(MM,NN)
      NTIME=MM
 1600 CONTINUE
C
C CALCULATE ACTUAL AREA UNDER THE ENTIRE CURVE AND THE TIME AVERAGE TEMPERATURE.
C THEN CALCULATE THE ACTUAL AREA, START TIME, END TIME, TOTAL TIME, AND TIME
C AVERAGE TEMPEFATURE FOR THE INTERVAL OF MAXIMUM OUTCUT.
C
      SUM1=SUM1*5.0
      AVTMP=SUM1/600.0
      SUM2=SUM2*5.0
      TYM=(FLOAT(ICOUNT))*5.0
      STYM=(FLOAT(NTIME-ICOUNT))*5.0
      FTYM=(FLOAT(NTIME))*5.0
      ATMP=SUM2/TYM
      IF(TYM.NE.0.0) GO TO  1685
      FTYM=0.0
      STYM=0.0
      ATMP=0.0
      SUM2=0.0
```

```
1685 CONTINUE
     WRITE(6,9070) NN,SUM1,AVTMP,SUM2,ATMP,STYM,FTYM,TYM,TMAX,TYMX
9070 FORMAT(1X,2X,I2,4X,F7.0,4X,F4.0,4X,F7.0,4X,F4.0,5X,F4.0,2X,F4.0,3X
    1,F4.0,8X,F4.0,9X,F4.0)
C
C THE AVERAGE AREA AND TIME AVERAGE TEMPERATURE FOR ALL THERMOCOUPLES IS
C CALCULATED FOR THE PERIOD DURING WHICH THE THERMOCOUPLE IS ABOVE TMIN.  THE
C AVERAGE START, END, AND TOTAL TIME FOR THESE PERIODS IS ALSO CALCULATED.
C
     IF(NN.GT.37) GO TO 1700
     SUM3=SUM2+SUM3
     TSTYM=TSTYM+STYM
     TFTYM=TFTYM+FTYM
     TTYM=TTYM+TYM
     IF(SUM2.EQ.0.0) GO TO 1700
     COUNT=COUNT+1.0
1700 CONTINUE
     SUM4=SUM3/FNTC
     ATSTYM=TSTYM/FNTC
     ATFTYM=TFTYM/FNTC
     ATTYM=TTYM/FNTC
     AAATMP=SUM4/ATTYM
     SUM3=SUM3/COUNT
     TSTYM=TSTYM/COUNT
     TFTYM=TFTYM/COUNT
     TTYM=TTYM/COUNT
     AATMP=SUM3/TTYM
     WRITE(6,9074) SUM4,AAATMP,ATSTYM,ATFTYM,ATTYM
9074 FORMAT(1H0,15HAVE OF ALL TC'S,13X,F6.0,4X,F4.0,5X,F4.0,2X,F4.0,3X,
    1F4.0)
     WRITE(6,9075) SUM3,AATMP,TSTYM,TFTYM,TTYM
9075 FORMAT(1H ,18HAVE FOR TC'S ABOVE/1X,8HMAX TEMP,20X,F6.0,4X,F4.0,5X
    1,F4.0,2X,F4.0,3X,F4.0)
C
C READ THREE VALUES, INIT, IFIN, AND INCREM, TO DEFINE THE FIRST INTERVAL TO BE
C PLOTTED, THE LAST TIME INTERVAL TO BE PLOTTED, AND THE INCREMENTS IN WHICH TO
C PRINT THEM.  THERE ARE  120 TIME INTERVALS WHICH CAN BE PLOTTED.
C
```

```
      READ(5,9080) INIT,IFIN,INCREM
 9080 FORMAT(3I3)
C
C INITIALIZE TIME ARRAY TO CONTAIN TWELFTH MINUTES CORRESPONDING TO 5 SECONDS.
C
      DO 1800 LN=1,120
      TIME(LN)=(FLOAT(LN))*0.083333
 1800 CONTINUE
C
C PLOT TEMPERATURE-TIME CURVES FOR THE TIME INTERVALS REQUESTED.
C
      DO 1900 LK=INIT,IFIN,INCREM
      WRITE(6,9999) NARR(1)
      CALL PLOT1(NSCALE,10,7,10,11)
      CALL PLOT2(GRAPH,852,0.0,10.0,0.0,1000.0)
      CALL PLOT3(GRAPH,1H*,TIME(1),ARRAY(1,LK),120)
      CALL PLOT4(GRAPH,44,44H              TEMPERATURE DEGREES
     1C)
      WRITE(6,9090)
 9090 FORMAT(1H0,62X,12HTIME MINUTES)
      WRITE(6,9100) LK
 9100 FORMAT(1H0,50X,35HTEMPERATURE VERSUS TIME FOR CHANNEL,I3)
 1900 CONTINUE
C
C READ LIMITS ON DO LOOP PLOTING TEMPERATURE MAP OF THERMOCOUPLE GRID.
C
      READ(5,9080) IBEG,IEND,ICHG
C
C PRINT OUT TEMPERATURE MAP OF THERMOCOUPLE GRID AT SPECIFIED TIME INTERVALS.
C
      DO 2000 II=IBEG,IEND,ICHG
      TYME=(FLOAT(II))*5.0
      WRITE(6,9110) TYME,NARR(1)
 9110 FORMAT(1H1,19HTHERMOCOUPLE MAP AT,F4.0,5H SEC.,5X,A10)
      WRITE(6,9120) ARRAY(II,1)
      WRITE(6,9130)(ARRAY(II,IT),IT=2,3)
```

```
      WRITE(6,9140)(ARRAY(II,IT),IT=4,6)
      WRITE(6,9150)(ARRAY(II,IT),IT=7,10)
      WRITE(6,9160)(ARRAY(II,IT),IT=11,15)
      WRITE(6,9170)(ARRAY(II,IT),IT=16,18),ARRAY(II,37),(ARRAY(II,IT),IT
     1=19,21)
      WRITE(6,9160)(ARRAY(II,IT),IT=22,26)
      WRITE(6,9150)(ARRAY(II,IT),IT=27,30)
      WRITE(6,9140)(ARRAY(II,IT),IT=31,33)
      WRITE(6,9130)(ARRAY(II,IT),IT=34,35)
      WRITE(6,9180) ARRAY(II,36)
 9120 FORMAT(1H+,65X,F4.0///////)
 9130 FORMAT(60X,2(F4.0,8X)///////)
 9140 FORMAT(54X,F4.0,7X,F4.0,9X,F4.0///////)
 9150 FORMAT(49X,F4.0,7X,F4.0,8X,F4.0,9X,F4.0///////)
 9160 FORMAT(43X,2(F4.0,7X),3(F4.0,9X)///////)
 9170 FORMAT(38X,2(F4.0,7X),2(F4.0,2X),3(F4.0,9X)///////)
 9180 FORMAT(65X,F4.0)
 2000 CONTINUE
      STOP
      END
      SUBROUTINE PLOT1 (N1,N2,N3,N4,N5)
C
C     PLOT1 SETS UP THE GRID SPACING AND THE TOTAL WIDTH AND LENGTH OF
C     THE GRAPH IMAGE.  IT ALSO DETERMINES THE LOCATION OF THE DECIMAL
C     POINTS AND THE MULTIPLYING FACTORS (POWERS OF 10 FOR VALUES OF THE
C     ORDINATE AND ABSCISSA TO BE PRINTED AT THE GRID LINES)
C
      REAL LINPLNY
      INTEGER WORDS,COLS,COLM1
      DIMENSION IVT(15), NP2(4), N1(5), SCALE(5)
      COMMON /CCMPLOT/ NSCALE(5),NHL,NSBH,NVL,NSBV,XMAX,XMIN,YMAX,YMIN,I
     1BCD,NDATA,IOMIT,NOBOT,NOORD,NOAB,VT(15),COLM1,COLS,LINES,WORDS,IDA
     2SH(12),ISPACE(12),UNYPLIN,UNXPCOL,LINPUNY,CCLPUNX,MAT1(3),MAT2(2),
     3MAT3(3),ISIZE,KORE,LIMIT,BAD1,BAD2,BAD3,I,J,K,MPC,NCHAR,NGT9,LAB
      EQUIVALENCE (VT,IVT), (NP2,NHL), (NSCALE,SCALE)
      DATA IZ,M1,M2,M3,M4,M5/33B,77000000000000B,77777700000000B,1000000
     1000000B,770000B,1000000000B/
```

```
C      NSCALE(5)        PARMS (USED TO ALTER STANDARC PLOTS)
C      NHL              NO. HORIZONTAL GRID LINE
C      NSBH             NO. OF SPACES BETWEEN HOR. GRIDS
C      NVL              NO. OF VERTICAL GRID LINES
C      NSBV             NO. OF SPACES BETWEEN VERT. GRIDS
C      XMAX             VALUE OF ABSCISSA AT RIGHT GRID
C      XMIN             VALUE OF ABSCISSA AT LEFT GRID
C      YMAX             VALUE OF ORDINATE AT TOP GRID
C      YMIN             VALUE OF ORDINATE AT BOTTOM GRID
C      IBCD             BCD PLOT CHARACTER
C      NDATA            NO. OF POINTS TO PLOT (SINGLE CALL)
C      ICMIT            VALUE OF ARG CF OMIT CALL
C      NOBOT            FLAG FOR OMITTING BOTTOM GRID LINE
C      NOORD            FLAG FOR OMITTING CRDINATE VALUES
C      NOAB             FLAG FOR OMITTING ABSCISSA VALUES
C      VT(15)           TEMPORARY WORKING AREA
C      COLM1            NO. OF COLUMNS-1 IN A LINE (IMAGE)
C      COLS             NO. COLUMNS IN A LINE (IMAGE)
C      LINES            NO. OF LINES TO BE PLOTTED
C      WORDS            NO. OF WORDS IN A LINE
C      IDASH(13)        USED FOR GENERATING HOR. GRID LINES
C      ISPACE(13)       USED FOR GENERATING VERT GRID LINES
C      UNYPLIN          UNITS OF Y PER LINE
C      UNXPCOL          UNITS OF X PER COLUMN
C      LINPUNY          LINES PER UNIT OF Y
C      COLPUNX          LINES PER UNIT OF X
C      MAT1(3)          VARIABLE FCRMAT (HOR GRIC LINE)
C      MAT2(2)          VARIABLE FORMAT (NCN-GRID LINE)
C      MAT3(3)          VARIABLE FCRMAT (ORDINATE VALUES)
C      ISIZE            SIZE OF IMAGE AREA (WORDS*LINES)
C      KORE             NO. OF CHARACTERS/MEMORY WORD (6600=10)
C      LIMIT            MAX NO. CHARACTERS/LINE (501 PRINTER = 123)
C      BAD1             FLAG (BAD PLOT 1 CALL)
C      BAD2             FLAG (BAD PLOT 2 CALL)
C      BAD3             FLAG (BAD PLOT 3 CALL)
C      I                COMMON VAR
```

```
C     J                   COMMON VAR
C     K                   COMMON VAR
C     MPC                 RIGHTMOST CHARACTER MASK
C     NCHAR               NO. CHARACTERS IN LABEL ARRAY
C     NGT9                NO.SPACES BETWEEN PRINTER VERT GRIDS
C     LAB                 TEMPORARY
C     IZ                  BIAS TO CONVERT TO DISPLAY CODE
C
      BAD1=0.0
      BAD2=0.0
      BAD3=0.0
      NSCALE(1) = N1(1)
      NHL=N2
      NSBH=N3
      NVL=N4
      NSBV=N5
      IF (NSCALE(1)) 10,80,10
   10 NSCALE(2) = N1(2)
      NSCALE(3) = N1(3)
      NSCALE(4) = N1(4)
      NSCALE(5) = N1(5)
      IF (NSCALE(2)) 40,30,40
   30 SCALE(2)=1.0
      GO TO 50
   40 SCALE(2)=10.0**NSCALE(2)
   50 IF (NSCALE(4)) 70,60,70
   60 SCALE(4)=1.0
      GO TO 80
   70 SCALE(4)=10.0**NSCALE(4)
   80 DO 90 I=1,4
      IF (NP2(I)) 140,140,90
   90 CONTINUE
      IF (NSCALE(3).GT.7) NSCALE(3)=7
      IF (NSCALE(5).GT.8) NSCALE(5)=8
C
C     CALCULATE SIZE OF GRAPH (NUMBER OF WORDS REQUIRED TO STORE IT)
C
```

```
      LINES=NHL*NSBH+1
      COLM1=NSBV*NVL
      COLS=COLM1+1
      IF (COLS.GT.LIMIT) GO TO 140
      WORDS=(COLS+KORE-1)/KORE
      ISIZE=LINES*WORDS
C
C     BLANK OUT ARRAYS WHICH WILL CONTAIN GRID SYMBOLS FOR LABELED AND
C     UNLABELED HORIZONTAL LINES
C
      DO 100 I=1,24
  100 IDASH(I)=10H
      NGT9=NSBV
      DO 120 I=1,10
      IF (NGT9-10) 110,130,130
  110 NGT9=NGT9+NSBV
  120 CONTINUE
C
C     MODIFY VARIABLE FORMATS MAT1 AND MAT3 WHICH WILL BE USED BY PLOT4
C     TO PRINT THE GRAPH
C
  130 NT=NGT9-9
      IVT(1)=NT/100
      IVT(2)=(NT-IVT(1)*100)/10
      IVT(3)=NT-(IVT(1)*100+IVT(2)*10)+IZ
      NT=((IVT(1)+IZ)*10000B+(IVT(2)+IZ)*100B+IVT(3))*M5
      MAT3(2)=MAT3(2).AND..NOT.M2
      MAT3(2)=MAT3(2).OR.NT
      MAT1(2)=MAT1(2).AND..NOT.M1
      MAT1(2)=MAT1(2).OR.(NSCALE(3)+IZ)*M3
      LAB=SHIFT(NSCALE(5)+IZ,12)
      MAT3(1)=MAT3(1).AND..NOT.M4
      MAT3(3)=MAT3(3).AND..NOT.M4
      MAT3(1)=MAT3(1).OR.LAB
      MAT3(3)=MAT3(3).OR.LAB
C
```

```
C     FILL IN ARRAYS WHICH WILL CONTAIN GRID SYMBOLS FOR LABELED AND
C     UNLABELED HORIZONTAL LINES
C
      CALL DASPXXX
      RETURN
  140 BAD1=1.0
      PRINT 150
      RETURN
C
  150 FORMAT ( 16H BAD INPUT PLOT1)
      END
      SUBROUTINE DASPXXX
C
C     DASP FILLS IN THE ARRAYS WHICH WILL CONTAIN THE GRID SYMBOLS FOR
C     LABELED AND UNLABELED HORIZONTAL GRID LINES
C
      COMMON /COMPLOT/ NSCALE(5),NHL,NSBH,NVL,NSBV,XMAX,XMIN,YMAX,YMIN,I
     1BCD,NDATA,IOMIT,NOBOT,NOORD,NOAB,VT(15),COLM1,COLS,LINES,WORDS,IDA
     2SH(12),ISPACE(12),UNYPLIN,UNXPCOL,LINPUNY,COLPUNX,MAT1(3),MAT2(2),
     3MAT3(3),ISIZE,KORE,LIMIT,BAD1,BAD2,BAD3,I,J,K,MPC,NCHAR,NGT9,LAB
C
C     LAY A LINE OF DASHES
C
      CALL PLACE (IDASH,COLS,1,1R-)
C
C     INSERT + IN LINE OF DASHES WHERE VERTICAL LINE INERSECTS
C
      CALL PLACE (IDASH,NVL+1,NSBV,1R+)
C
C     LAY A LINE OF ! FOR LINES CONTAINING VERTICAL COLUMNS
C
      CALL PLACE (ISPACE,NVL+1,NSBV,1R!)
      RETURN
      END
      SUBROUTINE PLACE (IARRAY,MTIMES,MSKPCH,MCHAR)
      DIMENSION IARRAY(1)
      DATA MASK/777777777777777777008/
      MSHIFT=54
```

```
C
C     PLACE PLACES CHARACTERS (MCHAR) IN AN ARRAY (IARRAY)
C
C     MSHIFT     SHIFT COUNT TO GET PROPER CHARACTER LOCATION IN WORD
C     MTIMES     NUMBER OF TIMES TO INSERT THE CHARACTER
C     MSKPCH     NUMBER OF POSITIONS TO SKIP BETWEEN INSERTS
C     MCHAR      CHARACTER TO BE INSERTED
C
      I=1
      DO 30 J=1,MTIMES
C
C     INSERT CHARACTER IN WORD
C
      IARRAY(I)=(IARRAY(I).AND.SHIFT(MASK,MSHIFT)).OR.SHIFT(MCHAR,MSHIFT
     1)
C
C     SKIP MSKIPCH CHARACTERS
C
      DO 20 K=1,MSKPCH
      MSHIFT=MSHIFT-6
      IF (MSHIFT) 10,20,20
   10 I=I+1
      MSHIFT=54
   20 CONTINUE
   30 CONTINUE
      RETURN
      END
      SUBROUTINE PLOT2 (IMAGE,LMT,P2,P1,P4,P3)
C
C     PLOT2 PREPARES THE GRID,EXAMINES THE MAXIMUM AND MINIMUM VALUES
C     OF THE ABSCISSA AND ORDINATE AND ESTABLISHES INTERNALLY A FORMULA
C     FOR COMPUTING THE LOCATION IN THE IMAGE REGION CORRESPONDING TO
C     THE POINT (X,Y)
C
```

```
      REAL LINPUNY
      INTEGER WORDS,COLS,COLM1
      DIMENSION IMAGE(1)
      COMMON /COMPLOT/ NSCALE(5),NHL,NSBH,NVL,NSBV,XMAX,XMIN,YMAX,YMIN,I
     1BCD,NDATA,IOMIT,NOBOT,NOORD,NOAB,VT(15),COLM1,COLS,LINES,WORDS,IDA
     2SH(12),ISPACE(12),UNYPLIN,UNXPCOL,LINPUNY,CCLPUNX,MAT1(3),MAT2(2),
     3MAT3(3),ISIZE,KORE,LIMIT,BAD1,BAD2,BAD3,I,J,K,MPC,NCHAR,NGT9,LAB
      DATA NGT9,BAD1,BAD2,BAD3/10,0,0,0/
      DATA MAT1/10H(1X,R1,2X,,10HF8.3,1X,12,4HA10)/
      DATA MAT2/10H(1X,R1,11X,7H,12A10)/
      DATA MAT3/10H(8X,F9.3, ,10H14(  1X,  ,10H    F9.3))/
C     ----------    ----------    ----------
C     (1X,R1,2X,    F8.3,1X,12    A10)
C     (1X,R1,11X    ,12A10)
C     (8X,F9.3,     14(  1X,          F9.3))
C     ----------    ----------    ----------
      DATA MPC/77B/
      DATA NHL,NSBH,NVL,NSBV/5,3*10/,NOBOT,NOORD,NOAB/3*0/,COLM1,COLS,LI
     1NES,WORDS,ISIZE,KORE,LIMIT/100,101,51,11,561,10,120/
      DATA (IDASH(K),K=1,11)/10*10H+---------,1H+/
      DATA (ISPACE(K),K=1,11)/11*1H!/
      DATA NSCALE/0,1.0,3,1.0,3/
      IF (BAD1) 10,10,100
   10 IF (ISIZE-LMT) 20,20,100
   20 XMAX=P1
      XMIN=P2
      YMAX=P3
      YMIN=P4
      IF (XMAX-XMIN) 103,100,30
   30 IF (YMAX-YMIN) 100,100,40
C
C     CALCULATE SCALING FACTORS TO BE USED TO CONVERT RAW DATA POINTS
C     TO GRID POSITIONS
C
```

```
   40 UNXPCOL=(XMAX-XMIN)/COLM1
      UNYPLIN=(YMAX-YMIN)/(LINES-1)
      LINPUNY=(LINES-1)/(YMAX-YMIN)
      COLPUNX=CCLM1/(XMAX-XMIN)
      K1=-WORDS
      IG=0
C
C     PLACE GRIC LINES IN GRAPH IMAGE
C
      DO 90 I=1,LINES
      K1=K1+WORDS
      IF ((I-IG*NSBH)-1) 70,50,70
   50 IG=IG+1
      DO 60 K=1,WORDS
   60 IMAGE(K+K1)=IDASH(K)
      GO TO 90
   70 DO 80 K=1,WORDS
   80 IMAGE(K+K1)=ISPACE(K)
   90 CONTINUE
      RETURN
  100 BAD2=2.0
      PRINT 110
      RETURN
C
  110 FORMAT ( 16H BAD INPUT PLOT2)
      END
      SUBROUTINE PLCT3(IMAGE,KAR,X,Y,NK)
C
C     PLOT3 PLACES A SPECIFIED BCD PLOTTING CHARACTER IN THE APPROPRIATE
C     POSITION(S) CORRESPONDING TC THE GIVEN VALUES(S) OF (X,Y)
C
      REAL LINPUNY
      INTEGER WORDS,COLS,COLM1
      COMMON /CCMPLOT/ NSCALE(5),NHL,NSBH,NVL,NSBV,XMAX,XMIN,YMAX,YMIN,I
     1BCD,NDATA,IOMIT,NOBOT,NOORD,NOAB,VT(15),COLM1,CCLS,LINES,WORDS,IDA
     2SH(12),ISPACE(12),UNYPLIN,UNXPCOL,LINPUNY,COLPUNX,MAT1(3),MAT2(2),
     3MAT3(3),ISIZE,KORE,LIMIT,BAD1,BAD2,BAD3,I,J,K,MPC,NCHAR,NGT9,LAB
      DIMENSION X(1), Y(1), IMAGE(1)
      IF (NK) 90,90,10
```

```
   10 IF (BAD2) 20,20,90
   20 IBCD=SHIFT(KAR,6).AND.MPC
      NDATA=NK
C
C     POSITION NDATA CHARACTERS IN PLOT IMAGE
C
      DO 80 I=1,NDATA
      K1=((YMAX-Y(I))*LINPUNY)+1.5
      IF (K1-LINES) 30,30,70
   30 IF(1-K1) 40,40,70
   40 K2=((X(I)-XMIN)*COLPUNX)+1.5
      IF (1-K2) 50,50,70
   50 IF (K2-COLS) 60,60,70
   60 IS=(K2+KORE-1)/KORE
      MOVE=(KORE*IS-K2)*6
      IS=IS+(WORDS*(K1-1))
      IMAGE(IS)=IMAGE(IS).AND..NOT.SHIFT(MPC,MOVE).OR.SHIFT(IBCD,MOVE)
      GO TO 80
C
C     GO HERE FOR A POINT WHICH IS OFF THE PLOTS SCALE
C
   70 BAD3=-3.0
   80 CONTINUE
      RETURN
   90 BAD3=3.0
      PRINT 100
      RETURN
C
  100 FORMAT ( 28H NO PLOT2 OR BAD INPUT PLOT3)
      END
      SUBROUTINE PLOT4(IMAGE,NN,LABEL)
C
C     PLOT4 PRINTS THE IMAGE OF THE COMPLETED GRAPH.  A LABEL FOR THE
C     ORDINATE IS PRINTED VERTICALLY (ONE CHARACTER PER LINE) AT THE
C     LEFT EDGE OF THE PAGE.  VALUES OF THE ABSCISSA AND ORDINATE ARE
C     PRINTED AT THE GRID LINES OUTSIDE THE BOTTOM AND LEFT EDGE OF
C     THE GRAPH
```

```
C
      REAL LINPLNY
      INTEGER WCRDS,COLS,COLM1
      DIMENSION LABEL(1), IMAGE(1), SCALE(5)
      COMMON /CCMPLOT/ NSCALE(5),NHL,NSBH,NVL,NSBV,XMAX,XMIN,YMAX,YMIN,I
     1BCD,NDATA,IOMIT,NOBOT,NOORD,NOAB,VT(15),COLM1,COLS,LINES,WORDS,IDA
     2SH(12),ISPACE(12),UNYPLIN,UNXPCOL,LINPUNY,COLPUNX,MAT1(3),MAT2(2),
     3MAT3(3),ISIZE,KORE,LIMIT,BAD1,BAD2,BAD3,I,J,K,MPC,NCHAR,NGT9,LAB
      EQUIVALENCE (NSCALE,SCALE)
      IF (BAD1+BAD2+BAD3) 20,20,10
   10 PRINT 180
      RETURN
   20 J=LINES
      IF (NOBOT) 30,40,30
   30 J=J-1
   40 NCHAR=NN
      K2=0
      K4=0
      DO 130 I=1,J
C
C     LOCATE,MASK OFF AND STORE THE NEXT CHARACTER IN THE ORDINATE LABEL
C
      IF (I-NCHAR) 50,50,80
   50 K1=(I+KORE-1)/KORE
      IF (K1-K2) 70,70,60
   60 K2=K1
      LAB=LABEL(K2)
   70 LAB=SHIFT(LAB,6)
      GO TO 90
   80 LAB=1H
   90 K3=K4+1
      K4=K4+WORDS
      IF (MOD(I,NSBH)-1) 120,100,120
  100 IF (NOORD) 120,110,120
```

```
C
C     CALCULATE THE VALUE OF THE ORDINATE TO BE PRINTED AT THE GRID LINE
C     OUTSIDE THE LEFT EDGE OF THE GRAPH
C
  110 VALUE=(YMAX-(I-1)*UNYPLIN)*SCALE(2)
      PRINT MAT1, LAB,VALUE,(IMAGE(K),K=K3,K4)
      GO TO 130
  120 PRINT MAT2, LAB,(IMAGE(K),K=K3,K4)
  130 CONTINUE
      IF (NOAB) 170,140,170
C
C     CALCULATE THE VALUES OF THE ABSCISSA TO BE FRINTED AT THE GRID
C     LINES OUTSIDE THE BOTTOM OF THE GRAPH
C
  140 J=0
      I=1
  150 J=J+1
      VT(J)=(XMIN+FLOAT(I-1)*UNXPCOL)*SCALE(4)
      I=I+NGT9
      IF (I-COLS) 150,150,160
C
C     FOLLOWING MHS CODE INSERTS PROPER REPEAT FACTOR IN MAT3
C
  160 LAB=1000000000000B*(MOD(J-1,10)+100B*((J-1)/10)+3333B)
      MAT3(2)=(MAT3(2).AND.7777777777777777B).OR.SHIFT(LAB,12)
      PRINT MAT3, (VT(I),I=1,J)
  170 RETURN
C
  180 FORMAT ( 13H NO PLOT MADE)
      END
```

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