NATIONAL BUREAU OF STANDARDS REPORT

10 813

FIRE ENDURANCE TESTS
OF
ALUMINUM BULKHEAD AND DECK ASSEMBLIES

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
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FIRE ENDURANCE TESTS OF ALUMINUM BULKHEAD AND DECK ASSEMBLIES

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SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

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ABSTRACT

Fire endurance tests were performed on ten aluminum deck and bulkhead assemblies. Both double and single faced bulkheads were tested. The insulation configurations included various thicknesses of Marinite, marine veneer, mineral wool, and fibrous glass separated by air spaces. Interior as well as surface temperatures were recorded throughout the tests for all of the assemblies. For comparison purposes, both ASTM and IMCO type surface thermocouple installations were used, and the differences were found to be minimal.

A one inch layer of mineral wool, a one inch air space, and a 3/4 inch Marinite panel between the aluminum plate and the fire proved to be adequate to achieve a Class A-60 rating for the double faced bulkhead assembly.

A 3/4 inch Marinite panel and a one inch air space between the aluminum plate and the fire was sufficient to achieve a Class A-30 rating for the single faced assembly.

Neither of the decks tested qualified for a Class A rating because the core temperature failures occurred within 60 minutes. Delamination of the fire exposed 3/16 inch thick marine veneer, 23 minutes into the test, was responsible for the failure of one of the decks.

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1.0 INTRODUCTION

At the request of the U. S. Coast Guard, letter of 22 December 1969, file 9930/5050/SNAME, fire endurance tests were performed on ten aluminum bulkhead and deck assemblies. These tests were sponsored by the Society of Naval Architects and Marine Engineers (SNAME). The assemblies were constructed by the Peterson Ship Building Company in Sturgeon Bay, Wisconsin using drawings prepared by Gibbs and Cox, Inc., in New York City. Thermocouples were installed in the interior of the assemblies by a representative of the National Bureau of Standards during the construction period.

The assemblies were tested for Class A and B ratings according to the IMCO specification FP VI/17 ANNEX II dated 25 September 1967. Although the tests were based on surface temperatures measured with thermocouple installations following IMCO specifications, ASTM surface thermocouple installations were also included for comparison purposes. The furnace temperature was controlled by fast response mineral insulated thermocouples meeting the IMCO specifications.

Both single-faced and double-faced bulkhead assemblies were tested. The single-faced assemblies are intended for use where only single sided fire exposures are possible. The insulation materials used in these assemblies were Marinite, mineral wool, and fibrous glass.

This series of tests was proceeded by a single exploratory test of an aluminum bulkhead protected by a 3/4 inch, 36 PCF density Marinite panel (Reference 1). In that test, which was conducted on May 26, 1967, ASTM thermocouples were used for measuring the surface temperature and for controlling the furnace temperature. The average failure time based on a 139 degree centigrade rise of the ASTM surface thermocouples was 42 minutes.

The core temperature failure, based on a 200 degree C average rise of the same thermocouples, occurred in 66.5 minutes.

2.0 TEST SPECIMENS

2.1 Bulkheads

The horizontal cross-sections of the eight bulkhead assemblies are shown in Figures 1 through 7. The thin outline around each drawing indicates the limits of the space occupied by the assembly. The core of each assembly consisted of a 5/16 inch thick aluminum plate, 8 feet high and 6 feet 3 inches wide, with two full height vertical stiffeners, of aluminum angles, 4 x 3 x 3/8 inches welded in place. The edges of the plate were welded to the inside surface of an open aluminum box, 8 feet long, 6 feet 3 inches wide, and 10 5/16 inches deep. The stiffener side of the box, forming the fire exposed face of Assembly 4, was closed with perforated steel sheeting. The other assemblies were closed on the fire exposed side with two sheets of Marinite, 36 PCF density, supported in formed steel channels (see Figure 8).

The joints between the panels were similar to those customarily used in the erection of Class B bulkheads. Details for the single faced assemblies are shown in Figure 9 and those for the double faced constructions are shown in Figure 10.

The thickness of the Marinite as well as the type of joint varied from one assembly to another. The unexposed face of the box was left open in the case of the single faced assemblies 2, 2A, and 4. Marinite of various thicknesses was used to close the unexposed face of the box in the case of the double faced assemblies 2B, 3, 3C, 3D, and 3F.

In some cases mineral wool or fibrous glass insulation was attached to the aluminum plate, either by aluminum or steel studs and speed clips. The aluminum fastener is shown in Figure 11. The spacing between the Marinite or perforated steel plate and the aluminum bulkhead or the insulation attached to it was at least 1 inch. The differences between the various bulkhead and deck assemblies are tabulated in Table 1. For additional construction details consult the original drawings by Gibbs and Cox (References 2 and 3).

Two bulkhead assemblies were tested simultaneously by mounting them in the double opening test frame used with the NBS wall testing furnace. The space between the specimen and the perimeter of the opening was filled in with fire bricks. The assembly was then grouted in place with a portland cement and sand paste. This filling was covered with a spray-applied fire proof plaster on the side exposed to the furnace.

The test frame containing the two bulkhead specimens was moved in front of the wall testing furnace and the joints between the frame and the furnace were plastered. The details of the wall furnace are shown in Figure 12. Since the specimens were not loaded for this test, the loading beam (O) and the hydraulic jacks (P) shown in the figure were not included in the test frame used.

2.2 Decks

Vertical cross sections of the two aluminum deck assemblies are shown in Figures 13 and 14. These were single faced construction with the underside insulated and exposed to the NBS floor testing furnace. In each assembly the 5/16 inch thick aluminum deck was 12 feet 10 3/4 inches long and 8 feet 3 3/4 inches wide, supported by three deck beams, 12 feet 9 inches long, in the form of aluminum angles, 6 x 3 1/2 x 3/8 inches, welded in place. The aluminum plate formed the top surface of an aluminum box, 12 feet 9 inches long, 8 feet 2 inches wide, and 12 1/2 inches deep. The bottom of the box was closed with three sheets of 3/16 inch thick Marinite, 36 PCF density, in assembly 5A and with perforated steel sheet in assembly 5B1. A 3 1/2 inch wide, 3/8 inch thick aluminum ledge extended around the outside of the box, 6 1/2 inches up from the bottom. This ledge was used to support the assembly in the deck furnace.

The Marinite or the perforated steel sheets were secured to furring strips which were supported by hangers attached to the stiffeners. The joints between the Marinite panels were covered on the underside by butt strips. See joiner details in Figure 15. For additional information on the construction details consult the original drawings by Gibbs and Cox (Reference 4).

The two assemblies were mounted in the NBS floor testing furnace and tested at the same time. The area around the edges of the assemblies was filled in with asbestos packing materials The details of the furnace are shown in Figure 16. Since the specimens were not loaded for this test, the load distributing mechanism was not used.

3.0 TEST PROCEDURE

The tests were run in accordance with the IMCO specifications FP VI/17 ANNEX II, dated 25 September 1967, for Class A and B ratings. The IMCO surface thermocouples consisted of No. 24 B and S gage alumel and chromel wires attached to 12 mm diameter by 0.2 mm thick copper disks covered by 4 x 50 x 50 mm asbestos pads. One thermocoupleswas located approximately in the center of each quarter section of the test specimen, one was located near the center of the specimen, and one was placed in line with each of the central stiffeners. All of the joints in the assemblies tested were in line with a central stiffener so that additional thermocouples located over the joints, as specified in FP VI/17, were not required.

In the case of the double faced assemblies the aluminum core temperature was determined from the average temperature of three thermocouples located on the unexposed face of the aluminum bulkhead, at the center and at the two quarter points along one of the diagonals away from any stiffeners. For the single faced assemblies the aluminum core temperatures were obtained from the average of the five IMCO thermocouples located at the center of each quadrant and at the center of the specimen.

In addition to the above thermocouples required for rating the assemblies, surface thermocouples meeting the ASTM specifications were included for comparison purposes. Also several interior thermocouples were installed at strategic locations for analyzing the heat flow. The location of the thermocouples can be seen on the sketch accompanying the temperature plots in Figures 30 through 39. These locations are tabulated in Appendix II.

The furnace temperature was controlled by the average of twelve rapid response mineral-insulated thermocouples whose junctions were set 10 cm from the exposed face of the specimen. The average furnace temperature was made to follow the ASTM E119 standard time temperature curve by controlling the gas flow to the burners. The neutral pressure zone in the furnace was maintained at a level corresponding to one-third of the specimen height by controlling the size of the opening for the inlet air under the base of the test frame.

All of the temperatures were recorded digitally at 2 minute intervals on a data logger. Cards were punched from these records and used with the NBS computer to produce the temperature charts given in this report.

4.0 RESULTS

The assemblies were tested two at a time in the order indicated in Table II. The results are presented in the form of temperature records, visual observations during the test (Appendix II) and before and after photographs. The times to failure are given in Table IV.

4.1 Temperature Data

The temperature data for the complete series of SNAME aluminum ceiling and bulkhead assemblies are contained in Figures 17 through 39. These figures are copies of CAL-COMP plots generated by a computer program for reduction of fire data. Figures 17 through 26 show the unexposed surface temperature rises used to determine the time of failure for each assembly. They are presented in the chronological order in which the assemblies were tested. The letters S and N designate south and north sides of the furnace respectively. The assembly designations appear in parentheses in the title of each figure.

Both IMCO Class A and B and ASTM Class A and B temperatures and failure times are displayed on the figures for comparison between these four types of measurement. The horizontal lines indicate the four critical temperatures and the vertical lines drawn through their points of intersection with the relevant curves indicate the times of failure. The locations of the vertical lines are automatically determined by the computer program utilizing linear interpolation between the data points.

Class A implies that the average surface temperature rise includes the thermocouples in line with the stiffeners as well as those used in determining the Class B average. The Class B average is based on the five thermocouples located at the center of each quadrant and at the center of the specimen. The temperature failure criteria are summarized in Table III.

The failure temperatures determined from the temperature charts were corrected for errors due to the departure of the average furnace temperature curve from the standard time temperature curve according to the procedure described in ASTM E119. The correction to be added to the measured failure time is given by:

$$C = \frac{2I(A-A_s)}{3\ (A_s+L)}$$

When C is the correction term in minutes, I is the indicated fire resistance period in minutes, A is the area under the average furnace temperature curve for the first 3/4 of the indicated fire resistance period, A_s is the area under the standard time temperature curve for the same part of the indicated period, and L is a lag correction in the same units as A and A_s. L is equal to 1800 degrees C minutes. A, A_s and their difference were tabulated as a function of time by the computer program for convenience in calculating this correction. The corrected failure times for each assembly are recorded in Table IV. The data taken directly from the temperature curves are shown in parentheses. The corrections never exceeded 2 minutes.

Figures 27, 28, and 29 compare the average surface temperature rise, the maximum surface temperature rise, and the average temperature rise of the aluminum core for all of the assemblies tested.

In the comparison of the average and maximum temperature rises between different assemblies only the Class A temperature data from the IMCO thermocouples are used. When the aluminum formed the unexposed surface of the assembly the core temperature rise was taken to be the average surface temperature rise determined from the five IMCO thermocouples used for the Class B average rise.

Figures 30 through 39 show the average temperatures at various locations inside of each assembly. Each average temperature curve shown in the last ten figures is derived from the average of all of the thermocouples located at equivalent positions within the assembly. The average unexposed surface temperature is determined from the five IMCO thermocouples used to calculate the Class B average surface temperature rise. These positions are described in Appendix I, where the numbers correspond to those shown on the curves. The number in parentheses is the number of thermocouples at equivalent locations included in the average. For convenience, the positions are also illustrated in the abbreviated sketch included with each plot.

4.2 Summary of Visual Observations on the Deck Assemblies

The marine veneer started to crack and delaminate after five minutes. The cracking was signaled by several loud bangs (heard again at 6:15). By 15 minutes there were minor cracks in all three panels, some local delaminations of the west panel, and considerable delamination of the center panel. The perforated steel plate was sagging appreciably at 15 minutes.

The two assemblies deflected down, as expected, with the maximum at the center, for approximately 25 minutes. Then 5B1, and after 35 minutes, 5A, assumed an approximate S shape so that the deflection at the center was no longer a simple measure of the maximum deflection. After about 50 minutes, both decks were bowed up, reaching their maximum, and final, deflections at approximately 70 minutes. This was 3.4 inches for 5B1 and 3.8 inches for 5A. These deflections remained unchanged the next day.

4.3 Before and After Photographs

Figures 40 through 54 show before and after photographs of the unexposed and exposed faces of the bulkhead assemblies. The after picture of the unexposed surfaces for Test 479 (Assemblies 3 and 3F) is missing. However, there was very little change in appearance of these surfaces during the test because of their very small temperature rise.

Figure 55 shows the top surface of the deck assemblies prior to the test. Figures 56 and 57 show the undersides of Assemblies 5B1 and 5A respectively. The delamination of the Marinite and the melting of the aluminum stiffeners in Assembly 5A can be seen in Figure 58. The melting of the aluminum speed clips and pins with the attendant release of sections of mineral wool insulation can also be seen in this figure. Figure 59 shows the exposed face of Assembly 5B1 after the test with one of the perforated panels removed. The buckling of the panels and the melting of the aluminum stiffeners is apparent in the picture. The steel pins and speed clips as well as the insulation are seen to be unaffected.

5.0 DISCUSSION OF RESULTS

5.1 Double Faced Bulkhead Assemblies

Table V compares the Class A average surface temperature and core temperature failure times with the amount and type of insulation contained in the assemblies. The number of air spaces in the heat path through Assemblies 4 and 5B1 was taken to be zero since the hot furnace gases could easily penetrate the perforated metal plates. It is noted that there were no surface temperature failures in the case of the double faced constructions, since the surface temperatures in all of these cases were well below the permissible limits.

Two of the double faced constructions qualified for a Class A-60 rating. The core failure time was 63 minutes for 2B and was projected to be 66 minutes for 3F. The principle difference in the insulation configuration of these assemblies was in the thickness of the joiner panels on the unexposed side. The thicknesses were 1-3/4 inches for 2B and 3F respectively. The extra insulation on the side away from the furnace would cause the interior temperatures to be slightly higher. Also Assembly 3B was tested at an ambient temperature about 10 degrees cooler than that of Assembly 3F. Since the failure criteria are based on rises in temperature while the furnace is made to follow an absolute temperature curve, the assembly tested at the lowest ambient temperature should fail somewhat eariler. These effects could easily account for the 3 minute difference in the core failure times of 2B and 3F. The results for these assemblies indicate that a 3/4 inch thick Marinite panel, a 1 inch air space, and 1 inch of mineral wool insulation between the aluminum core and the fire are adequate to prevent a core temperature rise of 200 degrees C in one hour provided that there is no insulation on the unexposed surfaces of the aluminum.

There are two opposing effects of adding the insulation to the unexposed side. After thermal equilibrium is established in the structure, this insulation tends to bring the aluminum closer to the furnace temperature. While the assembly is heating up, the heat capacity and the latent heat of the absorbed moisture of the added insulation tends to hold the temperature down throughout the structure. Because of the long thermal time constants and the increasing furnace temperature the later effect is probably predominant over the first hour of exposure. However, a double faced construction with 3/4 inch Marinite panels on each side and one inch of mineral wool insulation on both faces of the aluminum should be tested to make sure of this point. The results of the present test indicate that the surface temperature criteria would be easily met with this configuration.

Comparing Assembly 3C with Assembly 3 we see that the effect of adding one inch of mineral wool to the unexposed side of the plate increases the core failure time from 37 to 48 minutes. This increase is due to the heat capacity and moisture content of the mineral wool. In going from 3C to 3D it is seen that moving the insulation to the exposed side of the aluminum plate while reducing the thickness of the Marinite panel from 3/4 to 1/2 inch further increased the core failure time to 55 minutes. Here the temperature drop across the insulation, as well as the heat capacity and moisture content, served to lower the temperature of the aluminum core. It is possible that one inch of mineral wool on both sides of the aluminum plate would have increased the failure time beyond 60 minutes with 1/2 inch panels on both sides. The improvement brought about by using a 3/4 inch instead of a 1/2 inch panel is seen by comparing Assemblies 3D and 3F where the failure time increased from 55 to 66 minutes.

5.2 Single Faced Bulkhead Assemblies

The core temperature criteria were met, although barely, in all of the single faced assemblies tested. The surface temperature failures occurred between 30 and 60 minutes. However, these temperature rises would be occurring in an area where no fire is possible according to the specified use of these constructions. The longest average surface failure time observed for these assemblies was 53 minutes for Assembly 2A which had a 3/4 inch panel and one inch of fibrous glass insulation.

5.3 Deck Assemblies

The deck assemblies tested had both surface temperature and core temperature failures within one hour. Assembly 5A performed better than 5B1 in spite of the delamination of the asbestos cement board panel and the subsequent loss of insulation due to the melting of the aluminum speed clips and pins. Core failure occurred in 56 minutes with the 3/16 inch panels. By 28 minutes the breakup of the panels allowed hot flame gases to contact the mineral wool insulation. After a delay in passing through 2 inches of insulation the additional heat caused the core temperature to start rising rapidly at about 37 minutes, as seen in Figure 35. The even faster rate of temperature rise observed in this figure after 56 minutes was caused by direct exposure of the aluminum plate to the fire following the falling off of the insulation. The first visual report of aluminum plate exposure occurred at 52 minutes. If the panel had remained intact, the assembly might have met the requirements of Class A-30 and possibly Class A-60 as well.

5.4 General

The failure times registered by the IMCO thermocouples were slightly longer than those determined by the ASTM thermocouples, except for Assembly 2. In no case did this difference exceed one minute for the Class A average failure time or 3 minutes for the Class B average failure time. The largest difference was 5 minutes for the Class A maximum failure time for Assembly 2. The use of ASTM thermocouples in determining the failure times would not have affected the ratings of any of the constructions tested.

6.0 CONCLUSIONS

1. All of the assemblies tested satisfied the Class B requirements. There were no surface or core temperature failures within the first 30 minutes.
2. All of the single faced bulkhead constructions satisfied the Class A-30 requirements. There were no core temperaature failures within one hour and no surface temperature failures within 30 minutes.
3. None of the single faced constructions qualified for a Class A-60 rating because surface temperature failures occurred on all constructions at less than 60 minutes.
4. Neither of the decks tested qualified for a Class A rating because core temperature failures occurred within 60 minutes. Delamination of the marine veneer early in the test (starting at 23 minutes) was responsible for the failure of Assembly 5A.
5. Double faced bulkhead Assemblies 2B and 3F satisfied the Class A-60 requirements. There were no surface or core temperature failures within 60 minutes. However, the double faced bulkhead assemblies may not have passed if they had been exposed on the opposite face.
6. None of the other double faced bulkhead assemblies satisfied the Class A requirements since the core temperature failures all occurred within one hour.
7. The failure times determined by the IMCO thermocouples were very slightly longer than those found by the ASTM thermocouples. However, the use of ASTM thermocouples in determining the failure times would not have affected the ratings of any of the constructions tested.
8. Steel pins and speed clips should be used in fastening the insulation to the aluminum.
9. Further testing should include bulkheads with insulation attached to both sides.

APPENDIX I

THERMOCOUPLE LOCATIONS

Assemblies 2 and 2A

1 - Unexposed face of joiner panel, behind H post (2)
2 - Unexposed face of joiner panel, clear of H post (2)
3 - Middle of air space (2)
5 - Unexposed face of aluminum bulkhead, (5)
7 - Exposed face of aluminum bulkhead, opposite stiffener (2)

Assembly 2B

1 - Exposed face of joiner panel away from furnace, attached to H post (2)
2 - Exposed face of joiner panel away from furnace, clear of H post (2)
3 - In air space on unexposed side of aluminum bulkhead
5 - Unexposed face of joiner panel away from furnace (7)
7 - Unexposed face of aluminum bulkhead, behind stiffener (2)

Assembly 3

2 - Unexposed face of joiner panel away from furnace (7)
5 - Unexposed face of aluminum bulkhead stiffener flange (4)
6 - Unexposed face of joiner panel next to furnace, behind H post (2)
7 - Unexposed face of joiner panel next to furnace, clear of H post (2)
7a - Exposed face of joiner panel away from the furnace (2)
8 - Middle of air space on exposed side of aluminum bulkhead (2)
8a - Middle of air space on unexposed side of aluminum bulkhead (2
9 - Unexposed face of aluminum bulkhead (3)
10 - Exposed face of aluminum bulkhead, opposite stiffener (2)

( ) number of thermocouples

Assembly 3G

2 - Unexposed face of joiner panel away from furnace (7)
5 - Unexposed face of aluminum bulkhead stiffener flange, behind insulation (4)
6 - Unexposed face of joiner panel next to furnace, clear of H post (1)
77 - Unexposed face of joiner panel next to furnace, clear of H post (2)
8 - Middle of air space on exposed side of aluminum bulkhead (2)
9 - Unexposed face of aluminum bulkhead, behind insulation (3)
10 - Exposed face of aluminum bulkhead, opposite stiffener (2)

Assembly 3F

2 - Unexposed face of joiner panel away from furnace (7)
5 - Unexposed face of aluminum bulkhead stiffener flange (4)
6 - Unexposed face of joiner panel next to furnace, behind H post (2)
6a - Exposed face of joiner panel away from furnace, behind H post (2)
7 - Unexposed face of joiner panel next to furnace, clear of H post (2)
7a - Exposed face of joiner panel away from furnace (2)
8 - Middle of air space on exposed side of aluminum bulkhead (2)
8a - Middle of air space on unexposed side of aluminum bulkhead (2)
9 - Unexposed face of aluminum bulkhead (3)
10 - Exposed face of aluminum bulkhead, opposite stiffener and behind insulation (2)

Assembly 4

3 - Unexposed face of aluminum bulkhead (7)
5 - Exposed face of aluminum bulkhead stiffener,flamge, behind insulation (4)
6 - Middle of air spaces (2)

( ) number of thermocoupless

Assembly 5A

2 - Unexposed face of aluminum deck (8)

5 - Exposed face of aluminum deck beam flange, behind insulation (4)

6 - Middle of air space (2)

7 - Unexposed side of joiner panel (2)

8 - On joiner furring web behind joiner panel butt joint (2)

9 - Exposed face of aluminum deck beam flange, behind insulation and clear of hangers (2)

Assembly 5B1

2 - Unexposed face of aluminum deck (8)

5 - Exposed face of aluminum deck beam flange, behind insulation (4)

6 - Middle of air space (2)

7 - On back of perforated sheet metal panel (2)

8 - On perforated sheet metal panel furring web behind lapped butt joint (2)

9 - Exposed face of aluminum deck beam flange (behind insulation) clear of studs and speed clips (2)

( ) number of thermocouples

VISUAL OBSERVATIONS

Test 467 (2 and 2A)

6 minutes	Joint facing on 2A buckled.
7 minutes	Joint facing on 2 buckled.
10 minutes	Wavy surface on insulation.
13 minutes	Perimeter caulking is buckling.
14 minutes	Noise from 2A.
	Steam at lower corner of 2 where thermocouple wire comes through.
40 minutes	Center plate of 2 buckled out and into furnace.
	Same on 2A but less pronounced.
	Marinite on 2 into furnace at joint small amount.
	Small flames along bottom joint are flashing out.
44 minutes	Buckling of Marinite at the joint more pronounced.
45 minutes	Outside frame on both panels buckled.

Test 469 (3D, 3C)

4 1/2 minutes	Slight buckle of the lower portion of the H post on 3C furnace side.
8 minutes	More buckling of H posts.
11 minutes	Flame issuing into the furnace from the 3D joint.
15 minutes	Flaming diminished along joint.
18 minutes	Flaming ceased along joint.
20 minutes	H post on 3C deformed badly.
30 minutes	Steam escaping from upper furnace joints.
32 minutes	Small amount of flaming along and below bottom edge of panel 3D.

35 minutes	Bowing of aluminum frame from raceway at lower left corner of unexposed side of 3C.
	Panel 3D exposed side deformed.
	Light grey smoke escaping at the top of panel 3C.
38 minutes	Dull noise.
	Slight flaming at left hand edge of 3D.
42 1/2 minutes	Louder noise on 3C.
44 1/2 minutes	Louder noise from panel 3D.
50 minutes	Horizontal crack on Marinite on fire side of panel 3C approximately 1/3 height.
	Slight bowing at lower left of unexposed corner of 3D are similar to 3C at 35 minutes.
53 minutes	Aluminum retainer buckled out approximately 1/2 inch over a 4 inch length at upper left corner of 3C.
55 minutes	Slight bowing at lower right unexposed corner of 3C.
58 minutes	No ignition of cotton pads at upper left corner of 3C and 3D.

Test 473 (5B1, 5A)

1 minute	Sagging of perforated plate on 5B1.
18 minutes	Smoke from top center joint between assemblies (probably electrical tape where thermocouples come out of assembly.)
23 minutes	Severe delamination of center section of 5A.
	Bulging of perforated plate on 5B1 (maximum of 6 inches).
25 minutes	Part of center section of 5A fell into furnace.

25 minutes (cont'd)	Smoke increasing from top joint.
28 minutes	Can see through marine veneer in C and W sections* of 5A.
29 minutes	Can also see through E section.
32 minutes	Small section of aluminum flange visible.
37 minutes	Smoke (moderate) along length of upper joint. Some along east and south joints.
42 minutes	Aluminum stiffener flanges exposed. 95% of marine veneer down in W section. 100% of marine veneer down in C section. 70% of marine veneer down in E section.
52 minutes	Aluminum stiffener flange, E section of 5A panel, exposed. Approximately a 2 square foot section of aluminum deck, west end of 5A, exposed due to insulation drop off.
55 minutes	Insulation falling off lower side of deck, west side, in several sections.
60 minutes	Small pieces of molten aluminum dripping through perforated plate on 5B1 and from 5A panel (aluminum speed clips and hangers). There is no evidence of steel beam deflection.

Test 478 (4, 2B)

2 minutes	Some buckling on exposed surface especially at joint on 2B.
7 1/2 minutes	Severe buckling on exposed surface of perforated sheet metal on 4.
9 1/2 minutes	Exposed Marinite surface red hot on 2B.
27 minutes	Noticeable bowing of Marinite surface into furnace on 2B. Buckling of aluminum panel on 4.

* C is center, W is west, and E is east.

30 minutes	Perforated sheet was pulled away from joint at edge.
35 minutes	Severe bowing in of Marinite sheet, maximum at the joint.
50 minutes	Deflection of buckled aluminum panel on 4 reached 7 1/2 inches.

Test 479 (3F, 3)

3 minutes	Buckling of exposed surface of 3F.
8 minutes	Paint burning on exposed side of H post on 3.
13 minutes	Exposed surface of 3 deflected away from the furnace.
	H post separated from the wall at the bottom of the exposed surface.
25 minutes	Exposed section of the H post on 3 fell into the furnace.
50 minutes	Smoke escaping around H post at the top of the unexposed surface of 3.

7.0 REFERENCES

1. "National Bureau of Standards Report of Test of Aluminum Plate Marine Bulkhead Insulated with 3/4-Inch Marine Board for Marine Use," Report No. TG 10210-2149:FR3686.

2. G and C Project No. 50510-9, Gibbs and Cox, Inc., New York, New York, for Society of Naval Architects and Marine Engineers. Dr. No. 50510-9-1141-1 Sheet No. 1, Rev. C, Single Faced Aluminum Bulkhead Assemblies for Bureau of Standards Tests

3. G and C Project No. 50510-9, Gibbs and Cox, Inc., New York, New York, for Society of Naval Architects and Marine Engineers. Dr. No. 50510-9-1141-1 Sheet No. 2, Rev. C, Double Faced Aluminum Bulkhead Assemblies for Bureau of Standards Tests

4. G and C Project No. 50510-9, Gibbs and Cox, Inc., New York New York for Society of Naval Architects and Marine Engineers. Dr. No. 50510-9-1141-1 Sheet No. 3, Rev. C, Aluminum Ceiling Assemblies for Bureau of Standards Tests.

TABLE I

TEST VARIABLES

Assembly	Type of Panel and Thickness (in.)		Insulation on Plate and its Thickness (in.)		Material Used for Pins and Speed Clips	Type of Joints on Exposed Side (Figure Number)
	Exposed Face	Unexposed Face	Exposed Face	Unexposed Face		
2	M-3/4	None	None	None	---	9a
2A	M-3/4	None	F.G.-1	None	Al	9b
2B	M/3/4	M-1	MW-1	None	Steel	10a
3	M-3/4	M-3/4	None	None	---	10a
3C	M-3/4	M-3/4	None	MW-1	Al	10c
3D	M-1/2	M-3/4	MW-1	None	Al	10b
3F	M-3/4	M-3/4	MW-1	None	Al	10c
4	PSS	None	MW-2	None	Steel	
5A	MV-3/16	None	MW-2	None	Al	15
5B1	PSS	None	MW-2	None	Steel	

M = Marinite
MV= Marine veneer
PSS= Perforated Steel Sheet (#16 USCG, 3/16 inch diameter holes, 3/8 inch center, 23% open area)
F.G.= Fibrous Glass
Al= Aluminum
MW= mineral wool

TABLE II TEST DATES

DATE	TEST DESIGNATION	TEST ASSEMBLY
June 8, 1970	467 S	2
	467 N	2A
June 19, 1970	469 S	3D
	469 N	3C
August 7, 1970	473 S	5B1
	473 N	5A
Nov 17, 1970	478 S	4
	478 N	2B
Dec 4, 1970	479 S	3F
	479 N	3

TABLE III TEMPERATURE FAILURE CRITERIA

TYPE OF FAILURE	CRITICAL TEMPERATURE RISE (deg C)
Class A-average	139
-maximum	180
Class B-average	139
-maximum	225
Core	200

TABLE IV TEMPERATURE FAILURE TIMES IN MINUTES

ASSEMBLY	TYPE OF FAILURE								CORE
	IMCO				ASTM				
	Class A		Class B		Class A		Class B		
	AVE	MAX	AVE	MAX	AVE	MAX	AVE	MAX	
2	42(40)	46(44)	43(41)	63(61)	43(41)	51(49)	43(41)	61(59)	61(59)
2A	53(51)	64(62)	53(51)	*	52(50)	61(59)	52(50)	*	70(68)
2B	*	*	*	*	*	*	*	*	63(61)
3	*	*	*	*	*	*	*	*	37(37)
3C	*	*	*	*	*	*	*	*	48(46)
3D	*	*	*	*	*	*	*	*	55(53)
3F	*	*	*	*	*	*	*	*	*
4	40(39)	44(43)	42(41)	56(54)	39(38)	44(43)	39(38)	55(53)	60(58)
5A	45(44)	45(44)	48(47)	50(49)	44(43)	44(43)	45(44)	49(48)	56(55)
5B1	34(33)	35(34)	36(35)	42(41)	34(33)	34(33)	35(34)	40(39)	48(48)

( ) times in parentheses are uncorrected times taken directly from the temperature curves.

* failure temperature was not obtained during the exposure period which lasted for at least one hour..

TABLE V

EFFECT OF INSULATION ON FAILURE TIMES

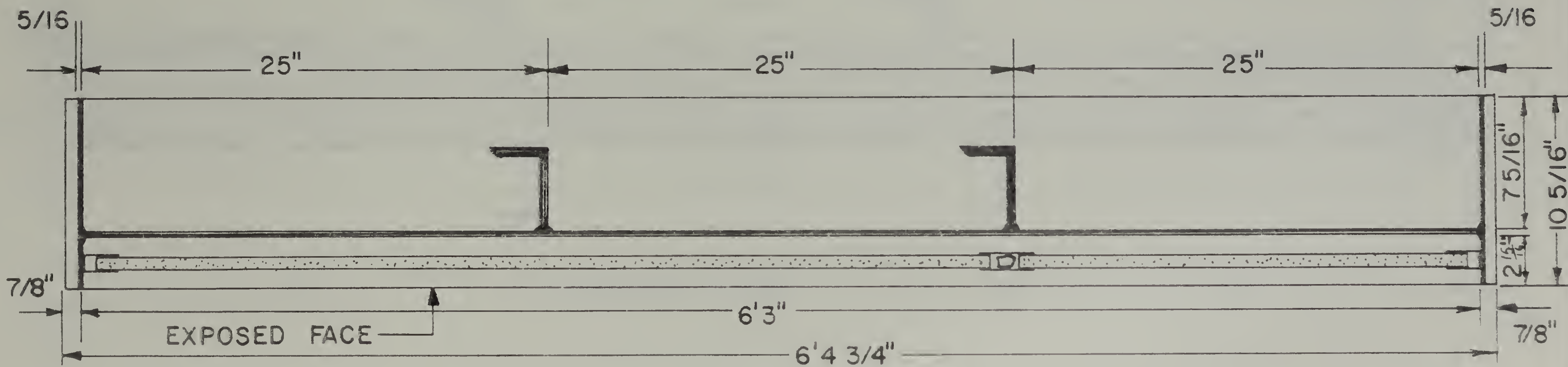
Assembly	Panel Thickness		Mineral Wool		Fibrous glass exposed side (in.)	Number of air spaces	Class A average surface Temp. Failure (min.)	Core Temp. failure (min.)
	Exposed Side (in.)	Unexposed Side (in.)	Exposed Side (in.)	Unexposed Side (in.)				
2	3/4	0	0	0	0	1	42	61
2A	3/4	0	0	0	1	1	53	70
2B	3/4	1	1	0	0	2	**	(63)
3	3/4	3/4	0	0	0	2	**	37
3C	3/4	1/2	0	1	0	2	**	48
3D	1/2	3/4	1	0	0	2	**	55
3F	3/4	3/4	1	0	0	2	**	(66)
4	*	0	2	0	0	0	40	60
5A	3/16	0	2	0	0	1	45	56
5B1	*	0	2	0	0	0	34	48

* Perforated steel sheet

** Did not fail during exposure time of greater than one hour.

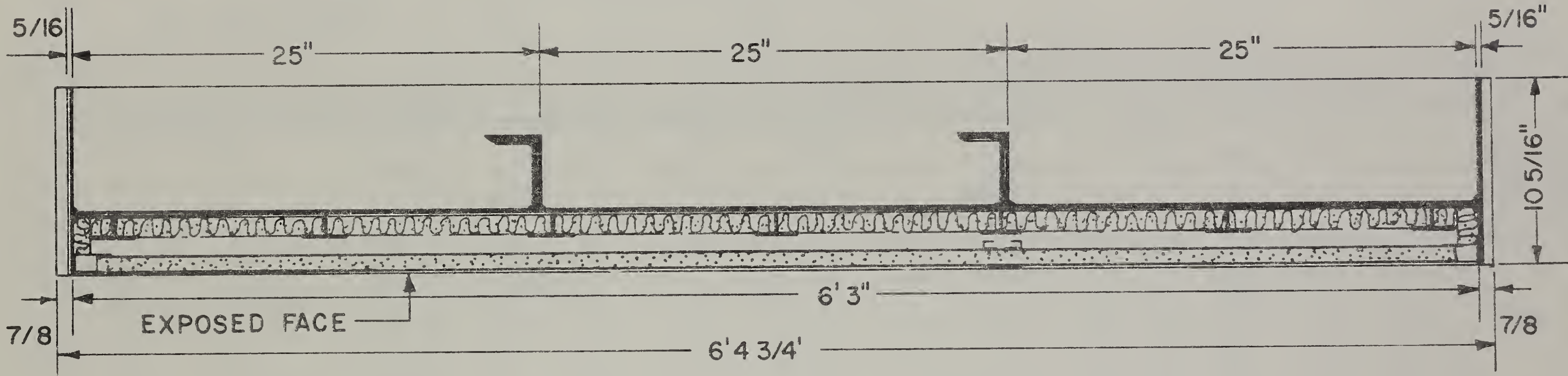
( ) numbers in parentheses are projected times.

FIGURE I HORIZONTAL CROSS SECTION OF ASSEMBLY 2



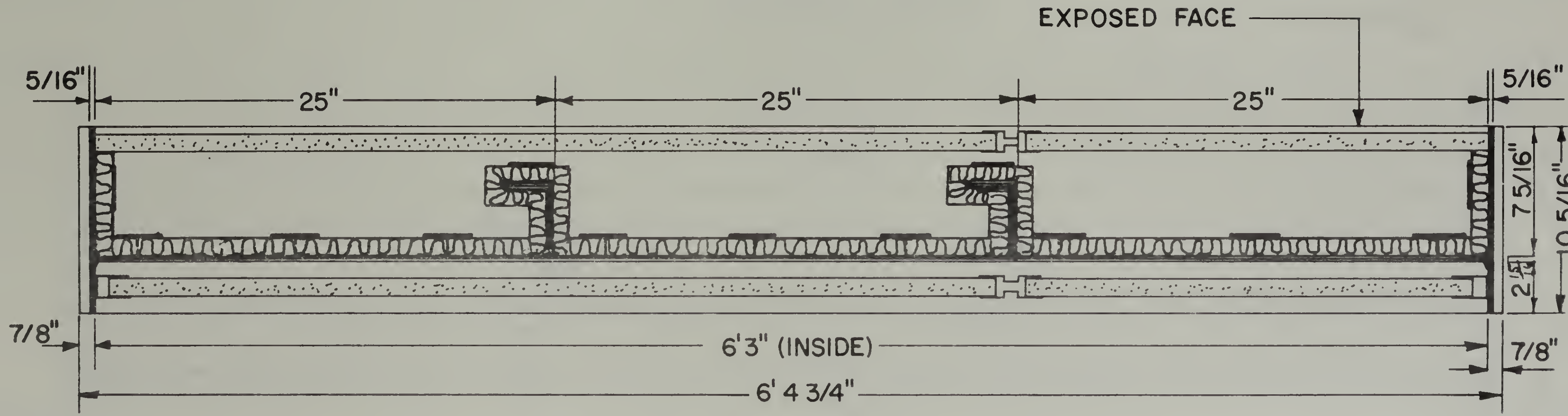
ASSEMBLY 2

FIGURE 2 HORIZONTAL CROSS SECTION OF ASSEMBLY 2A



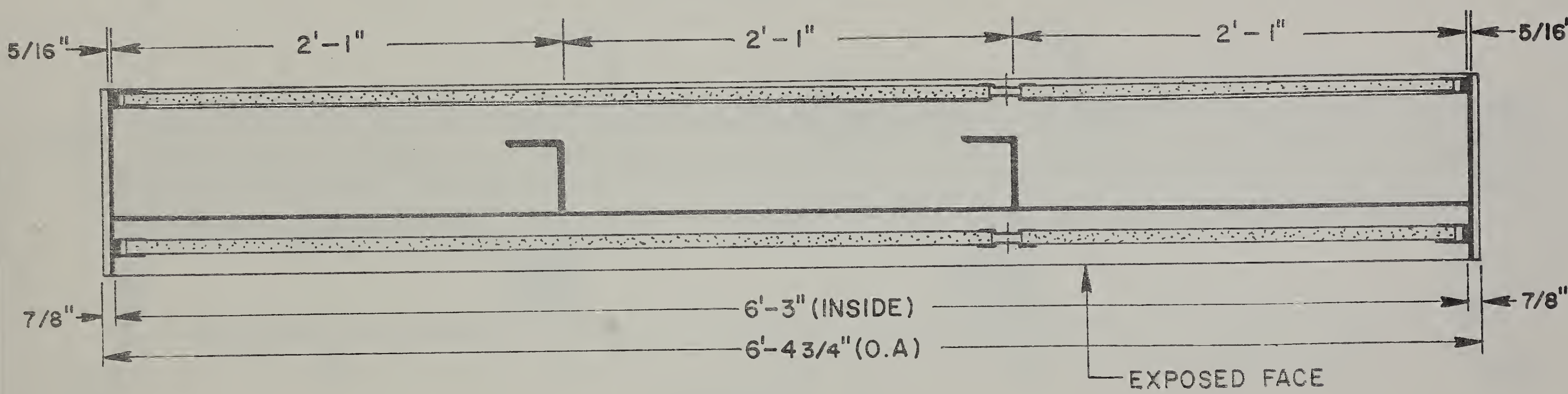
ASSEMBLY 2-A

FIGURE 3 HORIZONTAL CROSS SECTION OF ASSEMBLY 2B



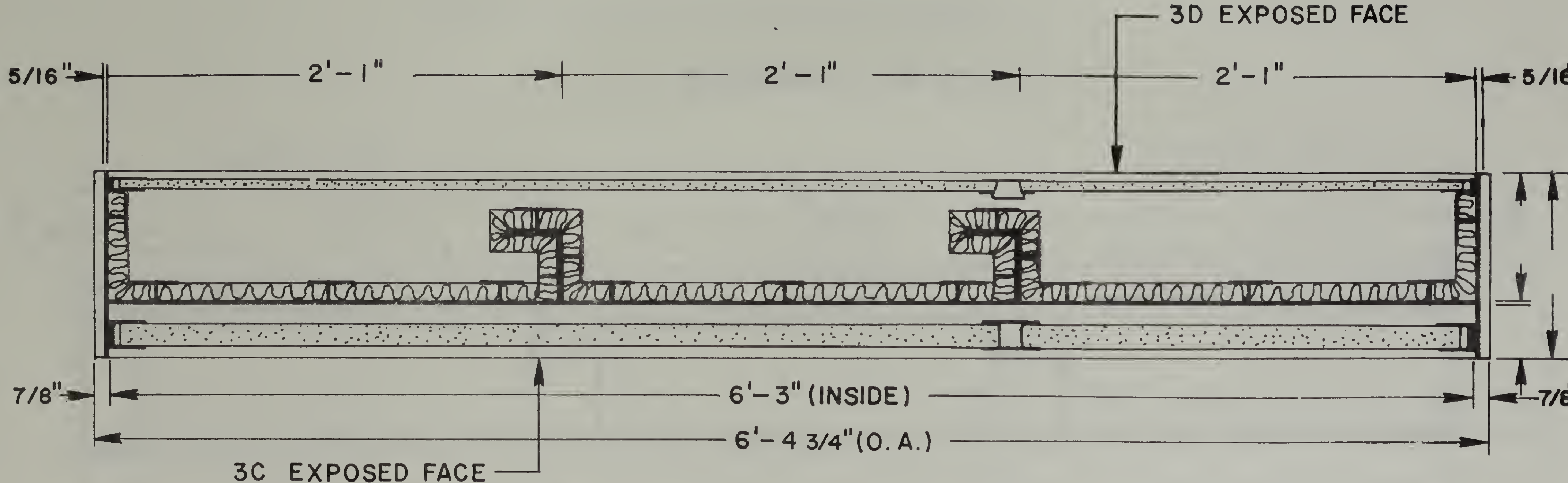
ASSEMBLY 2-B

FIGURE 4 HORIZONTAL CROSS SECTION OF ASSEMBLY 3



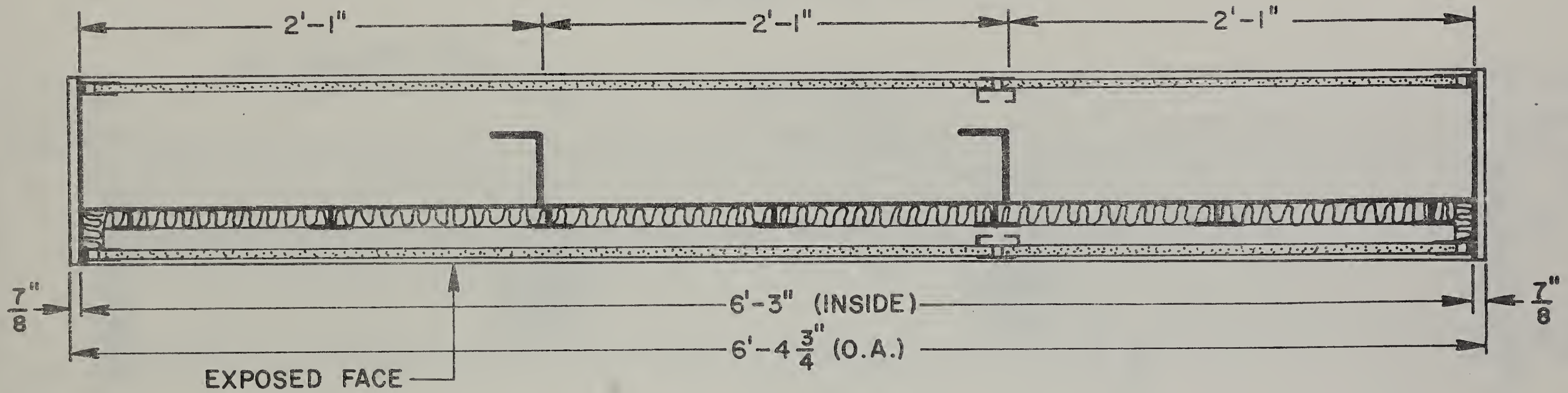
ASSEMBLY NO. 3

FIGURE 5 HORIZONTAL CROSS SECTION OF ASSEMBLIES 3C and 3D



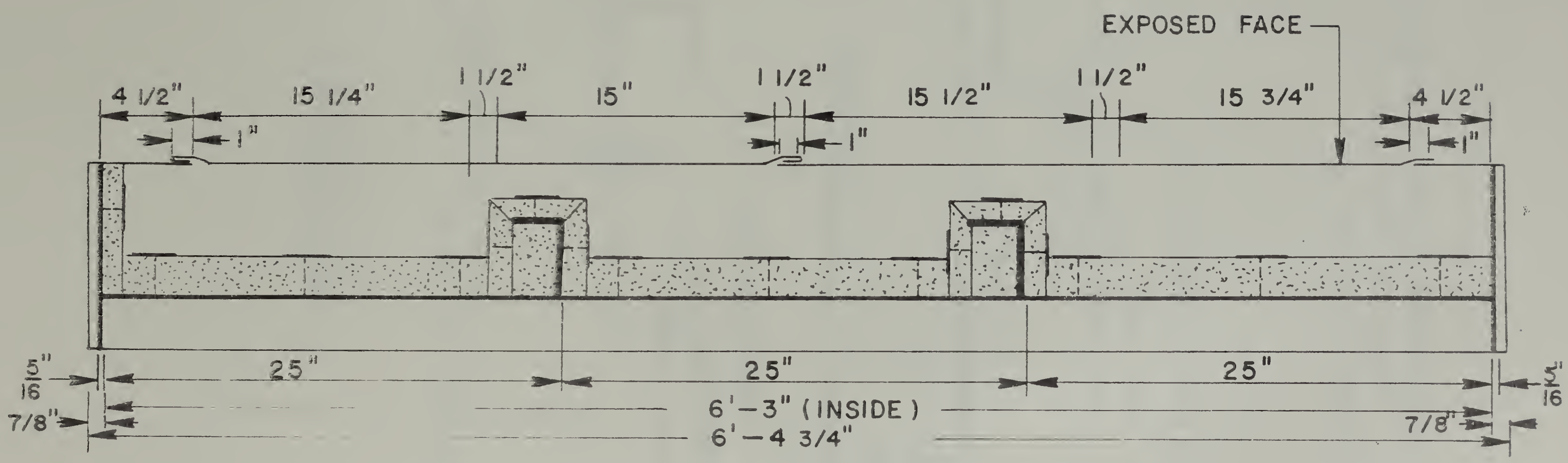
ASSEMBLY NO. 3-C & 3-D

FIGURE 6 HORIZONTAL CROSS SECTION OF ASSEMBLY 3F



ASSEMBLY NO. 3-F

FIGURE 7 HORIZONTAL CROSS SECTION OF ASSEMBLY 4



ASSEMBLY 4

FIGURE 8 TYPICAL SIDE SHOE INSTALLATION FOR SECURING PANEL TO ALUMINUM BOX

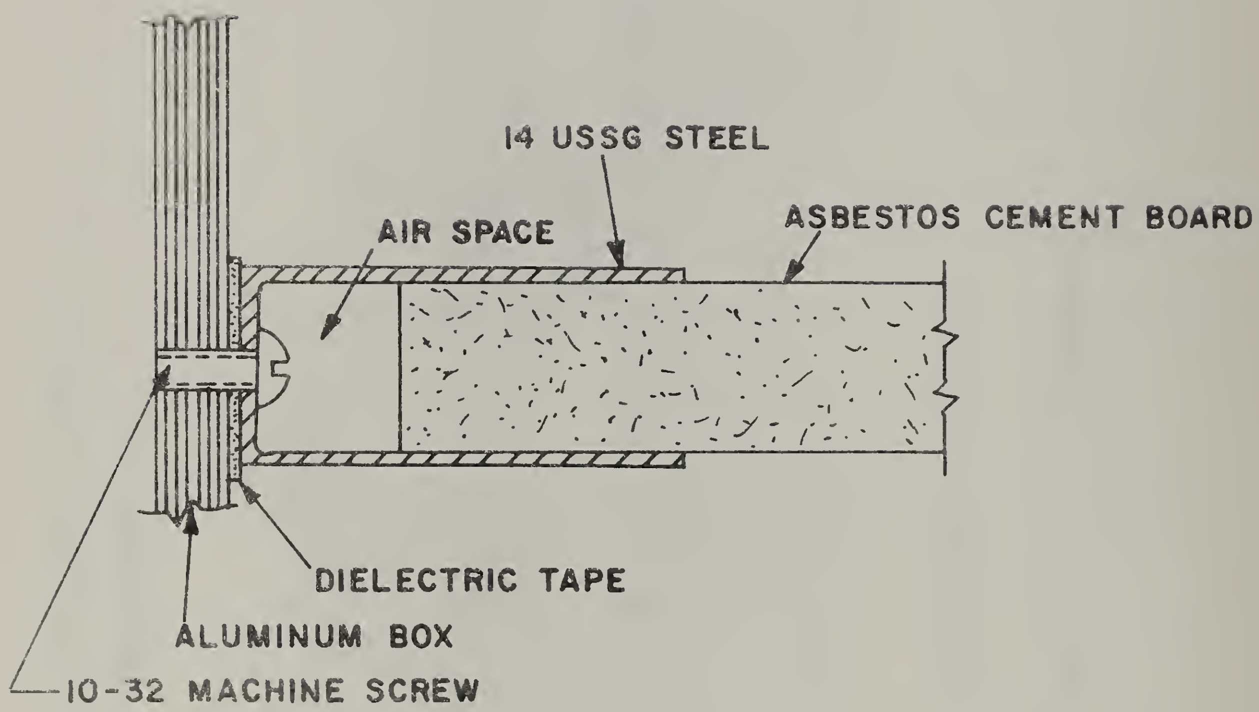
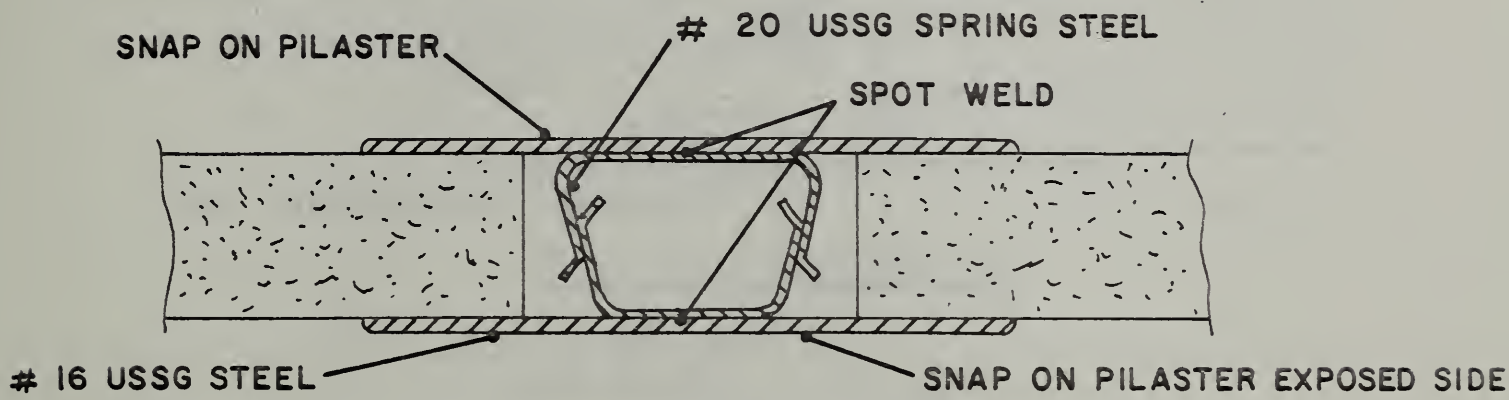
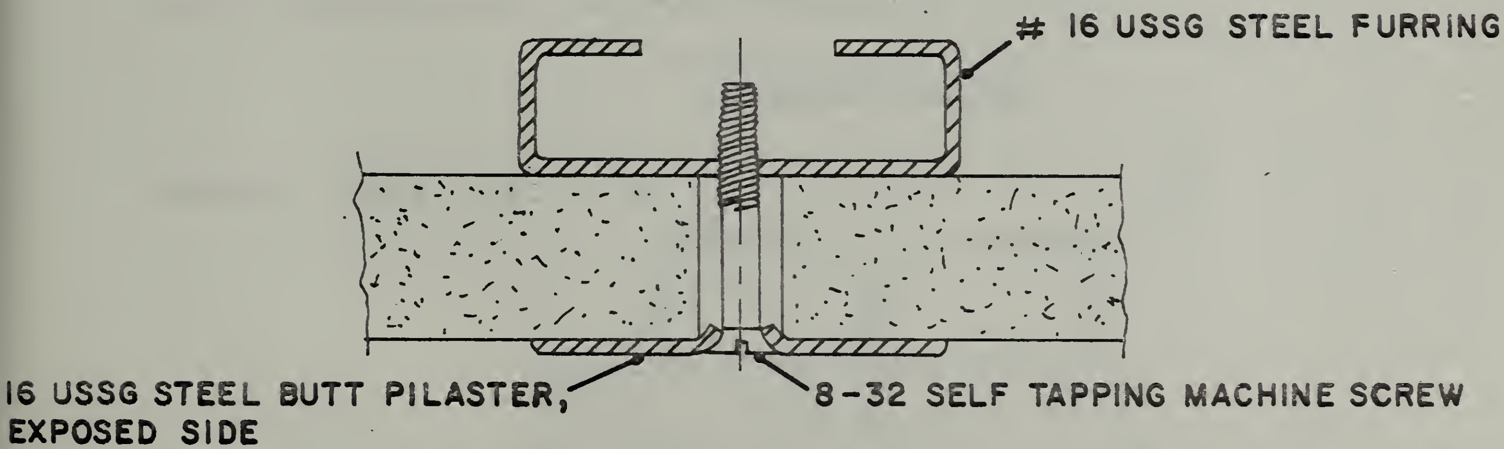


FIGURE 9 JOINER DETAILS FOR SINGLE FACED CONSTRUCTIONS

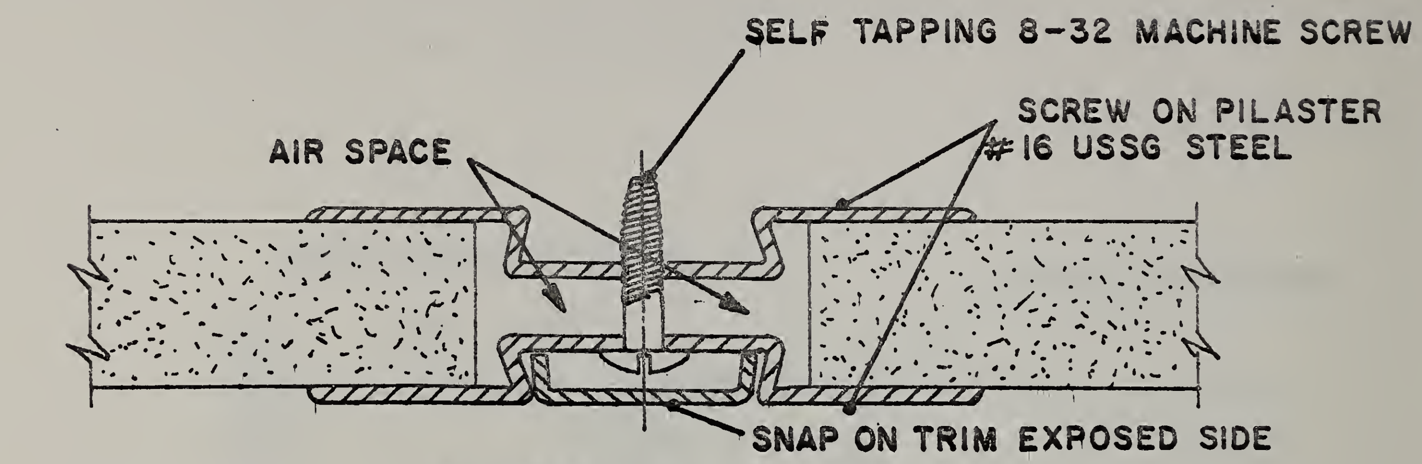


ASSEMBLY 2

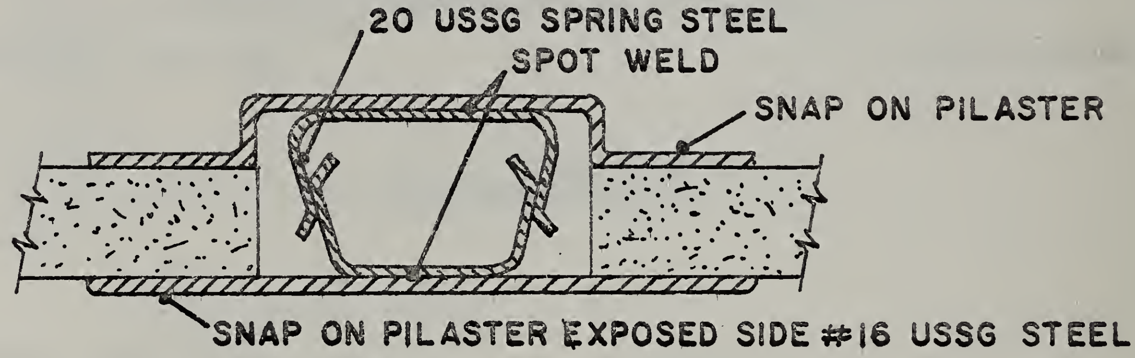


ASSEMBLY 2A

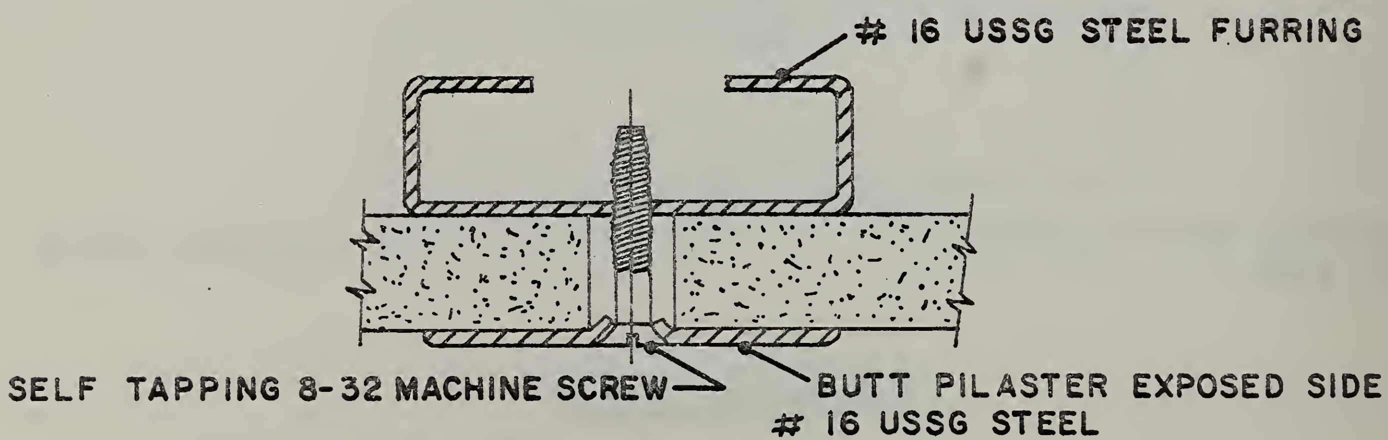
FIGURE 10 JOINER DETAILS FOR DOUBLE FACED CONSTRUCTIONS



ASSEMBLIES 2B & 3

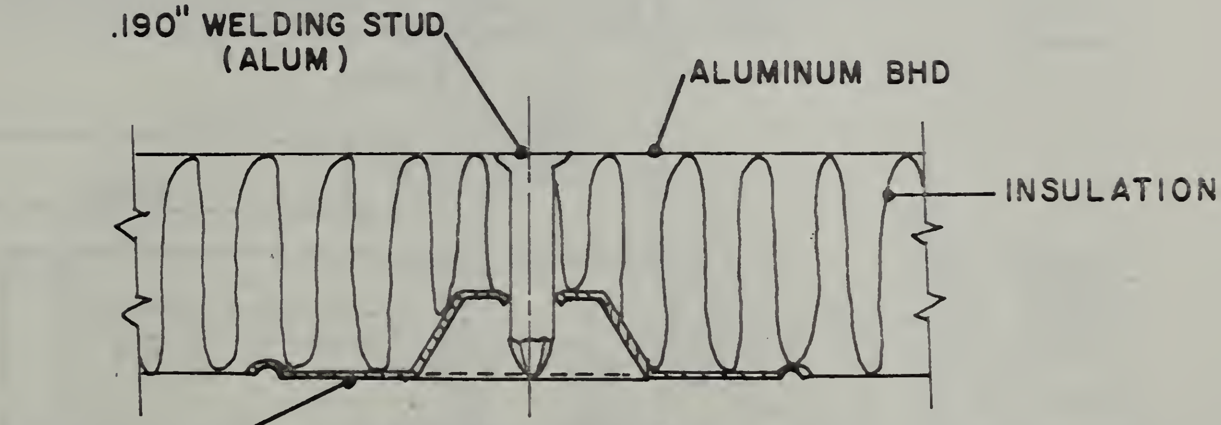


ASSEMBLY 3D

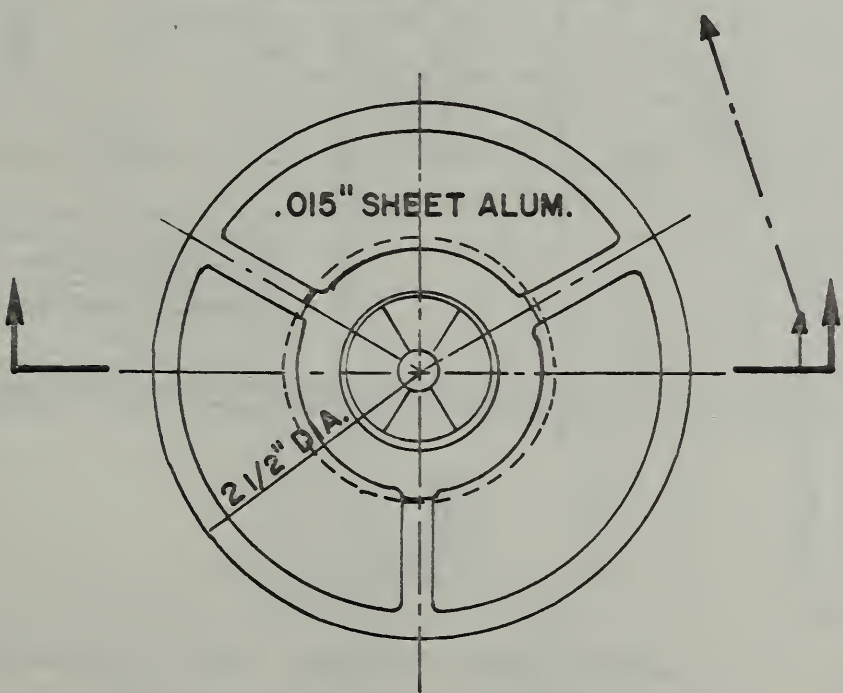


ASSEMBLIES 3C & 3F

FIGURE 11 ALUMINUM INSULATION FASTENER



SECTION AT STUD



SPEED CLIP

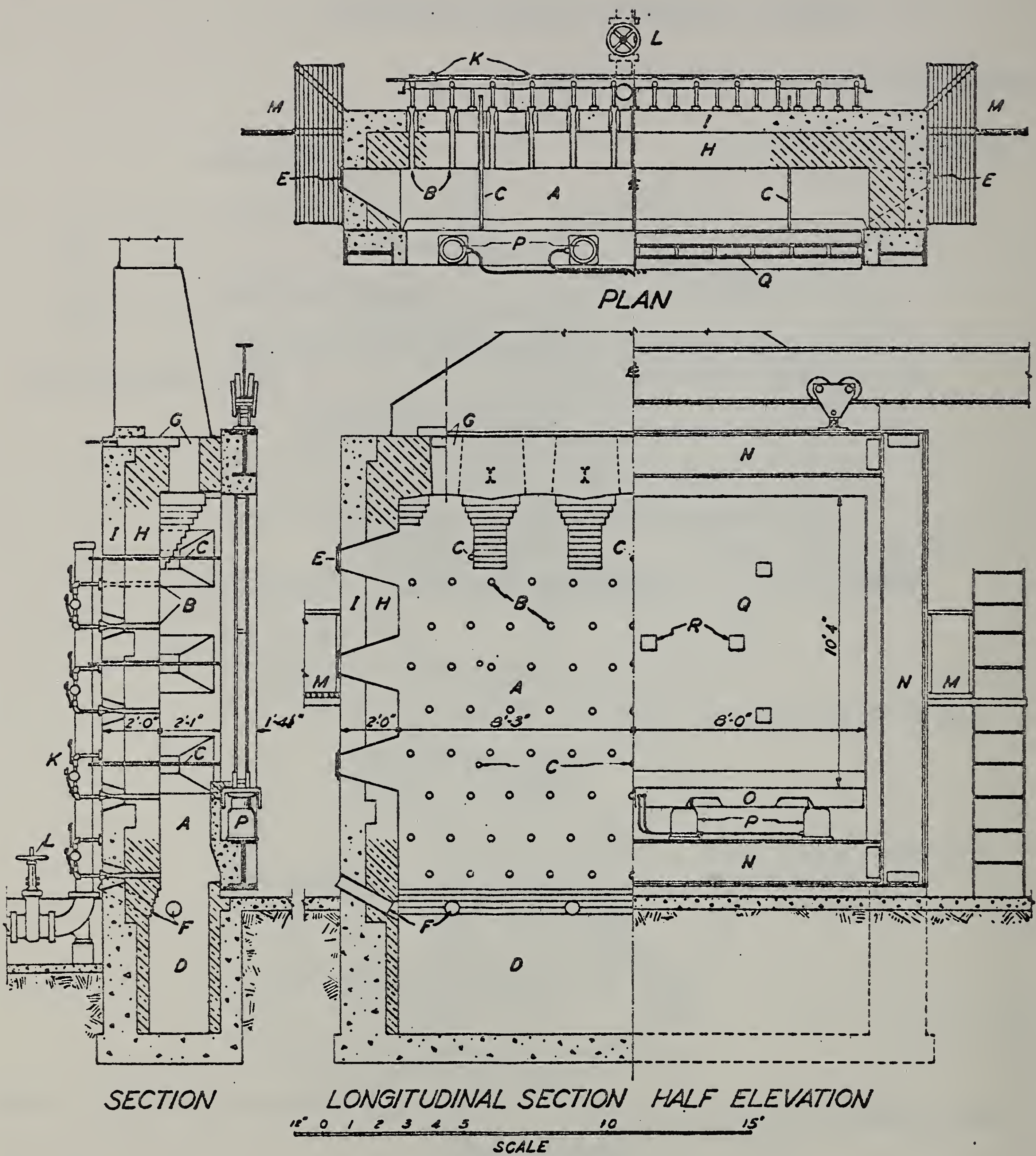
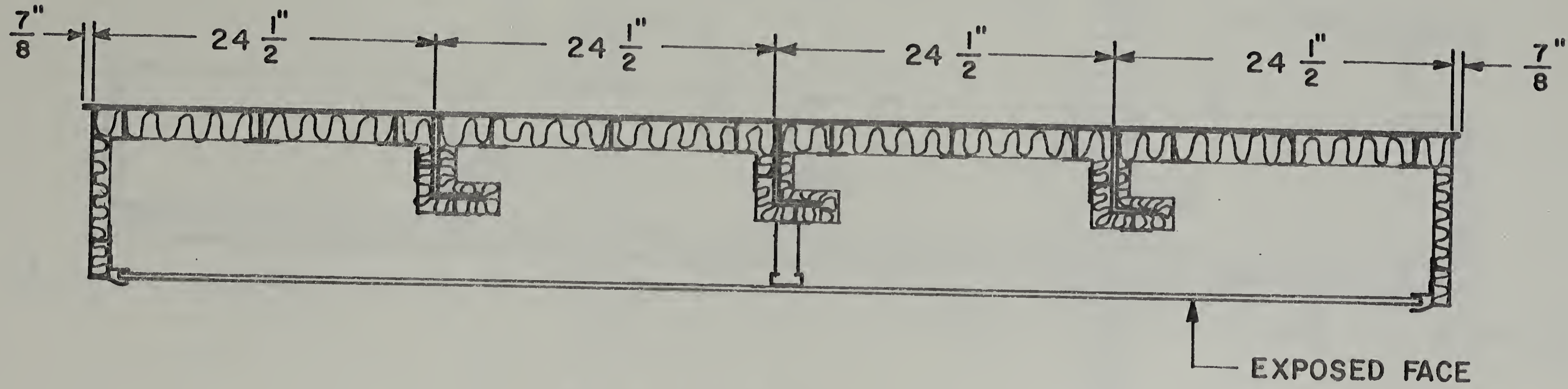


FIGURE 32 DETAILS OF WALL-TESTING FURNACE.

A, FURNACE CHAMBER; B, BURNERS; C, THERMOCOUPLE PROTECTION TUBES; D, PIT FOR DEBRIS; E, OBSERVATION WINDOWS; F, AIR INLETS; G, FLUE OUTLETS AND DAMPERS; H, FIREBRICK FURNACE LINING; I, REINFORCED CONCRETE FURNACE-SHELL; K, GAS COCKS; L, CONTROL VALVE; M, LADDERS AND PLATFORMS TO OBSERVATION WINDOWS; N, MOVABLE FIREPROOFED TEST FRAME; O, LOADING BEAM; P, HYDRAULIC JACKS; Q, TEST WALL; R, ASBESTOS FELTED PADS COVERING THERMOCOUPLES ON UNEXPOSED SURFACE OF TEST WALL.

FIGURE 13 VERTICAL CROSS SECTION
ASSEMBLY 5A



TEST ASSEMBLY No. 5-A

FIGURE 14 VERTICAL CROSS SECTION
ASSEMBLY 5B1

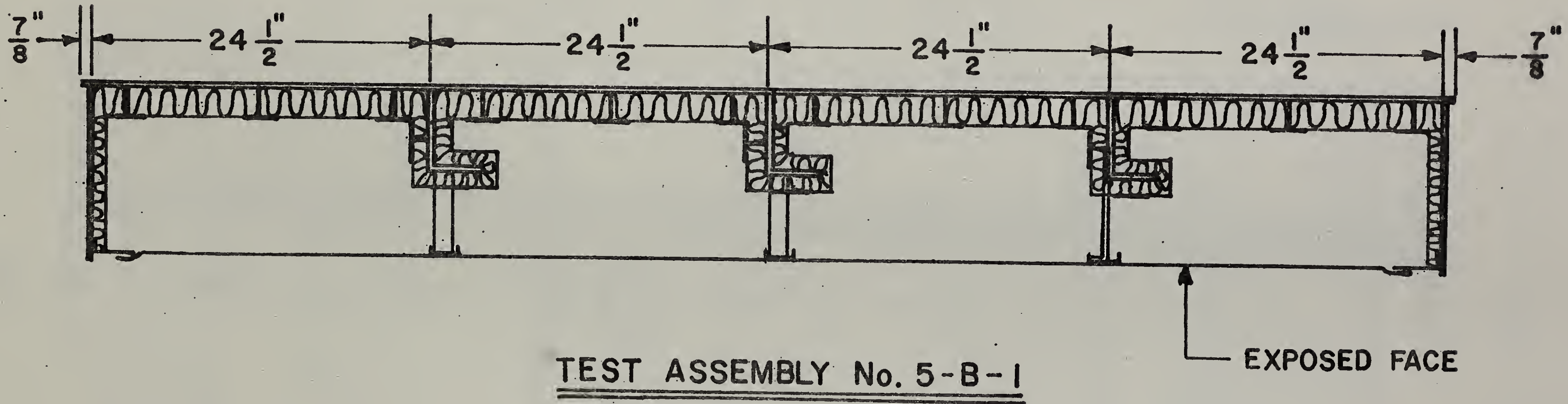
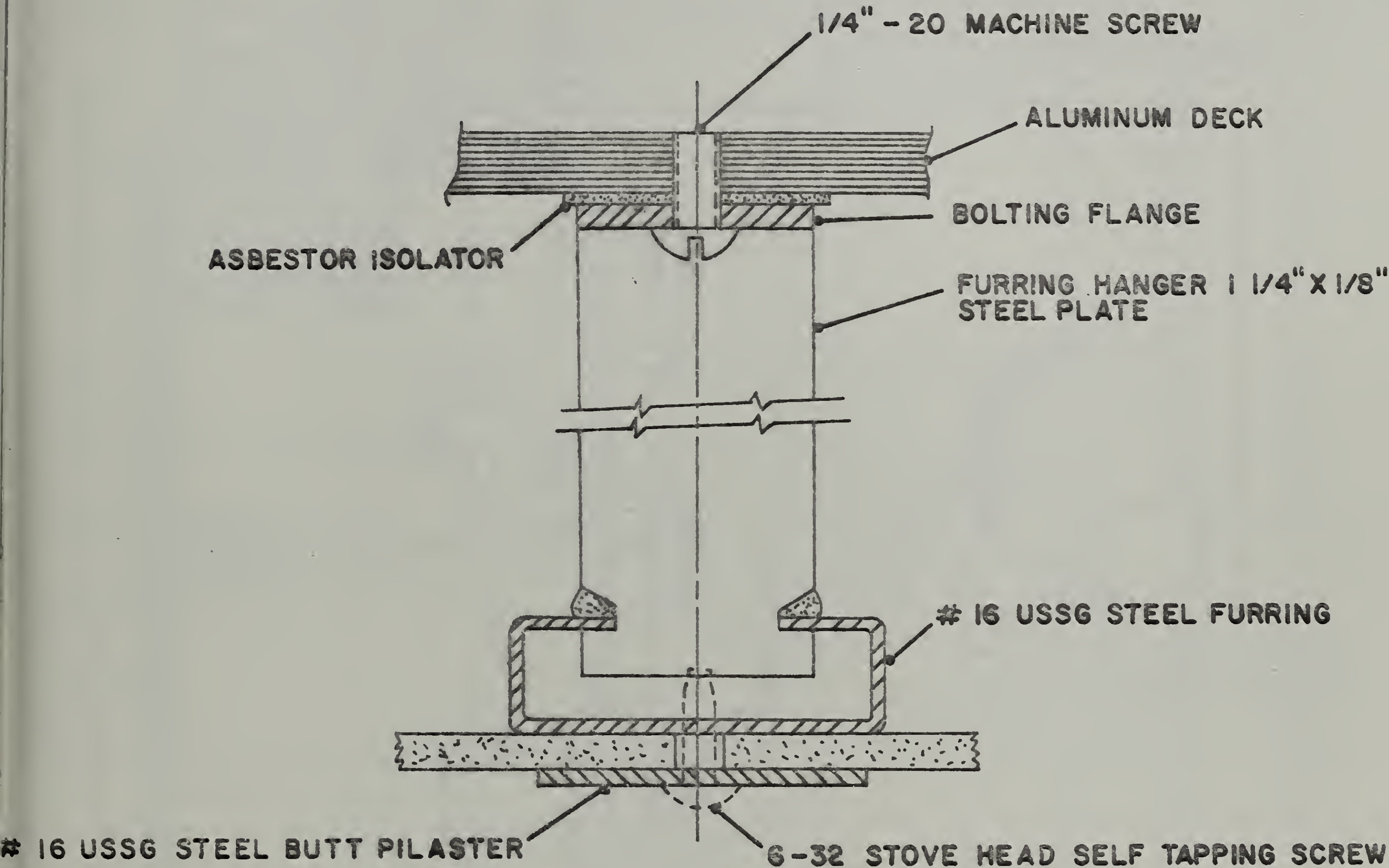


FIGURE 15 JOINER DETAILS FOR DECK ASSEMBLY 5A



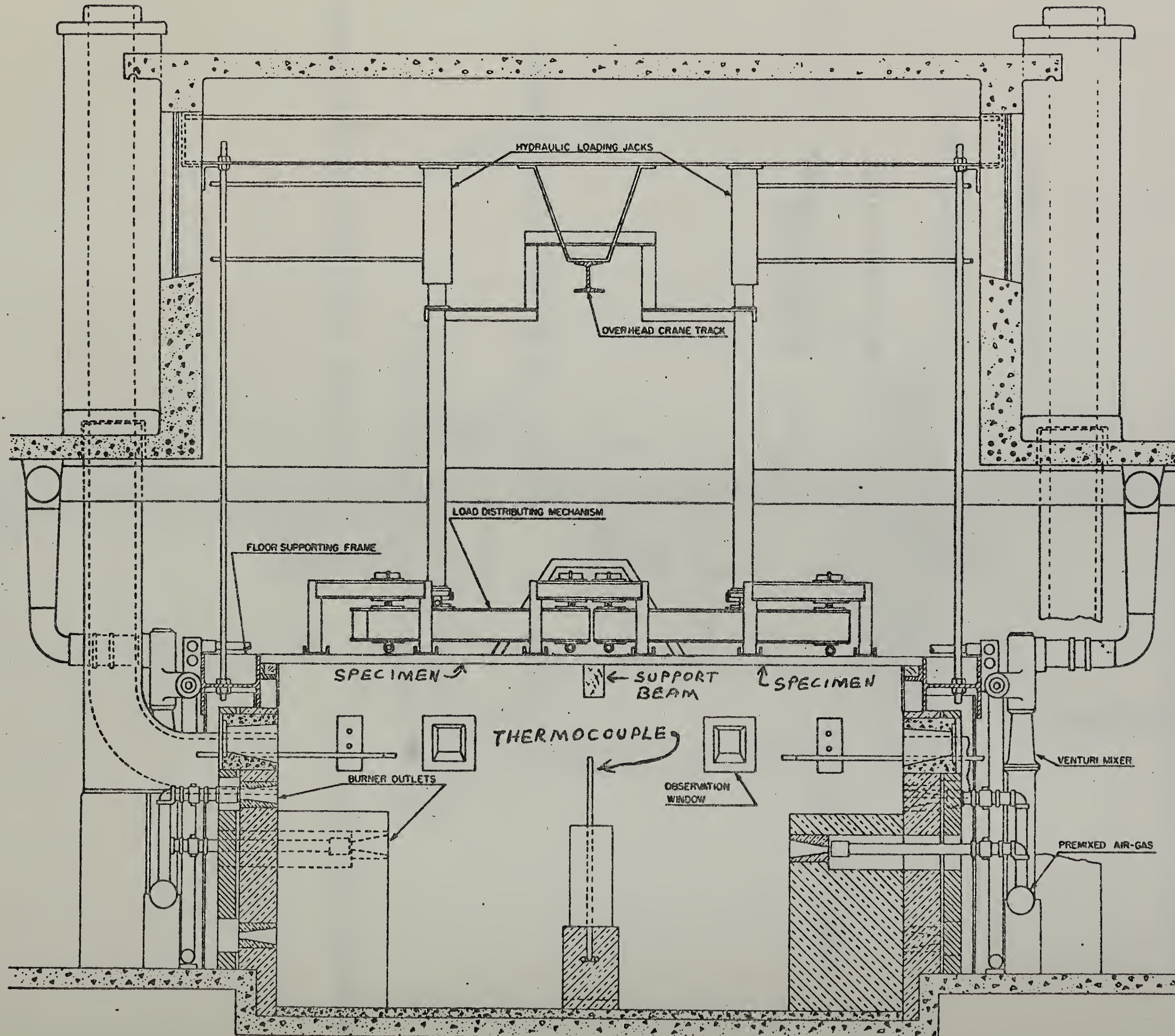


FIGURE 16. Section of the large floor-test furnace at NBS.

FIGURE 17

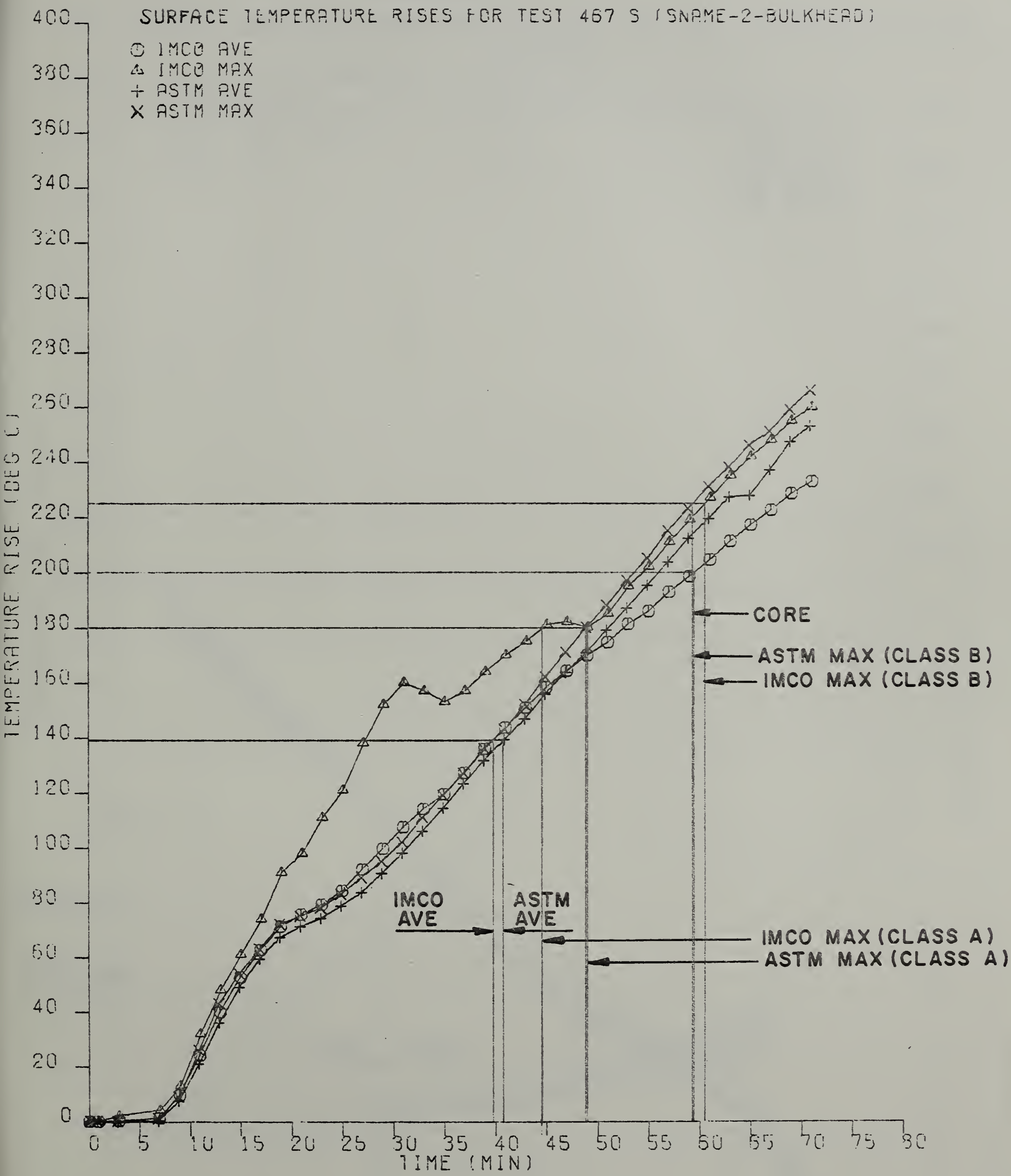

SURFACE TEMPERATURE RISES FOR TEST 467 S (SNAME-2-BULKHEAD)
IMCO AVE
IMCO MAX
ASTM AVE
ASTM MAX
TEMPERATURE RISE (DEG C)
TIME (MIN)
CORE
ASTM MAX (CLASS B)
IMCO MAX (CLASS B)
IMCO AVE
ASTM AVE
IMCO MAX (CLASS A)
ASTM MAX (CLASS A)

FIGURE 18

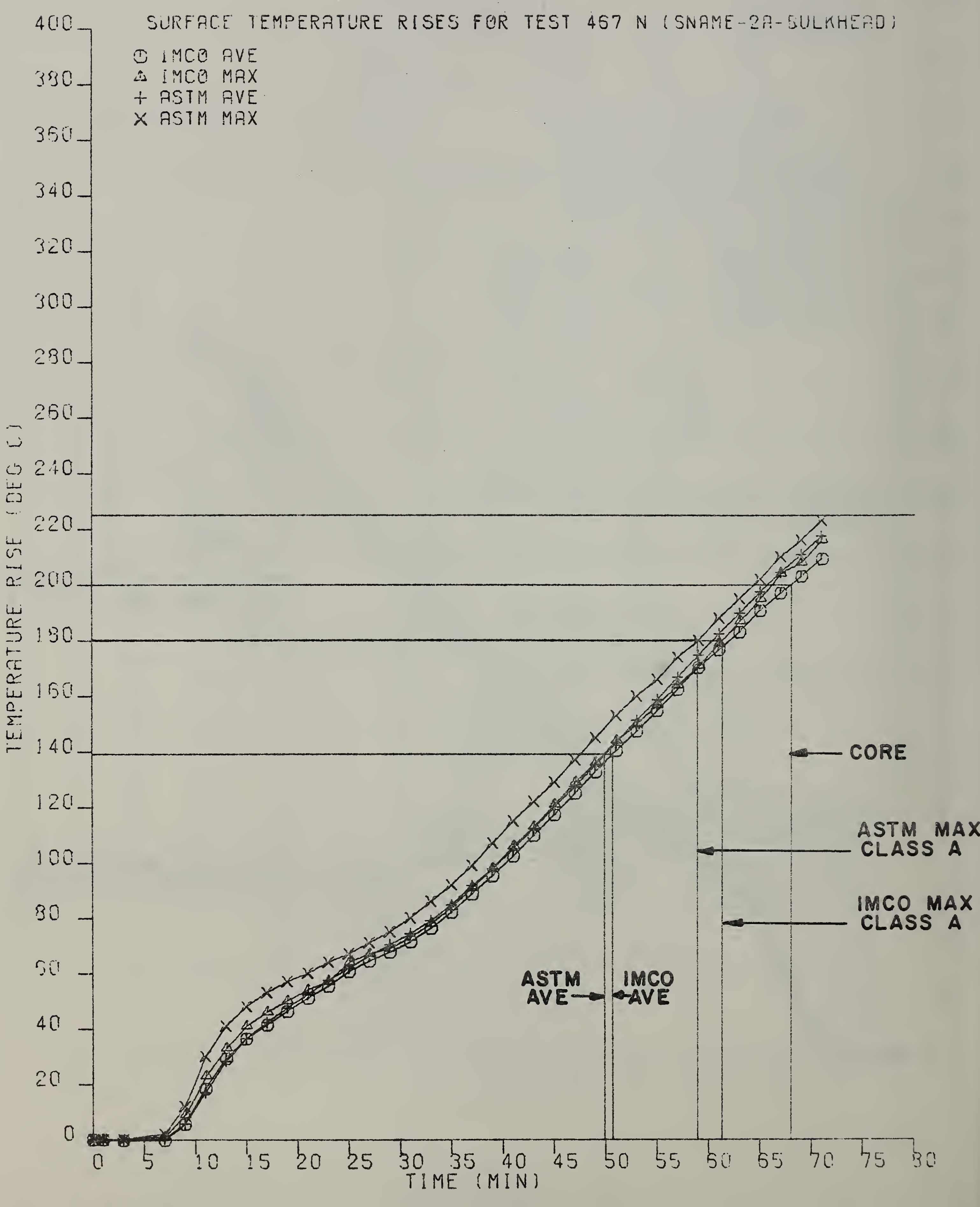

SURFACE TEMPERATURE RISES FOR TEST 467 N (SNAME-2A-BULKHEAD)
IMCO AVE
IMCO MAX
ASTM AVE
ASTM MAX
TEMPERATURE RISE (DEG C)
TIME (MIN)
CORE
ASTM MAX CLASS A
IMCO MAX CLASS A
ASTM AVE
IMCO AVE
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

FIGURE 19

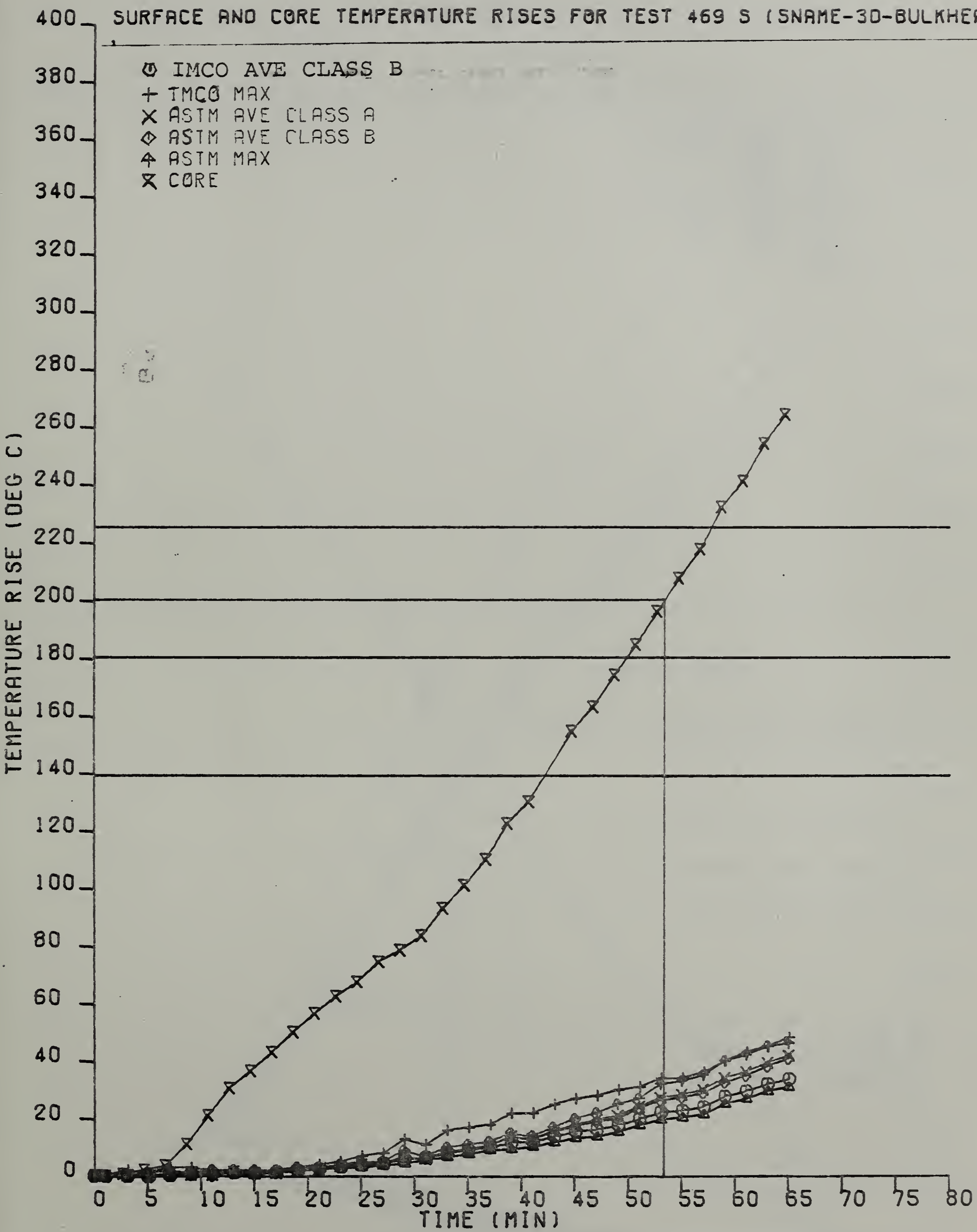
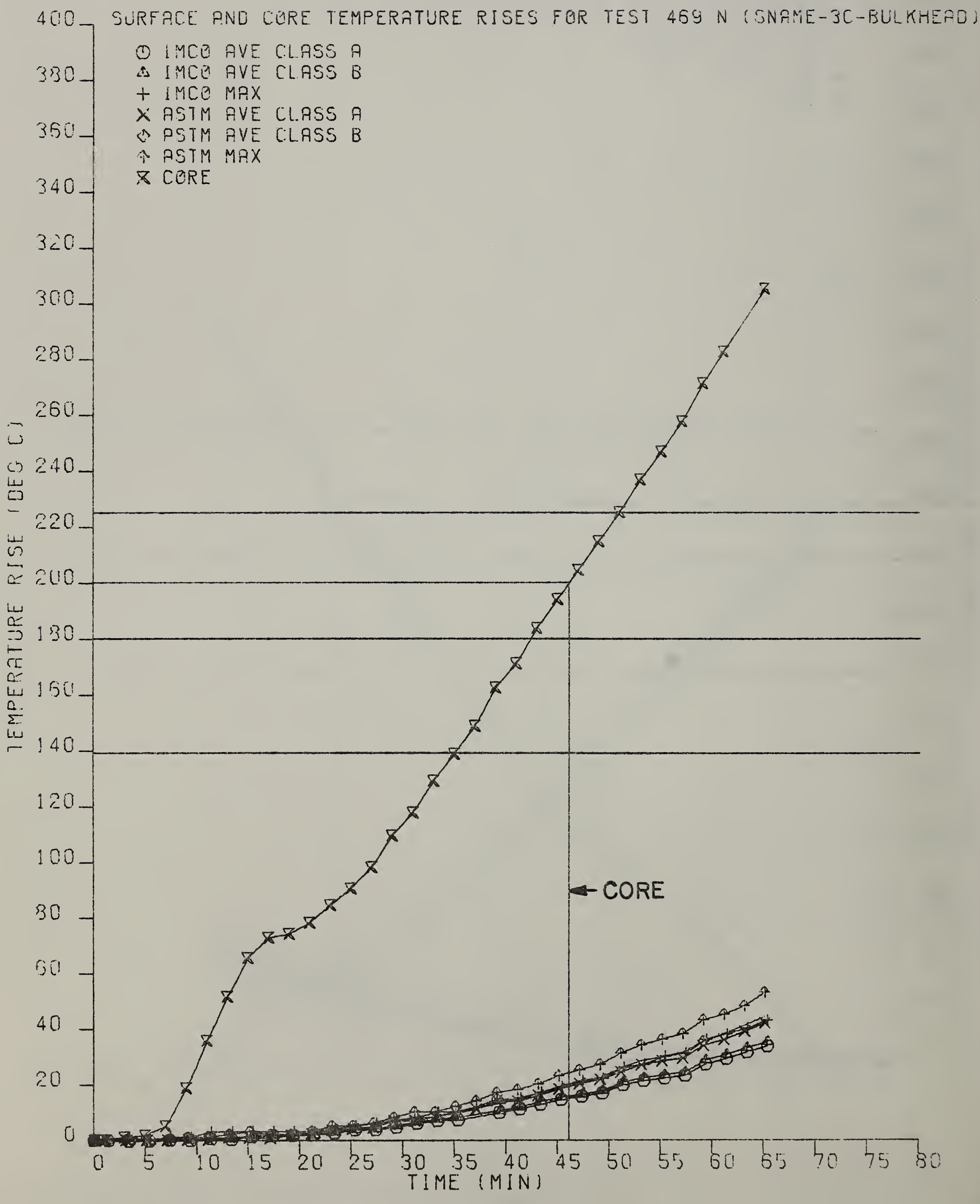

SURFACE AND CORE TEMPERATURE RISES FOR TEST 469 S (SNAME-30-BULKHEAD)
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
CORE
TEMPERATURE RISE (DEG C)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
TIME (MIN)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 20



SURFACE AND CORE TEMPERATURE RISES FOR TEST 469 N (SNAME-3C-BULKHEAD)
IMCO AVE CLASS A
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
CORE
TEMPERATURE RISE (DEG C)
TIME (MIN)
CORE
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 21

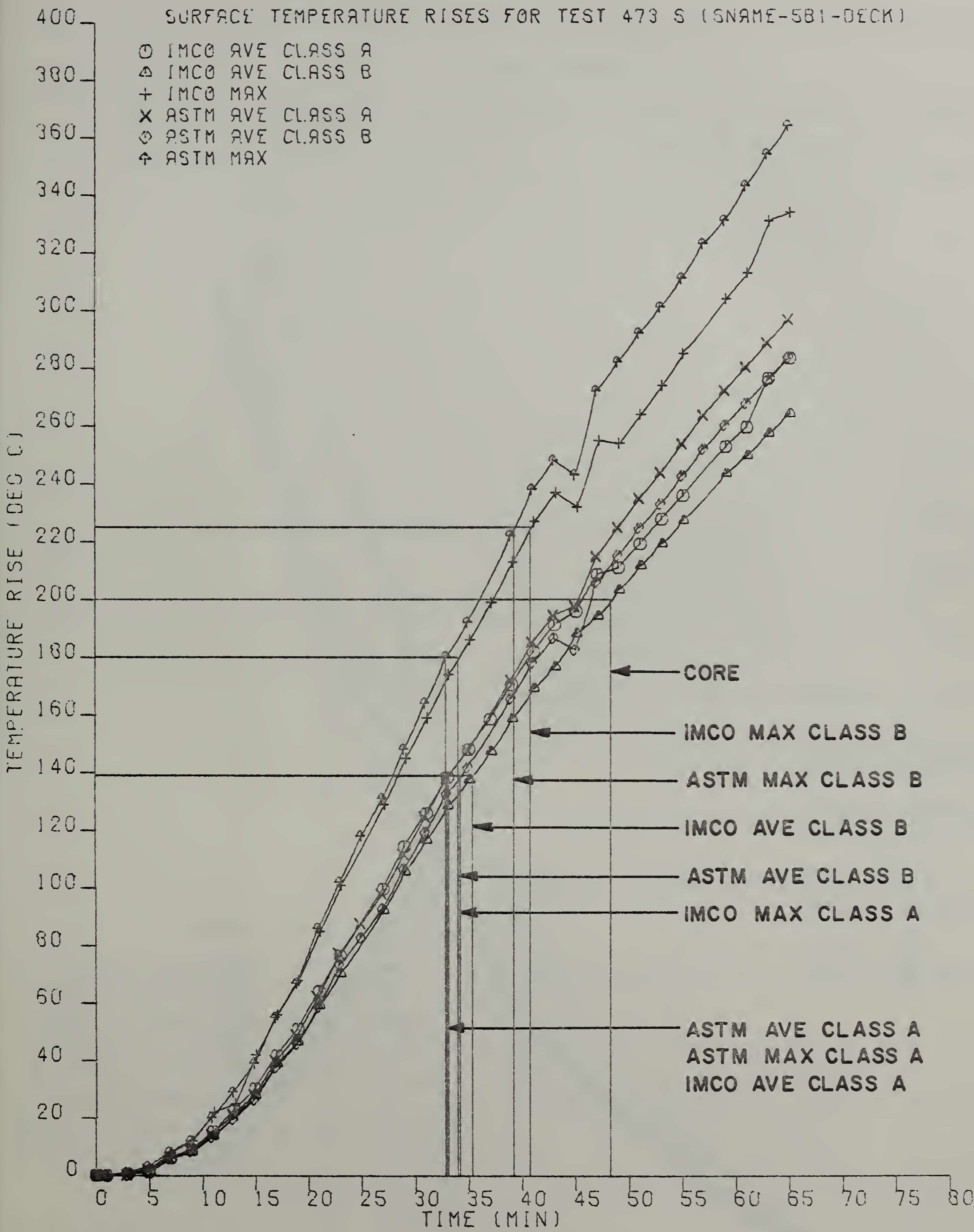

SURFACE TEMPERATURE RISES FOR TEST 473 S (SNAME-581-DECK)
IMCO AVE CLASS A
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
TEMPERATURE RISE (DEG C)
TIME (MIN)
CORE
IMCO MAX CLASS B
ASTM MAX CLASS B
IMCO AVE CLASS B
ASTM AVE CLASS B
IMCO MAX CLASS A
ASTM AVE CLASS A
ASTM MAX CLASS A
IMCO AVE CLASS A

FIGURE 22

SURFACE TEMPERATURE RISES FOR TEST 473 N (SNAME-5A-DECK)

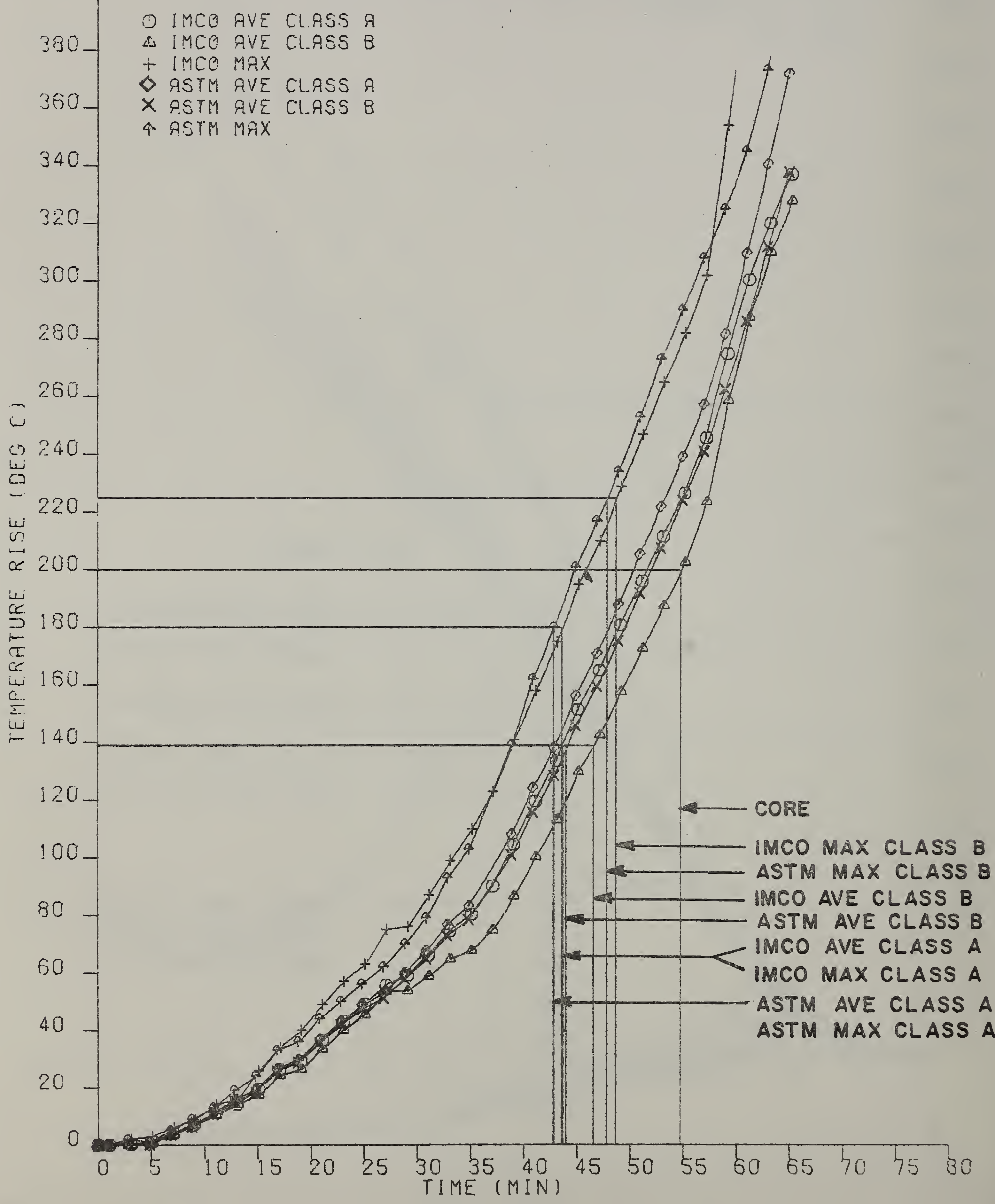
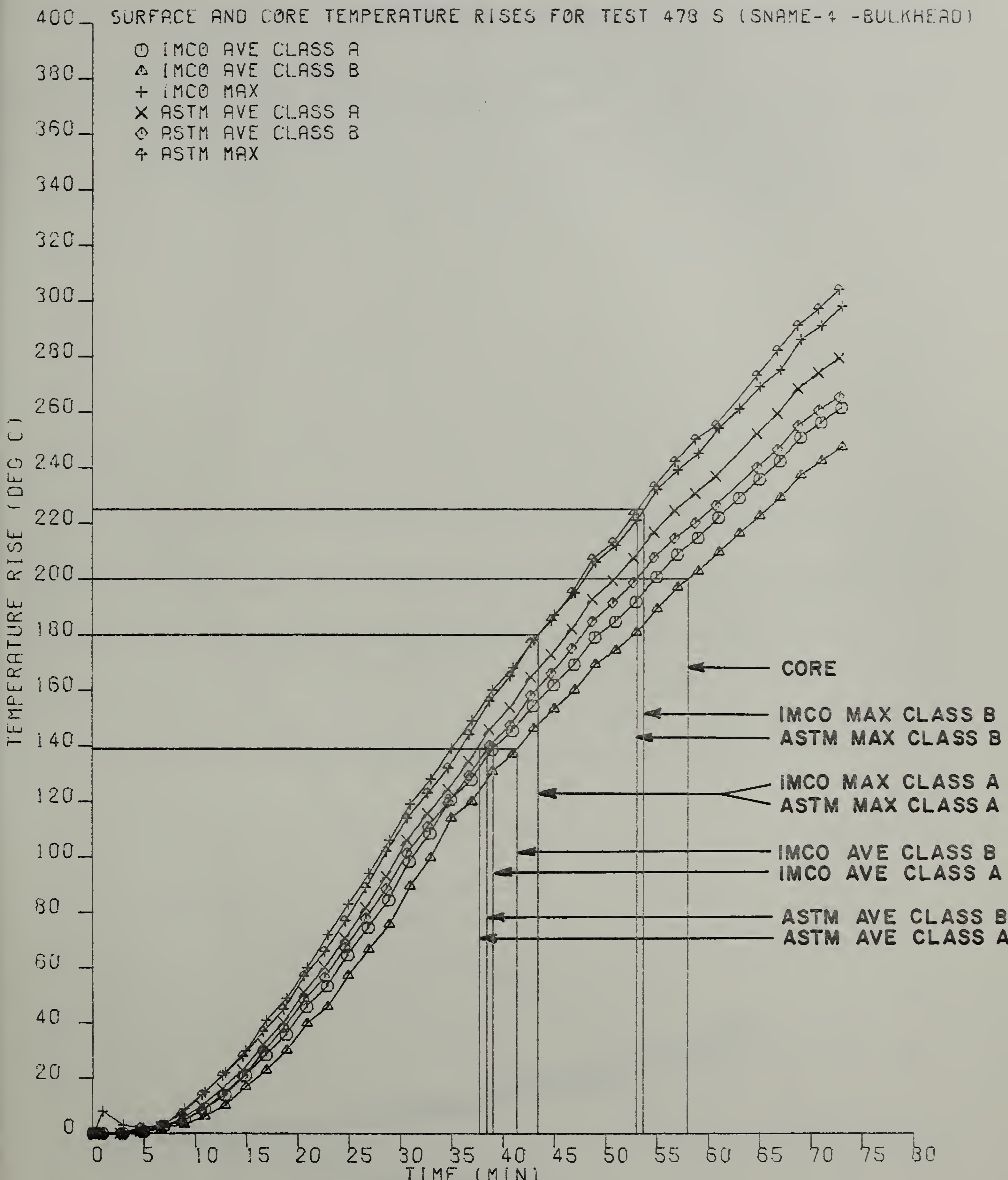


FIGURE 23



SURFACE AND CORE TEMPERATURE RISES FOR TEST 478 S (SNAME-4 -BULKHEAD)
IMCO AVE CLASS A
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
TEMPERATURE RISE (DEG C)
TIME (MIN)
CORE
IMCO MAX CLASS B
ASTM MAX CLASS B
IMCO MAX CLASS A
ASTM MAX CLASS A
IMCO AVE CLASS B
IMCO AVE CLASS A
ASTM AVE CLASS B
ASTM AVE CLASS A

FIGURE 24

SURFACE AND CORE TEMPERATURE RISES FOR TEST 47B N (SNAME-25-BULKHEAD)

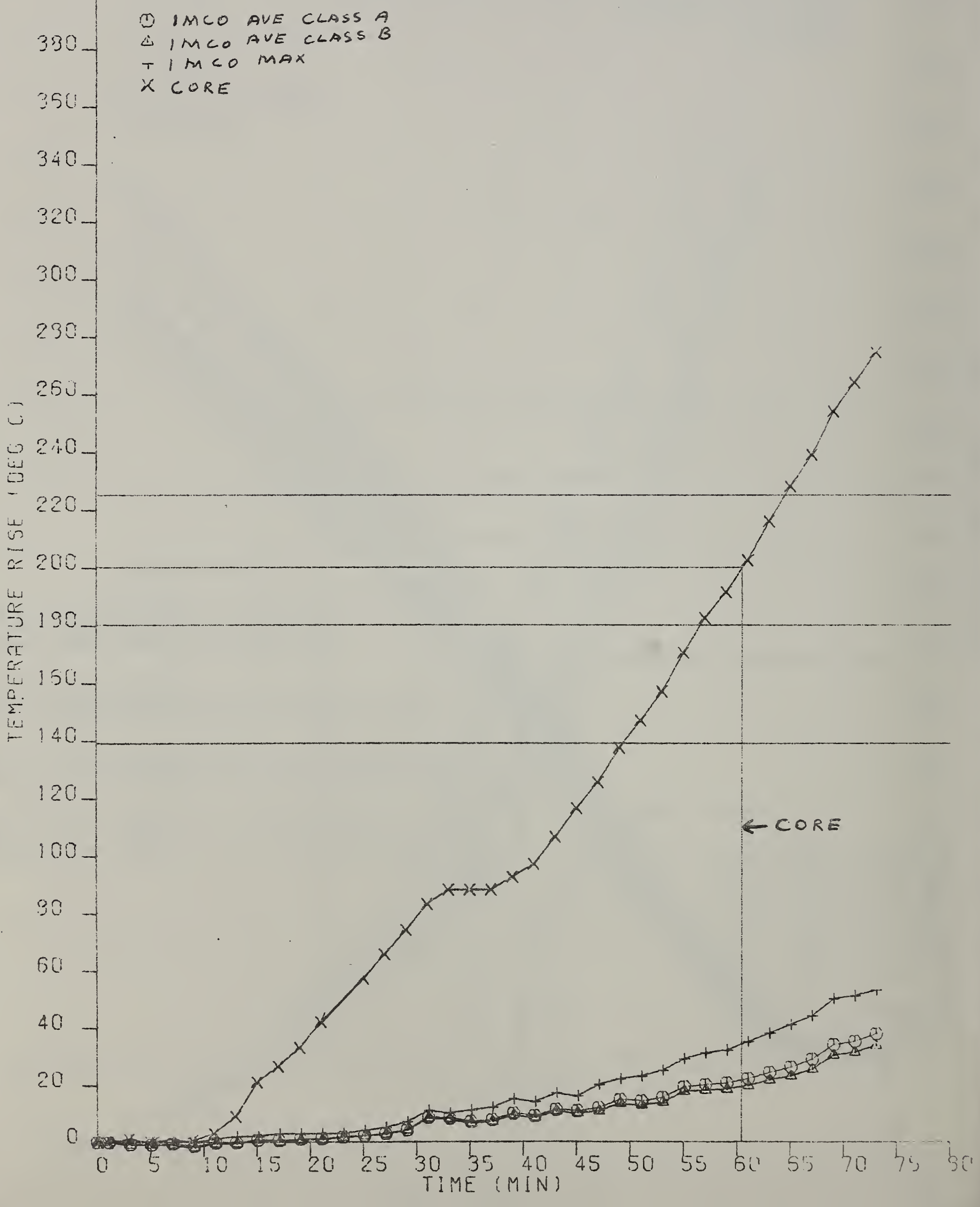


FIGURE 25

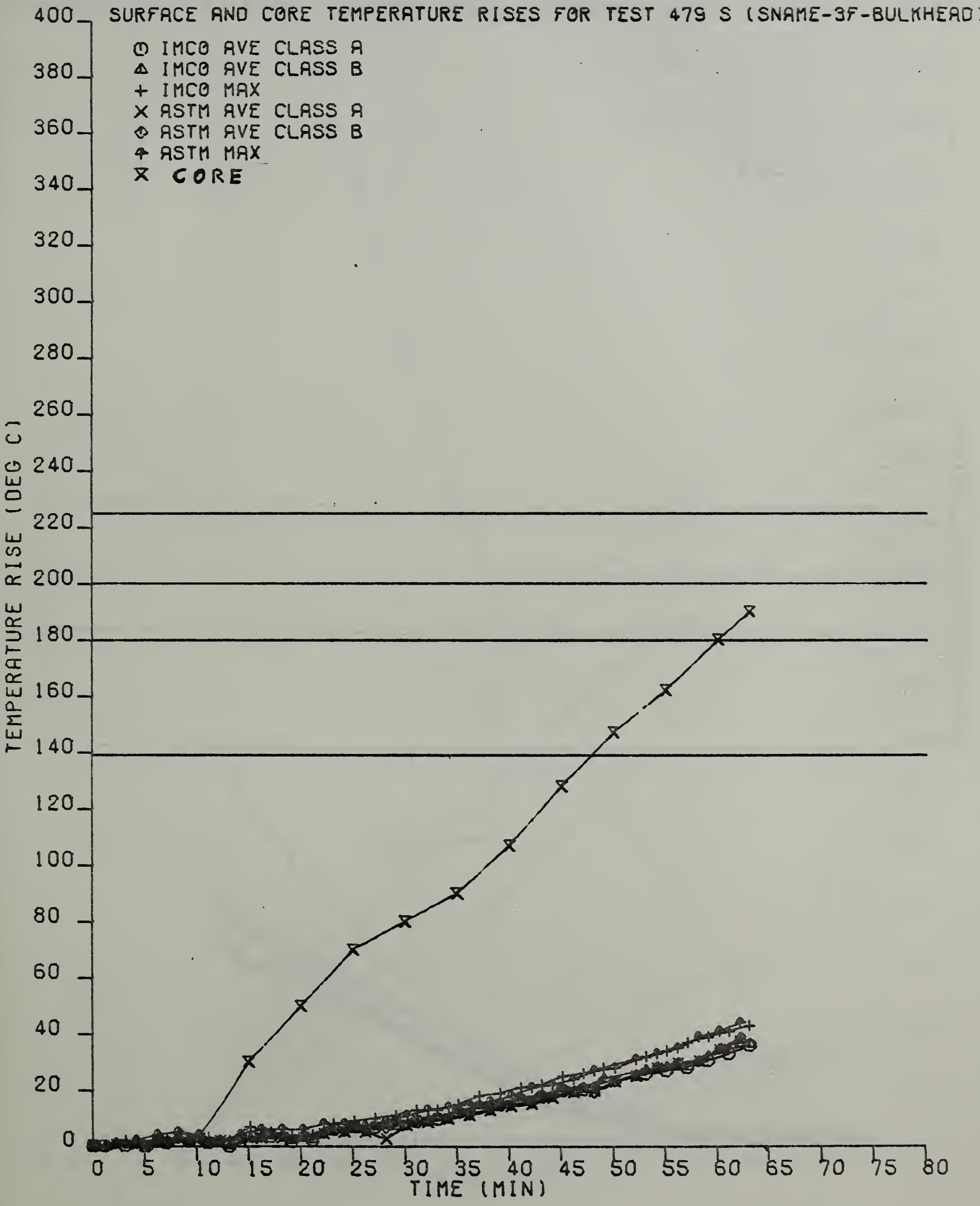
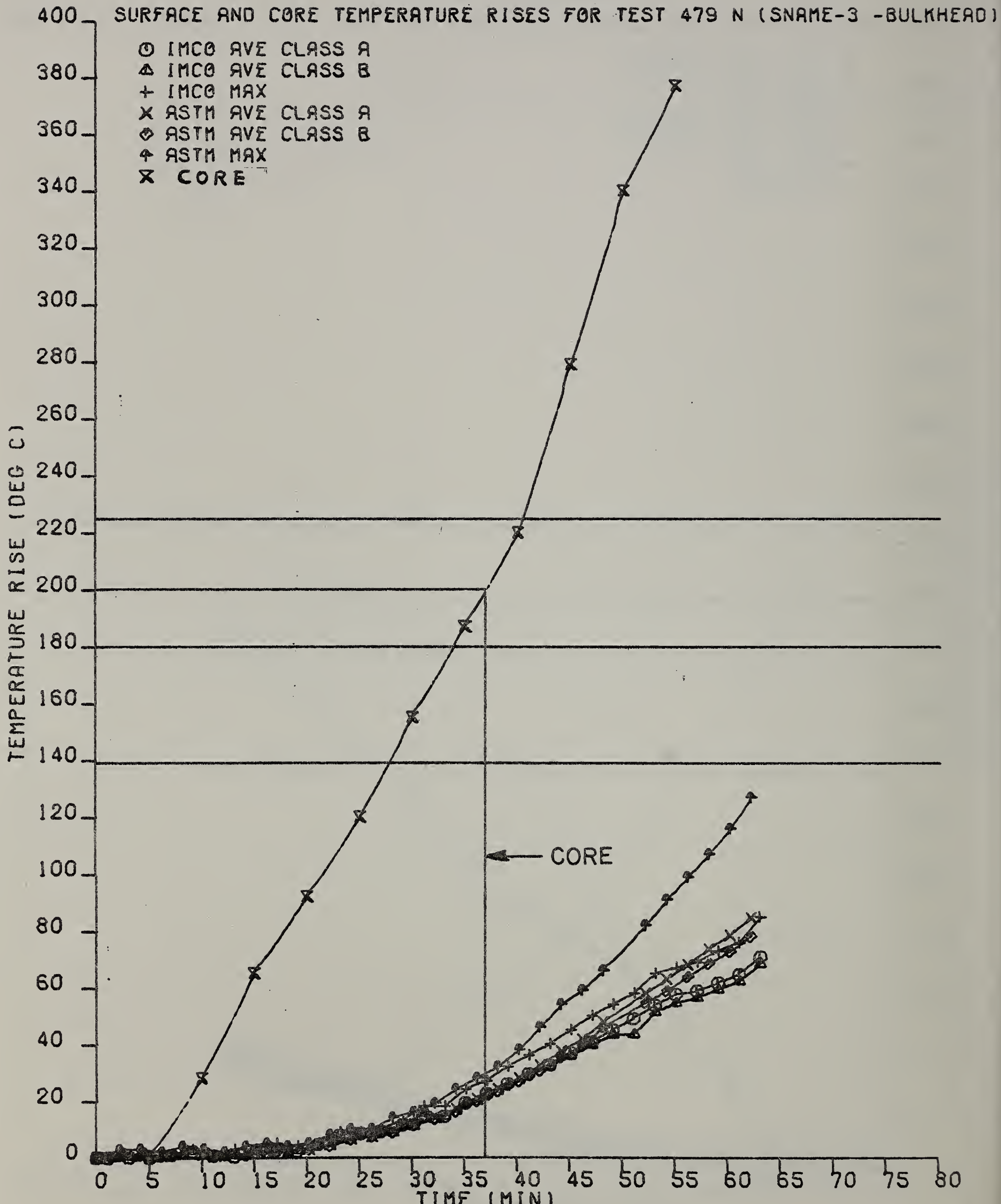

SURFACE AND CORE TEMPERATURE RISES FOR TEST 479 S (SNAME-3F-BULKHEAD)
IMCO AVE CLASS A
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
CORE
TEMPERATURE RISE (DEG C)
TIME (MIN)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 26



SURFACE AND CORE TEMPERATURE RISES FOR TEST 479 N (SNAME-3 -BULKHEAD)
IMCO AVE CLASS A
IMCO AVE CLASS B
IMCO MAX
ASTM AVE CLASS A
ASTM AVE CLASS B
ASTM MAX
CORE
CORE
TEMPERATURE RISE (DEG C)
TIME (MIN)
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 27

AVERAGE SURFACE TEMPERATURE RISES FOR THE SNAME BULKHEADS AND DECKS

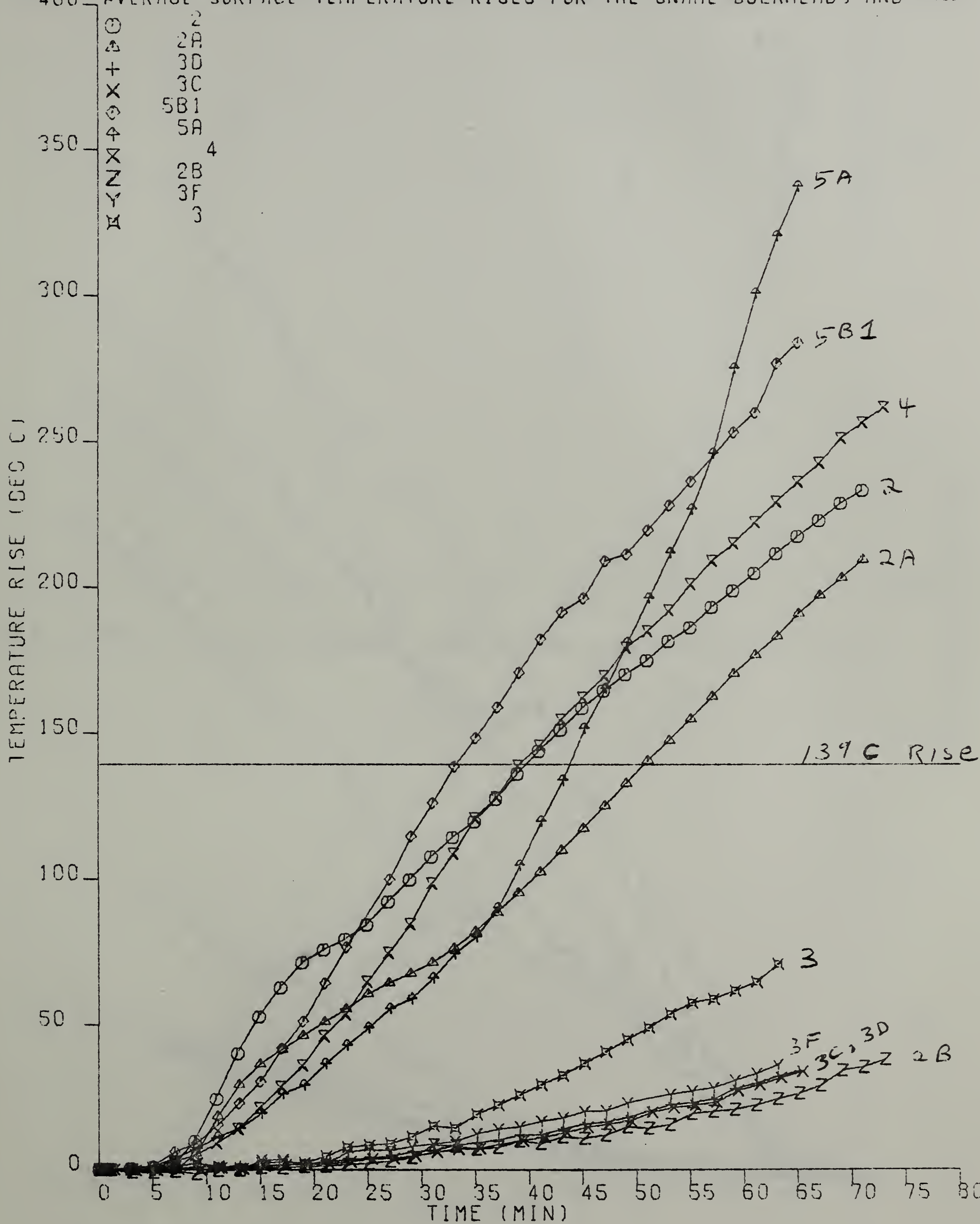
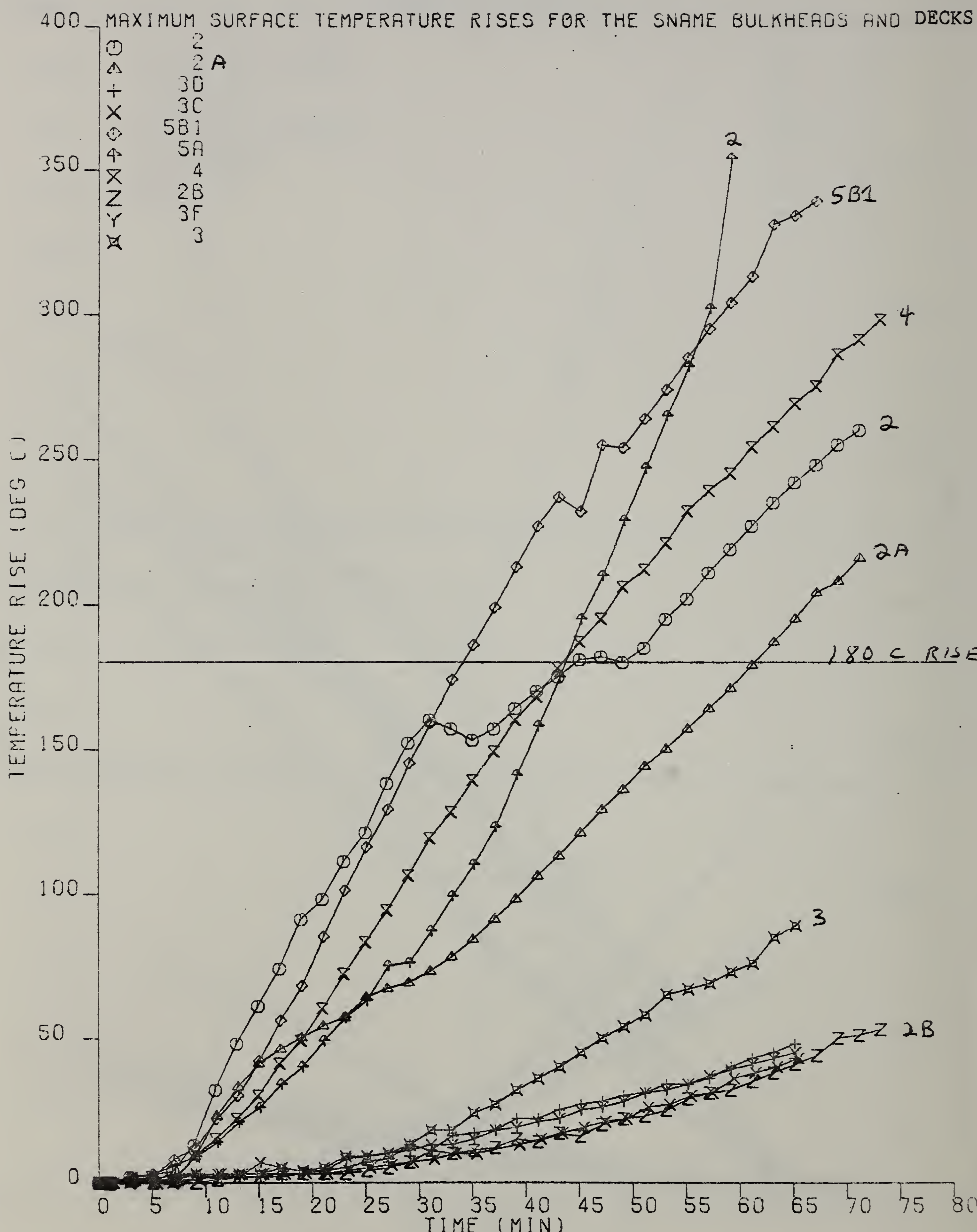


FIGURE 28



MAXIMUM SURFACE TEMPERATURE RISES FOR THE SNAME BULKHEADS AND DECKS
2
2A
3D
3C
5B1
5A
4
2B
3F
3
TEMPERATURE RISE (DEG C)
TIME (MIN)
180 C RISE
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 29

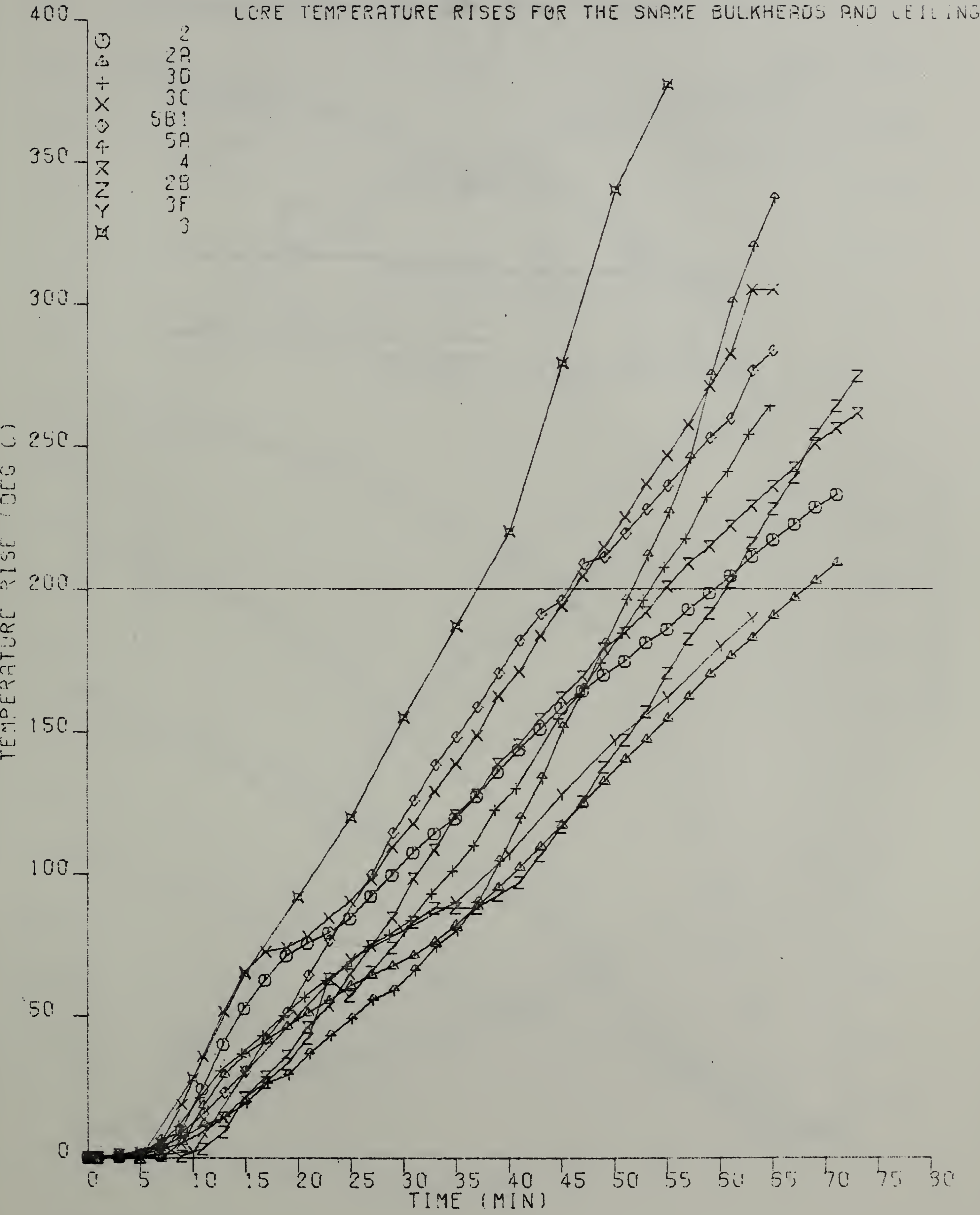
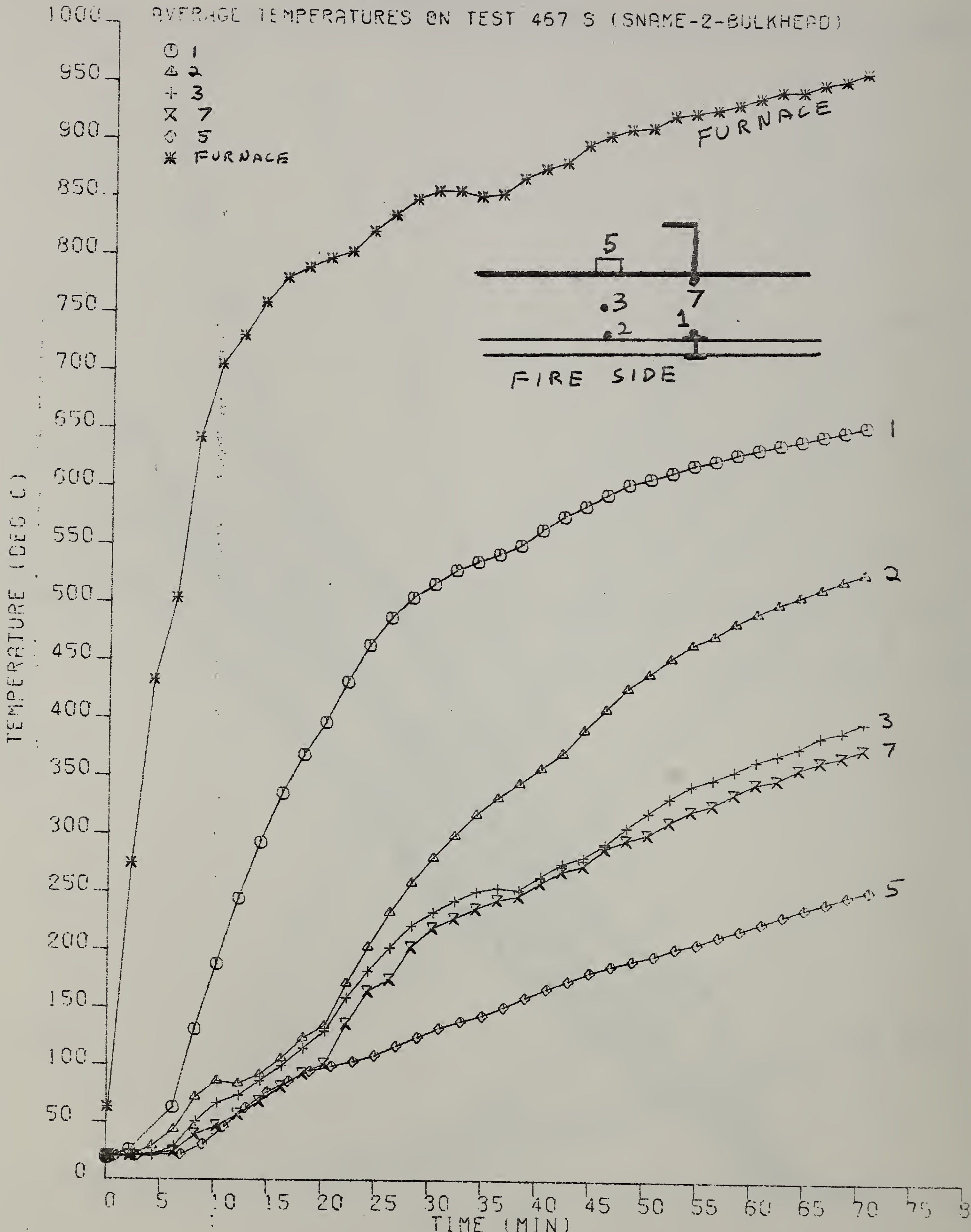

CORE TEMPERATURE RISES FOR THE SNAME BULKHEADS AND CEILING
2
2A
3D
3C
5B1
5A
4
2B
3F
3
TEMPERATURE RISE (DEG C)
TIME (MIN)
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 30



AVERAGE TEMPERATURES ON TEST 467 S (SNAME-2-BULKHEAD)
1
2
3
7
5
FURNACE
FURNACE
5
7
3
2
1
FIRE SIDE
1
2
3
7
5
TEMPERATURE (DEG C)
TIME (MIN)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 31

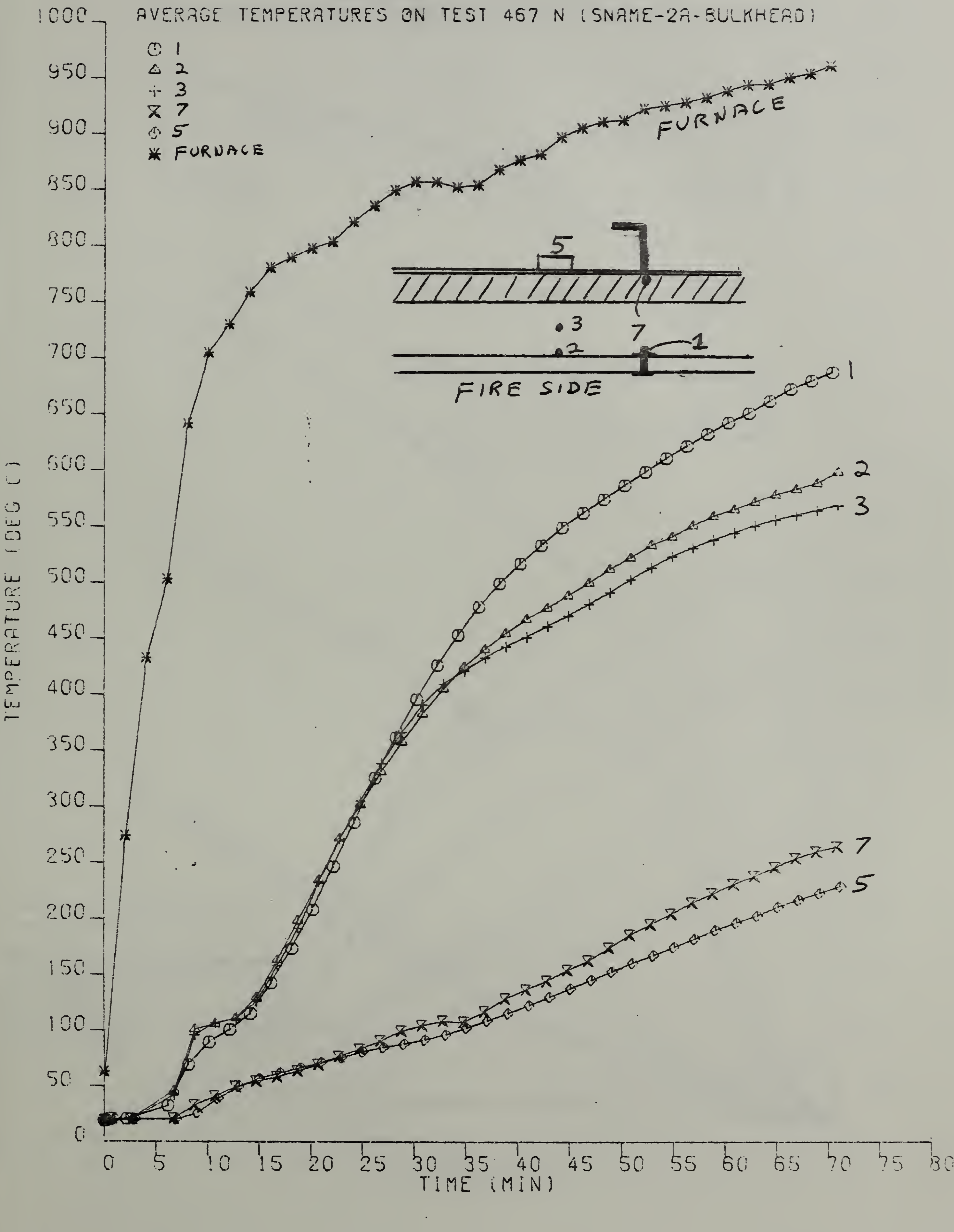

AVERAGE TEMPERATURES ON TEST 467 N (SNAME-2A-BULKHEAD)
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
TEMPERATURE (DEG C)
1
2
3
7
5
FURNACE
FURNACE
5
3
7
2
1
FIRE SIDE
1
2
3
7
5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
TIME (MIN)

FIGURE 32

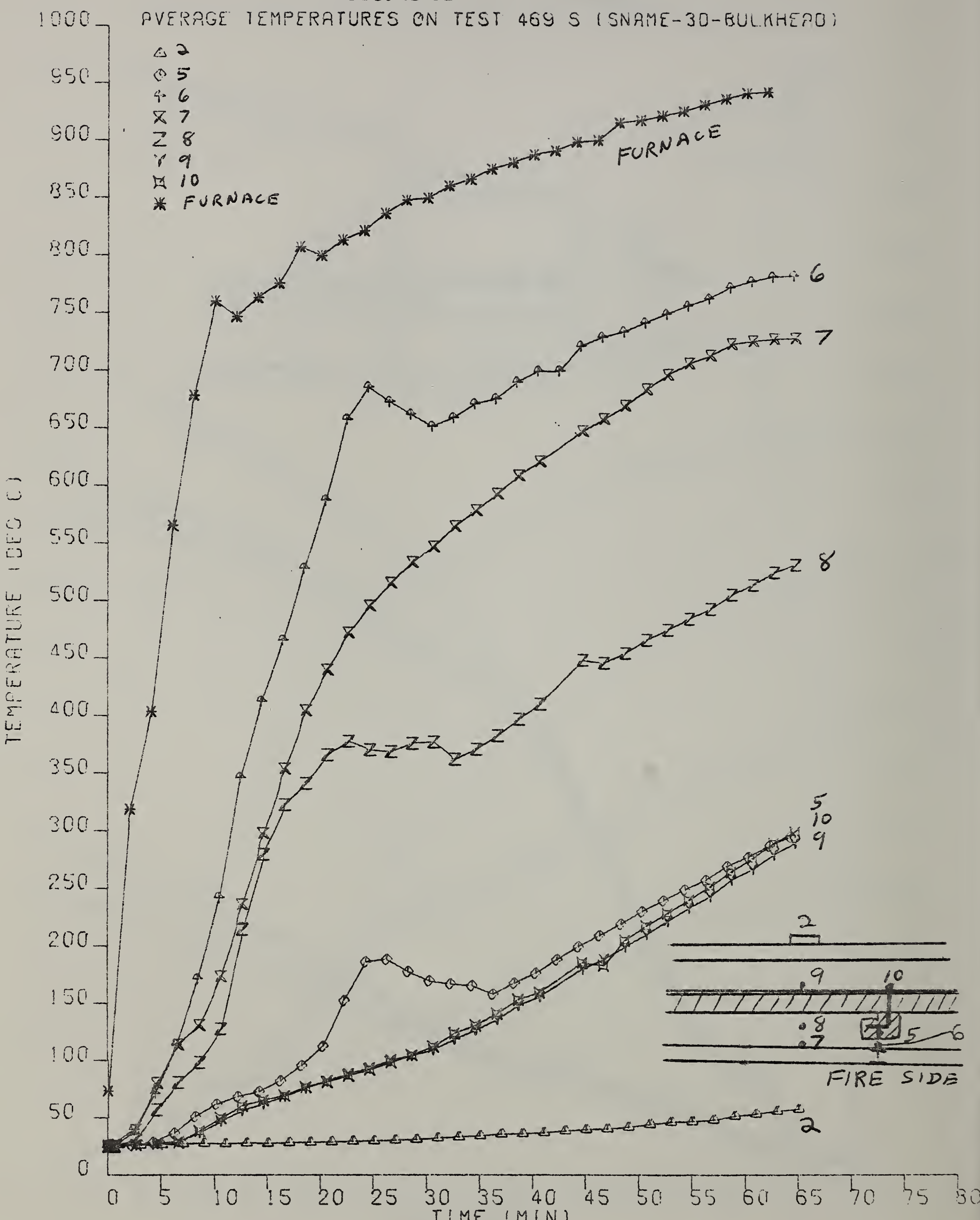

AVERAGE TEMPERATURES ON TEST 469 S (SNAME-30-BULKHEAD)
2
5
6
7
8
9
10
FURNACE
TEMPERATURE (DEG C)
TIME (MIN)
FIRE SIDE

FIGURE 33

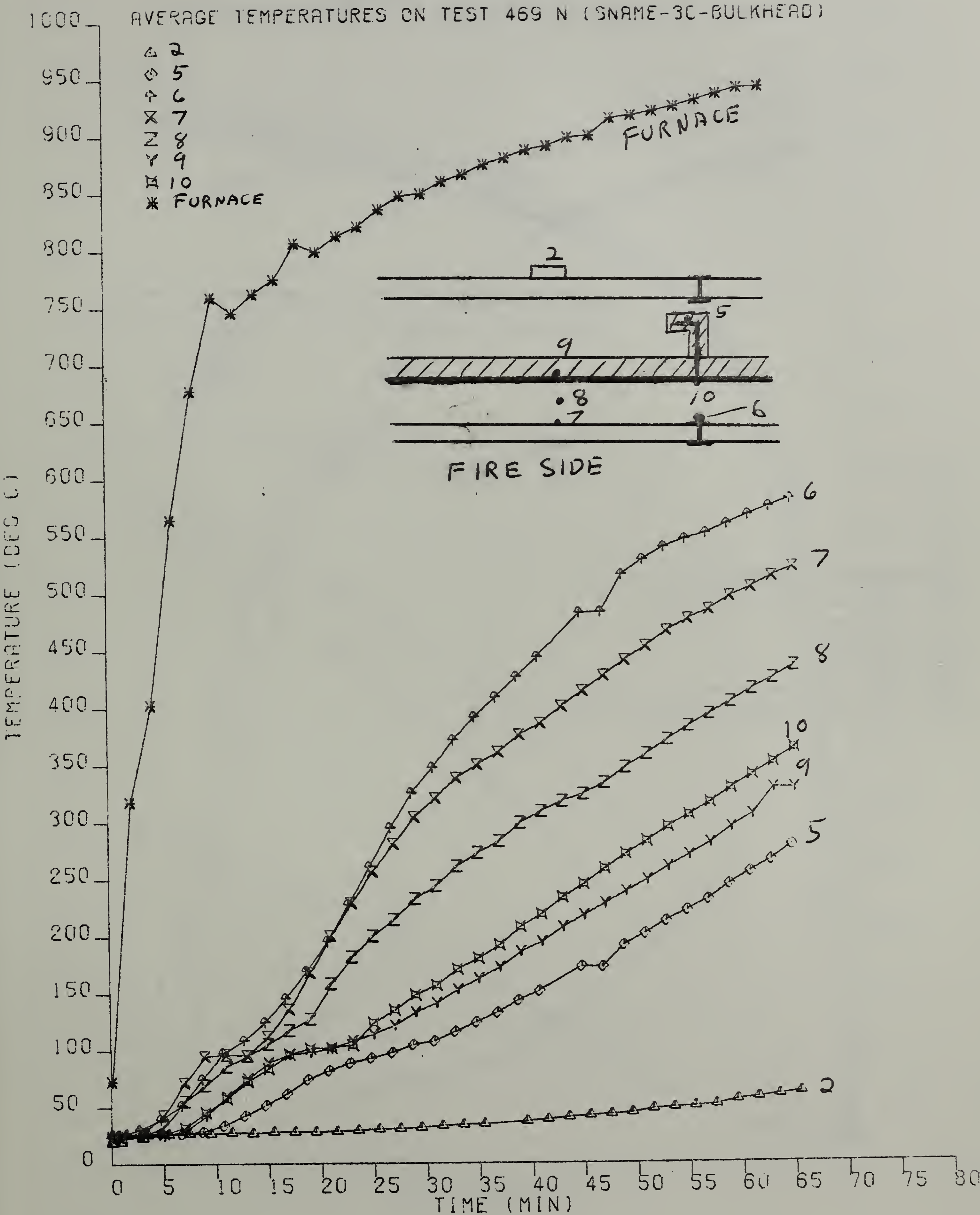

AVERAGE TEMPERATURES ON TEST 469 N (SNAME-3C-BULKHEAD)
TEMPERATURE (DEG C)
TIME (MIN)
2
5
6
7
8
9
10
FURNACE
FIRE SIDE
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 34

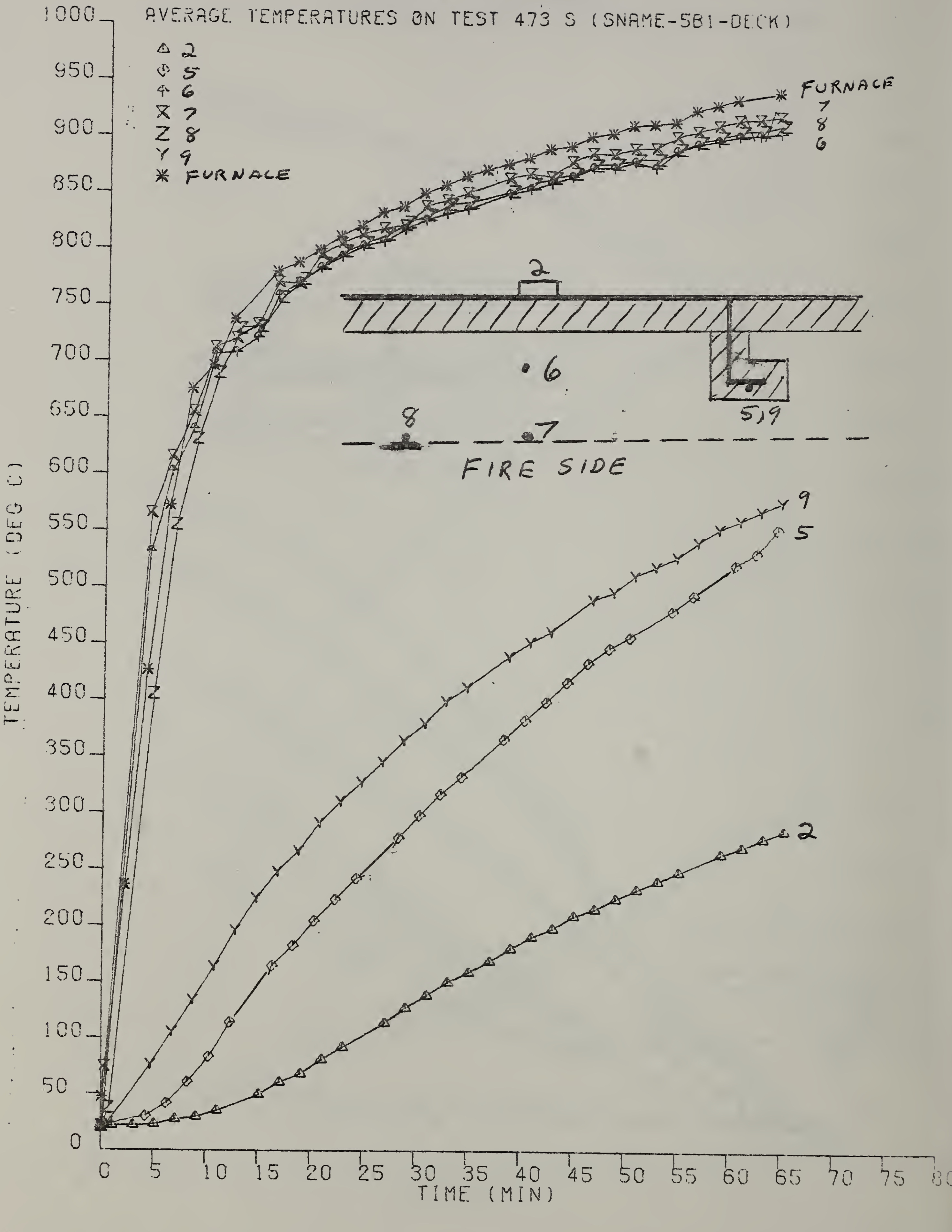

AVERAGE TEMPERATURES ON TEST 473 S (SNAME-5B1-DECK)
2
5
6
7
8
9
FURNACE
FIRE SIDE
5,9
TEMPERATURE (DEG C)
TIME (MIN)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

FIGURE 35

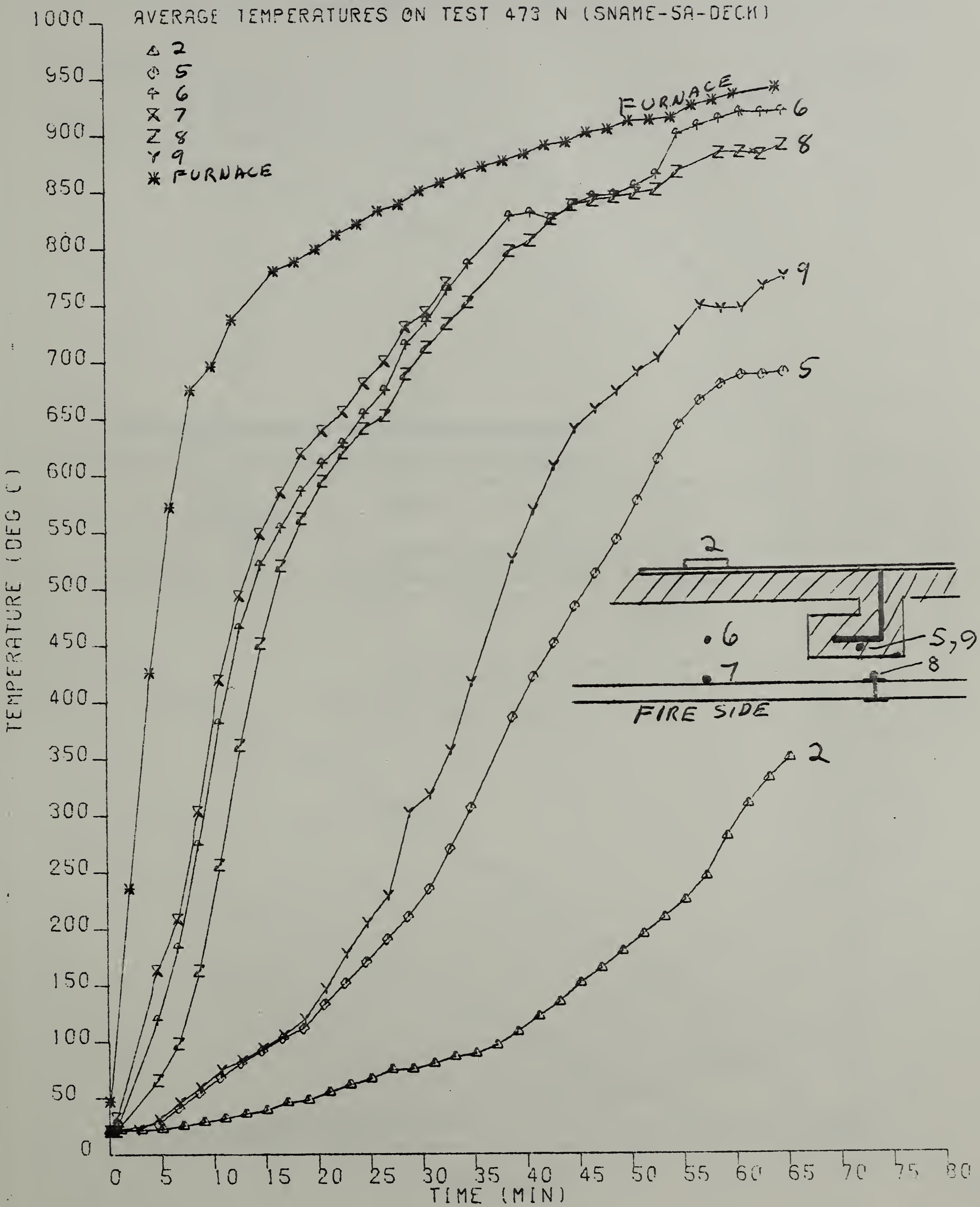

AVERAGE TEMPERATURES ON TEST 473 N (SNAME-SA-DECK)
TEMPERATURE (DEG C)
TIME (MIN)
△ 2
○ 5
+ 6
X 7
Z 8
Y 9
* FURNACE
FURNACE
6
8
9
5
2
2
.6
.7
5,9
8
FIRE SIDE

FIGURE 36

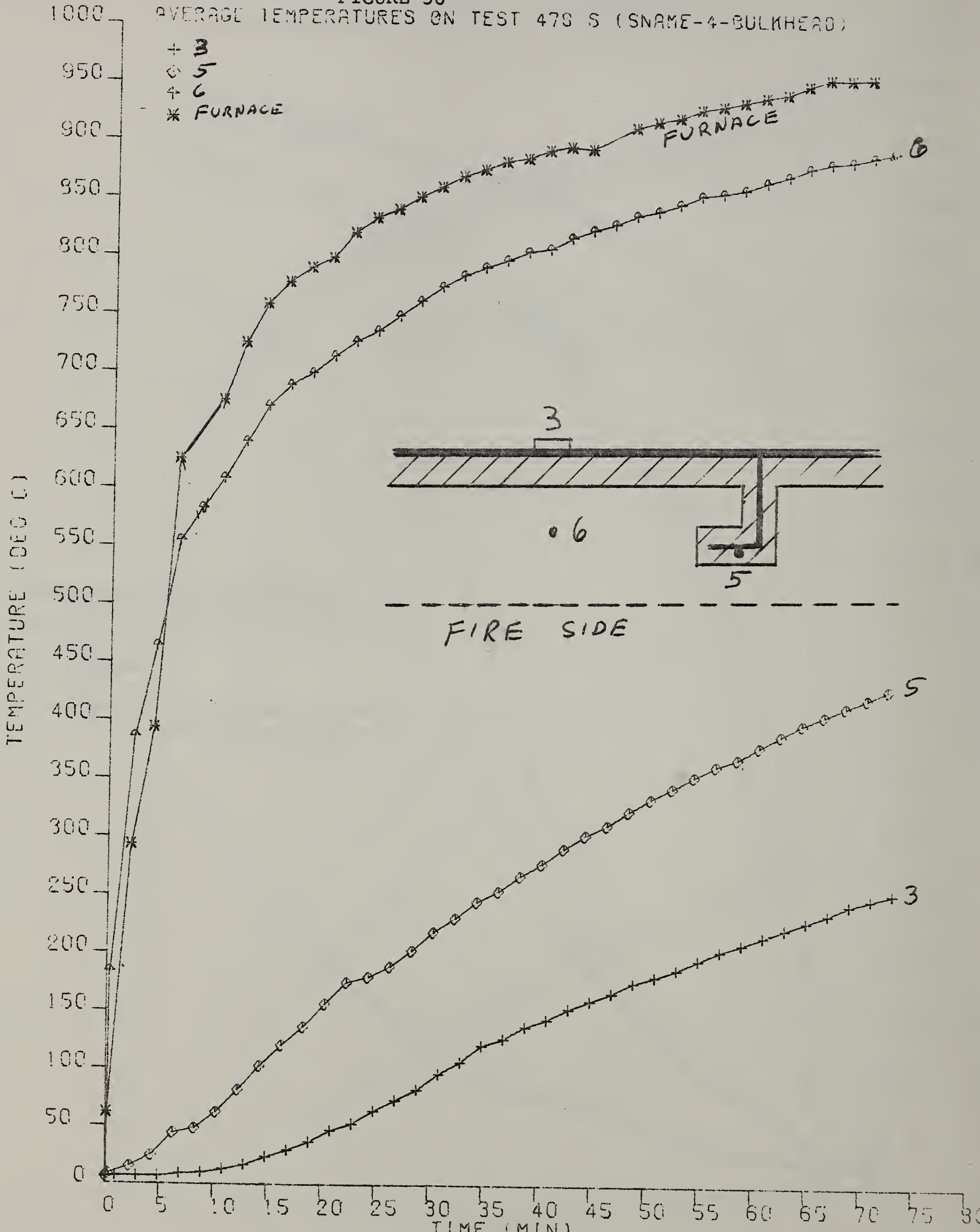

AVERAGE TEMPERATURES ON TEST 478 S (SNAME-4-BULKHEAD)
+ 3
◇ 5
+ 6
✱ FURNACE
FURNACE
6
5
3
FIRE SIDE
TEMPERATURE (DEG C)
TIME (MIN)
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

FIGURE 37

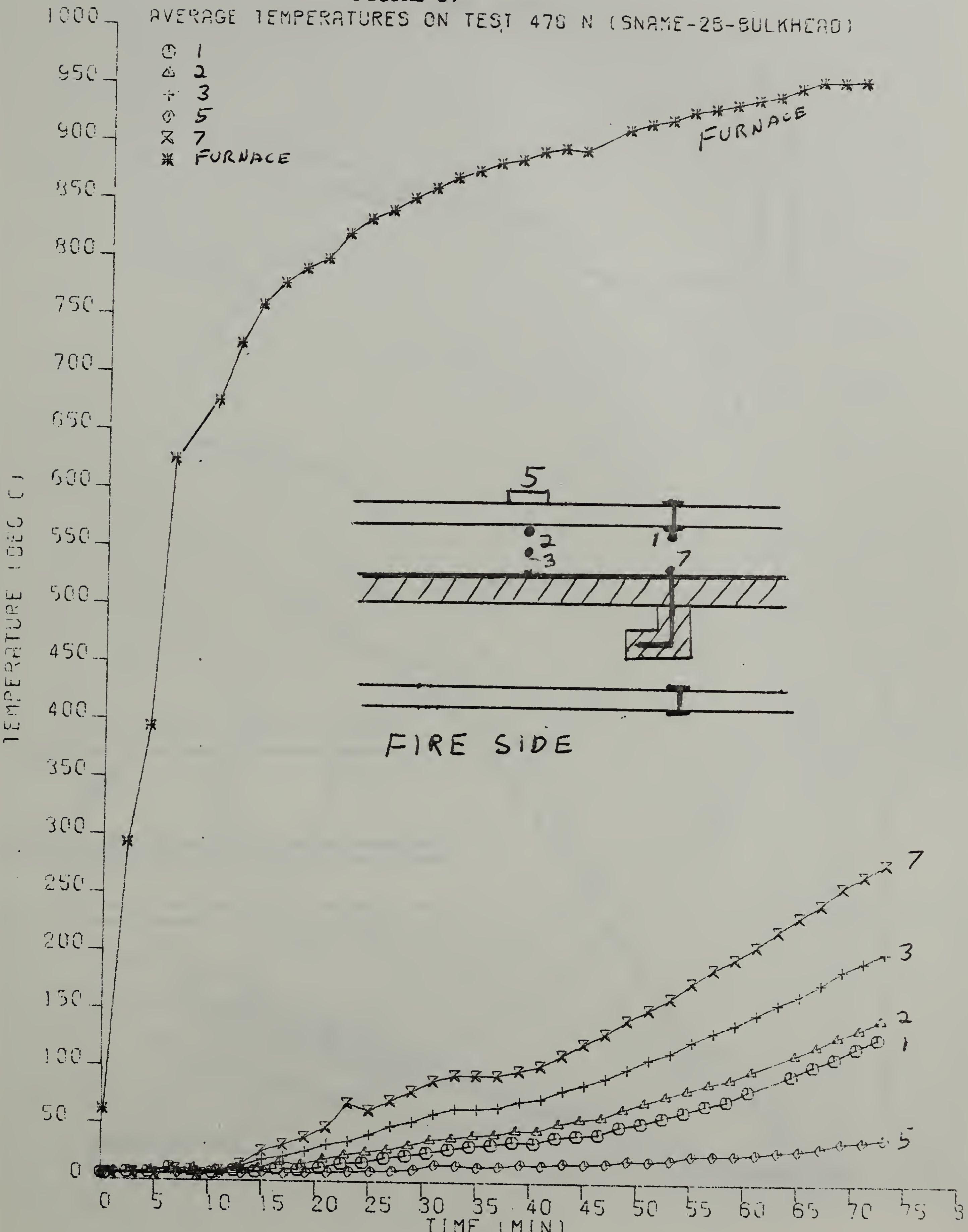
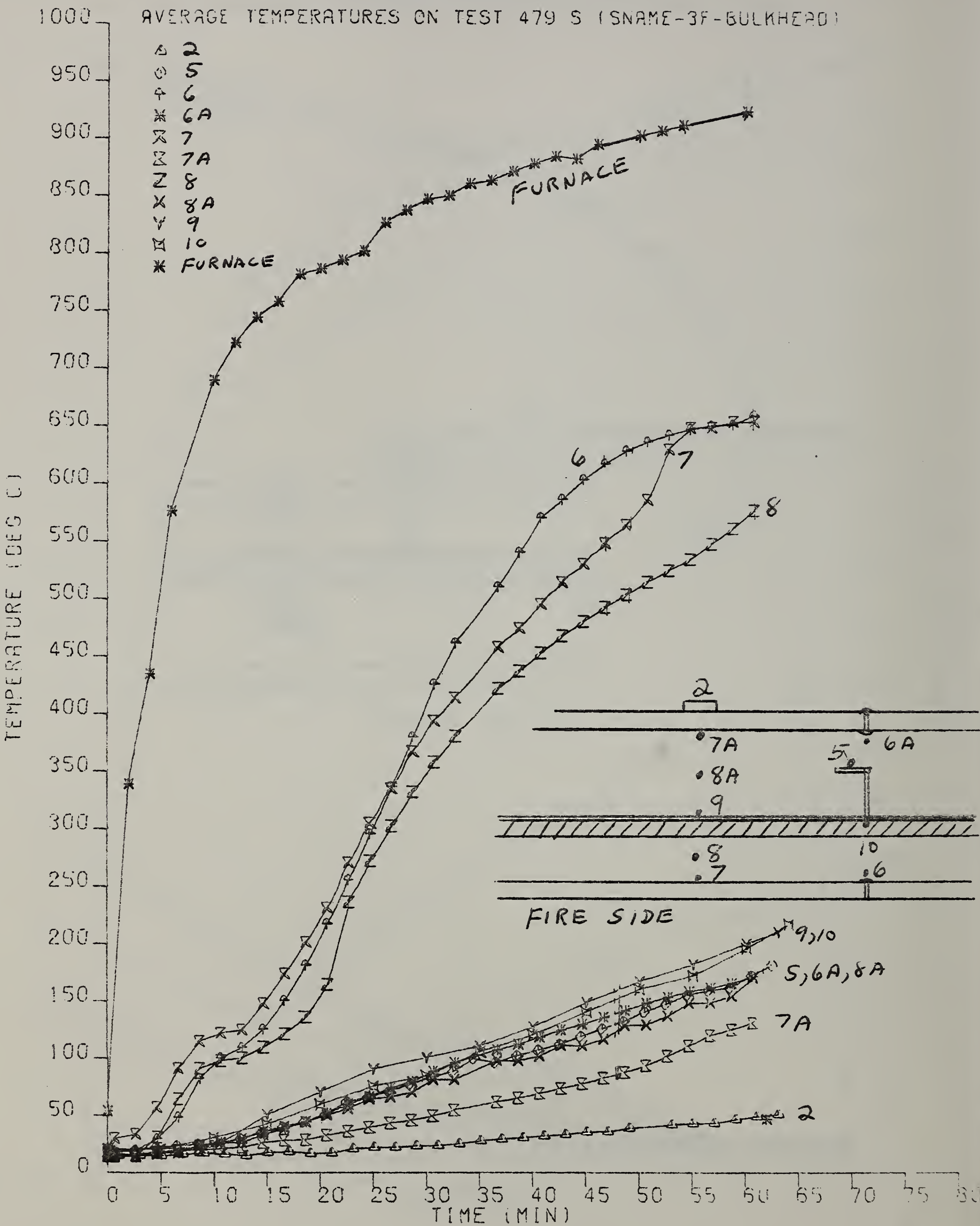

AVERAGE TEMPERATURES ON TEST 478 N (SNAME-26-BULKHEAD)
1
2
3
5
7
FURNACE
TEMPERATURE (DEG C)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
TIME (MIN)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
FIRE SIDE

FIGURE 38



AVERAGE TEMPERATURES ON TEST 479 S (SNAME-3F-BULKHEAD)
2
5
6
6A
7
7A
8
8A
9
10
FURNACE
FURNACE
6
7
8
9,10
5,6A,8A
7A
2
2
7A
6A
5
8A
9
10
8
7
6
FIRE SIDE
TEMPERATURE (DEG C)
TIME (MIN)

FIGURE 39

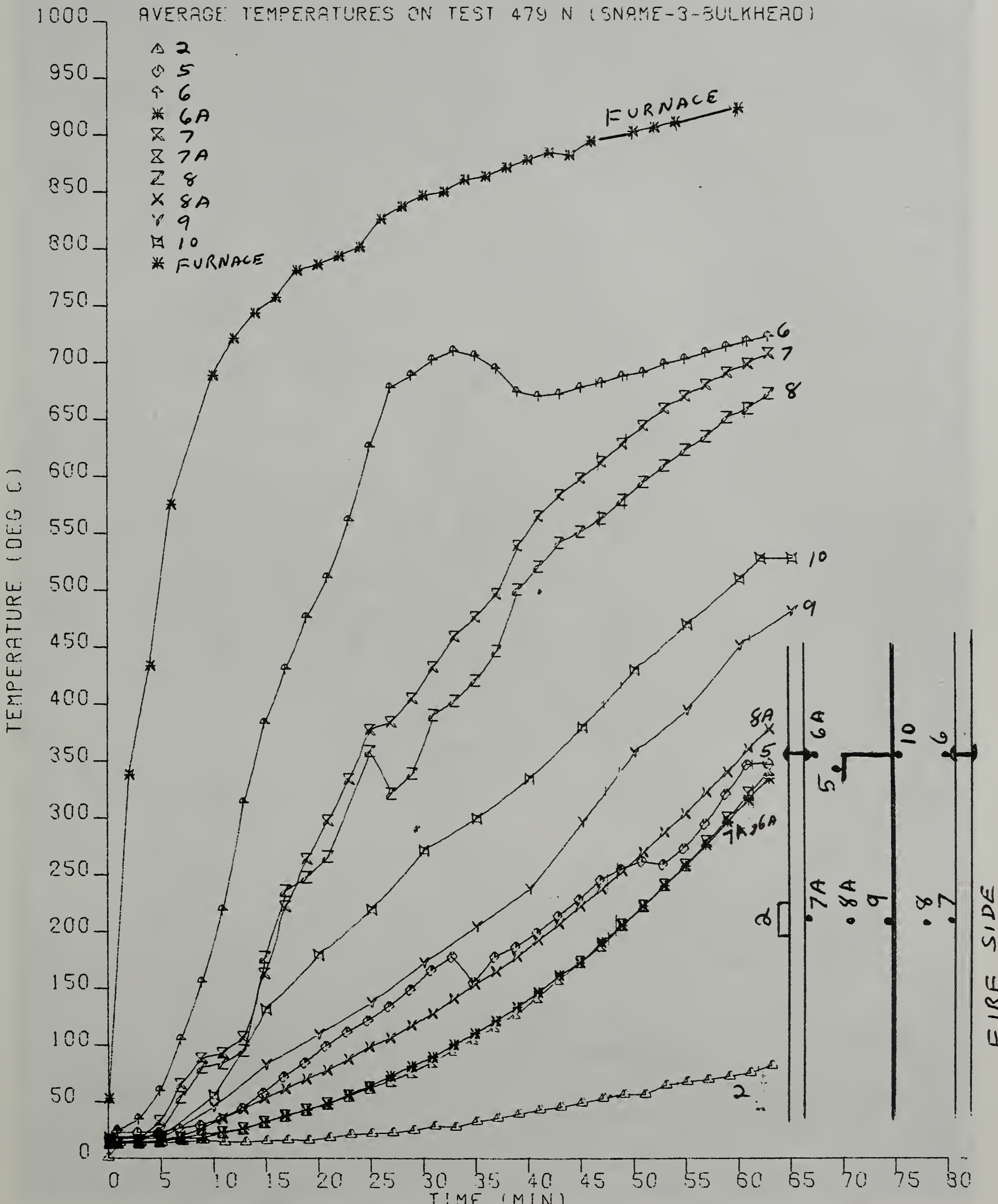

AVERAGE TEMPERATURES ON TEST 479 N (SNAME-3-BULKHEAD)
2
5
6
6A
7
7A
8
8A
9
10
FURNACE
TEMPERATURE (DEG C)
TIME (MIN)
FIRE SIDE
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

Figure 40 - Unexposed Surfaces of Assemblies 2 and 2A before the Test

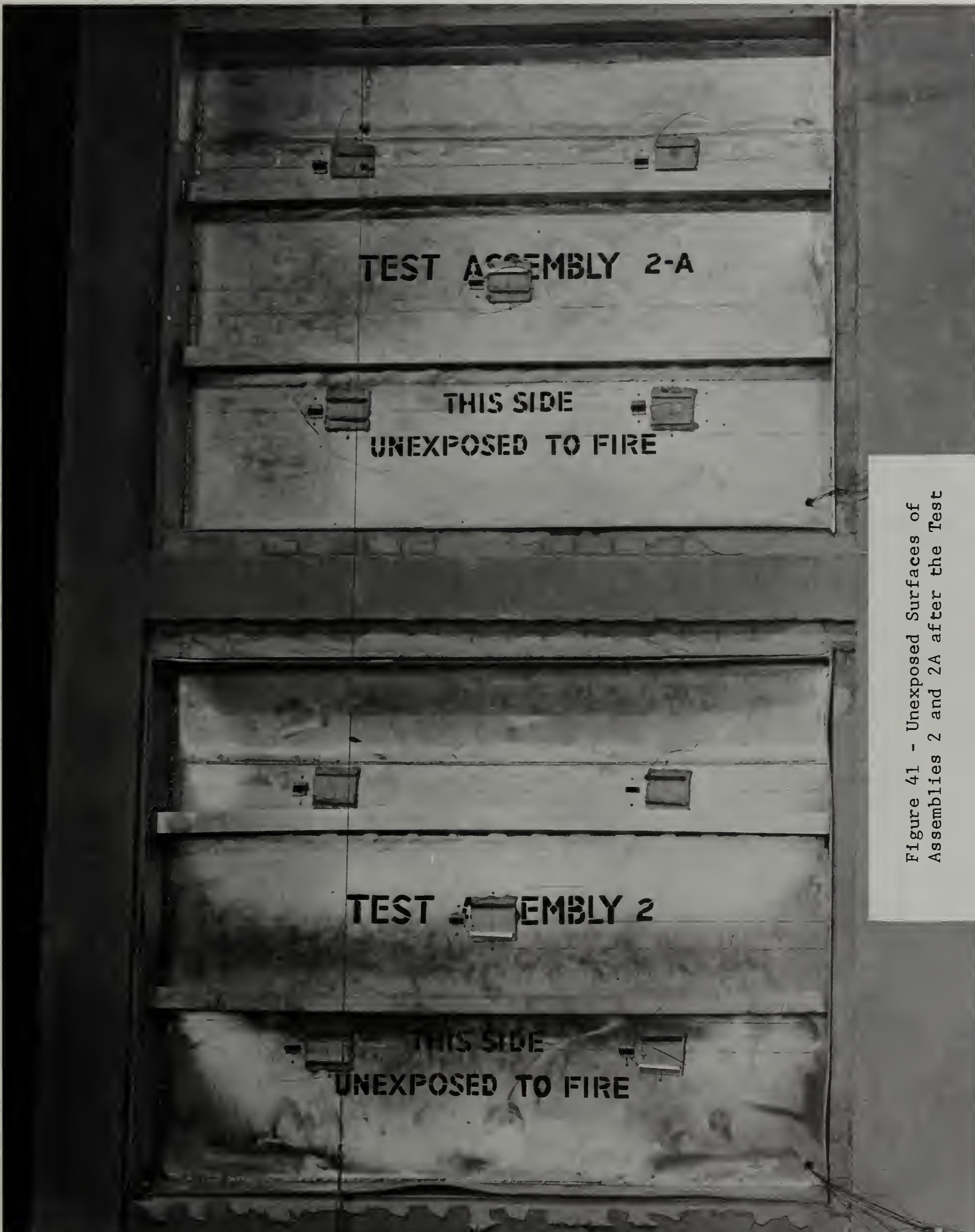


Figure 41 - Unexposed Surfaces of Assemblies 2 and 2A after the Test

Figure 42 - Exposed Surface of Assemblies 2 and 2A before the Test

Figure 43 - Exposed Surfaces of
Assemblies 2 and 2A after the Test

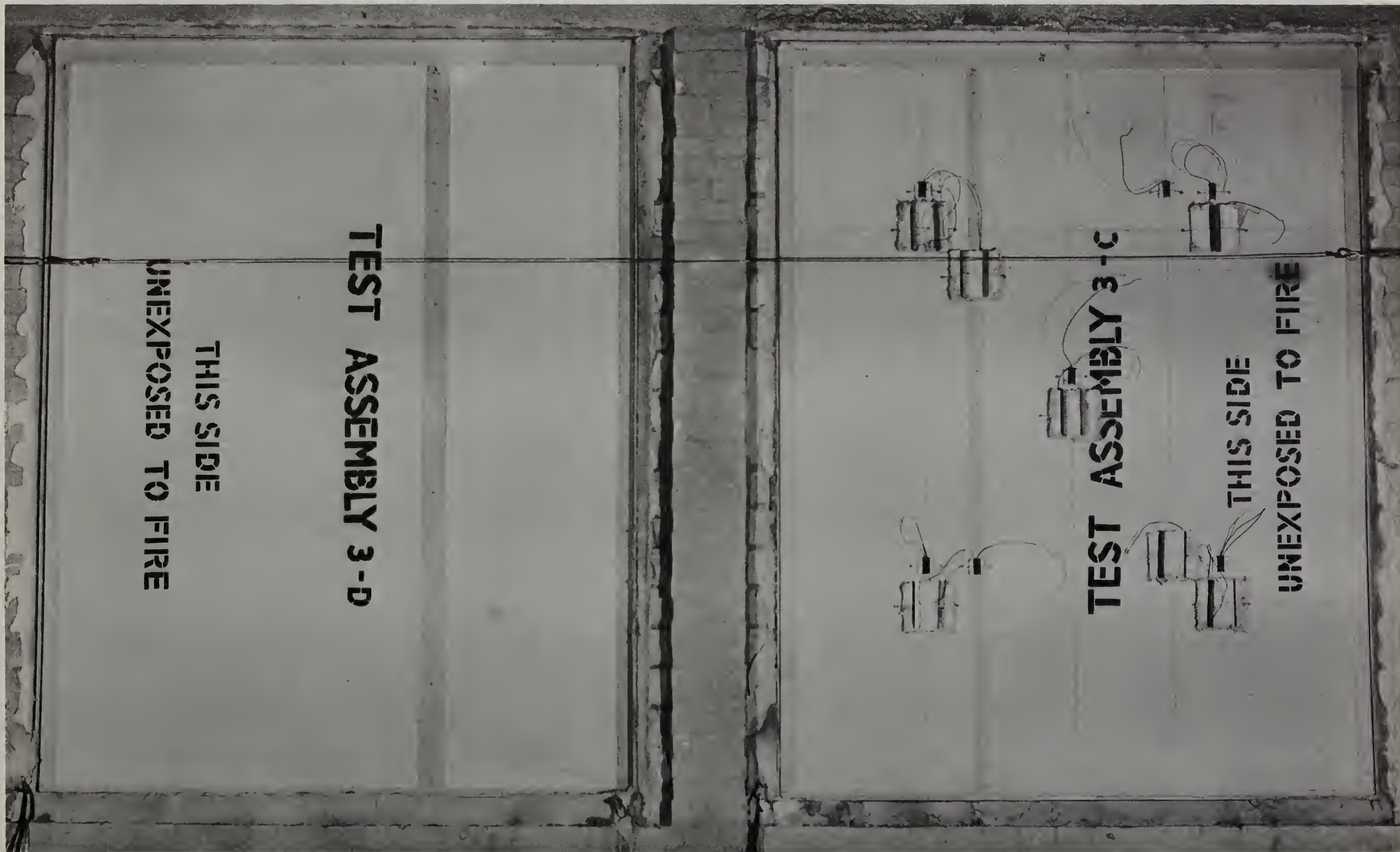


Figure 44 - Unexposed Surfaces of
Assemblies 3D and 3D before the Test

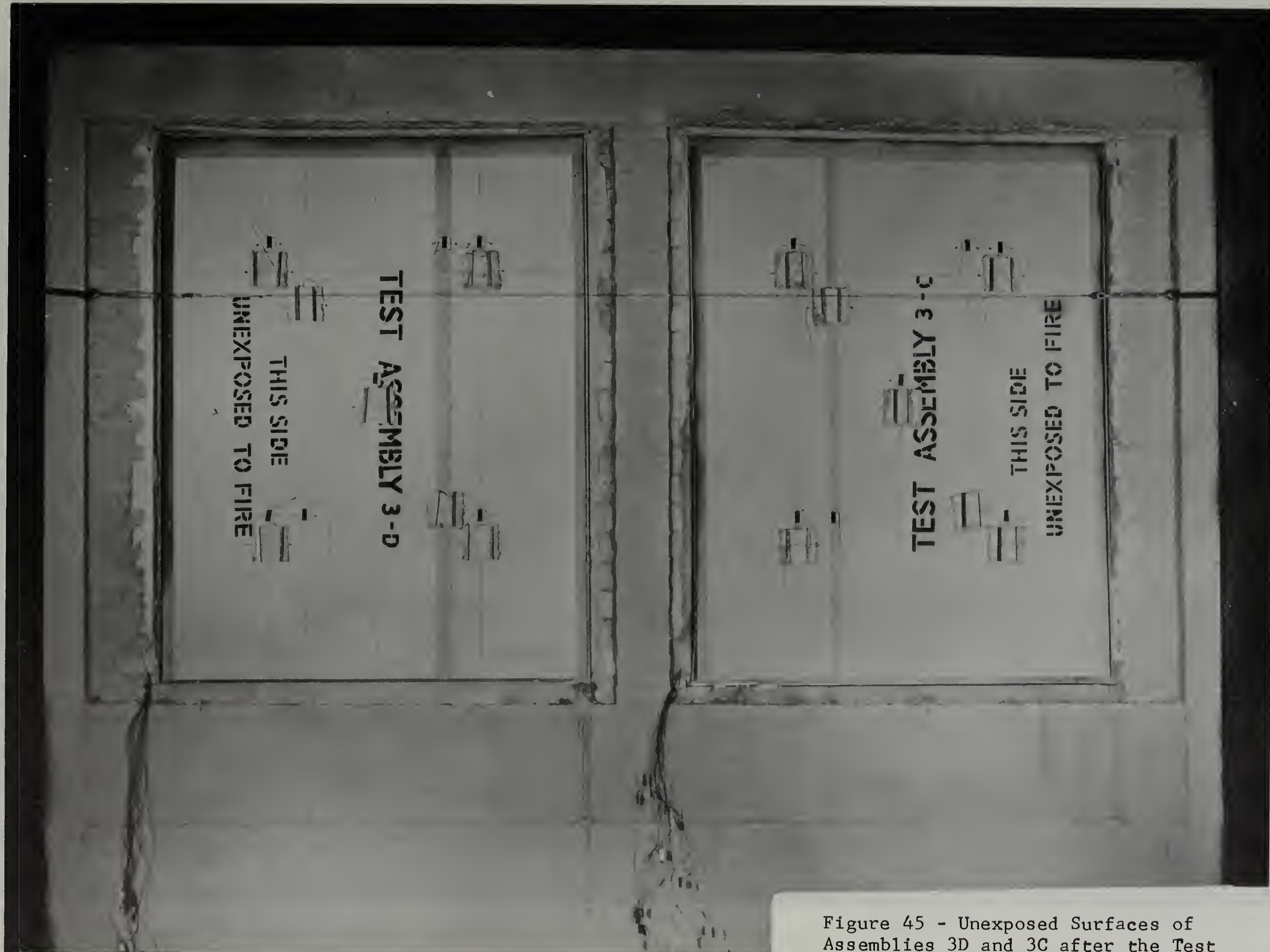


Figure 45 - Unexposed Surfaces of Assemblies 3D and 3C after the Test

Figure 46 - Exposed Surfaces of A
Assemblies 3D and 3C before the Test

Figure 47 - Exposed Surfaces of
Assemblies 3D and 3C after the Test

Figure 48 - Unexposed Surfaces of Assemblies 4 and 2B before the Test

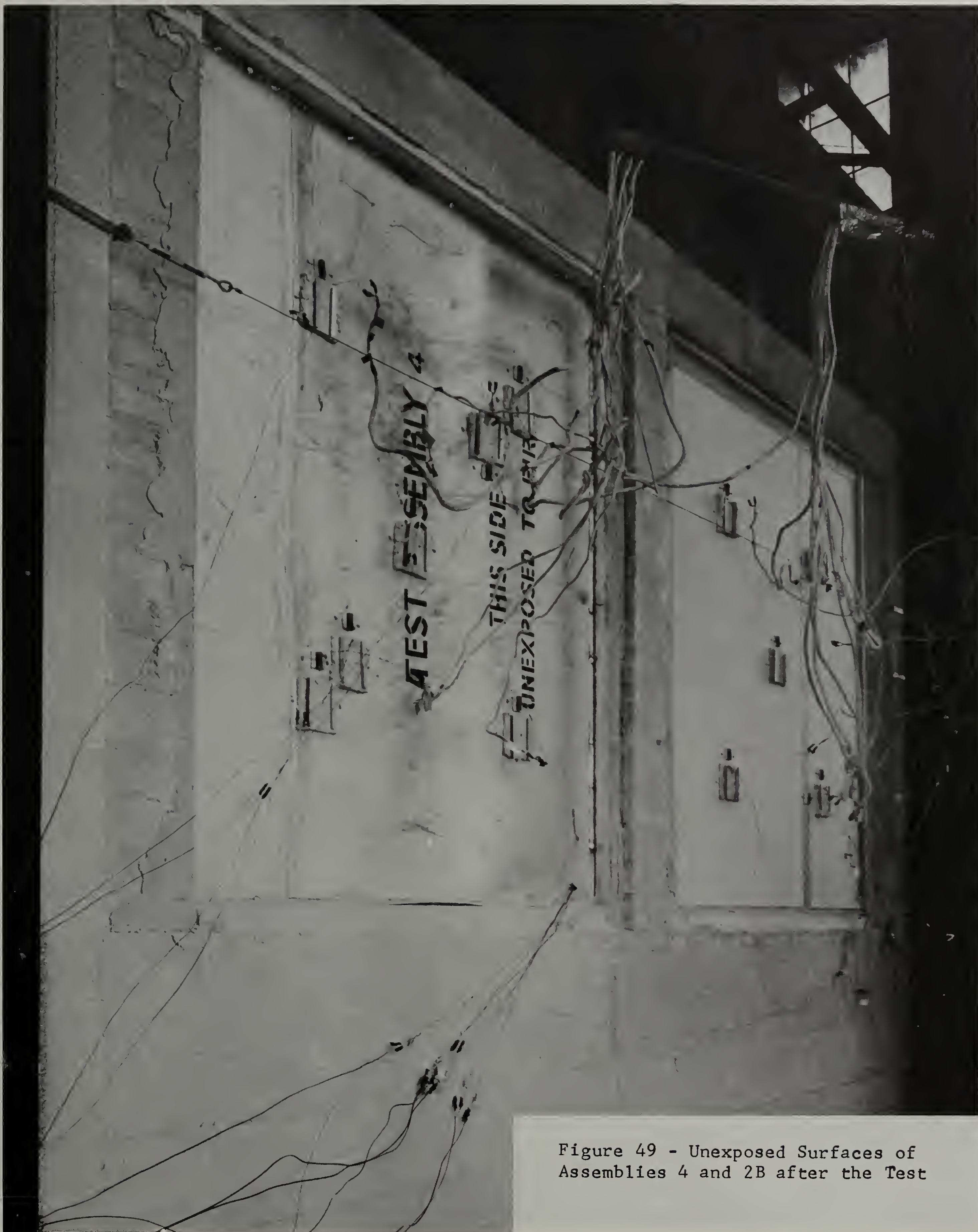


Figure 49 - Unexposed Surfaces of Assemblies 4 and 2B after the Test

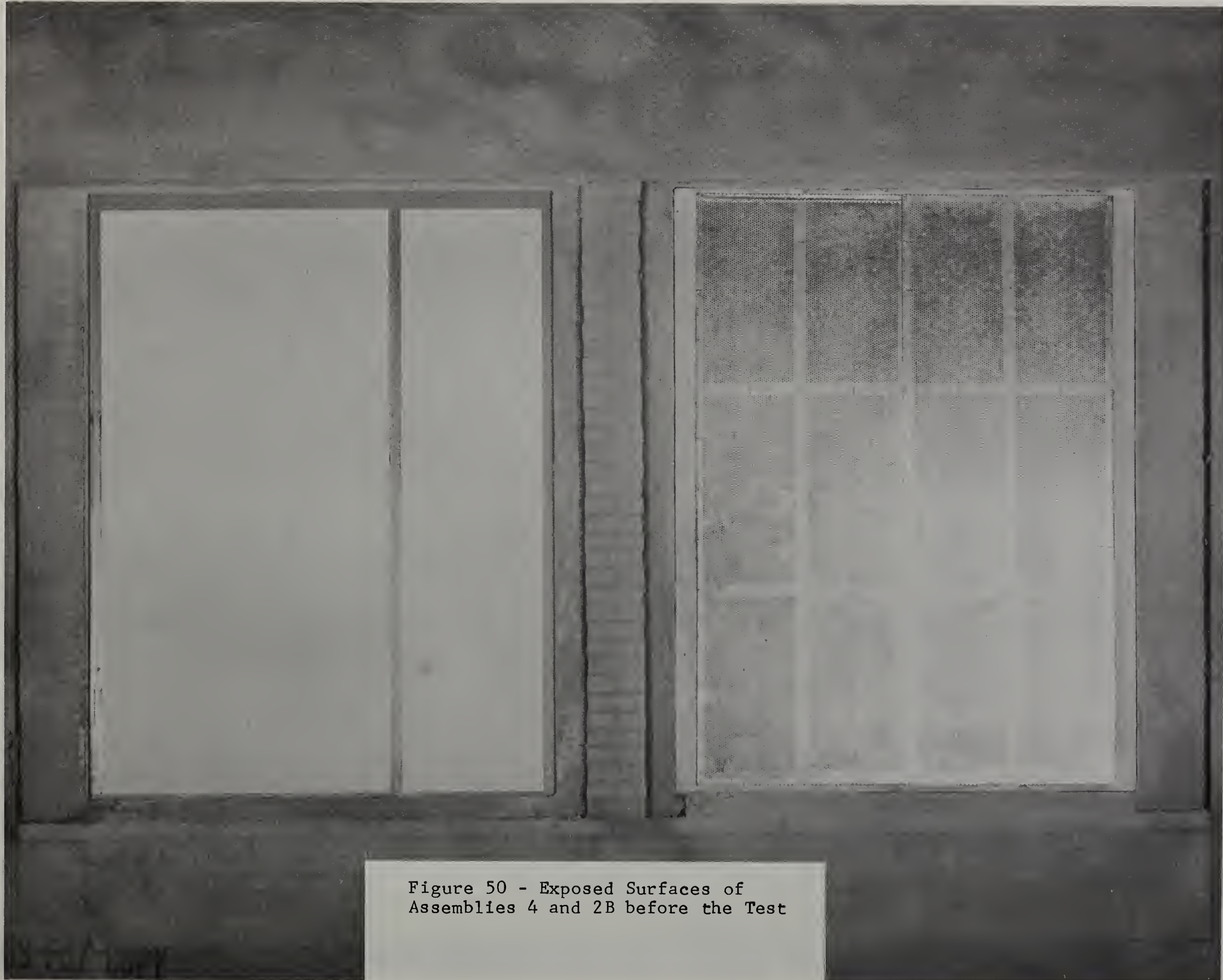


Figure 50 - Exposed Surfaces of
Assemblies 4 and 2B before the Test

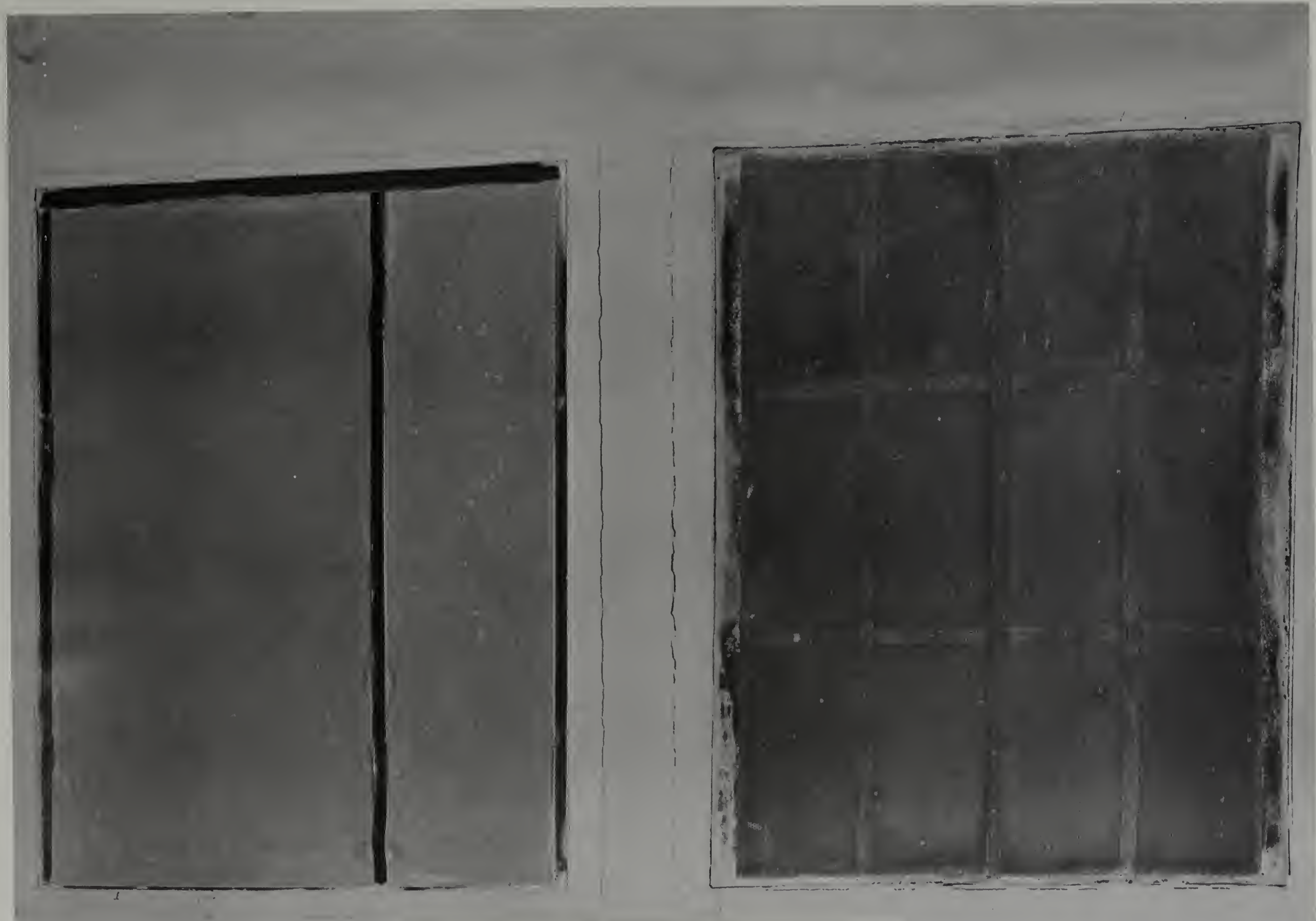


Figure 51 - Exposed Surfaces off Assemblies 4 and 2B af ter the Test

Figure 52 - Unexposed Surfaces of Assemblies 3F and 3 before the Test

Figure 53 - Exposed Surfaces of Assemblies 3F and 3 before the Test

Figure 54 - Exposed Surfaces of
Assemblies 3F and 3 after the Test

Figure 55 - Top Surface of Deck Assemblies before the Test

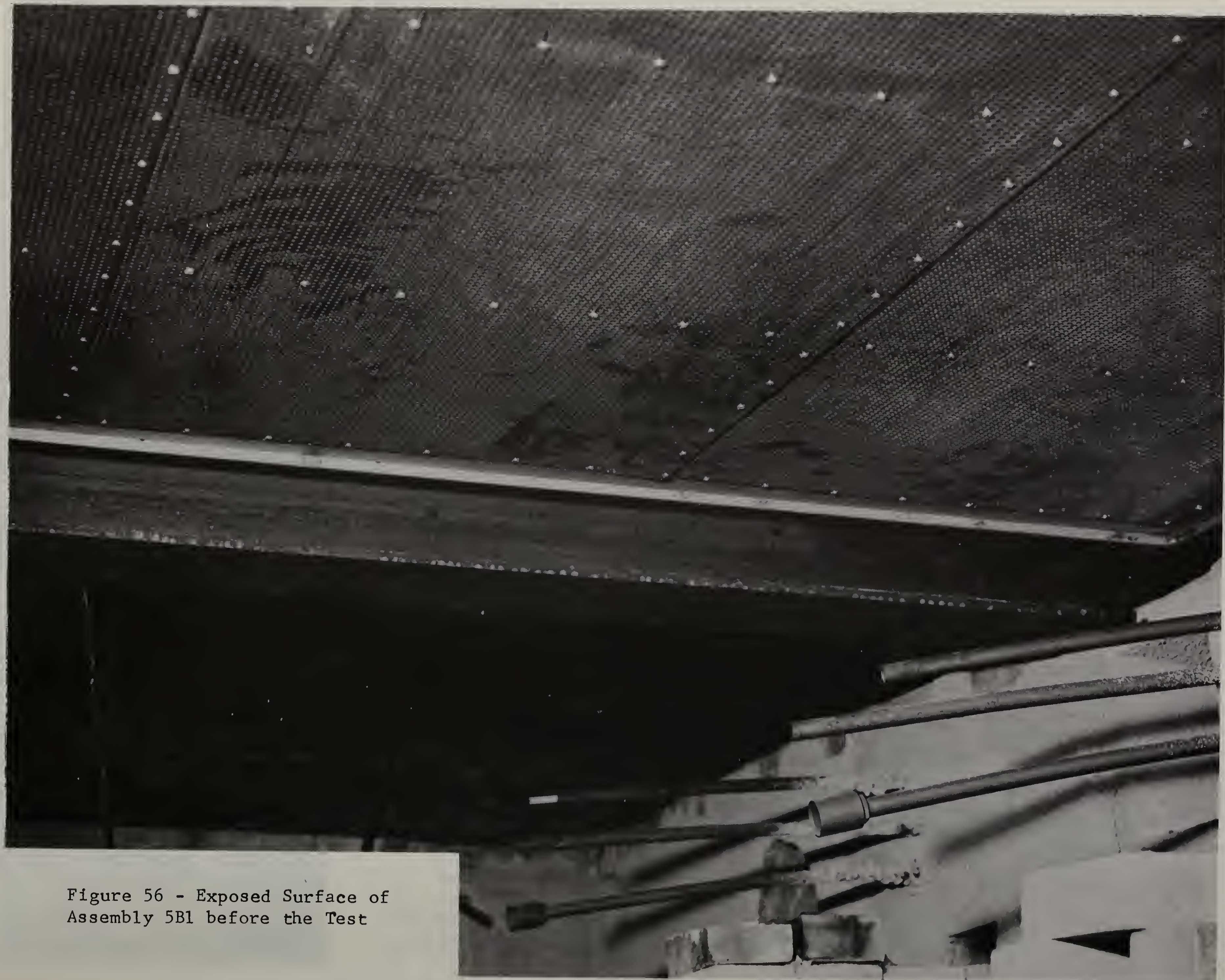


Figure 56 - Exposed Surface of Assembly 5B1 before the Test

Figure 57 - Exposed Surfaces of Assembly 5A before the Test

Figure 58 - Underside of Assembly 5A before the Test

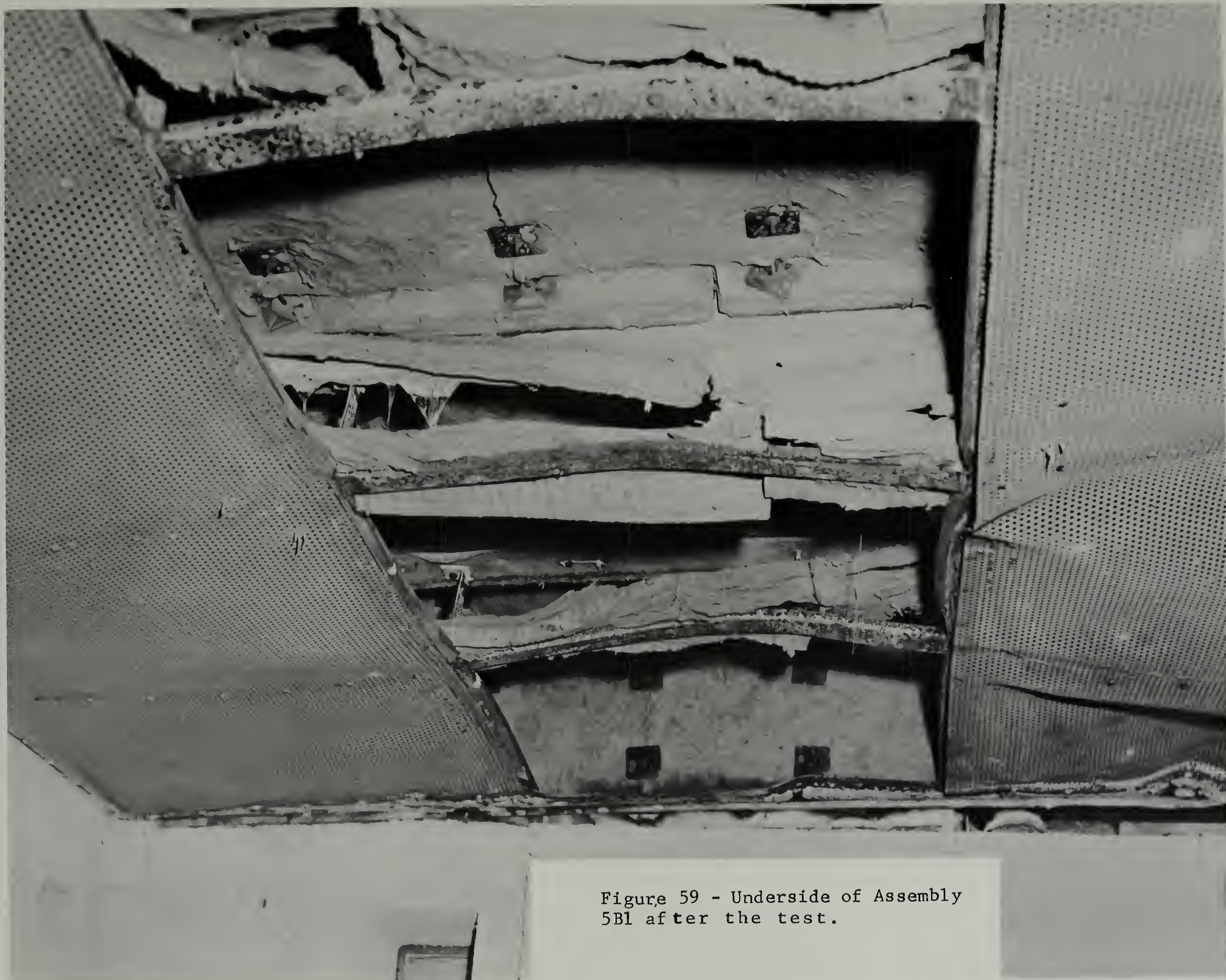


Figure 59 - Underside of Assembly 5B1 after the test.