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REPORT NO. U-6213

THERMAL PROTECTIVE COATINGS

FINAL REPORT FOR PERIOD 11 DECEMBER 1974 - 31 MARCH 1976

Prepared by:

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31 MARCH 1976

Under Contract:


N00123-75-C-0655 *used*

Prepared for:

Naval Weapons Center  
China Lake, California 93555

Distribution: Approved for public release; distribution unlimited

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*391253*  
*11 10 1976*

UNCLASSIFIED

④ final repr. 11 Dec 74-31 Mar 77

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE  |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                                     |
|--|-----------------------|---|
| 1. REPORT NUMBER   | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER   |
| 4. TITLE (and Subtitle)<br>⑥ Thermal Protective Coatings, ✓  |                       | 5. TYPE OF REPORT & PERIOD COVERED<br>Final - 11 December 1974 to 31 March 1976 |
| 7. AUTHOR(s)<br>⑩ J. L. Perry, G. R. Wittman   |                       | 6. PERFORMING ORG. REPORT NUMBER<br>U-6213 ✓                                    |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Aeronutronic Ford, Aeronutronic Division<br>Ford Road<br>Newport Beach, California 92663 ✓  |                       | 8. CONTRACT OR GRANT NUMBER(s)<br>⑮ N00123-75-C-0655 NEW                        |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Naval Weapons Center<br>China Lake, California 93555  |                       | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>--               |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)<br>Naval Weapons Center<br>China Lake, California 93555  |                       | 12. REPORT DATE<br>⑪ 31 March 76  |
|  |                       | 13. NUMBER OF PAGES<br>64 ⑫ 68 p.   |
|  |                       | 15. SECURITY CLASS. (of this report)<br>Unclassified                            |
|  |                       | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE                                      |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited   |                       |   |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)<br><br>Approved for public release; distribution unlimited  |                       |   |
| 18. SUPPLEMENTARY NOTES  |                       |   |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br><br>Intumescent coatings<br>Thermal insulation<br>Inorganic fillers  |                       |   |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>An exploratory research and development program was performed for the purpose of providing an effective thermal barrier for aircraft and pilot protection in the event of an aircraft fire. The primary objective of the program was Task I, which consisted of examining the effectiveness of expanding naturally occurring fillers (Perlite and Vermiculite) when used in combination with organic and inorganic matrix coating systems. Both filler systems expand and increase in volume up to 20 times when exposed to heat and liberate no toxic gases. |                       |   |

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Thin coatings of these filler systems combined with various organic intumescent paints and inorganic matrix systems were developed and thermally evaluated. Test specimens were exposed to a frontface thermal flux environment of  $13.5 \text{ BTU/ft}^2\text{-sec}$  ( $15.3 \text{ joules/cm}^2\text{-sec}$ ) within the door opening of an electric furnace while the aluminum substrate specimen backface temperature rise with respect to time of exposure was continuously monitored and autographically recorded.

The most effective thermal coating developed was composed of an intumescent paint, No. 3 grade Vermiculite and 0.5 inch (1.27 cm) length graphite fiber in the respective ratios of 65.8 percent, 33.9 percent, and 0.03 percent by weight. This coating when applied at a thickness of 0.060 inch (0.15 cm) to an aluminum substrate and tested as described will insulate the substrate for a period of 6.8 minutes before a temperature of  $500^\circ\text{F}$  ( $260^\circ\text{C}$ ) is reached and for a period of 17.4 minutes before a temperature of  $800^\circ\text{F}$  ( $427^\circ\text{C}$ ) is reached.

Task II consisted of thermally characterizing 60 government furnished ceramic felts by exposing them to a thermal flux of  $15 \text{ BTU/ft}^2\text{-sec}$  ( $17 \text{ joules/cm}^2\text{-sec}$ ) by the same test method as described for Task I specimens. These specimens were bonded to aluminum substrates and the backface temperature rise with respect to time of exposure was also continuously monitored and autographically recorded.

The best coating system evaluated in Task I was used in conjunction with glass/honeycomb for prefabricated test panels for Task III. In this task, prefabricated thermal barrier sections were installed in the front bulkhead and floor sections of an A-4 aircraft cockpit on site at the Naval Weapons Center at China Lake, California. The effectiveness of this insulative concept will be evaluated during a fuel fire test in the latter part of 1976 by NWC personnel.

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## FOREWORD

This document is the final report prepared by Aeronutronic Division, Aeronutronic Ford under the Naval Weapons Center Contract N00123-75-C-0655 concerning thermal insulative materials for aircraft fire protection. The work was conducted at Aeronutronic Ford under J. L. Perry, Supervisor of the Composite and Graphite Section. The work was administered under the direction of the Naval Weapons Center, China Lake, California with Mr. W. T. Burt and Mr. A. San Miguel as project engineer. This report covers work conducted from December 1974 to April 1976.

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## SUMMARY

An exploratory research and development program was performed for the purpose of providing an effective thermal barrier for aircraft and pilot protection in the event of aircraft fire.

Task I, which is the primary objective of the program, consisted of examining the effectiveness of expanding naturally occurring fillers (perlite and vermiculite) when used in combination with organic and inorganic matrix coating systems. Both filler systems expand and increase in volume up to 20 times when exposed to heat and liberate no toxic gases.

Thin coatings of these filler systems combined with various organic intumescent paints and inorganic matrix systems were developed and thermally evaluated. Test specimens were exposed to a frontface thermal flux environment of 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec) within the door opening of an electric furnace while the aluminum substrate specimen backface temperature rise with time of exposure was continuously monitored and autographically recorded. The most effective thermal coating developed was composed of an intumescent paint, No. 3 grade vermiculite and 1/2 inch (1.27 cm) length graphite fiber in the respective ratios of 65.8 percent, 33.9 percent, and 0.3 percent by weight. This coating when applied at a thickness of 0.060 inch (0.15 cm) to an aluminum substrate and tested as described will insulate the substrate for a period of 6.8 minutes before a temperature of 500°F (260°C) is reached and for a period of 17.4 minutes before a temperature of 800°F (427°C) is reached.

Task II consisted of thermally characterizing 60 government furnished ceramic felts by exposing them to a thermal flux of 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) by the same test method as described for the Task I specimens. These specimens were attached to aluminum substrates and the backface temperature rise with time of exposure was also continuously monitored and autographically recorded.

The best coating system evaluated in Task I was used in conjunction with glass/honeycomb for prefabricated test specimens for Task III. In this task, prefabricated thermal barrier sections were installed in the front bulkhead and floor sections of an A-4 aircraft cockpit on site at the Naval Weapons Center at China Lake, California. The effectiveness of this insulative concept will be evaluated during a fuel fire test in the latter part of 1976 by NWC personnel.

Task IV consisted of the application of a pyrex glass mosaic overlay to the plexiglas canopy of an A-4 aircraft. Squares of pyrex glass were bonded to the entire surface of the plexiglas canopy with a transparent silicone adhesive. An evaluation of the effectiveness of this overlay in increasing the heat resistance of the plexiglas during an actual fuel fire test environment will also be conducted by NWC personnel in the latter part of 1976.

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## SECTION 1

### INTRODUCTION

This program is concerned with the development and evaluation of thermal protective coatings and composites for use in aircraft and pilot compartment protection in the event of an aircraft fire. Carrier based aircraft, under conditions of a general shipboard fire beneath or around the wings and fuselage, are limited to a very short exposure time. Fuel tank rupture can occur in 40 seconds and pilot survivability, in the cockpit area, is on the order of 90 seconds. Fuel spillage and fuel spread exposes and endangers adjacent aircraft and initiates a chain reaction which can result in extensive loss of aircraft and personnel.

Fire fighting personnel and fire fighting techniques cannot effectively respond to this situation within the allowable exposure time. However, if this very short exposure time could be increased on the order of several minutes then the existing fire control measures would have sufficient time to either control the fire or remove the aircraft to an isolated area. It is the objective of this program to develop and evaluate promising potential thermal coating and thermal barrier concepts which offer such a time distinction from the existing 40 seconds to a goal of 5 minutes. Fire retardant paints and coatings are of two general types, intumescent and nonintumescent. The nonintumescent coatings are suitable for noncombustible surfaces only because of their much higher thermal conductivity properties and were not considered to be promising for this application. Intumescent coatings contain foaming agents which are decomposed by heat and when subjected to high temperatures they increase in volume and produce a highly effective insulating carbon foam. However, the resulting expanded mass is lacking in structural integrity and in addition the precursor resin matrix liberates considerable amounts of toxic gases. A viable approach to enhance the performance of intumescent coating systems is by the addition of expanding inorganic mineral fillers such as perlite and vermiculite.

Perlite is a naturally occurring glassy volcanic rock containing 2.0 percent to 5.0 percent chemically combined water. Perlite, when rapidly heated to its softening temperature, (1400°F to 2500°F) suddenly pops or expands (one to two seconds) and increases in volume up to 20 times its original size. The expansion is caused from the pressure generated by the chemically combined superheated water. The expansion is symmetrical about the geometrical center of the particle and produces an expanded particle consisting of a foam structure composed of microscopic sealed void cells. Due to this structure, expanded perlite is extremely light in weight (2 to 15 lbs/ft.<sup>3</sup>) and very low in thermal conductivity (0.25 to 0.50 BTU/hr/ft<sup>2</sup>/°F/in.). The low thermal conductivity is attributed to the discontinuous heat conduction paths of the cellular structure and the increased path length after expansion. Several potential advantages of perlite when used as an in-situ thermal protective material are: (a) the conversion of heat energy to mechanical energy by the expansion mechanism, (b) the cooling effect of the released water vapor, and (c) the low thermal conductivity of the expanded perlite.

The term vermiculite is given to a group of hydrous micas, usually alteration products of phlogopite or biotite micas, characterized by the ability, when heated above 150°C, to expand at right angles to the cleavage to a volume 6 to 20 times (average 16) that of the unexpanded mineral.

The property of expansion has been explained by at least two theories. The most generally accepted one is that the expansion is caused by the pressure of steam generated by heating the water of composition. This process is similar to that involved in the "popping" of perlite, and the product is somewhat similar except in one detail. The expansion is in one direction only at 90 degrees to the cleavage plane. The flake may increase from 10 to 30 times its original thickness. The second theory is that much of the expansion is due to warping of individual laminae because of unequal strains set up by steam pressure. This theory is used to account for the fact that expansion takes place even with very slow heating. In addition to the increase in volume and the development of the minute voids responsible for its insulating value, the vermiculite is altered by oxidation of its iron content. The addition of these inorganic fillers to intumescent matrices should produce a foamed structure with increased strength properties and should decrease the amount of toxic gases liberated during the expansion phenomena. This program consisted of the following four tasks. Task I, the primary task, was the development and evaluation of thin intumescent coatings containing fillers such as vermiculite and perlite. Task II consisted of testing and evaluating 60 Government furnished thermal resistant ceramic felts by the same thermal test evaluation method used for the Task I specimens. Task III was the installation of the most effective thermal coating concept evaluated in Task I in certain areas of an A-4 cockpit. The areas to be protected were the front bulkhead and floor sections of the cockpit and would utilize the coating in combination with a glass/phenolic honeycomb. Installation was to be performed at the Naval Weapon Center at China Lake, California. Task IV was concerned with the thermal protection of the plexiglas cockpit canopy during a fire environment. This task consisted of adhesively bonding pyrex glass squares in a mosaic fashion over the external portion of the plexiglas canopy.

## SECTION 2

### APPROACH

This section presents the approach to each of the following tasks.

#### 2.1 TASK I

This project involved the evaluation and development of an effective thermal barrier coating to be used for aircraft and pilot compartment protection.

##### 2.1.1 MATERIALS

A wide range of materials (listed in Appendix A) were chosen for testing and evaluation. The types of materials examined were expanding fillers, intumescent paints and flame resistant phenolic/silica combined with matrix systems such as epoxy's, vinyl plastisols, silicones, urethanes, and elastomeric solutions.

##### 2.1.2 TEST SPECIMEN AND TEST CHAMBER DESIGN

A K. H. Huppert muffle furnace was selected to supply the high temperatures required for testing; it is capable of 3000°F (1649°C). 6061 T6 aluminum 0.040 inch (0.102 cm) was selected as the substrate base for the test specimens. The opening of the muffle furnace is 3.5 x 3.5 inches (8.89 x 8.89 cm), so to allow the specimen to be inserted into the opening of the furnace the aluminum substrate was cut to 3.4 inch (8.64 cm) squares.

A 1.025 inch (2.604 cm) circular hole was punched out of the center of the aluminum substrate and a 0.85 inch (2.16 cm) slug was bonded into this hole with a ceramic bonding agent (Sauereisen cement) such that there would be 0.0875 inch (0.2222 cm) of the ceramic bonding agent between the aluminum plate and the aluminum slug (see Figure 1). This isolation of the plug minimizes the effects of any unequal heating contributed by the surrounding aluminum plate. One face of the aluminum substrate was completely coated with the material to be tested (see Figure 2).

A door (shown in Figure 3) was hinged on the muffle furnace in such a way that when the specimen was mounted on the door it could be closed against the furnace and the specimen would line up with the opening of the furnace.

##### 2.1.3 TEST METHOD

The specimens were individually mounted on the door described above and when closed were exposed to 13.5 BTU/ft<sup>2</sup>sec (15.3 joules/cm<sup>2</sup>sec). To detect the rise in temperature of the backface of the aluminum substrate, a chromel alumel thermocouple was held against the backface of the isolated plug through a small hole in the door by a spring loaded device which insured contact. An oscillograph was used to record the rise in temperature with respect to time.

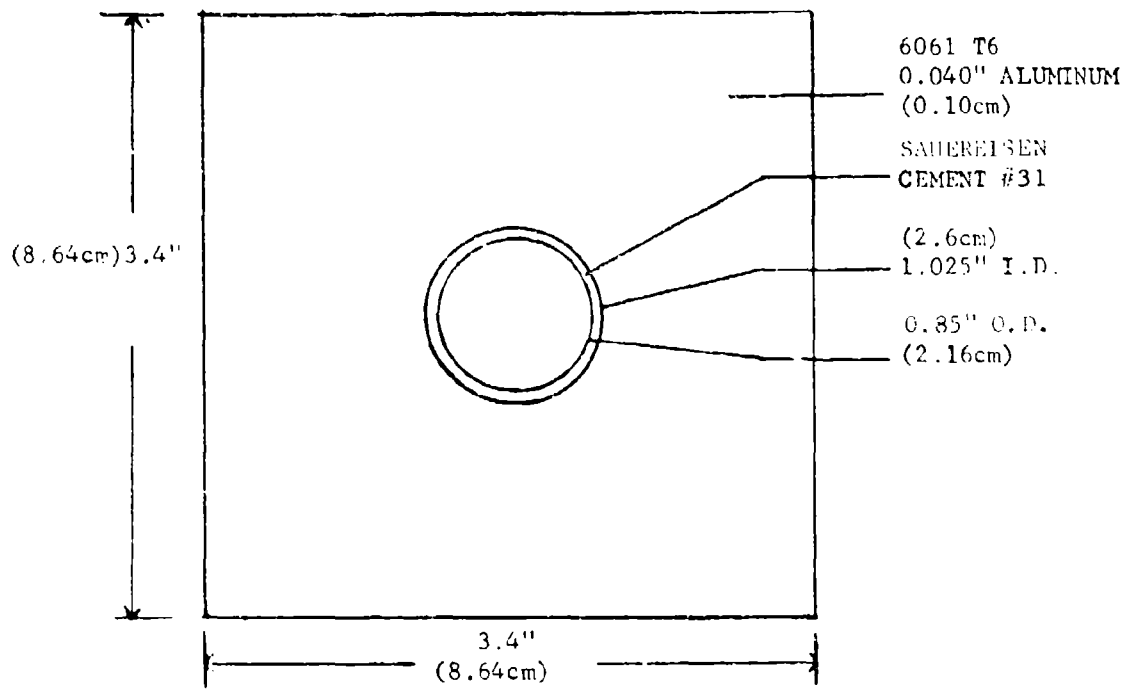


FIGURE 1. ALUMINUM SUBSTRATE

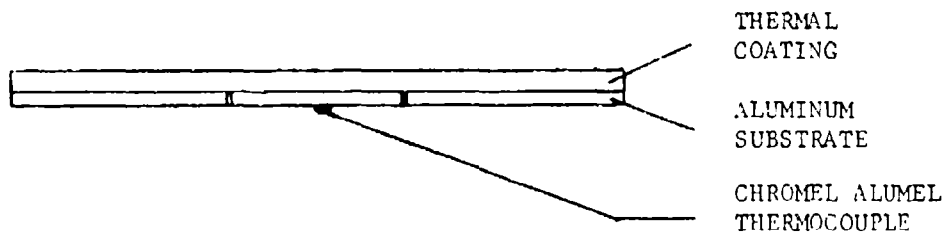


FIGURE 2. THERMAL COATING TEST SPECIMEN



FIGURE 3. DOOR HINGED TO MUFFLE FURNACE USED FOR MOUNTING TEST SPECIMENS

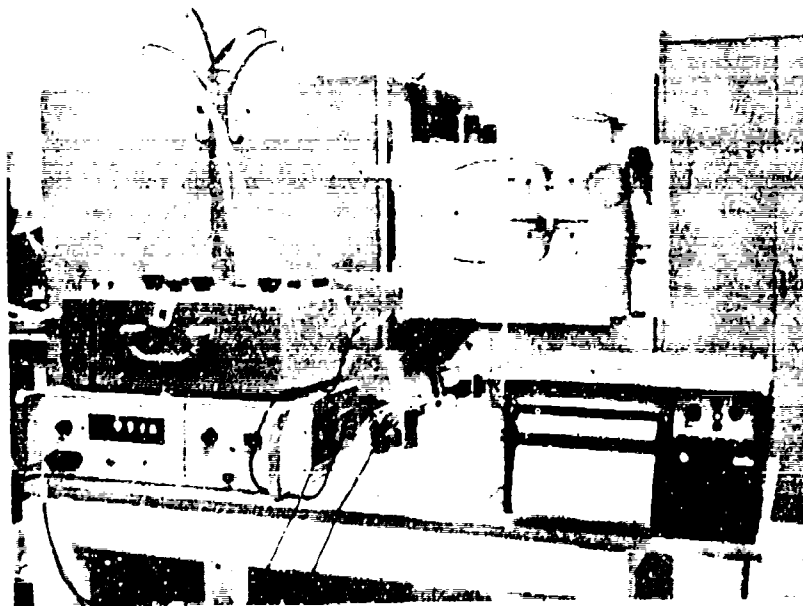


FIGURE 4. TESTING APPARATUS USED FOR RECORDING THERMAL RESPONSE

The oscillograph was calibrated with a battery potentiometer to be able to reduce the millivolt output signal of the thermocouple recorded on the strip chart to degrees Fahrenheit (or Celsius). This equipment can be seen in Figure 4. The furnace is in the background of Figure 4; the hoses leading to the door are used to supply water to the water jacket around the thermocouple, used only in cooling between runs to speed up the process of testing. A close-up of the thermocouple and water jacket is shown in Figure 5. The water jacket was used in conjunction with electric fans.

The backface of the aluminum substrate was allowed to reach 800°F (427°C) before being removed from the heat source.

## 2.2 TASK II

This task consisted of testing and evaluating 60 government furnished thermal resistant ceramic felts.

### 2.2.1 TEST SPECIMEN AND TEST CHAMBER DESIGN

The ceramic felts were cut to 3.4 inch (8.64 cm) squares and bonded to the same type of aluminum substrate used in Task I with Epibond 122 adhesive and 952 hardener. The same modified muffle furnace was used in this task as in Task I.

### 2.2.2 TEST METHOD

The test method used in Task II was the same as the test method used in Task I with one exception. The specimens were exposed to 15 BTU/ft<sup>2</sup>sec (17 joule/cm<sup>2</sup>sec) in this task where the specimens were exposed to 13.5 BTU/ft<sup>2</sup>sec (15.3 joules/cm<sup>2</sup>sec) in Task I.

## 2.3 TASK III

This task included taking the thermal barrier developed in Task I and incorporating it with phenolic glass honeycomb to produce a type of sandwich panel. The second part of this task was installing several sandwich panels in the cockpit of an A-4 jet.

## 2.4 TASK IV

This task consisted of mounting 2 x 2 x 0.25 inch (5.08 x 5.08 x 0.635 cm) pyrex glass section on the A-4 cockpit canopy assembly. This mosaic overlay was formed by bonding each pyrex square, piece by piece, to the plexiglas with a transparent silicone adhesive. A thin copper foil between each glass section and an overlay of safety wire attached to a brass peripheral strip was also installed.

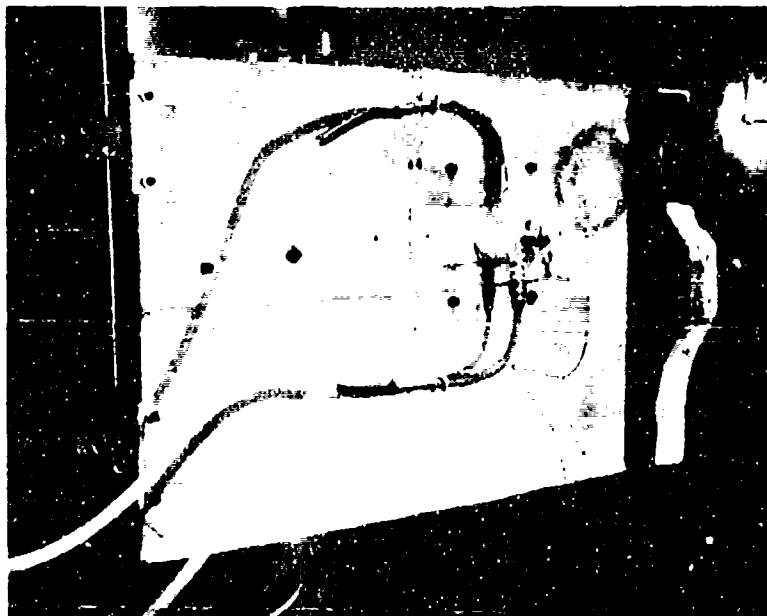


FIGURE 5. CLOSE UP OF WATER JACKET AND THERMOCOUPLE WIRE

## SECTION 3

### TECHNICAL DISCUSSION

#### 3.1 TASK I DEVELOPMENT OF AN EFFECTIVE THERMAL BARRIER COATING

One hundred and three test specimens were exposed to a thermal flux environment of 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec). Substrate backface temperature was recorded with respect to time for each specimen. A list of the different combinations of matrices and fillers plus the thickness of each specimen is in Appendix B.

A control specimen of Flamarest epoxy paint reached a 500°F (260°C) temperature within 3 minutes. The addition of Perlite to the Flamarest paint degraded the thermal characteristics by displaying a quicker time to 500°F (260°C). The Vermiculite filled specimens were all better than the unfilled Flamarest and resulted in 500°F (260°C) substrate temperature times of 4 to 4.5 minutes.

The use of a silicone elastomer also showed that vermiculite is more desirable as a filler than perlite. The time to 500°F with the perlite filler was within 30 seconds where the vermiculite filled elastomer was 2.5 minutes for the No. 2 vermiculite and within 2 minutes for the No. 4.

Sodium silicate was tested with aluminum hydroxide, perlite, vermiculite and borax filler systems. None of the systems offered the potential of an efficient thermal barrier but the best gain was again achieved with vermiculite.

Many systems were evaluated but none of them offered the potential of ALBI-107A. It was decided that ALBI-107A would be the matrix chosen for a more extensive evaluation.

##### 3.1.1 SELECTION OF FILLERS, PERCENTAGES OF FILLERS, AND COATING THICKNESS FOR OPTIMUM THERMAL CHARACTERISTICS

ALBI-107A was selected for its superior thermal insulative characteristics, both in the unaltered as received condition and after being mixed with various filler systems. In Figures 6 and 7 pictures of the pure ALBI-107A, initial coatings of 60 and 135 mils (0.15 and 0.34 cm), after frontface exposure to 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec) are shown. Displayed in Figures 8 and 9 are pictures of perlite No. 816 filled ALBI-107A and vermiculite No. 3 filled ALBI-107A specimens after being exposed to the same thermal flux mentioned above.

Grade B-25 and FT-102 glass bubbles were tested as fillers with ALBI-107A but neither of the two grades were found to be effective thermal barriers. They, in fact, reduced the thermal effectiveness of the matrix.

In order to establish a data base for comparative purposes, five specimens of unfilled ALBI-107A of increasing coating thickness were prepared. The effect of the coating thickness, 0.025 in. through 0.110 in. (0.064 cm through



FIGURE 6. SPECIMEN 35-1 - ALBI-107A MATRIX WITH NO FILLER.  
INITIAL THICKNESS WAS 60 MILS (0.15 CM)



FIGURE 7. SPECIMEN 35-7 - ALBI-107A MATRIX WITH NO FILLER.  
INITIAL COATING THICKNESS WAS 135 MILS (0.34 CM)



FIGURE 8. SPECIMEN 46-1 - ALBI-107A MATRIX WITH 34 PERCENT NO. 816 PERLITE FILLER. INITIAL COATING THICKNESS WAS 120 MILS (0.30 CM)



FIGURE 9. SPECIMEN 41-1 - ALBI-107A MATRIX WITH 34 PERCENT VERMICULITE FILLER. INITIAL COATING THICKNESS WAS 110 MILS (0.28 CM)

0.279 cm) is shown in Figure 10. The thickest coating specimen, 0.120 in. (0.305 cm), is not plotted because the thermal response for this specimen was between specimens of 0.070 in. (0.178 cm) and 0.110 in. (0.279 cm). The data show, as one would predict, that the thermal effectiveness is related to the coating thickness, but there is a maximum thickness to be used.

Presented in Figure 11 are the results obtained with four particle size grades of perlite, grade 816 the coarsest particle and grade 4500 the smallest particle, at a 34 percent filler concentration. The perlite specimens exhibit a definite trend for the thermal efficiency to decrease with the particle size of the perlite. Presented in Figure 12 are the results of different size particles of perlite at a 66 percent filler concentration, again the specimens exhibit the same tendency for a decrease in thermal protection with a decrease in particle size. Comparing Figures 11 and 12 you can see that a filler loading level of 34 percent is considerably more effective than 66 percent.

Presented in Figure 13 are the results of various particle size grades of vermiculite at 34 percent filler concentration. Grade No. 1 vermiculite is the largest and Grade No. 5 vermiculite is the smallest particle. Again there is the tendency for a decreased thermal protection with decreased particle size except specimen 41-1 with No. 3 particle size appears to exhibit better thermal protection than specimen 37-2 with No. 2 particle size.

Figure 14 shows the effects of two filler loading levels formulated with vermiculite No. 3 and two different lengths of carbon fiber which is at the concentration of 1 percent of the filler. The 34 percent filler concentration yields the best thermal properties and the addition of fibrous reinforcement appears to enhance the thermal insulative properties. The 3 inch (7.6 cm) and 0.5 inch (1.27 cm) long carbon fibers have nearly equivalent results, but in considering the difficulties in mixing the fire retardant, the 0.5 inch (1.27 cm) carbon fiber is superior. The carbon fiber was compared to blue asbestos fiber in a specimen test and the carbon fiber appears to be better than the asbestos when present with the vermiculite filler. A picture of the result of testing specimen No. 50-1 with 66 percent ALBI-107A and 34 percent filler (vermiculite No. 3 and 3 in. (7.6 cm) carbon fiber 1 percent of filler) is presented in Figure 15.

The results of 47 specimen tests are presented in Appendix C. Specimen 46-1 which was 34 percent 816 perlite filler and 66 percent ALBI-107A matrix had a time to 800°F of 20 minutes which is the best result obtained. This same combination was tested again and the time to 800°F was much lower. This inability to obtain repeatability may be linked to the large particle size of the filler.

### 3.2 TASK II

Each of the specimens, supplied to Aeronutronic Ford by NWC, China Lake, California, were cut to 3.4 inch (8.64 cm) squares and bonded to aluminum plates. The aluminum substrate were prepared in the same way as described in Task I and the same procedure and apparatus were used in testing the specimens with the exception that the heat flux was 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) instead of 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec) as used in Task I.

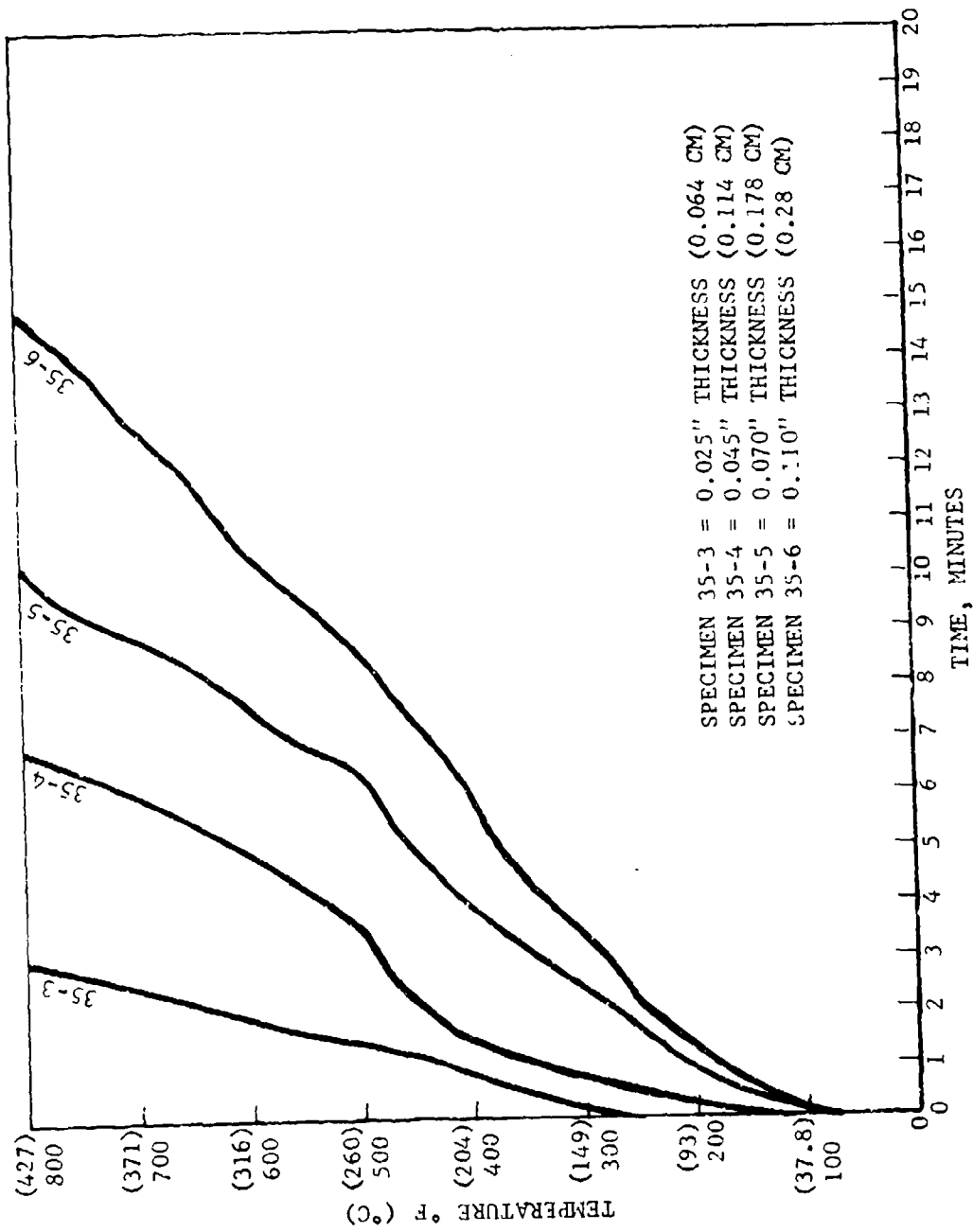


FIGURE 10. BACKFACE TEMPERATURE RISE FOR VARYING COATING THICKNESSES OF ALBI-107A EXPOSED TO 2000°F FRONTFACE TEMPERATURE

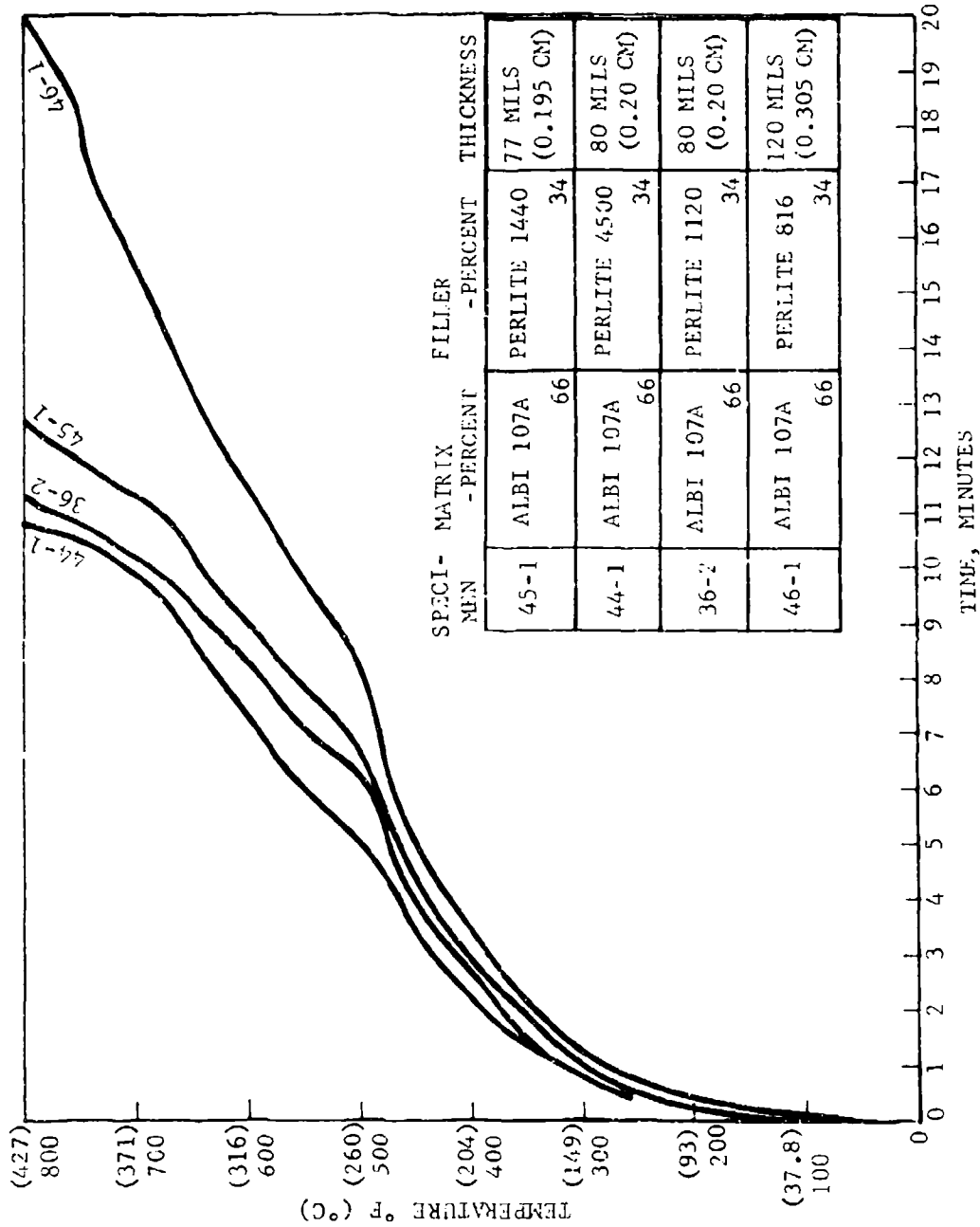


FIGURE 11. BACKFACE TEMPERATURE RISE FOR VARYING SIZES OF PERLITE (816 LARGEST)

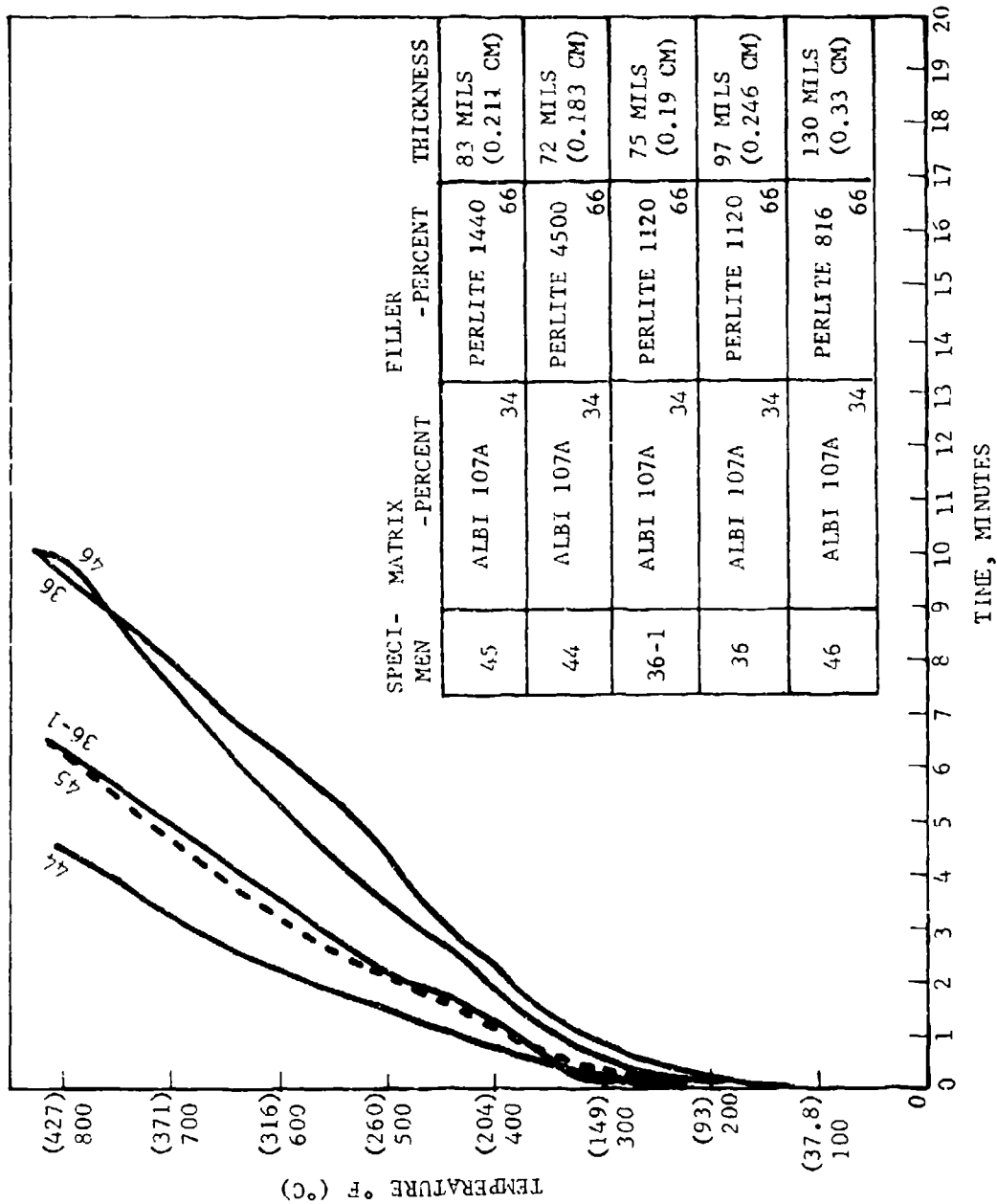


FIGURE 12. BACKFACE TEMPERATURE RISE FOR VARYING PARTICLE SIZE OF PERLITE AT THE CONCENTRATION OF 66 PERCENT

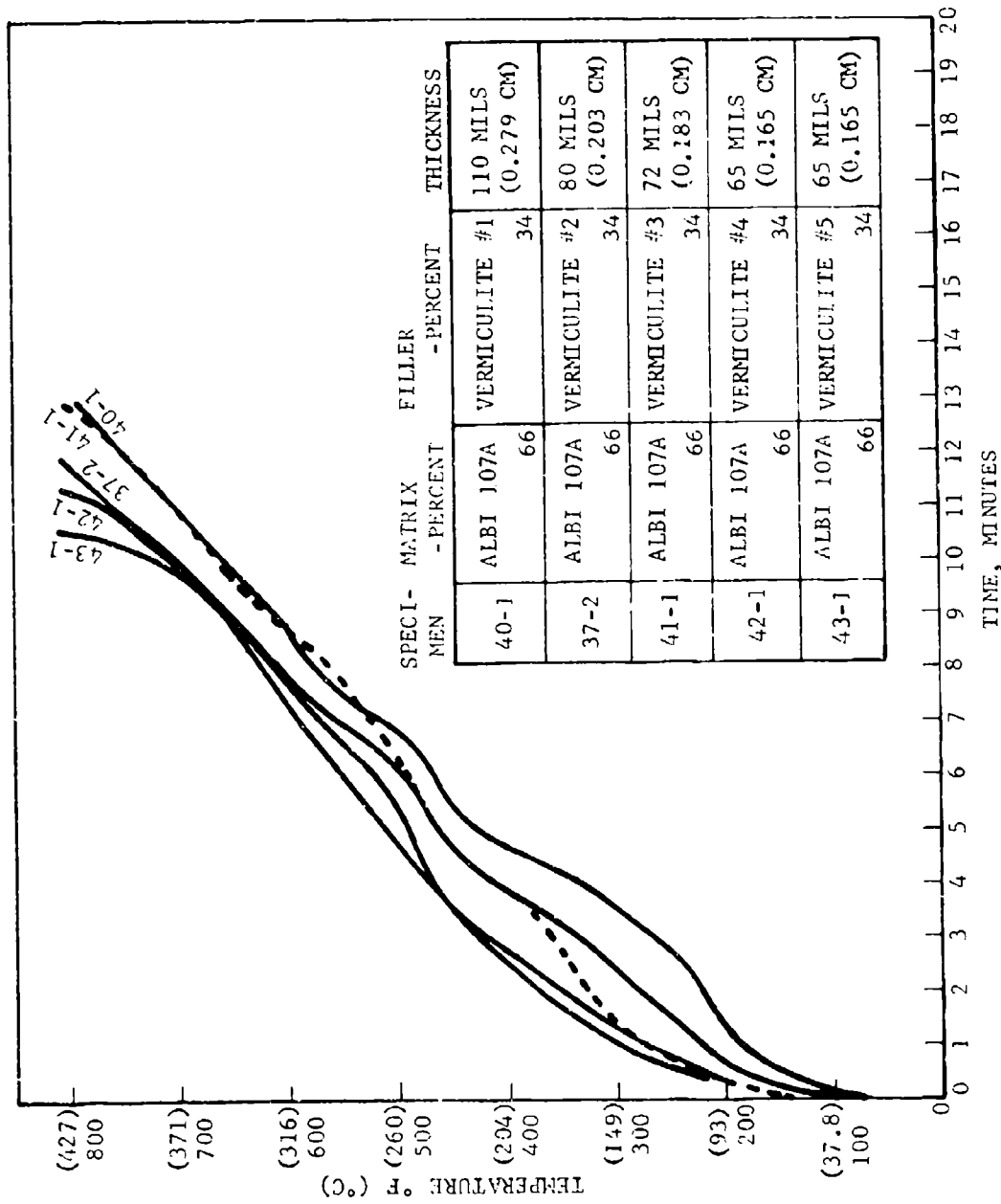


FIGURE 13. BACKFACE TEMPERATURE RISE OF VARYING PARTICLE SIZE OF VERMICULITE (#5 IS THE SMALLEST)

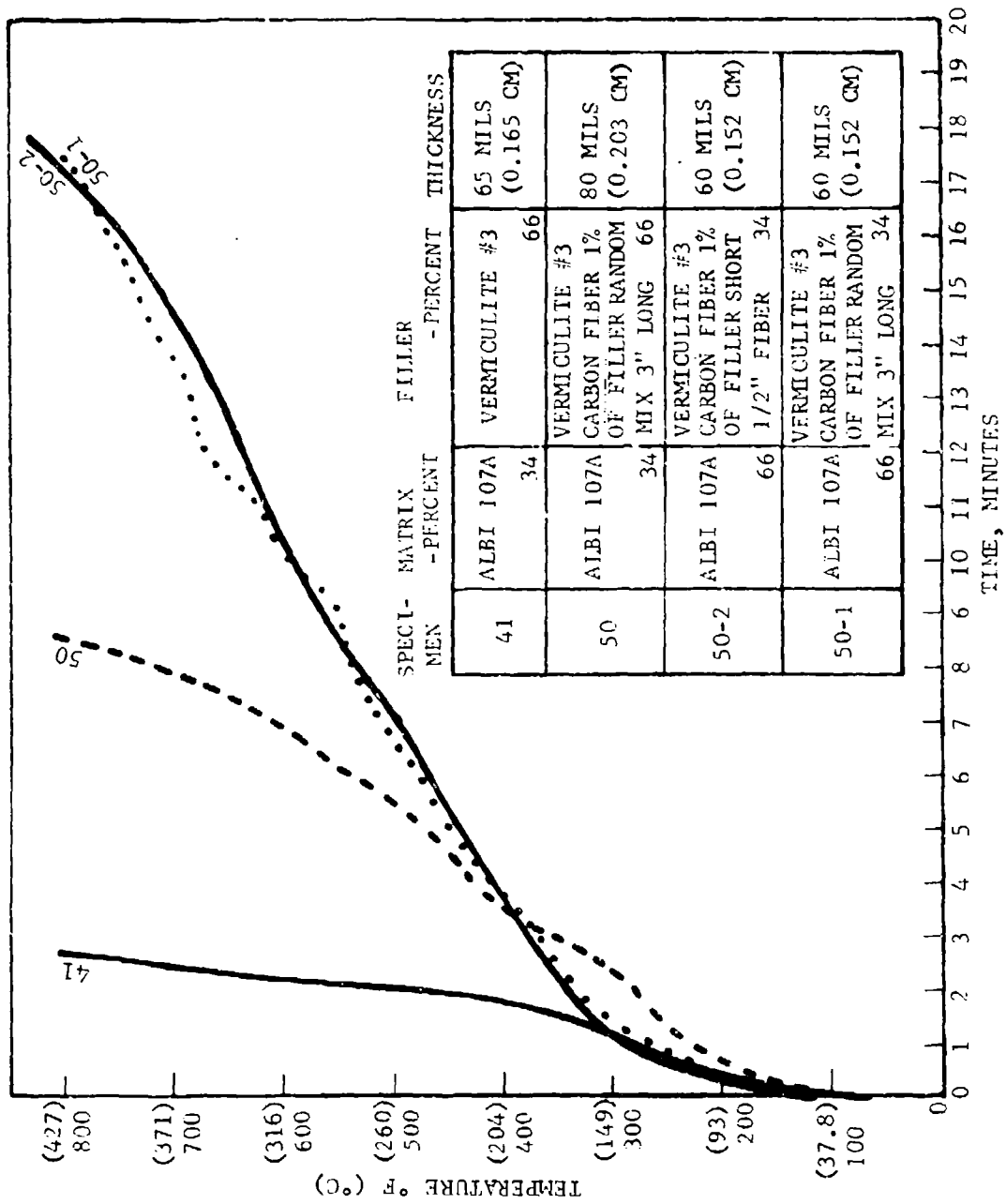


FIGURE 14. BACKFACE TEMPERATURE RISE WITH AND WITHOUT #3 VERMICULITE FILLER AT DIFFERENT CONCENTRATIONS, WITH TWO LENGTHS OF CARBON FIBER

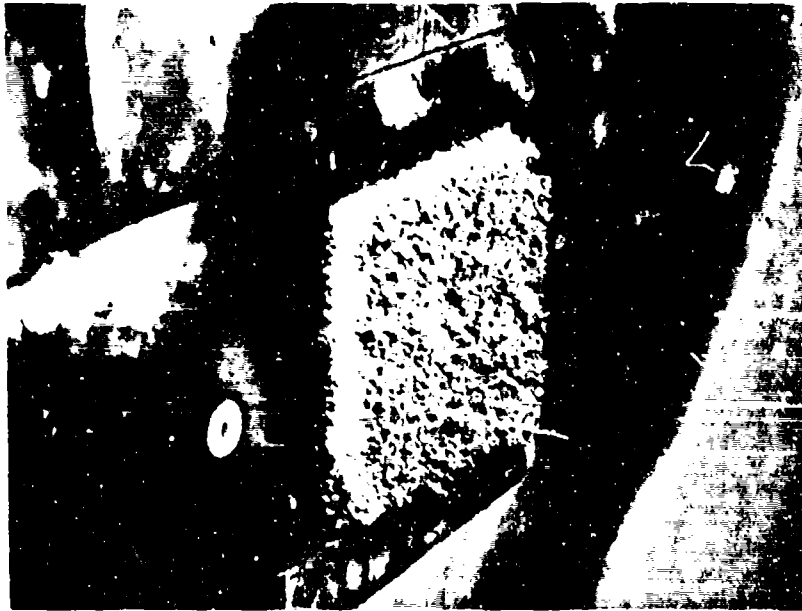


FIGURE 15. SPECIMEN 50-1 - ALBI-107A WITH 34 PERCENT #3 VERMICULITE AND 3 INCH (7.6 CM) CARBON FIBER FILLER. CARBON FIBER IS 1 PERCENT OF THE FILLER. INITIAL COATING THICKNESS WAS 60 MILS (0.152 CM)

The thermal response of each specimen was recorded and compiled (see Appendix D) and the specimens were divided into six categories according to their characteristic rise in temperature. A list of the different categories can be seen in Table 1.

Characteristics typical of type A are: a rapid rise in temperature, after exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) for 1 minute, to around 350°F (177°C) which is attained shortly after 2 minutes. Then the rise in temperature continues but at a slower rate. The average time to 800°F (427°C) is around 15 minutes.

Type A-1 characteristics are similar to type A in that they have the same rapid initial rise in temperature but type A-1 normally has a slightly increased rate of initial rise in temperature and reaches a higher point at which the rate of rise in temperature decreases. The average time to 800°F (427°C) is 10 minutes for type A-1.

Type A-1 can also be split into two categories A-1x and A-1z. They differ in the temperature at 1 minute. The average temperature of A-1x at 1 minute is 175°F (79°C) where A-1z has an average temperature of 250°F (121°C).

Type A-2 also has a rapid initial increase in temperature but it starts around 30 seconds of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) and at 1 minute the average temperature is 340°F (171°C). The average time to 800°F (427°C) is 9.5 minutes.

Type C doesn't have the rapid rise in temperature as in the above categories. It has a relatively steady increase in temperature with the exception of a leveling off or even a decrease in temperature around 2 to 3 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) in some specimens. The average time to 800°F (427°C) is 13 minutes.

Type C-1 also has a steady increase in temperature but has an outstanding average time of 27 minutes to 800°F (427°C) with one specimen going to 31 minutes, which was the only non-ceramic felt specimen. Graphs representative of each type are shown in Figures 16 and 17.

There are five specimens that have to be mentioned separately because they do not fall into these categories. T-119B and C showed a very rapid rise in temperature and had a time of about 4 minutes to 800°F (427°C), which was probably due to the fact that they were very thin. T-3 can almost be classified as type A-1 but the rapid increase in temperature did not start until after 2 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). T-107 and T-105 had a time to 800°F (427°C) of type A and the rapid increase in temperature similar to type A-1z.

Not all specimens displayed an always increasing rise in temperature. Some held a constant or almost constant temperature for a short while, usually from 30 seconds to 1 minute, starting anytime from 30 seconds to 3 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). Examples of this are T-2, T-4, T-5, T-6, T-8, T-10, and T-11 which displayed the leveling off period at

TABLE 1. LIST OF SPECIMENS IN EACH CATEGORY

| <u>Type A</u> | <u>Type A-1x</u> | <u>Type A-1z</u> | <u>Type A-2</u> |
|---------------|------------------|------------------|-----------------|
| T-1           | T-2              | T-9              | T-26            |
| T-13          | T-4              | T-24             | T-27            |
| T-15          | T-5              | T-51A            | T-106           |
| T-17          | T-6              | T-52A            |                 |
| T-18          | T-7              | T-52B            |                 |
| T-19          | T-8              | T-53             |                 |
| T-20          | T-10             | T-54             |                 |
| T-22          | T-11             | T-104            |                 |
| T-23          | T-14             | T-121            |                 |
| T-108         | T-21             | T-122B           |                 |
| T-109         | T-51B            |                  |                 |
| T-110         | T-112            |                  |                 |
| T-111         | T-120            |                  |                 |
| T-113         | T-125            |                  |                 |
| T-114         | T-S-2            |                  |                 |
| T-122A        |                  |                  |                 |
| T-124         |                  |                  |                 |
| T-126         |                  |                  |                 |
| T-127         |                  |                  |                 |
| T-128A        |                  |                  |                 |
| T-128B        |                  |                  |                 |
| T-S-1         |                  |                  |                 |
|               |                  | <u>Type C</u>    | <u>Type C-J</u> |
|               |                  | T-129B           | T-116           |
|               |                  | T-130A           | T-118           |
|               |                  | T-130B           | T-129A          |
|               |                  | T-131A           |                 |
|               |                  | T-131B           |                 |

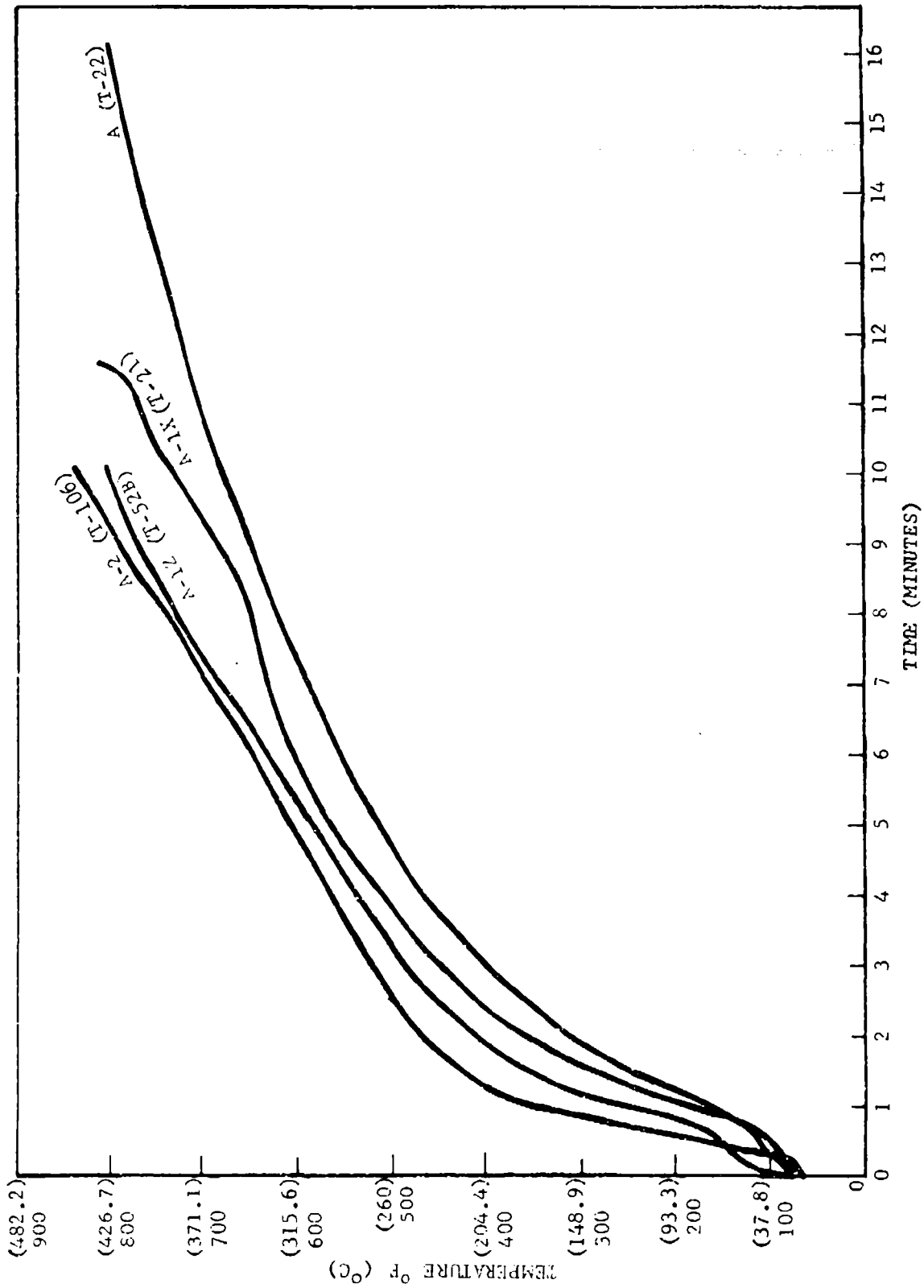
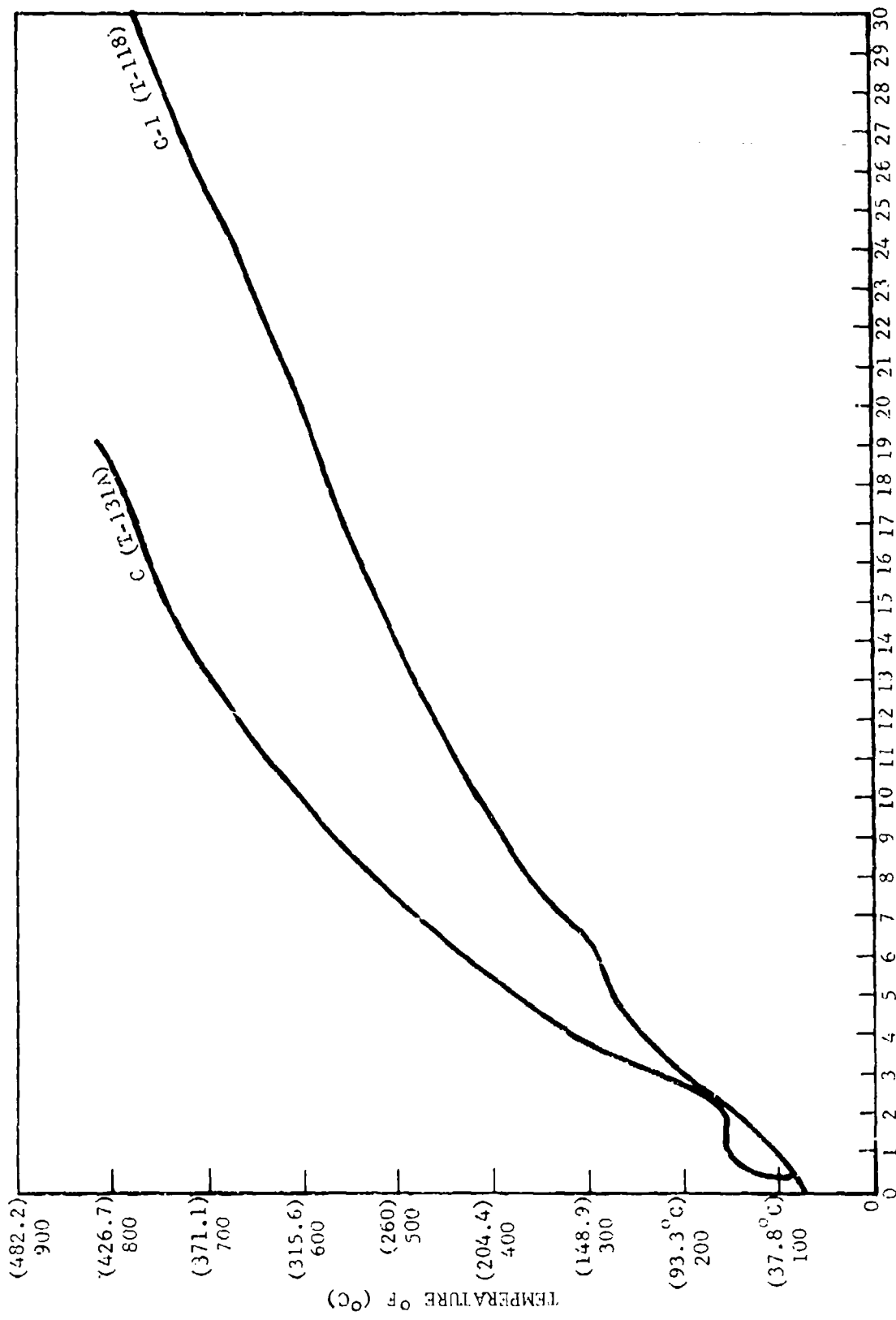


FIGURE 16. THERMAL RESPONSE REPRESENTATIVE OF TYPES A, A-1X, A-17 AND A-2



TIME OF EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC (17 JOULES/CM<sup>2</sup>-SEC) (MINUTES)

FIGURE 17. THERMAL RESPONSE REPRESENTATIVE OF TYPES C AND C-1

30 seconds to 1 minute of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). T-3 and T-129B both displayed a leveling off at 1 to 2 minutes of exposure to the heat source, T-130B (2 to 3 minutes) and T-129A (3 to 4 minutes). A graph is shown in Figure 17 of T-131A demonstrating this phenomenon.

Other specimens displayed a drop in temperature. Examples of this are T-7 and T-14 at 30 seconds to 1 minute of exposure to the heat source and T-131A at 1 to 2 minutes of exposure to the heat source.

All specimens that displayed a leveling or drop in temperature did so before reaching 200°F (93°C) with the exception of one. T-129A did display a leveling off period at 3 to 4 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec and 172°F (78°C) but also displayed a large drop in temperature after 14 minutes of exposure to the heat source at almost 600°F (315°C). A graph of T-129A is shown in Figure 18.

This phenomenon could be due to the felt coating flowing off of the felt and carrying the heat away from it.

Pictures of the six separate categories and uncategorized specimens are shown in Figures 19, 20, and 21. Identification diagrams are presented in Figures 22 and 23 to identify the specimens in Figures 19, 20, and 21.

A list of specimens including specimen number, date tested, thickness, and surface weights of the thermal resistant ceramic felts are in Appendix D. A table for the aluminum control runs is also in Appendix D.

### 3.3 TASK III

#### 3.3.1 FIRE PROTECTION OF PILOT COMPARTMENT

3.3.1.1 Fabrication of the Fire Barrier. The fire retardant material was mixed together in the following proportions: 33.9 percent No. 3 vermiculite, 65.8 percent ALBI-107A, and 0.3 percent high tensile strength graphite fiber 1/2 inch (1.27 cm) long. All percentages are by weight. Six sheets, 24.25 by 19 inches (61.60 by 48.26 cm), were made with 1/2 inch (1.27 cm) thick, 3/16 inch (0.48 cm) cell size, 5.5 lbs/ft<sup>3</sup> (88.1 kg/m<sup>3</sup>) glass/phenolic honeycomb set into the fire retardant material.

The sheets were prepared by placing a sheet of nylon film over an aluminum plate, then a layer of silicone impregnated fiber glass cloth (used for release) was placed over the nylon. The silicone impregnated fiber glass cloth was coated with a thin layer of ALBI-107A and allowed to dry to resist further absorption when the fire retardant mixture was applied.

A total of 1044g of the fire retardant was mixed and poured onto the release cloth and spread to an area approximately 24 x 19 inches (61 x 48 cm) which resulted in a thickness of about 0.080 inch (0.20 cm). The phenolic honeycomb was then placed on the fire retardant mixture. To push the honeycomb into the fire retardant mixture a press with a force of 20,000 pounds (88,964 newtons), which is approximately 45 psi (310,264 pascal), was used. When ALBI-107A had cured the release cloth was peeled off and the excess material was trimmed off.

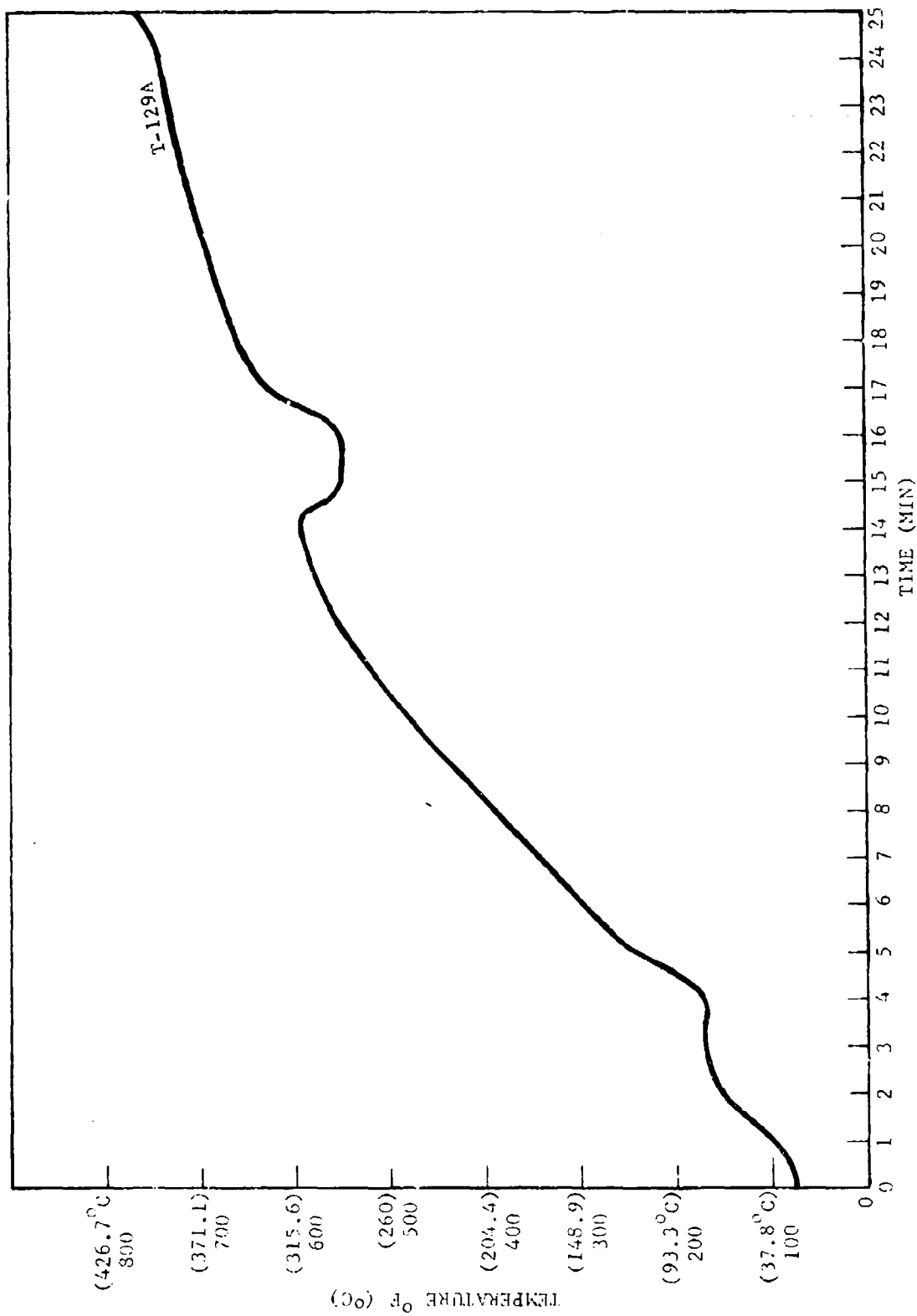


FIGURE 18. THERMAL RESPONSE OF SPECIMEN T-129A DISPLAYING A LARGE DROP IN TEMPERATURE AFTER 14 MINUTES

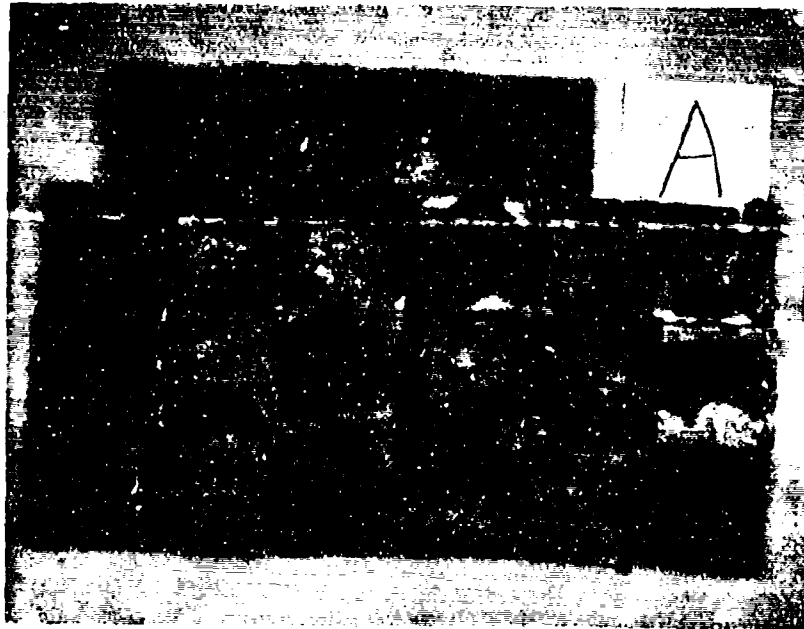


FIGURE 19. TYPE A SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC  
(17 JOULES/CM<sup>2</sup>-SEC)

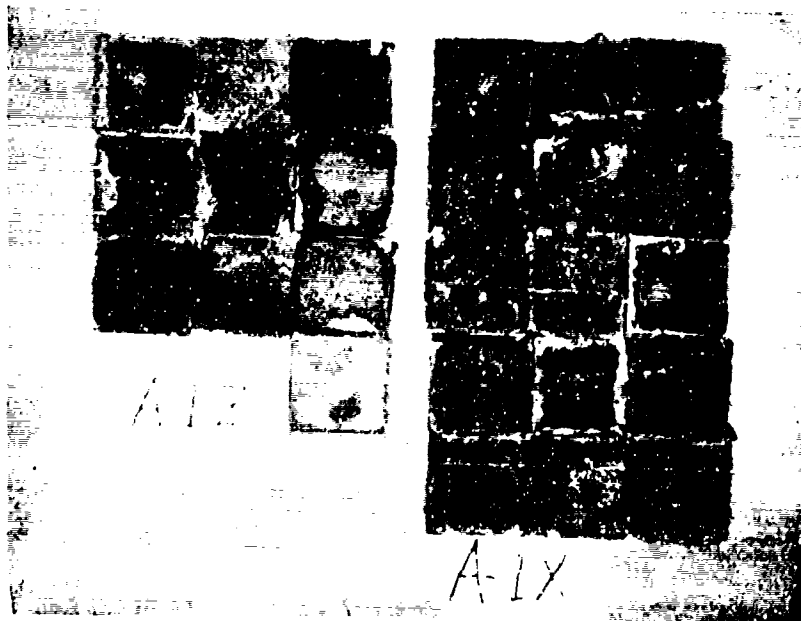


FIGURE 20. TYPE A-1 X AND Z SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC  
(17 JOULES/CM<sup>2</sup>-SEC)

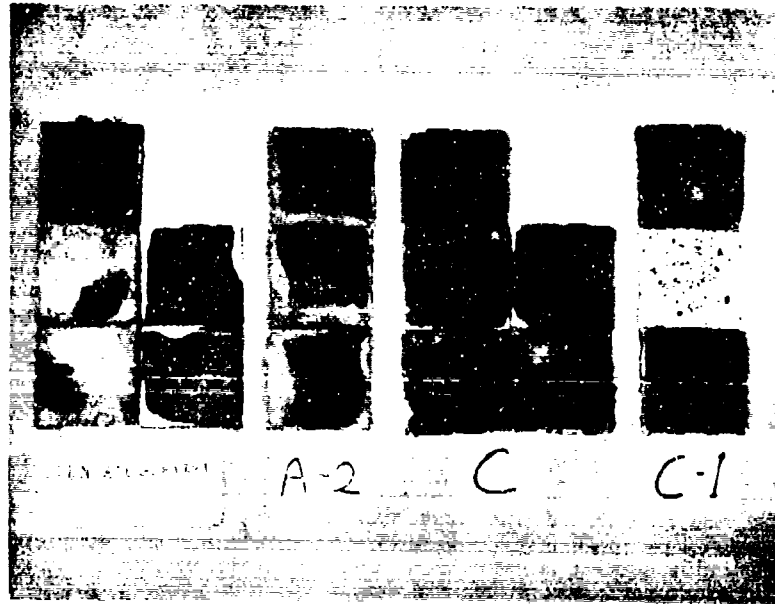


FIGURE 21. TYPES A-2, C, AND C-1 AND FIVE UNCATEGORIZED SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC (17 JOULES/CM<sup>2</sup>-SEC)

TYPE A

|       |       |        |        |       |       |
|-------|-------|--------|--------|-------|-------|
| T-127 |       | T-128A | T-128B | T-S-1 |       |
| T-111 | T-113 | T-114  | T-122A | T-124 | T-126 |
| T-20  | T-22  | T-23   | T-108  | T-109 | T-110 |
| T-1   | T-13  | T-15   | T-17   | T-18  | T-19  |

TYPE A-1X

TYPE A-1Z

|       |      |        |
|-------|------|--------|
| T-24  | T-9  | T-52B  |
| T-51A | T-53 | T-121  |
| T-52A | T-54 | T-122B |
|       |      | T-104  |

|     |      |       |
|-----|------|-------|
| T-2 | T-8  | T-51B |
| T-4 | T-10 | T-112 |
| T-5 | T-11 | T-120 |
| T-6 | T-14 | T-125 |
| T-7 | T-21 | T-S-2 |

FIGURE 22. IDENTIFICATION DIAGRAMS FOR FIGURES 19 AND 20

UNCATEGORIZED

|       |        |
|-------|--------|
| T-3   |        |
| T-105 | T-119B |
| T-107 | T-119C |

A-2

|       |
|-------|
| T-26  |
| T-27  |
| T-106 |

C

|        |        |
|--------|--------|
| T-129B |        |
| T-130A | T-131A |
| T-130B | T-131B |

C-1

|        |
|--------|
| T-116  |
| T-118  |
| T-129A |

FIGURE 23. IDENTIFICATION DIAGRAMS FOR FIGURE 21

Six sheets, 24 x 19 inches (61 x 48 cm), of fire retardant material were also made without the phenolic honeycomb using the same procedure described above.

3.3.3.2 Installation of the Fire Barrier into the A-4 Jet Pilot Compartment. Installation of the prefabricated fire retardant material was done on site at NWC, China Lake, California. To accomplish this, several of the pilot compartment components had to be removed such as the seat, side plates, foot pedals, partial disassembly of the control stick, some hydraulic lines, electrical boxes not fully identified, etc.

Clean up involved removal of the insulation pads and of the adhesive plus paint and primer, in some places, with rotary wire brushes and a drill motor. In some inaccessible areas, MEK and a scraper were used.

Cardboard templates were cut out and fitted into place before the fire retardant material was cut into sections. The sections were bonded with 122 adhesive and 952 catalyst. A total area of approximately 1400 square inches (9,032 square cm) was covered resulting in a weight gain of 3361g of fire retardant with honeycomb, 135g fire retardant without honeycomb, 950g 122 adhesive, and 700g wet fire retardant for patching, which is a total of approximately 5,146g.

The area covered included the entire floor area except for the center hump in the forward cockpit area.

The forward wall sections were covered within the area approximately 14 inches (35.6 cm) up from the floor and 13 to 15 inches (33 to 38 cm) back from the front bulkhead. Portions of the front bulkhead were also covered within the area 6 inches (15.2 cm) in from the walls, 14 inches (35.6 cm) up from the floor (left side), and 8 to 11 inches (20.3 to 27.9 cm) up from the floor (right side).

Some sections had to be cut into two or three sections to be fitted into place since the material does not bend very much. Figure 24 presents an exploded diagram of the sections installed in the cockpit of the A-4 jet. To fill in areas which were not covered because of inaccessibility or cracks between sections, a wet fire retardant mixture was mixed and used as putty would be used.

The project was finished by mounting a tent over the cockpit to protect the fire barrier from the elements since there was no canopy to keep the rain and dirt out.

#### 3.4 TASK IV

##### 3.4.1 PROCEDURE OF MOUNTING THE A-4 COCKPIT CANOPY ASSEMBLY OVERLAY

The plexiglas of the canopy was prepared by cleaning with soap and water then with ethyl alcohol. 2 by 2 inch (5.08 x 5.08 cm) squares, 0.125 inch (0.32 cm) thick were bonded to the plexiglas at five points, one in each corner and one in the center of each square, with RTV 108 silicone rubber made by G.E. RTV 108 was chosen for its bonding, translucent and heat resistant properties.

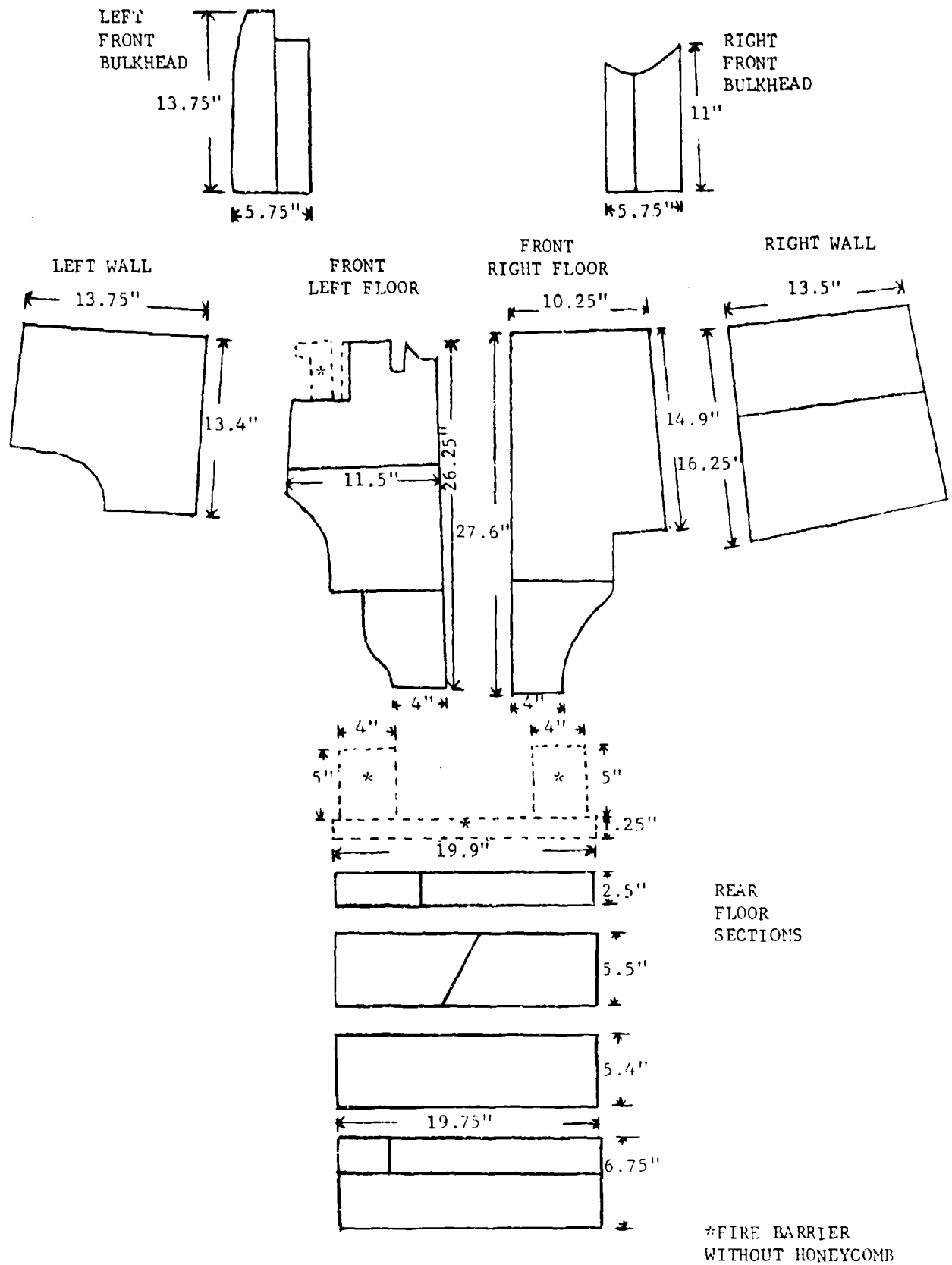


FIGURE 24. EXPLODED DIAGRAM OF FIRE BARRIER SECTIONS IN A-4 COCKPIT.

In bonding the pyrex squares to the plexiglas, a minimum gap of 0.030 inch (0.076 cm) was maintained between each square to allow for thermal expansion of the pyrex. Larger gaps resulted in some places because the curvature of the plexiglas prevented each square from completely lining up with the squares on each side.

A brass rod 1 inch (2.54 cm) wide and 1/4 inch (0.635 cm) thick was mounted around the plexiglas and held in place by some of the bolts that hold the plexiglas in place. Holes were drilled in the brass rod and threaded for screws to hold the safety wire in place. The surrounding brass rod can be seen in Figure 25.

When the brass rod, pyrex squares and cut pyrex squares, which were made to fill in the area between the brass rod and the full squares, were in place 0.002 inch (0.005 cm) copper strips, cut to the thickness of the pyrex, were placed in the gaps between the pyrex squares. In Figure 26 it can be seen that the spaces between the pyrex squares running from the front of the overlay to the rear are all in line, so a copper strip was cut to size and to the curvature of the plexiglas from the brass rod in front, to the brass rod in the rear for each row of gaps running lengthwise. For the gaps between the squares running from one side to the other 2 inch (5.08 cm) copper strips were used.

The procedure of putting the copper strips in place is as follows: first, a small bead of RTV 108 silicone rubber was placed in the gap and the copper strip was set in place. Then another bead of RTV 108 was run along the gap trying to partially fill it. This was accomplished by the use of a Semco air gun with a small opening. When the silicone rubber had fully cured, the excess was cut off with a razor blade. The entire overlay was sealed except for openings left in the rear to allow for escaping air.

The final step was to install 0.015 inch (0.038 cm) stainless steel safety wire. This was accomplished by attaching the wire to the screws provided on the brass strip (shown in Figure 25). One wire was strung for each row of pyrex squares running lengthwise and from one side to the other, shown in Figure 26. At each intersection of wire, one wire was looped around the other to hold them in place. As a final touch the brass strip was cleaned and coated with a clear polyurethane.

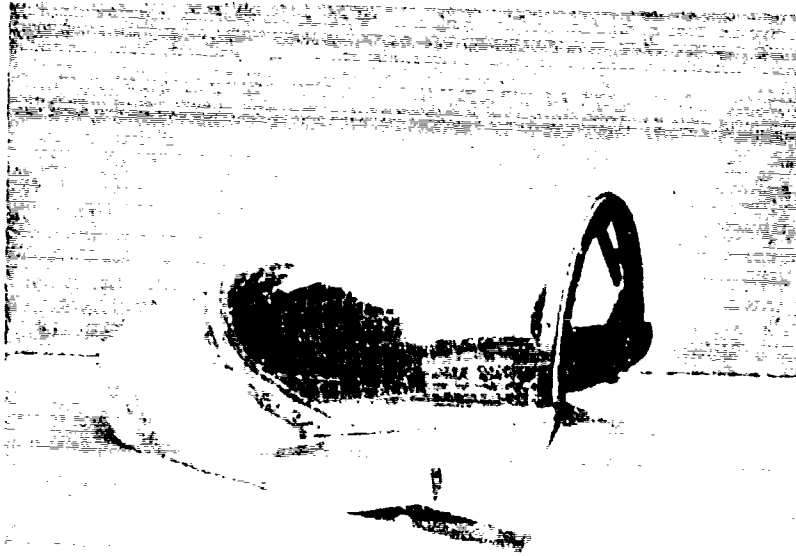


FIGURE 25. A-4 JET COCKPIT CANOPY ASSEMBLY



FIGURE 26. CLOSE UP OF THE MOSAIC OVERLAY

## SECTION 4

### CONCLUSIONS

#### 4.1 DEVELOPMENT OF AN EFFECTIVE THERMAL BARRIER COATING

The most efficient matrix system evaluated in this program was a solvent based modified vinyl coating identified as ALBI-107A. It is an organic intumescent coating which reacts to heat at 300°F (150°C) by foaming into a thick cellular insulation blanket and when exposed to test temperatures of 2000°F (1093°C) yields an insulative carbon foam. The best filler of the materials tested was unexpanded vermiculite, which is an inorganic intumescent mineral classified as a hydrous mica. Grade No. 3 vermiculite was found to be the most effective particle size when combined with ALBI-107A and the optimum matrix-filler proportion was 66 percent ALBI-107A and 34 percent vermiculite grade No. 3. The addition of a small amount of carbon fibrous reinforcement appears to further enhance the thermal protection.

Based upon testing conducted during this program, the best formulation is 65.84 percent ALBI-107A, 33.86 percent No. 3 vermiculite, and 0.03 percent 0.5 inch (1.27 cm) length high tensile strength carbon fiber. A 0.060 inch (0.15 cm) coating thickness of this formula on an aluminum substrate will protect the substrate 6.3 minutes to 500°F (260°C) and 17.4 minutes to 300°F (427°C) when exposed to 2000°F (1093°C).

This thermal barrier coating possesses good adhesion to an aluminum substrate and can be applied directly to the substrate or can be fabricated as a precured coating and secondarily bonded to the substrate.

#### 4.2 TASK II - EVALUATION OF GOVERNMENT FURNISHED THERMAL RESISTANT CERAMIC FELTS

The government furnished ceramic felts were not identified as to composition of the felt structure nor identified as to the coating which was present upon one surface. The felts were on the order of 0.5 inch (1.27 cm) thickness and varied considerably in weight. The following conclusions are based upon thermal insulation effectiveness only.

Specimen No. T-118 yielded the best thermal protection when exposed to a 2300°F (1260°C) frontface temperature, 14 minutes before an aluminum substrate temperature of 500°F (260°C) is reached and 31 minutes until 800°F (427°C) is reached. The next best specimens were T-116, T-129A, T-129B, and T-130A with values in the range of 9 minutes to 500°F (260°C) and 23 minutes to 800°F (427°C).

#### 4.3 TASK III - FABRICATION AND INSTALLATION OF THERMAL BARRIER COATING IN AN A-4 JET COCKPIT

The best coating formulation evaluated in Task I was combined with glass/phenolic honeycomb, prefabricated into precured panels and installed in the

cockpit area. It was determined that the installation could be accomplished without the use of special tooling and is feasible as a field installation. Further evaluations and conclusions can be made when the Naval Weapon Center personnel complete the actual fuel fire test environment evaluation which is scheduled for the latter part of 1976.

#### 4.4 TASK IV - PYREX GLASS MOSAIC OVERLAY OF A-4 JET PLEXIGLAS CANOPY

A mosaic pyrex glass overlay (individual pieces) was installed over the Plexi-glas portion of the canopy by adhesively spot-bonding with a transparent silicone adhesive. Image distortment, when viewed from inside the cockpit, was apparent; however, this could be significantly reduced by using a one or two piece preformed pyrex canopy overlay.

Further conclusions as to the effectiveness of this task can be made when Naval Weapon Center personnel complete their testing of this canopy under an actual fire test environment.

APPENDIX A

MATERIALS LIST FOR THE  
ENTIRE PROGRAM

APPENDIX A  
MATERIALS LIST FOR THE ENTIRE PROGRAM

| <u>Material</u>  | <u>Company Name</u>       | <u>Description</u>   |
|--|---------------------------|--|
| Flamarest Epoxy Paint<br>AVCO 1100   | AVCO Systems Division     | Three component catalyzed epoxy, semi rigid, intumescent coating |
| Monokote 5   | W. R. Grace and Co.       | One part fireproofing system mixed with water                    |
| Sodium Silicate  | L. A. Chemical Co.        |  |
| Dow Corning 325<br>Ablative Silicone   | Dow Corning Corp.         | Ablative Silicone Rubber   |
| Dow Corning 2106<br>Silicone Resin   | Dow Corning Corp.         | Silicone Resin with Catalyst                                     |
| Latex Compound   | B. F. Goodrich            | Latex  |
| APF Epoxy Deck Coating   | HYSOL                     | Two part epoxy system with nylon, sand, and asbestos fillers     |
| Butyl Rubber<br>11.7 Percent Solids  | B. F. Goodrich            | Butyl Rubber   |
| Urea-Resin Wilhold   | Wilhold Glues Inc.        | Plastic Resin Adhesive   |
| Carbopol 934   | B. F. Goodrich            | Water Thickening Agent   |
| 50 Percent 828<br>Epoxy Resin<br>50 Percent Versamid<br>(140 Polyamid Resin) | Shell<br>General Mills    | Two part epoxy resin system                                      |
| 35 Percent Magnesium<br>Oxide<br>65 Percent Magnesium<br>Chloride            | L. A. Chemical Co.        |  |
| MXS 6026/84  | Fiberite West Coast Corp. | Phenolic Prepreg   |
| ALBI-107A  | Sherwin Williams          | Intumescent solvent based modified vinyl coating                 |

| <u>Material</u>                  | <u>Company Name</u>               | <u>Description</u>  |
|----------------------------------|-----------------------------------|---|
| Pittsburgh Speedhyde             | PPG Industries Inc.               | Latex Fire Retardant Paint  |
| Vermiculite                      | W. K. Grace Co.                   | Naturally occurring mineral<br>(hydrous mica)   |
| Perlite                          | Redco, Inc.                       | Naturally occurring glassy<br>volcanic rock   |
| Pyrex Glass                      | Sudden Service<br>Glass Co.       | 2" x 2" x .25" Pyrex<br>(5.08 x 5.08 x .64 cm)  |
| Safety Wire                      | National Standard<br>Wire Co.     | .015" Diameter<br>(.038 cm)   |
| Brass Bar                        | Ducommun Metals<br>and Supply Co. | 1/4" x 1"<br>(.64 x 2.54 cm)  |
| RTV 108                          | Electron Specialties<br>(G.E.)    | Translucent Silicone<br>Rubber  |
| Phenolic/Glass<br>Honeycomb      | Hexcel                            | 3/16 inch (.48 cm) cell size<br>.5 inch (1.27 cm) thick<br>5.5 lb/ft <sup>3</sup> (88.1 kg/m <sup>3</sup> ) |
| EPI Bond 122 and<br>952 hardener | Furane Plastics Inc.              | 2 Part Adhesive System  |

APPENDIX B

THERMAL PROTECTIVE COATING TEST  
MATRIX AND FILLERS OF TASK I

## APPENDIX B

## THERMAL PROTECTIVE COATING TEST MATRIX AND FILLERS OF TASK I

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT |                         | COATING<br>THICKNESS |       | WEIGHT               |                      |
|-----------------|--|-------------------------|----------------------|-------|----------------------|----------------------|
|                 | MATRIX                                       | FILLER                  | MILS                 | (CM)  | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |
| 1               | Flamarest Epoxy Paint<br>Avco 1100 - 29%     | Perlite #1120 -<br>71%  | 75                   | (.19) | .47                  | (2.29)               |
| 1 - 1           | Same As #1 - 34%                             | Same As #1 - 66%        | 97                   | (.25) | .74                  | (3.61)               |
| 2               | Flamarest Epoxy Paint<br>Avco 1100 - 34%     | Vermiculite #3 -<br>66% | 75                   | (.19) | .59                  | (2.88)               |
| 2 - 1           | Same As #2 - 32%                             | Same As #2 - 68%        | 75                   | (.19) | .63                  | (3.07)               |
| 3               | Flamarest Epoxy Paint<br>Avco 1100 - 34%     | Vermiculite #2 -<br>66% | 71                   | (.18) | .50                  | (2.44)               |
| 3 - 1           | Same As #3 - 34%                             | Same As #3 - 66%        | 82                   | (.21) | .61                  | (2.98)               |
| 4               | Monokote 5<br>Zonolite MK-5<br>Fireproofing  | Not Known               | 32                   | (.81) | .09                  | (.44)                |
| 4 - 1           | Same As #4                                   | Same As #4              | 61                   | (.15) | .14                  | (.68)                |
| 5               | Sodium Silicate -<br>34%                     | Perlite #1120 -<br>66%  | 110                  | (.28) | .59                  | (2.88)               |
| 5 - 1           | Same As #5 - 34%                             | Same As #5 - 66%        | 100                  | (.25) | .58                  | (2.83)               |
| 6               | Sodium Silicate -<br>34%                     | Vermiculite #2 -<br>66% | 52                   | (.13) | .36                  | (1.76)               |
| 6 - 1           | Same As #6 - 34%                             | Same As #6 - 66%        | 59                   | (.15) | .51                  | (2.49)               |
| 7               | Dow Corning 325<br>Ablative Silicone - 34%   | Perlite #1120 -<br>66%  | 63                   | (.16) | .57                  | (2.78)               |
| 8               | Dow Corning 325<br>Ablative Silicone - 34%   | Vermiculite #2 - 66%    | 110                  | (.28) | .62                  | (3.02)               |
| 9               | Dow Corning 2106<br>Silicone Resin - 34%     | Perlite #1120 - 66%     | 100                  | (.25) | .52                  | (2.54)               |
| 10              | Dow Corning 2106<br>Silicone Resin - 28%     | Vermiculite #2 - 72%    | 76                   | (.19) | .53                  | (2.58)               |
| 11              | Aluminum Control<br>Specimen                 | None                    | --                   |       | ---                  |                      |

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT |   | COATING<br>THICKNESS        |      | WEIGHT               |                      |        |
|-----------------|--|---|-----------------------------|------|----------------------|----------------------|--------|
|                 | MATRIX                                       | FILLER  | MILS                        | (CM) | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |        |
| 12              | -0   | Flamarest Epoxy Paint   | Not known                   | 52   | (.13)                | .38                  | (1.85) |
|                 | -1   | Avco 1100 - 100%  |                             | 51   | (.13)                | .33                  | (1.61) |
|                 | -2   |   |                             | 63   | (.16)                | .41                  | (2.00) |
| 13              |  | Flamarest Epoxy Paint   | Vermiculite #4 -            | 67   | (.17)                | .62                  | (3.02) |
|                 |  | Avco 1100 - 34%   | 66%                         |      |                      |                      |        |
| 14              |  | Latex Compound  | Perlite #1120 -             | 100  | (.25)                | .55                  | (2.68) |
|                 |  | B.F. Goodrich - 34%   | 66%                         |      |                      |                      |        |
| 15              |  | Latex Compound  | Vermiculite #2 -            | 63   | (.16)                | .52                  | (2.54) |
|                 |  | B.F. Goodrich - 26.4%   | 73.6%                       |      |                      |                      |        |
| 16              |  | APF 100 Epoxy Deck Coat-<br>ing Aeronutronic Ford                               | Nylon, sand,<br>asbestos    | 60   | (.15)                | .49                  | (2.39) |
| 17              |  | Flamarest Epoxy Paint   | Perlite #4500 -             | 58   | (.15)                | .42                  | (2.05) |
|                 |  | Avco 1100 - 43.6%   | 56.4%                       |      |                      |                      |        |
| 18              |  | Dow Corning 325<br>Ablative Silicone - 100%                                     | Not Known                   | 72   | (.18)                | .31                  | (1.51) |
| 19              |  | Butyl Rubber<br>11.7% Solids - 2.7%   | Perlite #1120 -<br>97.3%    | 87   | (.22)                | .46                  | (2.24) |
| 20              |  | Butyl Rubber<br>11.7% Solids - 14.6%  | Vermiculite #2 -<br>85.4%   | 50   | (.13)                | .44                  | (2.14) |
| 21              |  | Plastic Resin Glue<br>Urea-Resin Wilhold - 34%                                  | Perlite #1120 -<br>66%      | 90   | (.23)                | .55                  | (2.68) |
| 22              |  | Plastic Resin Glue<br>Urea-Resin Wilhold - 34%                                  | Vermiculite #2 -<br>66%     | 52   | (.13)                | .46                  | (2.24) |
| 23              |  | Carbopol 934/H <sub>2</sub> O <sup>2</sup> - 34.5%<br>B.F. Goodrich             | Vermiculite #2 -<br>64.5%   | 62   | (.16)                | .38                  | (1.85) |
| 24              |  | 50% Shell 828 Epoxy Resin<br>50% Gen. Mils Versamid<br>140 Polyamid Resin - 34% | Aluminum Hydroxide -<br>66% | 62   | (.16)                | .53                  | (2.59) |
| 25              |  | Sodium Silicate - 34%   | Aluminum Hydroxide -<br>66% | 63   | (.16)                | .52                  | (2.54) |

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT   |   | COATING<br>THICKNESS |       | WEIGHT               |                      |
|-----------------|--|---|----------------------|-------|----------------------|----------------------|
|                 | MATRIX   | FILLER                                      | MILS                 | (CM)  | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |
| 26              | 50% Shell 828 Epoxy Resin<br>50% Gen. Mils Versamid<br>140 Polyamid Resin - 34.2%                | Borax -<br>65.8%                            | 54                   | (.14) | .39                  | (1.90)               |
| 27              | Sodium Silicate - 62%  | Borax - 38%                                 | 74                   | (.19) | .53                  | (2.59)               |
| 28              | 35% Magnesium Oxide<br>65% Magnesium Chloride<br>H <sub>2</sub> O 1.17 Density solution<br>84.8% | Phenolic Micro<br>Balloons - 15.2%          | 65                   | (.16) | .23                  | (1.12)               |
| 29              | 50% Shell 828 Epoxy Resin<br>50% Gen. Mils Versamid<br>140 Polyamid Resin - 34%                  | Potassium Nitrate<br>KNO <sub>3</sub> - 66% | 90                   | (.23) | .56                  | (2.73)               |
| 30              | MXS 6026/84<br>Fiberite Phenolic Prepreg<br>- 100%   | Not known                                   | 85                   | (.22) | .72                  | (3.51)               |
| 31              | Sodium Silicate - 34%  | Vermiculite # 4 - 66%                       | 68                   | (.17) | .48                  | (2.34)               |
| 32              | Dow Corning 325<br>Ablative Silicone - 34%   | Vermiculite #4 - 66%                        | 104                  | (.26) | .56                  | (2.73)               |
| 32 - 1          | Same As #32 - 34%  | Same As #32 - 66%                           | 77                   | (.20) | .56                  | (2.73)               |
| 33              | Dow Corning 2106<br>Silicone Resin - 34%   | Vermiculite #4 -<br>66%                     | 56                   | (.14) | .49                  | (2.39)               |
| 34              | Latex Compound<br>B.F. Goodrich - 25.2%  | Vermiculite #4 -<br>74.8%                   | 67                   | (.17) | .51                  | (2.49)               |
| 35              | Albi 107-A, Vinyl Fire<br>Retardant  | Not Known                                   | 52                   | (.13) | .34                  | (1.66)               |
| 35              | Albi 107-A - 100%  | Not Known                                   | 52                   | (.13) | .34                  | (1.66)               |
| 35 - 1          | Albi 107-A - 100%  | Not Known                                   | 60                   | (.15) | .39                  | (1.90)               |
| 35 - 2          | Albi 107-A - 100%  | Not Known                                   | 72                   | (.18) | .48                  | (2.34)               |
| 35 - 3          | Albi 107-A - 100%  | Not Known                                   | 25                   | (.06) | .16                  | (.78)                |
| 35 - 4          | Albi 107-A - 100%  | Not Known                                   | 45                   | (.11) | .32                  | (1.56)               |
| 35 - 5          | Albi 107-A - 100%  | Not Known                                   | 70                   | (.18) | .48                  | (2.34)               |
| 35 - 6          | Albi 107-A - 100%  | Not Known                                   | 110                  | (.28) | .67                  | (3.27)               |
| 35 - 7          | Albi 107-A - 100%  | Not Known                                   | 135                  | (.34) | .84                  | (4.10)               |

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT                 |                          | COATING<br>THICKNESS |       | WEIGHT               |                      |
|-----------------|--|--------------------------|----------------------|-------|----------------------|----------------------|
|                 | MATRIX   | FILLER                   | MILS                 | (CM)  | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |
| 36              | Albi 107-A, Vinyl Fire<br>Retardant - 34.2%                  | Perlite #1120 -<br>65.8% | 97                   | (.25) | .70                  | (3.42)               |
| 36 - 1          | Albi 107-A - 34%   | Perlite #1120 -<br>66%   | 75                   | (.19) | .49                  | (2.39)               |
| 36 - 2          | Albi 107-A - 66%   | Perlite #1120 -<br>34%   | 80                   | (.20) | .51                  | (2.49)               |
| 37              | Albi 107-A, Vinyl Fire<br>Retardant                          | Vermiculite #2 -         | 67                   | (.17) | .60                  | (2.93)               |
| 37 - 1          | Albi 107-A - 34%   | Vermiculite #2 - 66%     | 60                   | (.15) | .51                  | (2.49)               |
| 37 - 2          | Albi 107-A - 66%   | Vermiculite #2 - 34%     | 80                   | (.20) | .52                  | (2.54)               |
| 38              | MXS 6026/84 Fiberite<br>Phenolic Prepreg - 100%              | Not Known                | 89                   | (.23) | .72                  | (3.51)               |
| 39              | MXS 6026/84 Fiberite<br>Phenolic Prepreg - Charred<br>- 100% | Not Known                | 86                   | (.22) | .60                  | (2.93)               |
| 40              | Albi 107-A - 34%   | Vermiculite #1 - 66%     | 130                  | (.33) | .92                  | (4.49)               |
| 40 - 1          | Albi 107-A - 66%   | Vermiculite #1 - 34%     | 110                  | (.28) | 1.0                  | (4.88)               |
| 41              | Albi 107-A - 34%   | Vermiculite #3 - 66%     | 65                   | (.17) | .51                  | (2.49)               |
| 41 - 1          | Albi 107-A - 66%   | Vermiculite #3 - 34%     | 72                   | (.18) | .54                  | (2.64)               |
| 42              | Albi 107-A - 34%   | Vermiculite #4 - 66%     | 65                   | (.17) | .51                  | (2.49)               |
| 42 - 1          | Albi 107-A - 66%   | Vermiculite #4 - 34%     | 65                   | (.17) | .52                  | (2.54)               |
| 43              | Albi 107-A - 34%   | Vermiculite #5 - 66%     | 55                   | (.14) | .52                  | (2.54)               |
| 43 - 1          | Albi 107-A - 66%   | Vermiculite #5 - 34%     | 65                   | (.17) | .52                  | (2.54)               |
| 44              | Albi 107-A - 34%   | Perlite #4500 - 66%      | 72                   | (.18) | .47                  | (2.29)               |
| 44 - 1          | Albi 107-A - 66%   | Perlite #4500 - 34%      | 80                   | (.20) | .54                  | (2.64)               |
| 45              | Albi 107-A - 34%   | Perlite #1440 - 66%      | 83                   | (.21) | .51                  | (2.49)               |
| 45 - 1          | Albi 107-A - 66%   | Perlite #1440 - 34%      | 77                   | (.20) | .52                  | (2.54)               |
| 46              | Albi 107-A - 34%   | Perlite #816 - 66%       | 130                  | (.33) | .78                  | (3.81)               |
| 45 - 1          | Albi 107-A - 66%   | Perlite #816 - 34%       | 120                  | (.30) | .78                  | (3.81)               |
| 46 - 2          | Albi 107-A - 66%   | Perlite #816 - 34%       | 135                  | (.34) | .85                  | (4.15)               |

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT |          | COATING<br>THICKNESS                       |      | WEIGHT               |                      |        |
|-----------------|--|----------|--|------|----------------------|----------------------|--------|
|                 | MATRIX                                       | FILLER   | MILS                                       | (CM) | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |        |
| 47              | Pittsburgh 42-7                              | - 100%   | Not Known                                  | 48   | (.12)                | .26                  | (1.27) |
| 47 - 1          | Pittsburgh 42-7                              | - 100%   | Not Known                                  | 43   | (.11)                | .23                  | (1.12) |
| 47 - 2          | Pittsburgh 42-7                              | - 100%   | Not Known                                  |      |                      |                      |        |
| 48              | Pittsburgh 42-7                              | - 34%    | Vermiculite #2 - 66%                       | 78   | (.20)                | .52                  | (2.54) |
| 49              | Pittsburgh 42-7                              | - 34%    | Perlite #1120 - 66%                        | 85   | (.22)                | .55                  | (2.68) |
| 50              | Albi 107-A                                   | - 33.8%  | Vermiculite #3 -<br>65.8%                  | 80   | (.20)                | .52                  | (2.54) |
|                 |  |          | HTS Carbon Fiber .4%<br>3" length          |      |                      |                      |        |
| 50 - 1          | Albi 107-A                                   | - 65.84% | Vermiculite #3 -<br>33.86%                 | 60   | (.15)                | .52                  | (2.54) |
|                 |  |          | HTS Carbon Fiber, 0.3%<br>3" length        |      |                      |                      |        |
| 50 - 2          | Albi 107-A                                   | - 65.84% | Vermiculite #3<br>33.86%                   | 60   | (.15)                | .54                  | (2.63) |
|                 |  |          | HTS Carbon fiber, 0.3%<br>Short 1/2" fiber |      |                      |                      |        |
| 51              | Albi 107-A                                   | - 66%    | Vermiculite #5<br>34%                      | 50   | (.12)                | .37                  | (1.81) |
|                 |  |          | Carbon cloth 2 ply<br>from T-75 fiber      |      |                      |                      |        |
| 52              | Albi 107-A                                   | - 34%    | Vermiculite #2, 33%<br>#5, 33%             | 65   | (.17)                | .51                  | (2.49) |
| 52 - 1          | Albi 107-A                                   | - 66%    | Vermiculite #2, 17%<br>#5, 17%             | 50   | (.12)                | .56                  | (2.73) |
| 53              | Albi 107-A                                   | - 34%    | Layers #5, 33%<br>Vermiculite #2, 33%      | 74   | (.19)                | .53                  | (2.59) |
| 53 - 1          | Albi 107-A                                   | - 66%    | Layers #5, 17%<br>Vermiculite #2, 17%      | 70   | (.18)                | .59                  | (2.88) |
| 54              | Albi 107-A                                   | - 34%    | Layers Vermiculite<br>#5 - 33%             | 70   | (.18)                | .52                  | (2.54) |
|                 |  |          | Perlite 4500 - 33%                         |      |                      |                      |        |
| 54 - 1          | Albi 107-A                                   | - 66%    | Layers Same as 54<br>Vermiculite #5 - 17%  | 80   | (.20)                | .55                  | (2.68) |
|                 |  |          | Perlite 4500 - 17%                         |      |                      |                      |        |

| SPECIMEN<br>NO. | COATING FORMULATION AND<br>PERCENT BY WEIGHT |  | COATING<br>THICKNESS   |       | WEIGHT               |                      |
|-----------------|--|--|--|-------|----------------------|----------------------|
|                 | MATRIX                                       | FILLER   | MILS   | (CM)  | LBS/FT. <sup>2</sup> | (kg/m <sup>2</sup> ) |
| 55              | Albi 107-A                                   | - 34% Crocidolite<br>asbestos - 0.2%<br>Vermiculite #2 -<br>65.09% | 60   | (.15) | .49                  | (2.39)               |
| 55 - 1          | Albi 107-A                                   | - 66% C/asbestos - .53%<br>Vermiculite #2 - 33.47%                 | 60   | (.15) | .55                  | (2.68)               |
| 55 - 2          | Albi 107-A                                   | - 66% C/asbestos - .53%<br>Vermiculite #2 - 33.47%                 | 75   | (.19) | .56                  | (2.73)               |
| 56              | Albi 107-A                                   | - 54% C/asbestos - 0.2%<br>Perlite 1120 - 65.09%                   | 95   | (.24) | .5                   | (2.44)               |
| 56 - 1          | Albi 107-A                                   | - 66% C/asbestos - .53%<br>Perlite 1120 - 65.06%                   | 85   | (.22) | .54                  | (2.64)               |
| 57              | Albi 107-A                                   | - 79% Glass Bubbles B25B<br>(3M) - 21%                             | 60   | (.15) | .15                  | (.73)                |
| 57 - 1          | Albi 107-A                                   | - 90% Glass Bubbles B25B<br>(3M) - 10%                             | 80   | (.20) | .27                  | (1.32)               |
| 58              | Albi 107-A                                   | - 79% Eccospheres Ft. 102<br>(E.C.) - 21%                          | 60   | (.15) | .15                  | (.73)                |
| 58 - 1          | Albi 107-A                                   | - 90% Eccospheres FT 102<br>(E.C.) 10%                             | 85   | (.22) | .28                  | (1.37)               |
| 59              | Albi 107-A                                   | - 66% 3" Carbon fibers - .53%<br>Vermiculite #2 - 33.47%           | 76   | (.19) | .57                  | (2.78)               |
| 60              | Albi 107-A                                   | - 66% C/asbestos fiber - .53%<br>Vermiculite #2 - 33.47%           | 6 x 6 sample on 8" x 8"<br>plate, tested with plate<br>toward heat |       |                      |                      |
| 61              | Albi 107-A                                   | - 99.51% 3" carbon fibers,<br>HTS - .49%                           | 70   | (.18) | .48                  | (2.34)               |
| 62              | Albi 107-A                                   | - 99.51% C/asbestos fiber -<br>.49%                                | 63   | (.16) | .47                  | (2.29)               |

APPENDIX C

SUBSTRATE BACKFACE THERMAL RESPONSE FOR THE MOST  
SIGNIFICANT SPECIMENS TESTED IN TASK I

K $\sigma$ E 10 X 10 TO THE CENTIMETER 46 1513  
10 X 25 CM  
KEUFFEL & ESSER CO.

Figure C-1. Backface Temperature Rise Time For Pittsburgh 42-7 Coating With Various Fillers

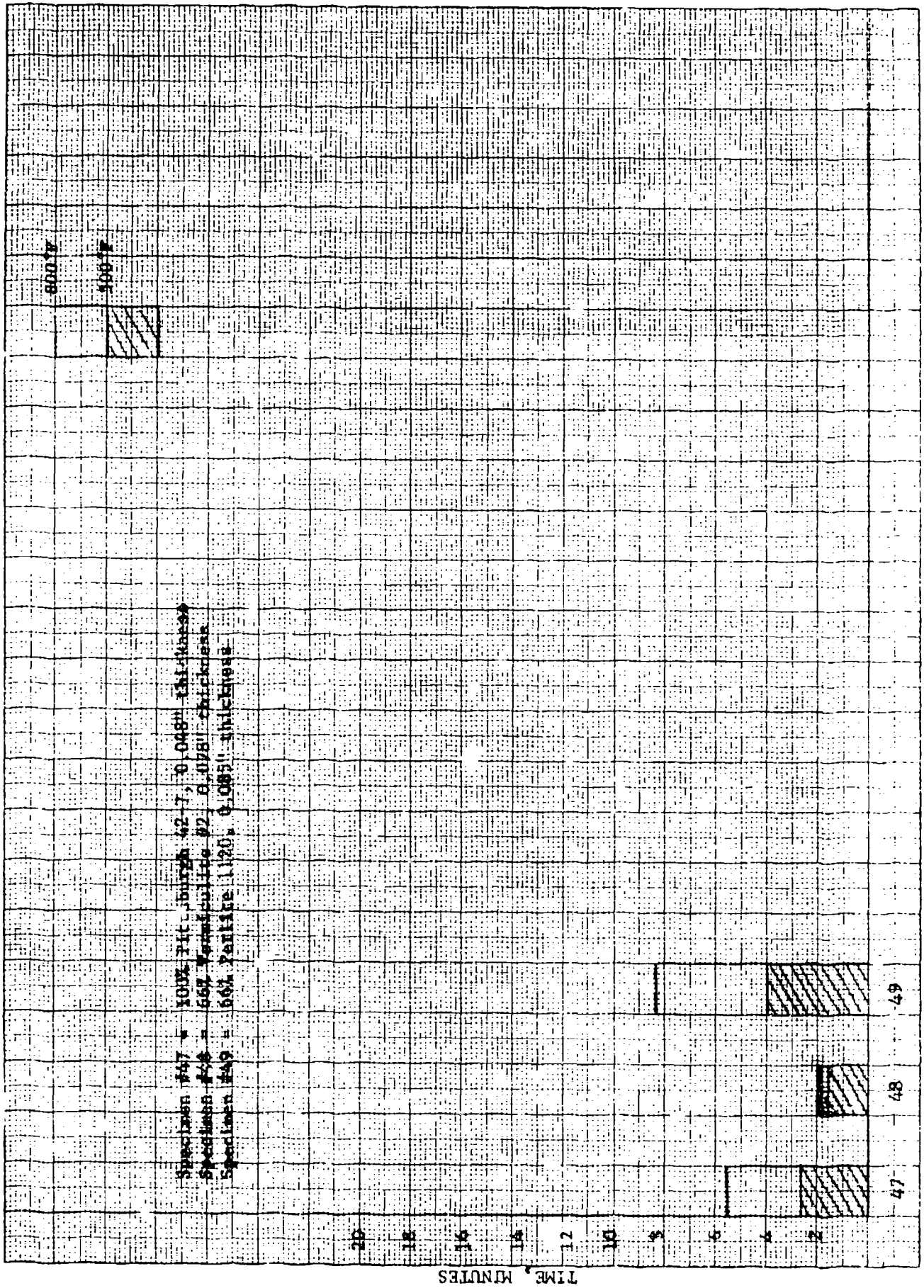


Figure C-2. Backface Temperature Rise Time For Albi 107-A/Glass Bubble Coatings

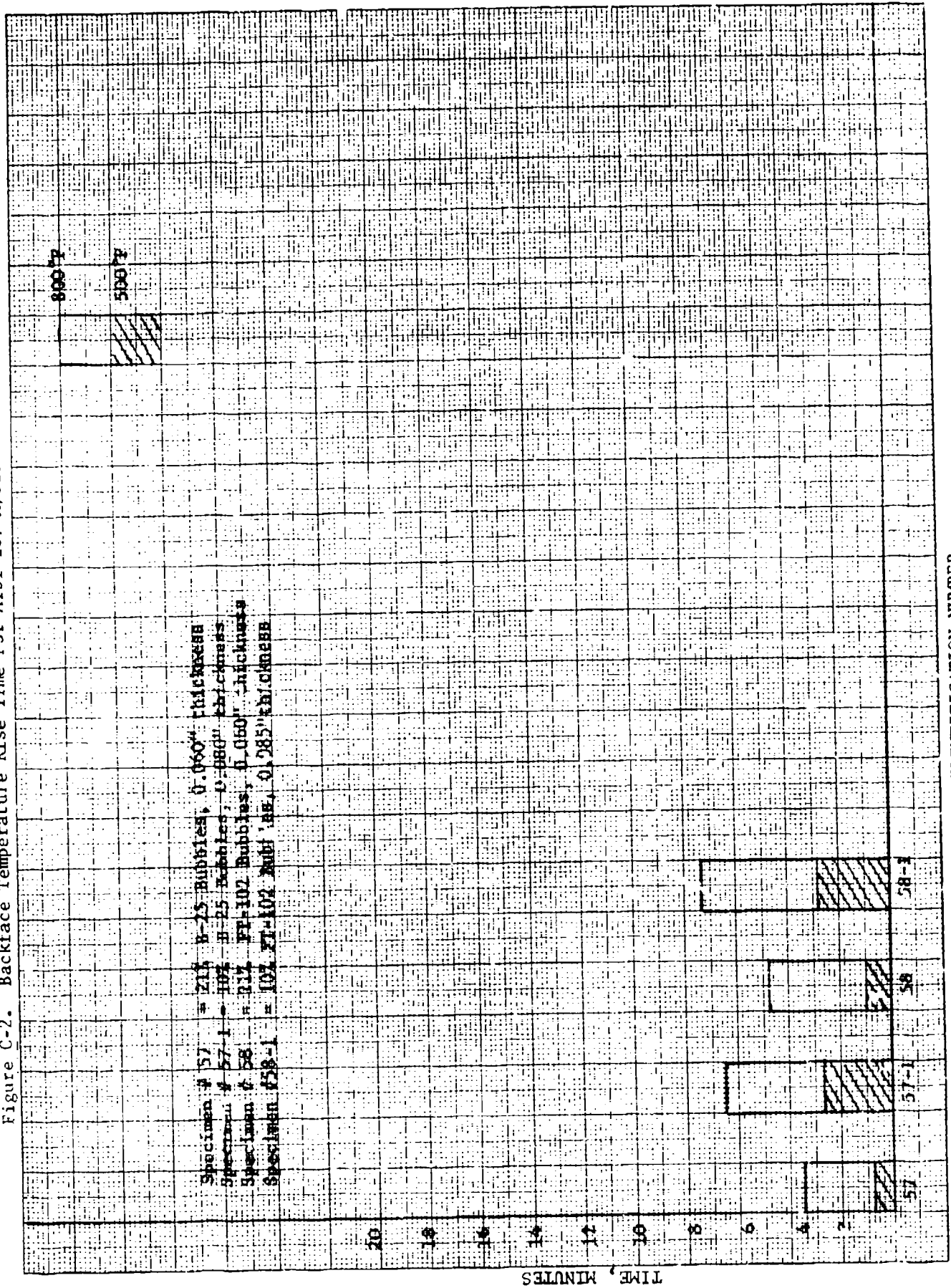
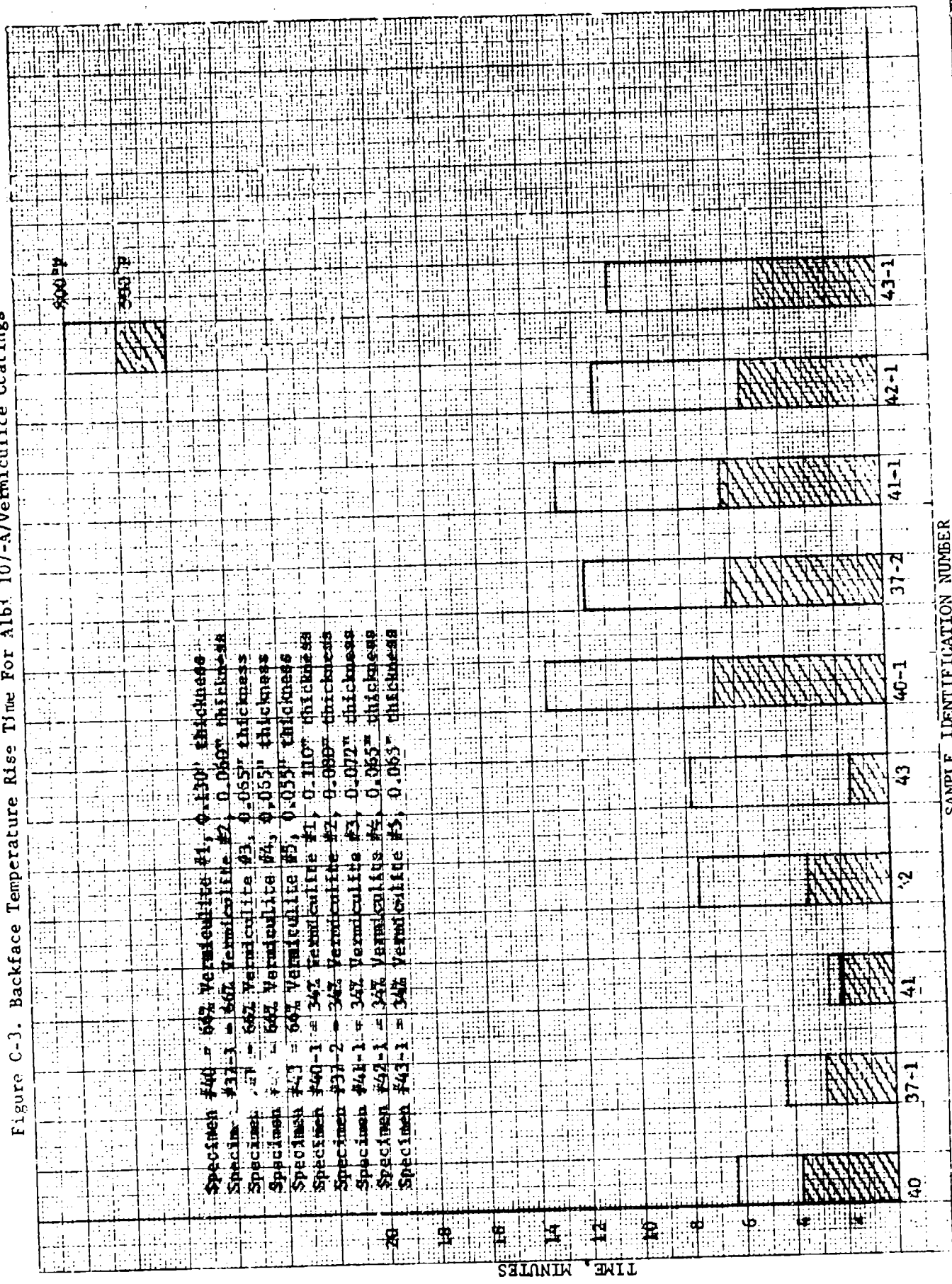
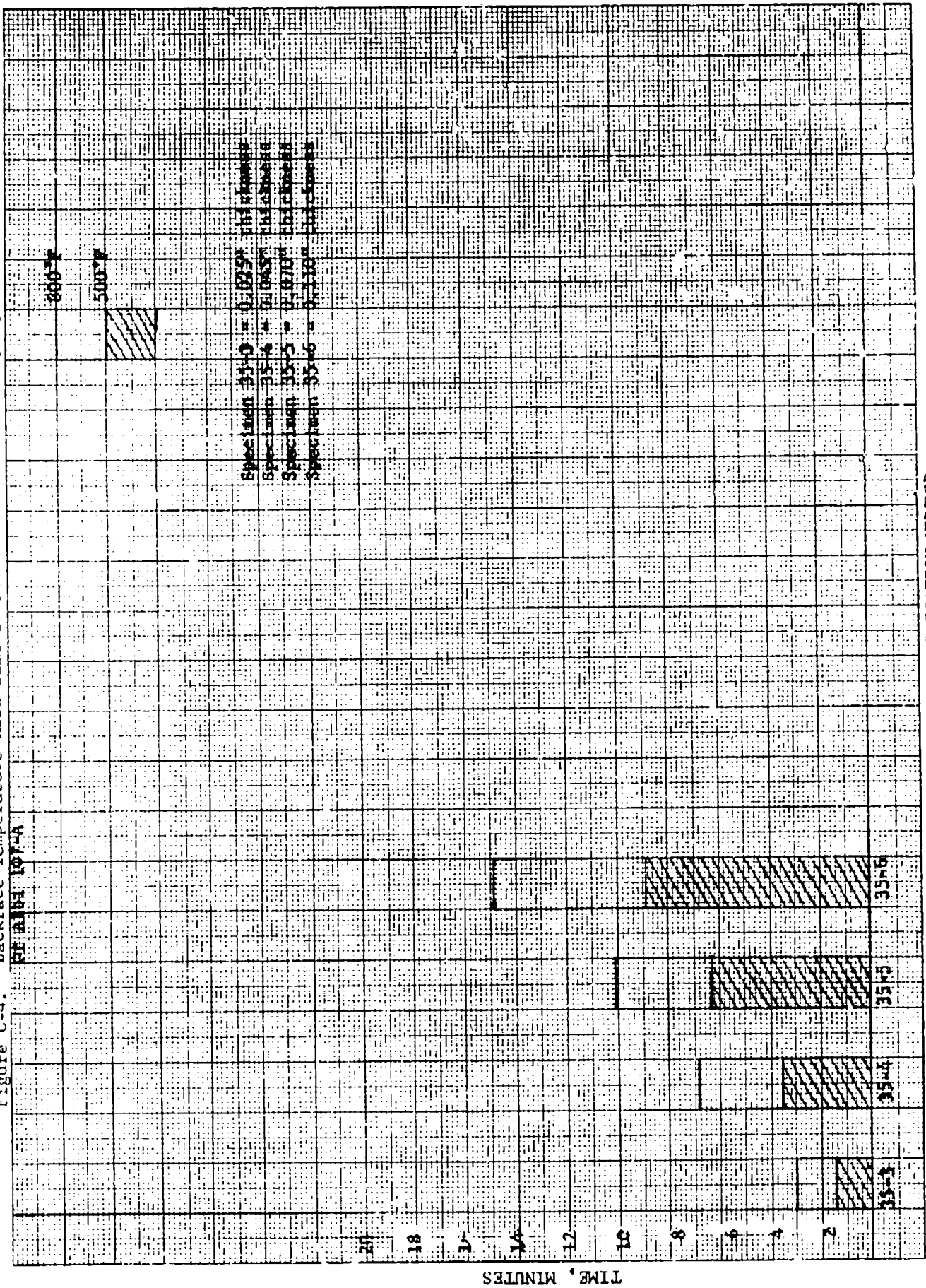


Figure C-3. Backface Temperature Rise Time For Al<sub>2</sub>O<sub>3</sub>/Vermiculite Coatings



SAMPLE IDENTIFICATION NUMBER

Figure C-4. Backface Temperature Rise Time To 500°F And 800°F For Varying Thicknesses



MOE 10 X 10 TO THE CENT MILEY 40 15 13

Figure C-5. Backface Temperature Rise Time For Albi 107-A/Perlite Coatings

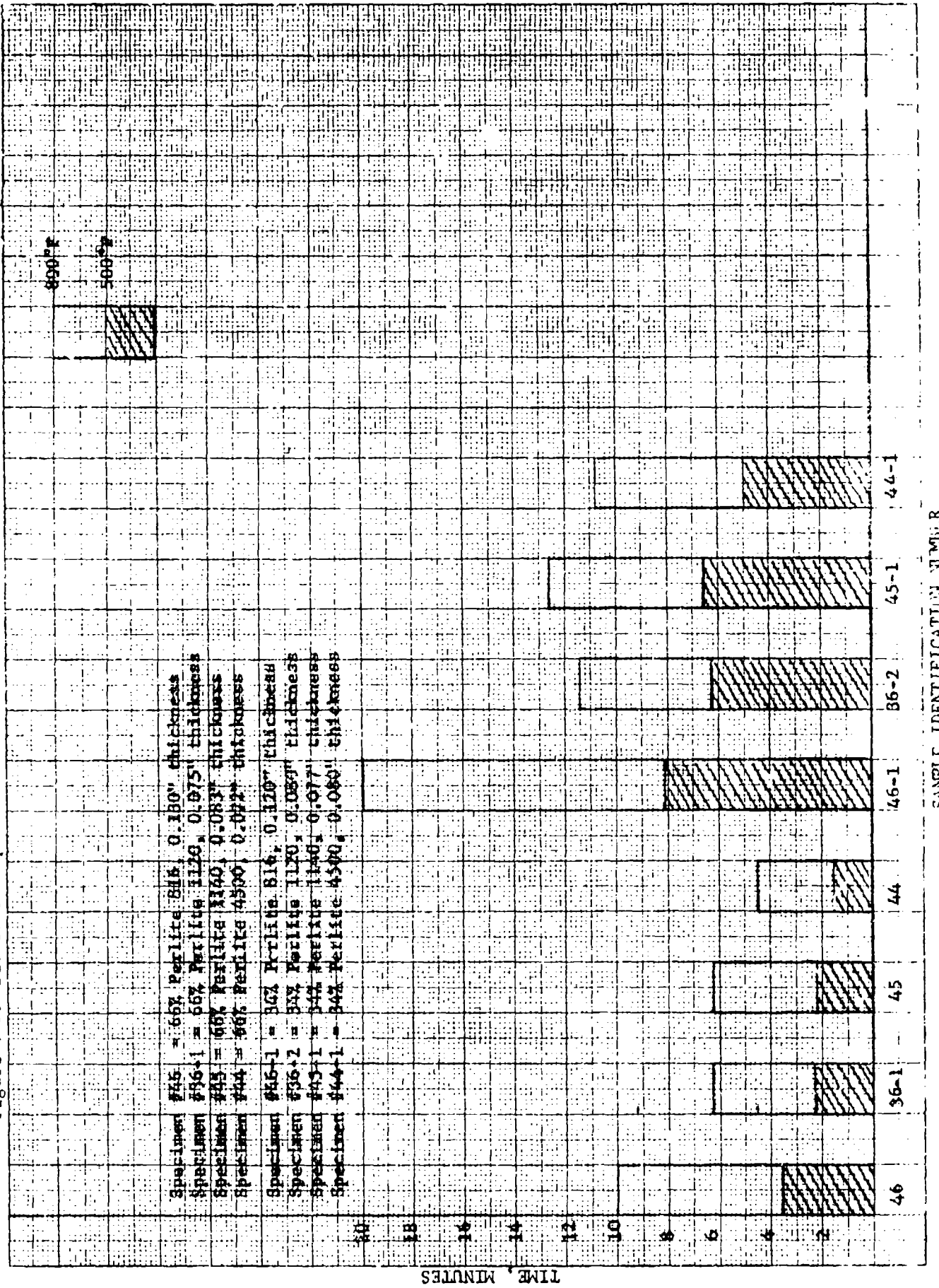
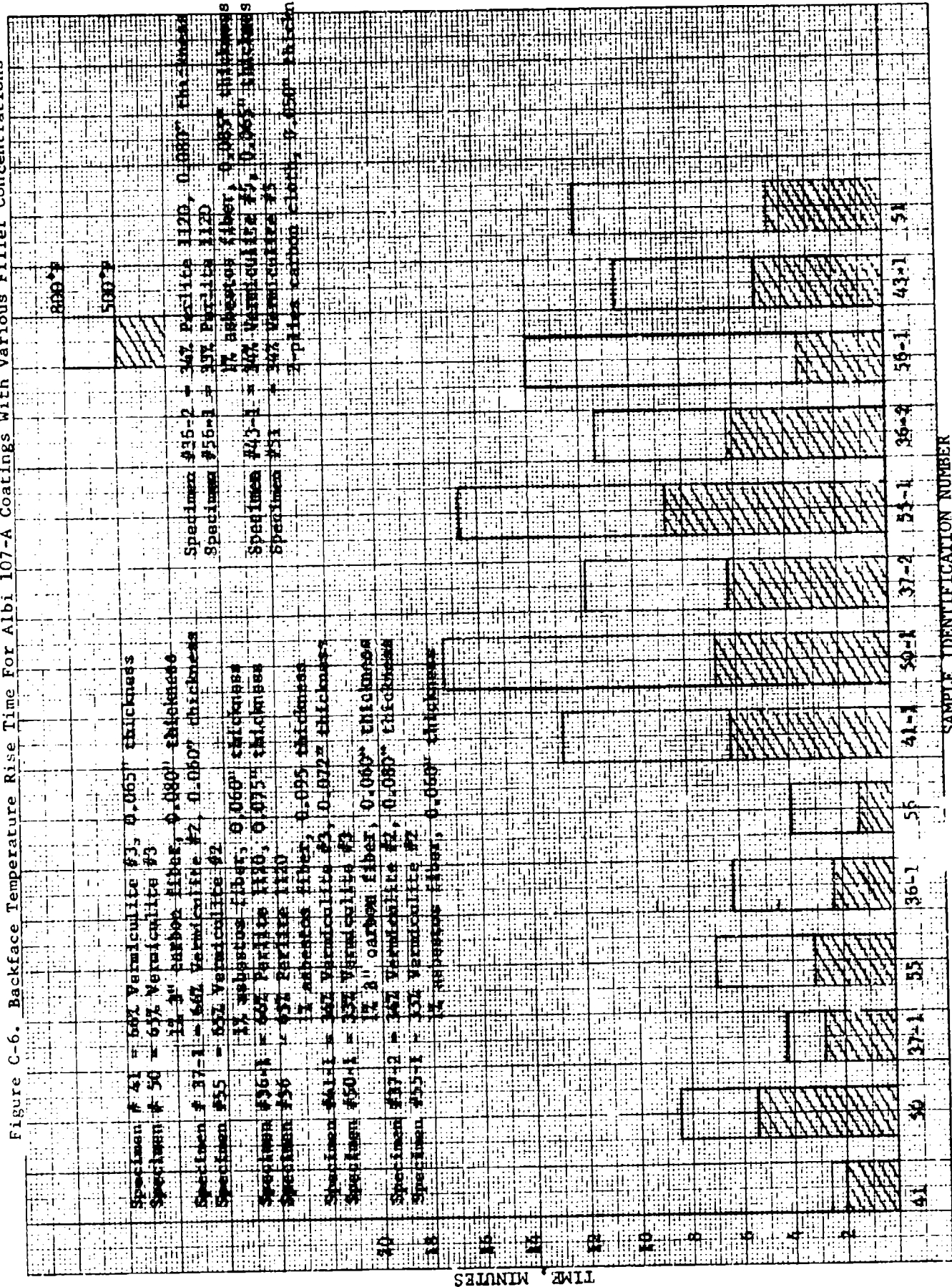
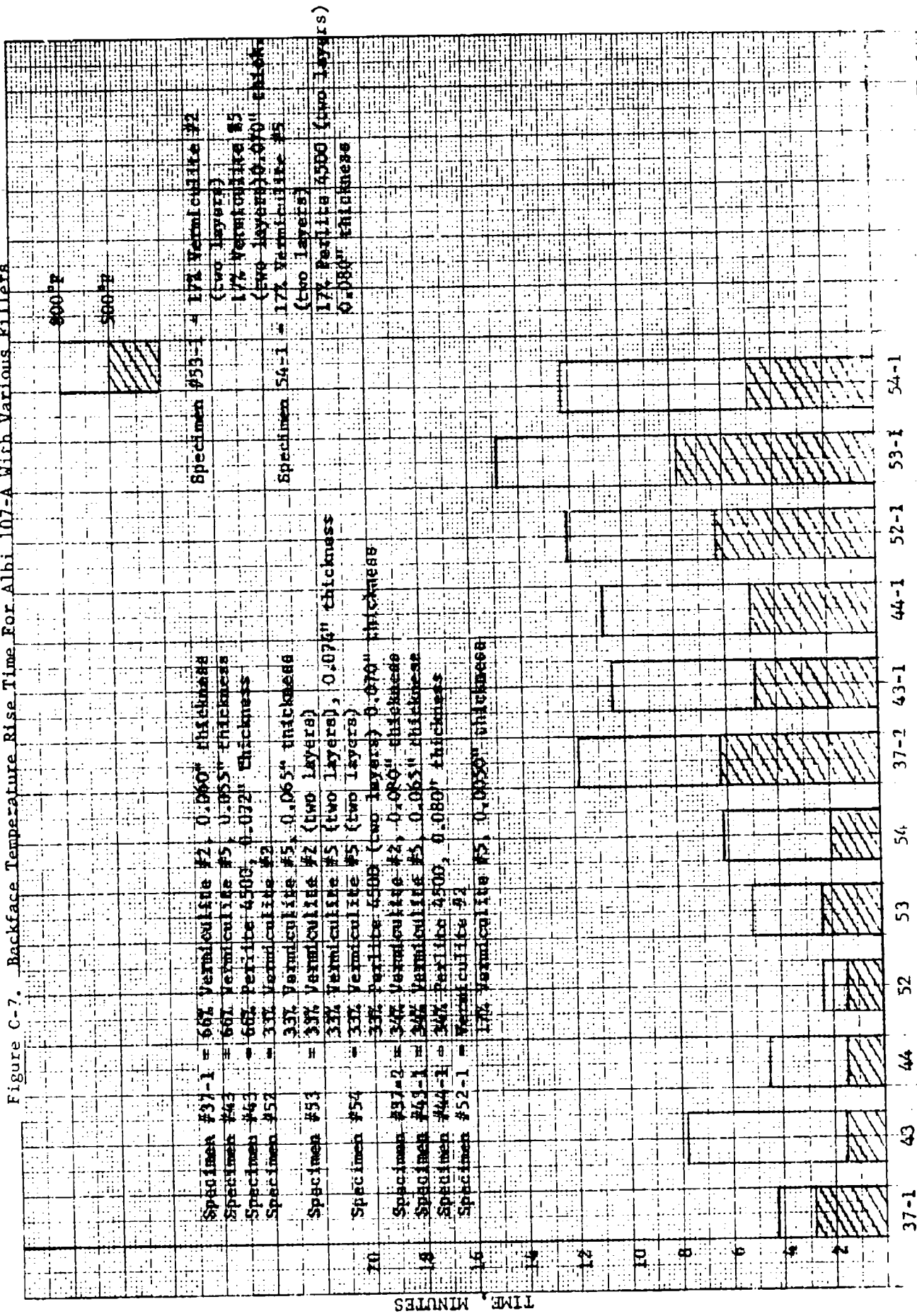


Figure C-6. Backface Temperature Rise Time For Albi 107-A Coatings With Various Filler Concentrations



SAMPLE IDENTIFICATION NUMBER

Figure C-7. Backface Temperature Rise Time For Albi 107-A With Various Fillers

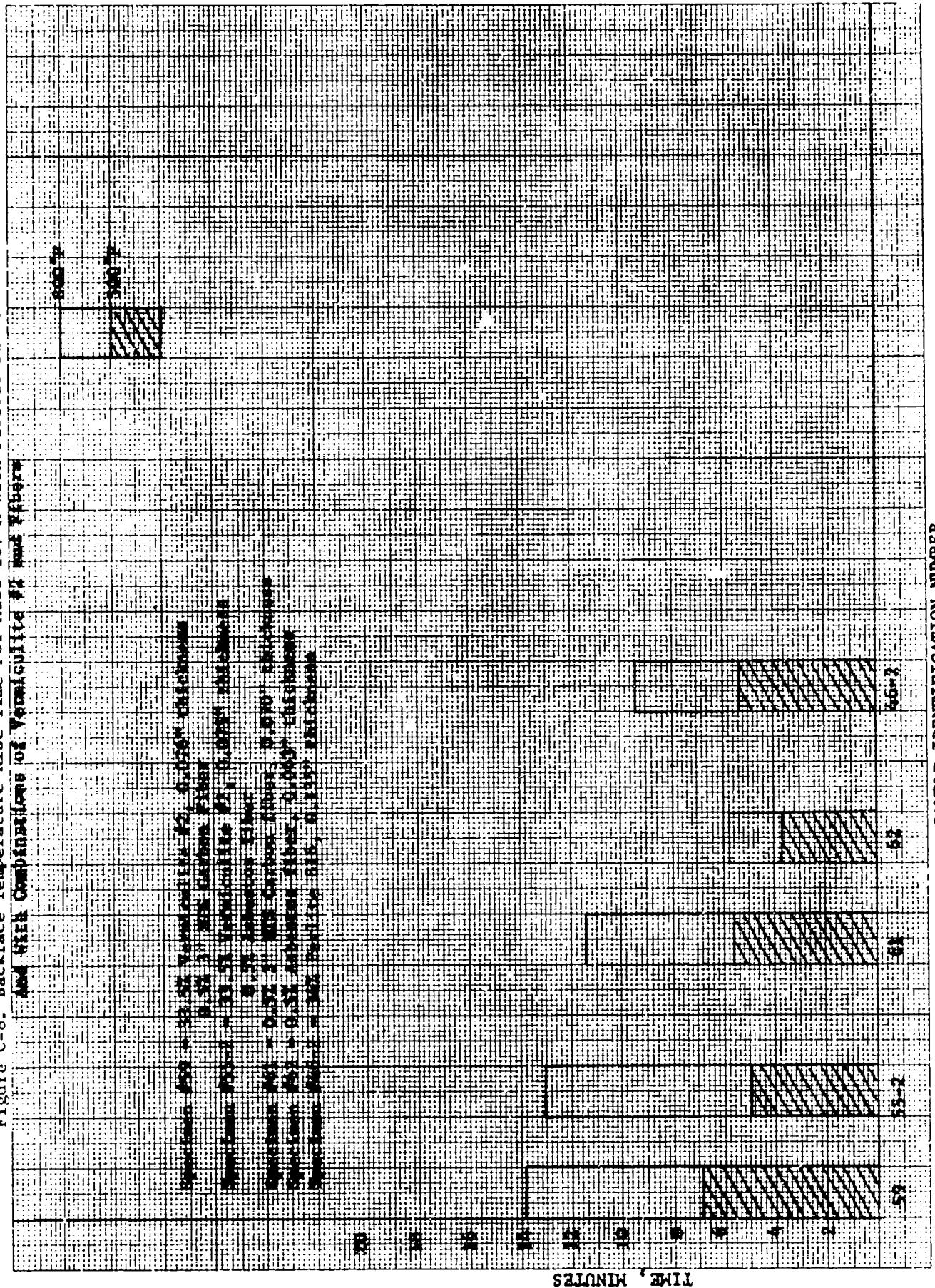


TIME, MINUTES

37-1 43 44 52 53 54 37-2 43-1 44-1 52-1 53-1 54-1

REPRODUCED FROM THE NATIONAL ARCHIVES

Figure C-8. Backface Temperature Rise Time For Albi 107-A With Fibrous Filler  
 And 45% Combinations of Vermiculite #2 and Fibers



APPENDIX D

PHYSICAL PROPERTIES AND THERMAL RESPONSE  
DATA OF TASK II

TABLE D.1 THERMAL RESPONSE DATA OF TASK II

| Time<br>Specimen<br>Number | Seconds         |      |      |      |    | Minutes |      |     |     |     |     |     |     |     |     |      |     |     |    |    |
|----------------------------|-----------------|------|------|------|----|---------|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|----|----|
|                            | 0               | 10   | 20   | 30   | 50 | 1       | 2    | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 12   | 14  | 16  | 18 | 24 |
|                            | Degrees Celsius |      |      |      |    |         |      |     |     |     |     |     |     |     |     |      |     |     |    |    |
| T-1                        | 23.8            |      | 42.2 | 46.6 |    | 81.1    | 167  | 208 | 238 | 264 | 280 |     | 316 |     | 346 | 371  | 393 | 424 |    |    |
| T-2                        | 23.8            | 35.6 | 65.5 | 64.1 |    | 66.1    | 176  | 282 | 314 | 342 | 371 | 402 | 422 |     |     |      |     |     |    |    |
| T-3                        | 26.1            | 26.7 | 53.9 | 72.9 |    | 77.8    | 82.2 | 214 | 255 | 289 | 312 | 339 | 358 | 377 | 392 | 433  |     |     |    |    |
| T-4                        | 26.7            | 29.4 | 55.6 | 67.8 |    | 73.9    | 113  | 204 | 269 | 306 | 330 | 358 | 385 | 414 |     |      |     |     |    |    |
| T-5                        | 28.9            | 31.1 | 66.1 | 68.9 |    | 71.1    | 207  | 265 | 294 | 323 | 355 | 385 | 412 | 434 |     |      |     |     |    |    |
| T-6                        | 28.3            | 30.0 | 69.4 | 75.6 |    | 75.6    | 174  | 258 | 287 | 313 | 340 | 367 | 394 | 420 | 449 |      |     |     |    |    |
| T-7                        | 27.2            | 29.4 | 69.4 | 71.3 |    | 65.5    | 140  | 229 | 268 | 299 | 326 | 353 | 378 | 399 | 427 |      |     |     |    |    |
| T-8                        | 23.8            | 25.0 | 59.4 | 71.7 |    | 73.9    | 114  | 246 | 279 | 313 | 348 | 382 | 410 | 439 |     |      |     |     |    |    |
| T-9                        | 23.8            | 30.0 | 40.0 | 51.8 |    | 127     | 233  | 274 | 300 | 313 | 327 | 338 | 371 | 391 | 410 |      |     |     |    |    |
| T-10                       | 25.6            | 31.1 | 60.5 | 81.3 |    | 83.3    | 103  | 188 | 216 | 264 | 289 | 320 | 342 | 368 | 401 | 427+ |     |     |    |    |
| T-11                       | 26.7            | 35.6 |      | 67.2 |    | 69.4    | 150  | 218 | 262 | 288 | 309 | 327 | 352 | 376 | 398 | 427+ |     |     |    |    |
| T-13                       | 28.9            | 36.1 |      | 51.6 |    | 67.2    | 141  | 194 | 234 | 272 | 294 | 303 | 318 | 336 | 358 | 391  | 428 |     |    |    |
| T-14                       | 25.6            | 26.7 | 58.3 | 66.7 |    | 63.3    | 91.7 | 189 | 251 | 293 | 318 | 346 | 366 | 375 | 396 | 427+ |     |     |    |    |
| T-15                       | 23.8            | 31.1 |      | 42.2 |    | 63.3    | 169  | 244 | 277 | 296 | 311 |     | 351 |     | 398 | 420  | 432 |     |    |    |
| T-17                       | 25.6            | 31.7 | 40.6 | 42.2 |    | 58.9    | 159  | 213 | 238 | 277 | 299 |     | 342 |     | 378 | 405  | 434 |     |    |    |
| T-18                       | 23.8            | 33.3 | 42.2 | 44.4 |    | 60.0    | 156  | 212 | 245 | 272 | 297 |     | 443 |     | 378 | 402  | 419 |     |    |    |
| T-19                       | 23.8            |      |      | 40.0 |    | 53.3    | 150  | 207 | 240 | 268 | 291 | 309 | 329 | 349 | 369 | 405  | 423 |     |    |    |
| T-20                       | 26.1            | 27.2 | 30.0 | 37.8 |    | 52.2    | 146  | 208 | 237 | 264 | 283 | 299 | 317 | 327 | 343 | 382  | 401 | 414 |    |    |
| T-21                       | 21.8            | 28.9 | 33.3 | 37.8 |    | 86.7    | 185  | 232 | 263 | 297 | 302 |     | 341 | 367 | 391 | 427+ |     |     |    |    |
| T-22                       | 27.2            | 30.6 | 40.6 | 43.9 |    | 76.7    | 158  | 204 | 242 | 271 | 291 | 307 | 324 |     | 359 | 387  | 406 | 427 |    |    |
| T-23                       | 26.1            | 28.9 | 35.6 | 40.0 |    | 50.0    | 169  | 215 | 261 | 280 | 297 |     | 340 |     | 376 | 406  | 432 |     |    |    |
| T-24                       | 26.7            | 37.8 | 43.9 | 61.1 |    | 126     | 186  | 227 | 255 | 282 | 306 | 333 | 347 |     | 388 | 429  |     |     |    |    |
| T-26                       | 26.1            | 29.4 | 51.1 | 80.0 |    | 162     | 230  | 264 | 294 | 314 | 330 | 371 | 378 | 409 | 428 |      |     |     |    |    |
| T-27                       | 23.8            | 29.4 | 49.4 | 93.9 |    | 182     | 247  | 270 | 299 | 319 | 354 | 367 | 391 | 409 | 426 |      |     |     |    |    |
| T-51A                      | 23.8            | 37.2 | 52.8 | 55.6 |    | 107     | 234  | 278 | 301 | 321 | 340 |     | 389 |     | 428 |      |     |     |    |    |
| T-51B                      | 23.8            | 40.6 |      | 53.3 |    | 93.9    | 212  | 253 | 283 | 306 | 322 | 371 |     |     | 418 |      |     |     |    |    |
| T-52A                      | 23.8            | 53.3 | 55.6 | 62.2 |    | 117     | 216  | 258 | 291 | 318 | 346 | 366 | 391 | 411 | 432 |      |     |     |    |    |
| T-52B                      | 23.8            | 55.0 | 55.6 | 67.2 |    | 128     | 213  | 250 | 280 | 308 | 333 | 360 | 387 | 409 | 429 |      |     |     |    |    |
| T-53                       | 23.8            | 46.7 | 49.4 | 60.6 |    | 131     | 213  | 238 | 270 | 296 | 327 | 348 | 382 | 429 | 414 |      |     |     |    |    |
| T-54                       | 23.8            | 36.7 |      | 62.8 |    | 134     | 212  | 248 | 276 | 299 | 322 | 348 | 372 | 393 | 414 |      |     |     |    |    |
| T-104                      | 23.8            | 25.0 | 32.2 | 51.1 |    | 113     | 183  | 221 | 252 | 278 | 298 |     | 340 |     | 378 | 413  |     |     |    |    |
| T-105                      | 25.0            |      | 31.7 | 43.3 |    | 100     | 189  | 227 | 260 | 284 | 303 |     | 336 |     | 368 | 406  | 423 |     |    |    |

TABLE D.1. THERMAL RESPONSE DATA OF TASK II (Continued)

| Time            | Seconds         |      |      |      |      |      | Minutes |      |     |     |     |     |     |     |     |     |     |     |     |               |
|-----------------|-----------------|------|------|------|------|------|---------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------------|
|                 | 0               | 10   | 20   | 30   | 1    | 2    | 3       | 4    | 5   | 6   | 7   | 8   | 9   | 10  | 12  | 14  | 16  | 18  | 24  |               |
| Specimen Number | Degrees Celsius |      |      |      |      |      |         |      |     |     |     |     |     |     |     |     |     |     |     |               |
| T-106           | 19.4            | 23.8 | 51.7 | 88.3 | 179  | 242  | 272     | 295  | 320 | 341 | 366 | 393 | 422 | 444 |     |     |     |     |     |               |
| T-107           | 21.1            |      | 31.1 | 50.0 | 116  | 152  | 227     | 258  | 280 | 299 |     | 336 |     | 467 | 396 | 425 |     |     |     |               |
| T-108           | 26.1            | 32.2 | 46.1 | 46.1 | 70.0 | 162  | 218     | 249  | 279 | 296 |     | 330 |     | 363 | 397 | 434 |     |     |     |               |
| T-109           | 26.7            | 36.7 | 46.7 | 46.7 | 77.2 | 167  | 210     | 240  | 266 | 284 |     | 320 |     | 356 | 384 | 412 |     |     |     |               |
| T-110           | 28.9            | 31.1 | 42.2 | 42.2 | 65.0 | 142  | 191     | 218  | 246 | 266 |     | 301 |     | 332 | 360 | 381 | 404 | 433 |     |               |
| T-111           | 26.1            | 35.6 | 47.2 | 50.6 | 74.4 | 160  | 205     | 235  | 263 | 281 |     | 311 |     | 338 | 364 | 386 | 410 |     |     |               |
| T-112           | 23.8            | 37.8 | 50.0 | 57.2 | 83.3 | 184  | 227     | 256  | 283 | 289 | 325 | 347 | 365 | 383 | 414 |     |     |     |     |               |
| T-113           | 23.8            | 33.9 | 46.1 | 46.1 | 82.8 | 180  | 221     | 254  | 274 | 296 |     | 332 |     | 368 | 398 | 432 |     |     |     |               |
| T-114           | 23.8            | 37.8 | 47.2 | 47.2 | 83.9 | 183  | 225     | 254  | 281 | 299 |     | 339 |     | 376 | 405 | 436 |     |     |     |               |
| T-116           | 23.8            |      | 32.2 | 37.8 | 47.2 | 58.9 | 93.3    | 137  | 171 | 199 |     | 244 |     | 274 | 295 | 313 | 327 | 348 | 404 | 27 Min<br>432 |
| T-118           | 23.8            |      | 29.4 |      | 40.0 | 70.0 | 97.2    | 119  | 137 | 143 | 168 | 187 |     | 213 | 238 | 262 | 282 | 298 | 352 | 31 Min<br>427 |
| T-119B          | 21.1            | 72.8 | 138  | 189  | 258  | 319  | 364     | 409  |     |     |     |     |     |     |     |     |     |     |     |               |
| T-119C          | 23.8            | 95.0 | 159  | 198  | 253  | 323  | 380     | 429  |     |     |     |     |     |     |     |     |     |     |     |               |
| T-120           | 23.8            | 25.0 | 28.9 | 35.6 | 66.7 | 151  | 204     | 240  | 271 | 299 |     | 352 |     | 388 | 414 |     |     |     |     |               |
| T-121           | 22.2            | 30.0 | 38.9 | 54.4 | 124  | 213  | 270     | 304  | 349 | 361 | 422 |     |     |     |     |     |     |     |     |               |
| T-122A          | 22.2            | 23.8 | 42.8 | 51.1 | 108  | 189  | 233     | 260  | 285 | 302 |     | 341 |     | 396 | 405 | 422 |     |     |     |               |
| T-122B          | 23.8            | 29.4 | 42.8 | 66.1 | 145  | 233  | 269     | 297  | 317 | 339 |     | 385 |     | 422 |     |     |     |     |     |               |
| T-124           | 21.1            | 28.9 | 40.0 |      | 80.0 | 185  | 225     | 250  | 272 | 287 |     | 312 |     | 343 | 368 | 387 | 405 | 431 |     |               |
| T-125           | 23.8            | 33.3 | 43.8 | 47.2 | 66.7 | 196  | 260     | 278  |     | 316 |     | 343 |     | 378 | 414 |     |     |     |     |               |
| T-126           | 26.7            | 35.0 | 46.7 | 46.7 | 91.1 | 172  | 221     | 254  | 286 | 301 |     | 329 |     | 358 | 392 | 427 |     |     |     |               |
| T-127           | 25.6            | 31.1 | 35.0 | 38.9 | 77.2 | 180  | 237     | 243  | 264 | 285 | 297 | 308 |     | 343 | 378 | 408 |     |     |     |               |
| T-128A          | 26.1            | 33.3 | 38.3 | 43.9 | 83.9 | 175  | 217     | 248  | 274 | 296 |     | 327 |     | 361 | 388 | 423 |     |     |     |               |
| T-128B          | 27.2            | 33.9 | 46.1 | 46.1 | 86.1 | 180  | 218     | 251  | 276 | 296 | 311 | 330 |     | 361 | 396 | 422 |     |     |     | 27 Min<br>440 |
| T-129A          | 25.0            |      | 28.9 |      | 38.9 | 68.3 | 77.8    | 77.8 | 118 | 147 |     | 200 |     | 250 | 289 | 312 | 286 | 346 | 393 |               |
| T-129B          | 25.0            |      | 35.6 |      | 67.8 | 71.1 | 117     | 162  | 196 | 226 |     | 275 |     | 322 | 354 | 377 | 390 | 410 |     | 20 Min<br>434 |
| T-130A          | 23.8            |      |      | 31.1 | 51.1 | 63.3 | 94.4    | 144  | 179 | 208 |     | 258 |     | 299 | 334 | 363 | 387 | 412 |     | 20 Min<br>436 |
| T-130B          | 23.8            | 25.0 | 28.9 | 31.7 | 51.1 | 71.1 | 76.1    | 130  | 176 | 209 |     | 266 |     | 311 | 349 | 387 | 422 |     |     |               |
| T-131A          | 28.9            | 28.9 | 36.7 | 53.9 | 68.9 | 68.3 | 107     | 158  | 191 | 224 |     | 274 |     | 316 | 352 | 384 | 403 | 437 |     |               |
| T-131B          | 23.8            | 23.8 | 35.0 | 48.9 | 58.3 | 74.4 | 128     | 162  | 193 | 225 |     | 282 |     | 322 | 357 | 380 | 400 | 419 |     |               |
| T-S-1           | 23.8            | 36.7 | 53.3 | 51.7 | 71.1 | 176  | 211     | 241  | 264 | 286 |     | 325 |     | 370 | 403 | 432 |     |     |     |               |
| T-S-2           | 25.0            | 31.1 | 61.1 |      | 77.2 | 214  | 249     | 283  | 311 | 336 |     | 390 |     | 433 |     |     |     |     |     |               |

TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II

| Specimen<br>No. | Date<br>Tested | Thickness |      | Weight                 |                      |
|-----------------|----------------|-----------|------|------------------------|----------------------|
|                 |                | (in.)     | (cm) | (lbs/ft <sup>2</sup> ) | (kg/m <sup>2</sup> ) |
| T-1             | 11-20-75       | 0.47      | 1.19 | 0.43                   | 2.10                 |
| T-2             | 12-2-75        | 0.39      | 0.99 | 0.77                   | 3.76                 |
| T-3             | 12-2-75        | 0.40      | 1.02 | 0.73                   | 3.56                 |
| T-4             | 12-2-75        | 0.41      | 1.04 | 0.69                   | 3.37                 |
| T-5             | 12-2-75        | 0.37      | 0.94 | 0.64                   | 3.12                 |
| T-6             | 12-1-75        | 0.41      | 1.04 | 0.74                   | 3.61                 |
| T-7             | 11-20-75       | 0.38      | 0.96 | 0.75                   | 3.66                 |
| T-8             | 11-20-75       | 0.36      | 0.91 | 0.70                   | 3.42                 |
| T-9             | 11-19-75       | 0.465     | 1.18 | 0.31                   | 1.51                 |
| T-10            | 11-18-75       | 0.44      | 1.12 | 0.81                   | 3.95                 |
| T-11            | 11-18-75       | 0.445     | 1.13 | 0.63                   | 3.08                 |
| T-13            | 11-18-75       | 0.50      | 1.27 | 0.58                   | 2.83                 |
| T-14            | 11-11-75       | 0.43      | 1.09 | 0.81                   | 3.95                 |
| T-15            | 12-5-75        | 0.48      | 1.22 | 0.51                   | 2.49                 |
| T-17            | 12-5-75        | 0.53      | 1.35 | 0.51                   | 2.49                 |
| T-18            | 12-5-75        | 0.55      | 1.40 | 0.61                   | 2.98                 |
| T-19            | 11-19-75       | 0.50      | 1.27 | 0.48                   | 2.34                 |
| T-20            | 11-19-75       | 0.51      | 1.30 | 0.50                   | 2.44                 |
| T-21            | 11-19-75       | 0.45      | 1.14 | 0.35                   | 1.71                 |
| T-22            | 11-19-75       | 0.48      | 1.22 | 0.37                   | 1.81                 |
| T-23            | 11-19-75       | 0.45      | 1.14 | 0.40                   | 1.95                 |

TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II - (Continued)

| <u>Specimen No.</u> | <u>Date Tested</u> | <u>Thickness</u> |             | <u>Weight</u>               |                           |
|---------------------|--------------------|------------------|-------------|-----------------------------|---------------------------|
|                     |                    | <u>(in.)</u>     | <u>(cm)</u> | <u>(lbs/ft<sup>2</sup>)</u> | <u>(kg/m<sup>2</sup>)</u> |
| T-24                | 11-19-75           | 0.465            | 1.18        | 0.22                        | 1.07                      |
| T-26                | 11-19-75           | 0.43             | 1.09        | 0.20                        | 0.98                      |
| T-27                | 11-19-75           | 0.44             | 1.12        | 0.19                        | 0.93                      |
| T-51A               | 12-5-75            | 0.49             | 1.24        | 0.41                        | 2.00                      |
| T-51B               | 12-5-75            | 0.48             | 1.22        | 0.37                        | 1.81                      |
| T-52A               | 12-2-75            | 0.45             | 1.14        | 0.37                        | 1.81                      |
| T-52B               | 12-3-75            | 0.45             | 1.14        | 0.33                        | 1.61                      |
| T-53                | 12-9-75            | 0.44             | 1.12        | 0.33                        | 1.61                      |
| T-54                | 12-3-75            | 0.45             | 1.14        | 0.35                        | 1.71                      |
| T-104               | 12-4-75            | 0.44             | 1.12        | 0.28                        | 1.37                      |
| T-105               | 12-4-75            | 0.49             | 1.24        | 0.32                        | 1.56                      |
| T-106               | 12-4-75            | 0.45             | 1.14        | 0.21                        | 1.03                      |
| T-107               | 12-4-75            | 0.48             | 1.22        | 0.29                        | 1.42                      |
| T-108               | 12-3-75            | 0.51             | 1.30        | 0.49                        | 2.39                      |
| T-109               | 12-3-75            | 0.50             | 1.27        | 0.47                        | 2.29                      |
| T-110               | 12-3-75            | 0.54             | 1.37        | 0.52                        | 2.54                      |
| T-111               | 12-3-75            | 0.55             | 1.40        | 0.48                        | 2.34                      |
| T-112               | 12-3-75            | 0.52             | 1.32        | 0.44                        | 2.15                      |
| T-113               | 12-4-75            | 0.58             | 1.47        | 0.40                        | 1.95                      |
| T-114               | 12-4-75            | 0.53             | 1.35        | 0.39                        | 1.90                      |

TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II  
 - (Continued)

| <u>Specimen No.</u> | <u>Date Tested</u> | <u>Thickness</u> |             | <u>Weight</u>               |                           |
|---------------------|--------------------|------------------|-------------|-----------------------------|---------------------------|
|                     |                    | <u>(in.)</u>     | <u>(cm)</u> | <u>(lbs/ft<sup>2</sup>)</u> | <u>(kg/m<sup>2</sup>)</u> |
| T-116               | 12-2-75            | 0.56             | 1.42        | 1.02                        | 4.98                      |
| T-118               | 12-2-75            | 0.44             | 1.12        | 1.42                        | 6.93                      |
| T-119B              | 12-9-75            | 0.18             | 0.46        | 0.08                        | 0.39                      |
| T-119C              | 12-9-75            | 0.14             | 0.36        | 0.07                        | 0.34                      |
| T-120               | 12-4-75            | 0.38             | 0.96        | 0.71                        | 3.47                      |
| T-121               | 12-5-75            | 0.29             | 0.74        | 0.53                        | 2.59                      |
| T-122A              | 12-5-75            | 0.52             | 1.32        | 0.51                        | 2.49                      |
| T-122B              | 12-5-75            | 0.41             | 1.04        | 0.35                        | 1.71                      |
| T-124               | 12-9-75            | 0.56             | 1.42        | 0.38                        | 1.85                      |
| T-125               | 11-11-75           | 0.56             | 1.42        | 0.42                        | 2.05                      |
| T-126               | 11-11-75           | 0.535            | 1.36        | 0.38                        | 1.85                      |
| T-127               | 11-11-75           | 0.59             | 1.50        | 0.36                        | 1.76                      |
| T-128A              | 12-3-75            | 0.57             | 1.45        | 0.33                        | 1.61                      |
| T-128B              | 12-3-75            | 0.54             | 1.37        | 0.35                        | 1.71                      |
| T-129A              | 11-20-75           | 0.67             | 1.70        | 1.33                        | 6.49                      |
| T-129B              | 11-20-75           | 0.64             | 1.63        | 0.81                        | 3.95                      |
| T-130A              | 11-20-75           | 0.68             | 1.73        | 0.81                        | 3.95                      |
| T-130B              | 12-1-75            | 0.71             | 1.80        | 1.06                        | 5.18                      |
| T-131A              | 12-4-75            | 0.78             | 1.98        | 1.13                        | 5.52                      |
| T-131B              | 12-4-75            | 0.595            | 1.51        | 0.83                        | 4.05                      |
| T-S-1               | 12-9-75            | 0.50             | 1.27        | 0.53                        | 2.59                      |
| T-S-2               | 12-9-75            | 0.43             | 1.09        | 0.59                        | 2.88                      |

TABLE D.3. DATA FROM ALUMINUM CONTROL AND CALORIMETER RUNS IN TASK II

| <u>Control No.</u> | <u>Date Tested</u> | <u>Time at</u>                       | <u>Time at</u>                         | <u>Radiant Heat</u>          |                                 |
|--------------------|--------------------|--------------------------------------|--|------------------------------|---------------------------------|
|                    |                    | <u>500°F (sec)</u><br><u>(260°C)</u> | <u>800°F (sec)</u><br><u>(426.7°C)</u> | <u>BTU/ft<sup>2</sup>sec</u> | <u>Joules/cm<sup>2</sup>sec</u> |
| AC-1               | 11-11-75           | 14.3                                 | 24.9                                   |                              |                                 |
| AC-2               | 11-11-75           | 14.5                                 | 25.0                                   | 15.5                         | 17.6                            |
| AC-5               | 11-19-75           | 16.6                                 | 27.0                                   | 15.5                         | 17.6                            |
| AC-6               | 11-20-75           | 19.2                                 | 35.5                                   |                              |                                 |
| AC-8               | 12-1-75            | 17.4                                 | 32.5                                   | 15.3                         | 17.4                            |
| AC-9               | 12-2-75            | 16.6                                 | 29.6                                   | 14.6                         | 16.6                            |
| AC-10              | 12-2-75            | 16.2                                 | 33.5                                   | 14.6                         | 16.6                            |
| AC-11              | 12-3-75            | 16.1                                 | 33.4                                   | 15.3                         | 17.4                            |
| AC-12              | 12-4-75            | 14.9                                 | 30.4                                   |                              |                                 |
| AC-13              | 12-5-75            | 17.8                                 | 33.1                                   | 15.1                         | 17.03                           |
| AC-14              | 12-9-75            | 18.5                                 | 35.0                                   | 14.6                         | 16.6                            |

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