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THERMAL DESIGN OF COMPOSITE MATERIAL HIGH TEMPERATURE ATTACHMENTS

NAS8-27041

NINTH PROGRESS REPORT
(THIRD QUARTERLY PROGRESS REPORT)
COVERING THE PERIOD
NOVEMBER 6, 1971 THROUGH FEBRUARY 6, 1972

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W. E. Neuenschwander
Project Manager

Details of illustrations in this document may be better studied on microfiche

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PREFACE

This is the third quarterly progress report on the program entitled, "Thermal Design of Composite Material High Temperature Attachments". This work is being conducted under the direction of the National Aeronautics and Space Administration. George C. Marshall Space Flight Center, under contract NAS8-27041. Mr. F. Huneidi is the principal Contracting Officer Representative.

The general purpose of the study is to evaluate the thermal aspects of utilizing advanced filamentary composite materials as primary structure on the shuttle vehicle. The technical objectives of this study are to: (1) establish and design concepts for maintaining composite materials' temperatures within allowable limits at TPS attachments and or penetrations applicable to the Space Shuttle; and (2) verify the thermal design analysis by testing selected concepts.

This technical effort is being conducted under the direction of W. E. Neuenschwander, Project Manager. Significant contributions to this report were made by: G. W. Mauss and M. Suppanz.

1.0 SUMMARY

During this quarter reporting period, the following was accomplished: detail test plan was developed; pre-test analysis was performed; design, fabrication and instrumentation of the test articles were completed; and testing was accomplished. Some testing difficulties were initially experienced that required re-instrumentation and re-test. The final tests were successful and good quality data were obtained; preliminary analysis of the data indicated that the test data verifies the thermal modeling techniques used in the design of composite material high temperature attachments.

Test data evaluation will be completed during the month of February and the results included in the first draft final report scheduled for completion on March 1, 1972.

2.0 TECHNICAL DISCUSSION

The general purpose of the study is to evaluate the thermal aspects of utilizing advanced filamentary composite materials as primary structure on the shuttle vehicle. The technical objectives of this study are to: (1) establish and design concepts for maintaining material temperatures within allowable limits at TPS attachments and or penetrations applicable to the Space Shuttle; and (2) verify the thermal design analysis by testing selected concepts. Specific composite materials being evaluated are Boron/Epoxy (B/E), Graphite/ Epoxy (G/E), Boron/Polyimide (B/PI), and Boron/Aluminum (B/Al); Graphite/Polyimide (G/PI) has been added to this list for property data identification and preliminary evaluation of thermal design problems.

The TPS standoff to composite structure attachment over-temperature problem is directly related to TPS maximum surface temperature. To provide a thermally comprehensive evaluation of attachment temperature characteristics, maximum surface temperatures of 900F, 1200F, 1800F, 2500F and 3000F are considered in this study. This range of surface temperatures and the high and low maximum temperature capability of the selected composite materials will result in a wide range of thermal requirements for composite/TPS standoff attachments.

The approach to realizing the objectives of this study is to accomplish the following tasks within the framework of the described study requirements:

(1) Thermal property determination - define the thermophysical properties of the advanced composite materials.

(2) Thermal requirements definition - perform parametric analysis to identify the nature of the attachment temperature problem as functions of the thermal parameters of typical TPS standoffs.

(3) Concept development - conceive composite/standoff attachment designs to keep the composite materials structure within acceptable temperature limits and perform detailed thermal analysis to provide temperature levels and gradients of selected concepts.

(4) Model assembly and testing - construct and test standoff to composite attachments to verify the detailed thermal analysis.

Figure 1 illustrates the schedule relationship of these tasks. Tasks 1, 2, and 3 are complete; Task 4 is essentially complete (except for final test data evaluation).

2.1 Thermal Property Determination (Task 1)

This task is complete as reported in the First Quarterly Progress Report. Results from the thermophysical property data location and collation effort evidenced a considerable lack of the type of property data (thermal conductivity and specific heat) that is of primary interest to this program. For example, there are no conductivity data for three out of the five classes of composite material systems being considered in this study (data is not available on B/PI, G/PI, and B/Al). For the purpose of this study, estimates of the properties for these materials were made from the constituent property data and/or analogy with similar material systems.

2.2 Thermal Requirement Definition (Task 2)

This task is complete and reported in the First Quarterly Progress Report. Representative heating environments were developed and parametric thermal analysis performed. Simplified two-dimensional thermal models representing a range of TPS standoff designs and composite structure substrates were used to develop composite structure temperatures as a function of heating level, standoff design variables, and composite substructure variables. Interpretations of the parametric results were used as guidelines to select specific TPS standoff/composite structure problem areas to be considered in the concept development of TPS attachments (Task 3).

2.3 Concept Development (Task 3)

This task is complete as reported in the Second Quarterly Progress Report. A relatively full complement of thermal design attachment concepts were formulated. The concepts were evaluated to identify the advantages and disadvantages of the various thermal concepts formulated. The results of this evaluation indicate that the simple attachment isolator concept will satisfy the thermal requirements for typical application with a relatively low weight penalty compared with other concepts. The isolator attachment concept was therefore selected as the concept on which detail design for each composite material was performed. These designs (presented in the Second Quarterly Report) were the basis for the test article designs developed and tested under Task 4.

2.4 Model Assembly and Testing (Task 4)

The major activities of this task were completed during this reporting period. Detailed thermal analyses were performed to define the two test environments, test requirements were finalized, detail design, fabrication, and assembly and instrumentation of test hardware was completed, and thermal testing was performed per the detailed Test Plan, which is included as Appendix A to this progress report.

Assembly of the G/E, B/Al, and B/PI test articles was completed after fabrication of the stainless steel standoffs and 4 x 7 inch composite structure panels and receipt of the thermal isolator blocks and bushings from the vendor (Whittaker Research and Development Company). Pertinent dimensions of each test article assembly were obtained from the configurations considered in the detailed thermal analysis for the 1800F surface temperature environment (Second Quarterly Progress Report). The stainless steel standoffs were fabricated to the same thickness to height ratio of the Haynes 188 standoffs, and the isolator block thickness for each test article matches that previously used in the thermal design analysis.

After assembly of the three test articles, each was instrumented with seven thermocouples. Three Chromel-Alumel thermocouples were spot-welded to the standoff: in the center of the standoff cap (location #1), halfway down the standoff height (location #2), and at the edge of the standoff leg (location #3). Four Chromel-Alumel thermocouples were bonded to the composite panel: on the composite panel lengthwise centerline directly below the location #3 (location #4), along the lengthwise centerline, .75 inches from location #4 (location #5), along the lengthwise centerline at the edge of the panel (location #6), and in direction perpendicular to the lengthwise centerline, 1.5 inches from location #4 (location #7). Refer to Figure 4 of Test Plan (Appendix A) for a pictorial representation of the thermocouple installation. The thermocouples at locations #1, #2, and #3 provide temperature gradient data in the standoff; the thermocouples at locations #4, #5, and #6 provide measurement of temperature gradients produced by the particular fiber orientations of each composite panel. A thermocouple was installed at location #7 as an aid in the evaluation of acquired data and potential data anomalies. Thermocouple identification for each location on each test article was made by adding 10 to each location for the G/E assembly, adding 20 to each location for the B/Al assembly, and adding 30 to each location for the B/PI (see Figure 3).

After completion of the thermocouple installation, 6 lb/ft^3 Dynaflex insulation was built up within and surrounding the standoffs, completing a 19 x 22 inch package. At this point in the assembly, only the cap of each test article standoff was visible (refer to Figure 2 of Test Plan). The thermocouple leads for each specimen were routed to the side of the test assembly, bundled together, and routed to a junction. Irish Refrasil cloth was placed on top and around the edges of the assembly, and Refrasil fabric was used to sew the cloth to the standoff caps to assure contact between the cloth and standoff. A Chromel-Alumel thermocouple was placed in the center of the test area below the cloth and sewn to it to hold it in place. The two radiant heating environments, corresponding to a 1200F and 1800F maximum surface temperature condition, were to be controlled by a pre-programmed surface temperature measured by the control thermocouple.

Detailed pre-test thermal analyses were performed to define the two test environments (1200F and 1800F maximum surface temperatures) that would result in the composite structure temperatures reaching a maximum of approximately two-thirds of design limit on the first test exposure, and 90 - 95% of design limit on the second test exposure. Uncertainty in the design property data of test article components (composite structure panels foamed isolator blocks, and molded bushings) was the reason for limiting the maximum composite structure temperatures to less than the maximum design values (350F for G/E, 650F for B/Al, and 600F for B/PI). The calculated composite structure maximum temperatures for the defined environments shown in Figures 1(a) and 1(b) of Test Plan, are: 260F, 435F, and 400F for the G/E, B/Al, and B/PI panels during the first exposure (1200F), and 330F, 575F, and 545F for the G/E, B/Al, and B/PI panels during the second exposure (1800F). The computed temperature histories for the thermocouple locations on the standoffs and composite structure panels (Figure 3) are presented in Figure 4 for the 1200F maximum surface condition and Figure 5 for the 1800F maximum surface temperature condition. Although not calculated in the two-dimensional pre-test thermal analyses, the thermal response at thermocouple location #7 on the G/E panel (T/C #17), B/Al panel (T/C #27), and B/PI panel (T/C #37) was expected to be about the same as that at thermocouple location #6. As mentioned previously, a thermocouple was installed at location #7 for post-test data evaluation purposes.

During the first heating exposure (1200F maximum surface temperature condition) it was noted that the control thermocouple was not following the programmed surface temperature, and the test was aborted after 8 minutes. The control thermocouple was replaced and found to be operating well after a short duration calibration run. The test assembly was then exposed to the two test environments (1200F and 1800F surface temperatures) and thermal data obtained for all thermocouples. Inspection of the recorded data indicated that a major portion of measured data was suspect although the control thermocouple response during both exposures was as planned. The test assembly was taken apart and inspected. It was found that many of the thermocouple leads had been carbonized by severe heating at the edge of the 19 x 22 inch test assembly. This carbonization of the thermocouple leads effectively created thermocouple junctions at the edge of the assembly which invalidated the temperature measurements obtained. There was evidence of binder condensation within the layers of the Dynaflex insulation material and on the test articles, but the test article assemblies appeared not to have been damaged such that they could not be re-tested after minor modifications to the test setup were made.

The G/E, B/Al, and B/PI test articles were again instrumented with Chromel-Alumel thermocouples sheathed in a glass fabric with high temperature capability, and the wires were run down through the bottom of the test assembly as a precaution. Aluminum tape was used this time to hold the composite structure thermocouples in place as the bonding material appeared to have lifted from the panels at some locations. The Dynaflex insulation was conditioned in a 1200F oven to bake out the rest of the binders as a further precaution to avoid extraneous test influences.

The following re-tests went smoothly with no visual outgassing of the insulation binder as had been observed previously. The acquired data has not been analyzed or interpreted fully, but preliminary indications are that it is of good quality for both the 1200F and 1800F surface temperature exposures, and appears consistent with pre-test expectations. As expected, maximum temperatures measured on the composite structure panels, in all cases, are lower than predicted. This was expected since a thermal design approach was utilized in the analytical modeling; the thermal modeling technique used in the pre-test analyses was identical to that used in the detailed thermal analysis (Task 3(c)). The maximum temperatures measured at each thermocouple location illustrated in Figure 3 are compared to the corresponding pre-test temperature predictions in Tables I and II. Computed and measured temperature histories for both test exposures at selected in-depth thermocouple locations are presented in Figures 6 and 7. On all three test articles for both test exposures, the response at thermocouple location #3 was underpredicted analytically while temperatures on each panel were consistently over-predicted. This result indicates that the thermal diffusivity of the isolator block is actually lower than that utilized in the analysis and or the existence of some contact resistance between the standoff leg and isolator block and between the isolator block and composite panel. These components were assumed to be in perfect contact in the pre-test evaluation. However, the composite structure panel temperatures were of primary importance in this study, and the thermal modeling employed was intended to yield moderately conservative composite temperature predictions.

Visual inspection of the G/E, B/Al, and B/PI test articles indicates no apparent thermal or mechanical degradation of test article components as a result of the tests. Some discoloration (surface oxidation) of the stainless steel standoffs occurred, as expected, and, as mentioned previously, re-solidification of the Dynaflex insulation binder condensate occurred on the isolator block and composite structure surfaces. The thermocouple and aluminum tape at location #5 on the B/Al composite (T/C #25) was found not to be in contact with the panel, which is the probable cause of suspect temperatures recorded for about 700 seconds during the 1800F maximum surface temperature test (second exposure).

3.0 PROPOSED EFFORT NEXT REPORTING PERIOD

Final analysis of the test results and drafting of the final report are scheduled for completion March 1, 1972 as originally scheduled. The technical activity is expected to be completed at this time.

4.0 CONCLUSIONS

The test data obtained in the Task 4 activity are of good quality and are interpreted to indicate that the test objective (obtaining verification of the thermal modeling techniques) was realized.

5.0 PROGRESS SCHEDULE

The program is on schedule with all technical activities completed except final test data analysis. It is planned that this remaining task be completed and the first draft of the final report be prepared and ready for submittal March 1, 1972 as originally scheduled (Figure 1). There appears to be no problem in completing the contract with remaining funds (Figure 2); actual expenditures and commitments at the end of this reporting period are approximately $21,276.

FIGURE 1. PROGRAM SCHEDULE FOR NAS 8-27041

THERMAL DESIGN OF COMPOSITE MATERIAL HIGH TEMPERATURE ATTACHMENTS

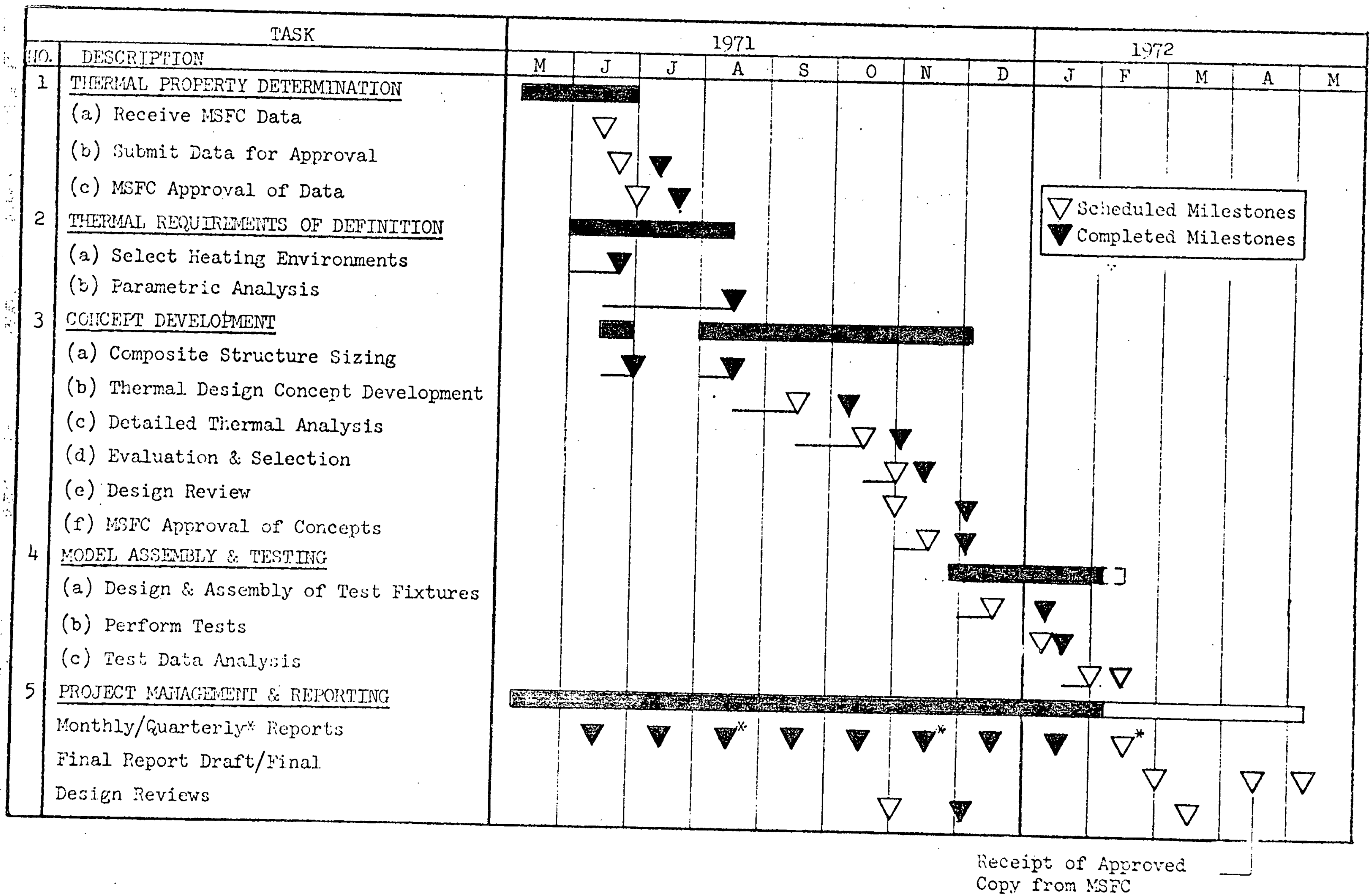
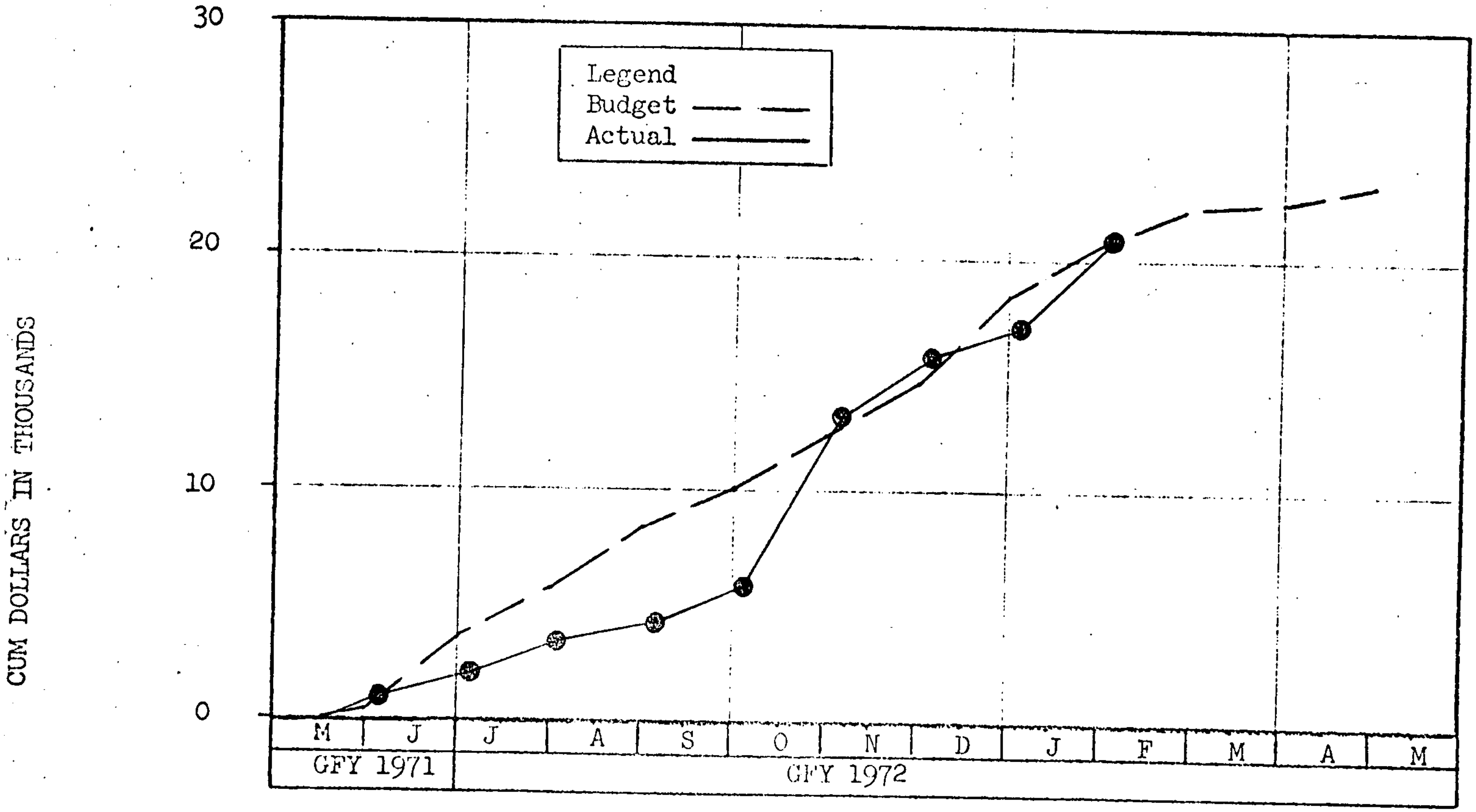


FIGURE 2. MANPOWER & FUNDING PLAN FOR NAS 8-27041

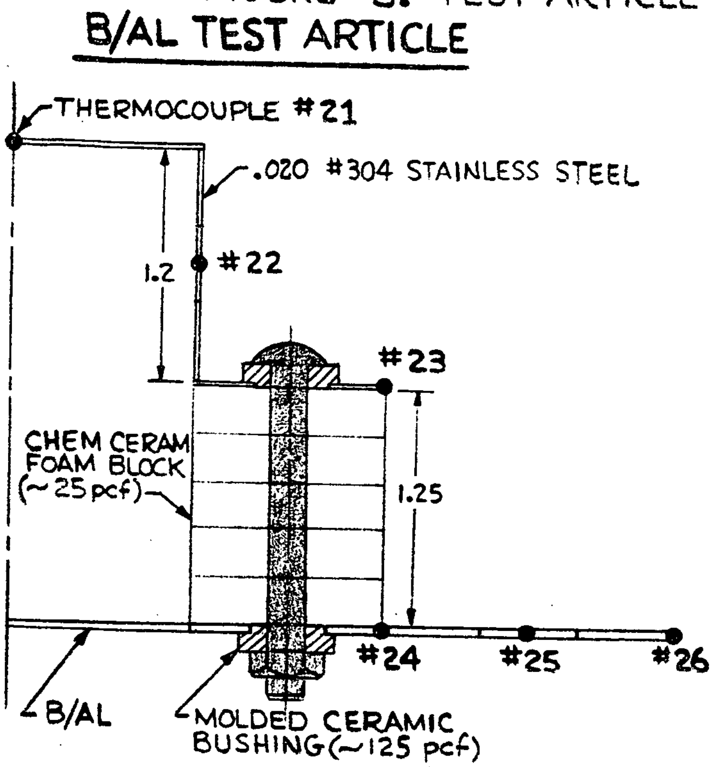
THERMAL DESIGN OF COMPOSITE MATERIAL HIGH TEMPERATURE ATTACHMENTS

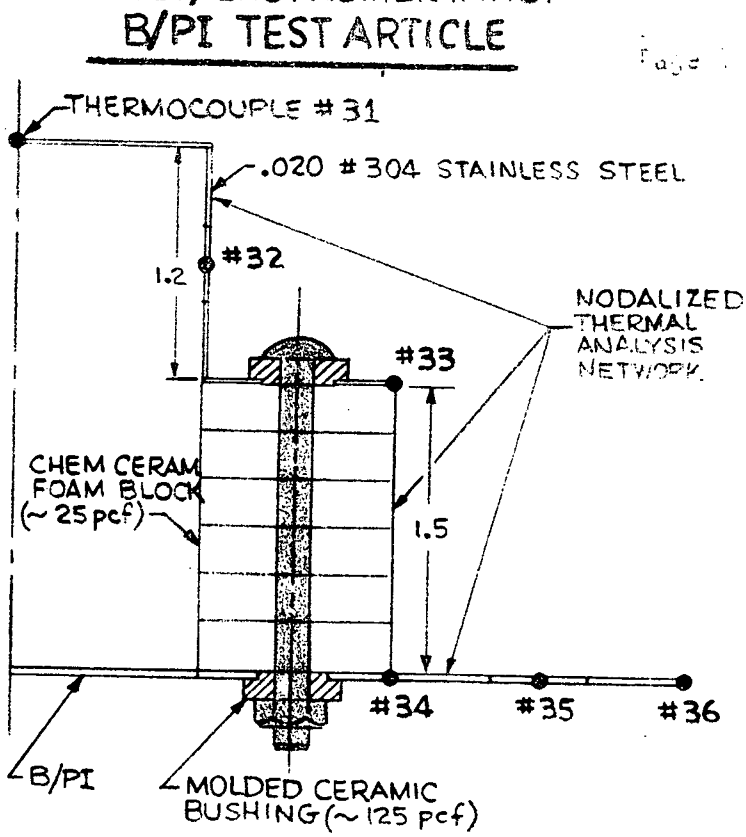


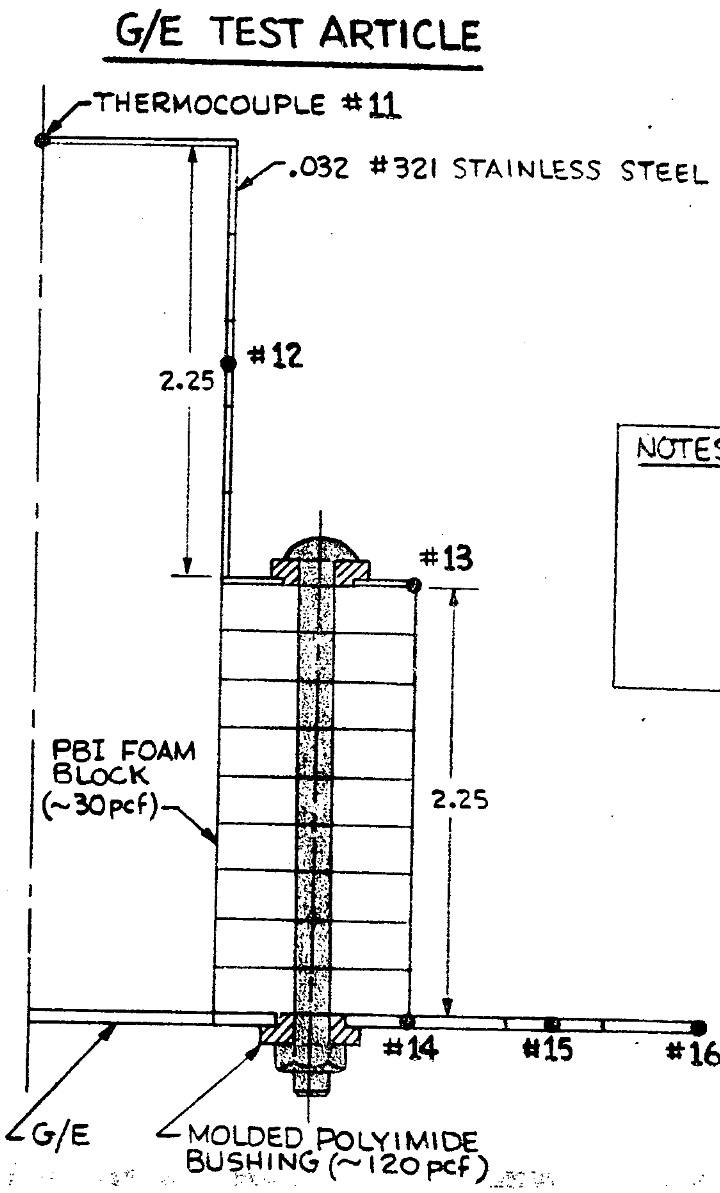
Direct Hours

	M	J	J	A	S	O	N	D	J	F	M	A	M	Totals
Budget	20	150	89	120	70	87	110	190	100	80	10	40		1066
Actual	51	49	46	24	96	298	70	40	228	40				972

FIGURE 3. TEST ARTICLE ASSEMBLY/INSTRUMENTATION







NOTES: 1. DYNAFLEX INSULATION NOT SHOWN

2. T/C #17, #27, #37 ARE LOCATED 1.5 INCHES FROM T/C #14, #24, #34 PERPENDICULAR TO THE LENGTHWISE CENTERLINE

FIGURE 4 (a). 1200F TEST ENVIRONMENT

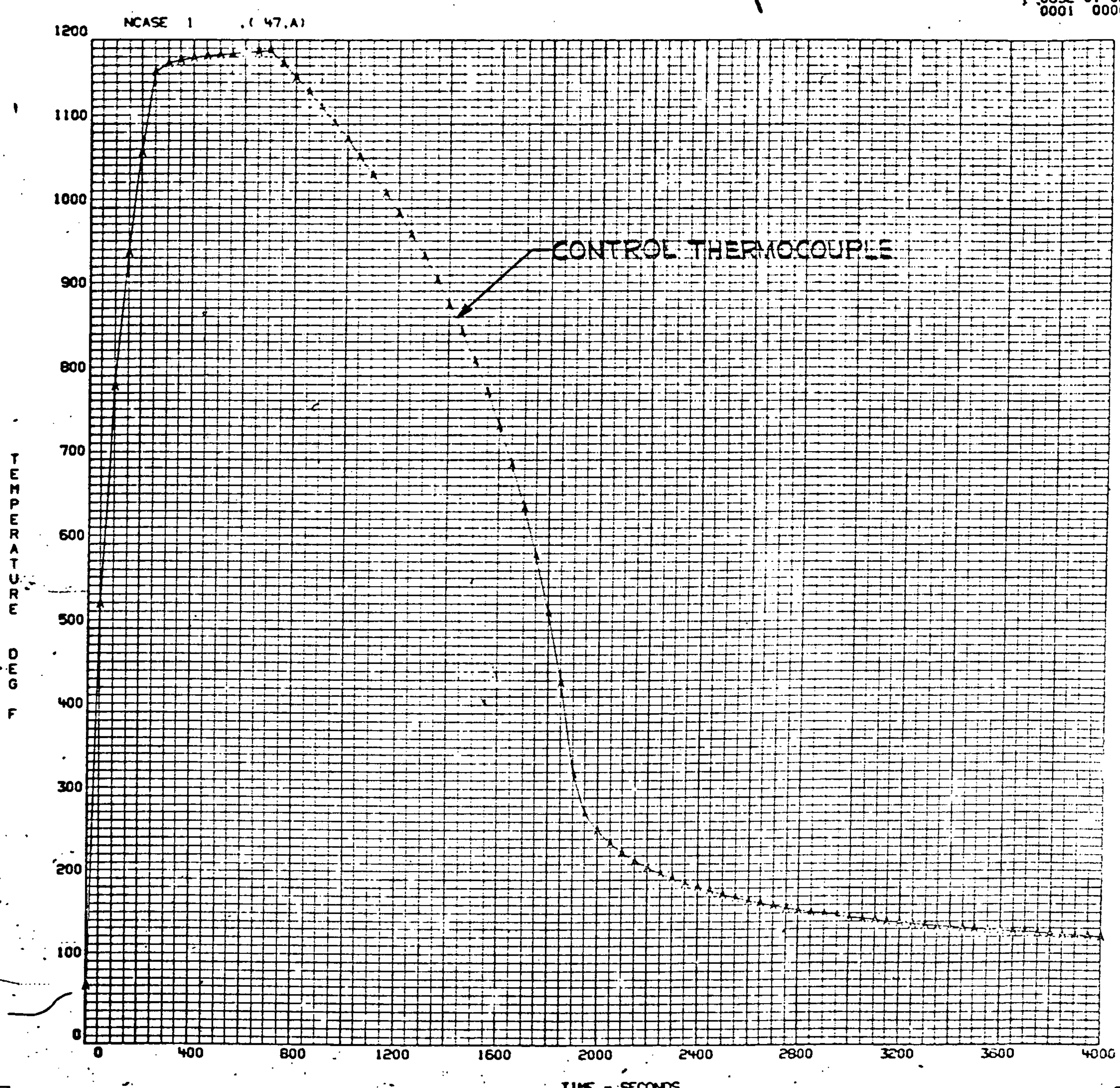


FIGURE 4(b). PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT – G/E TEST ARTICLE

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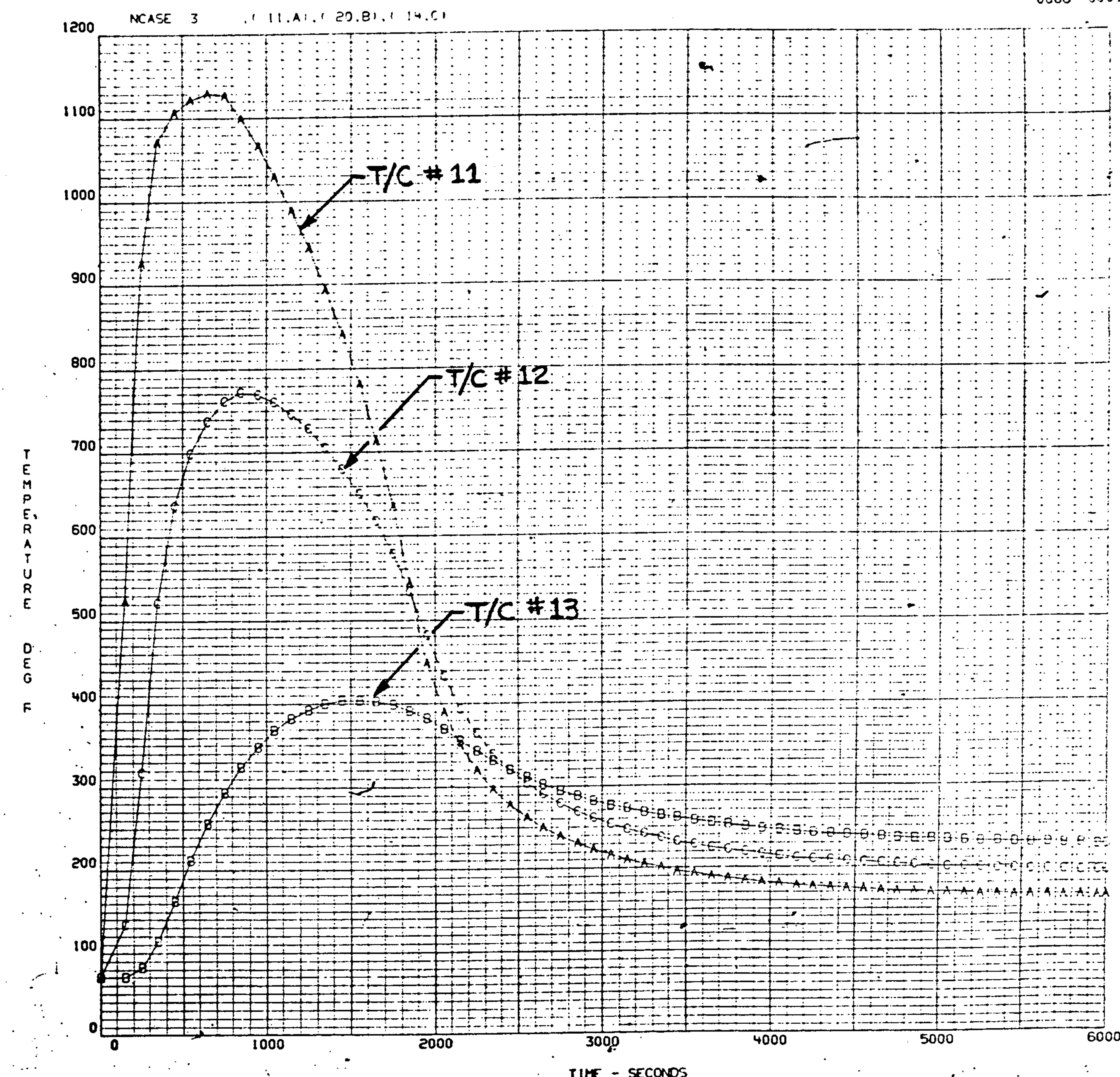

FIGURE 4(c). PRE-TEST PREDICTION OF G/E COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

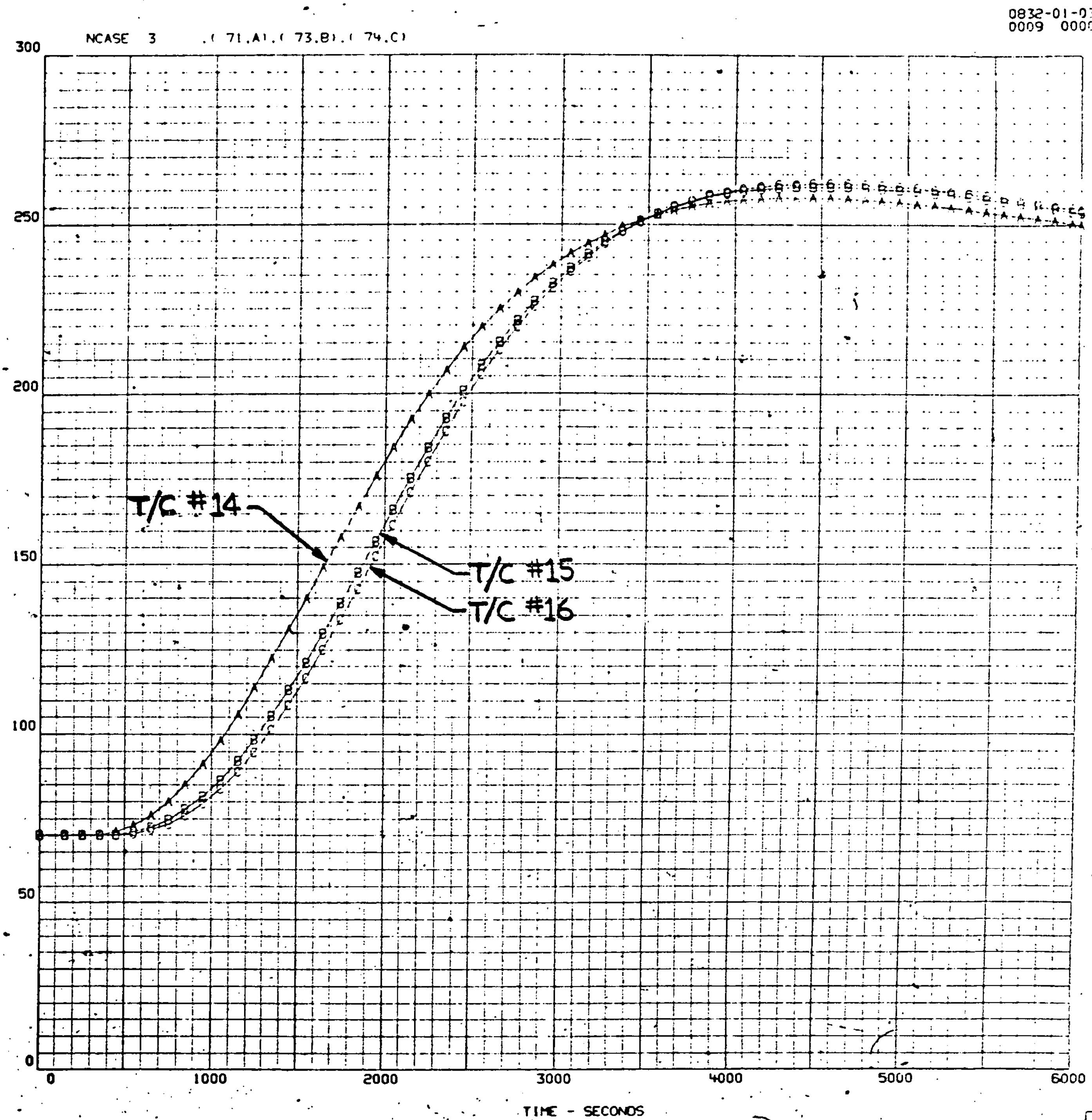

FIGURE 4(d) PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT– B/AL TEST ARTICLE

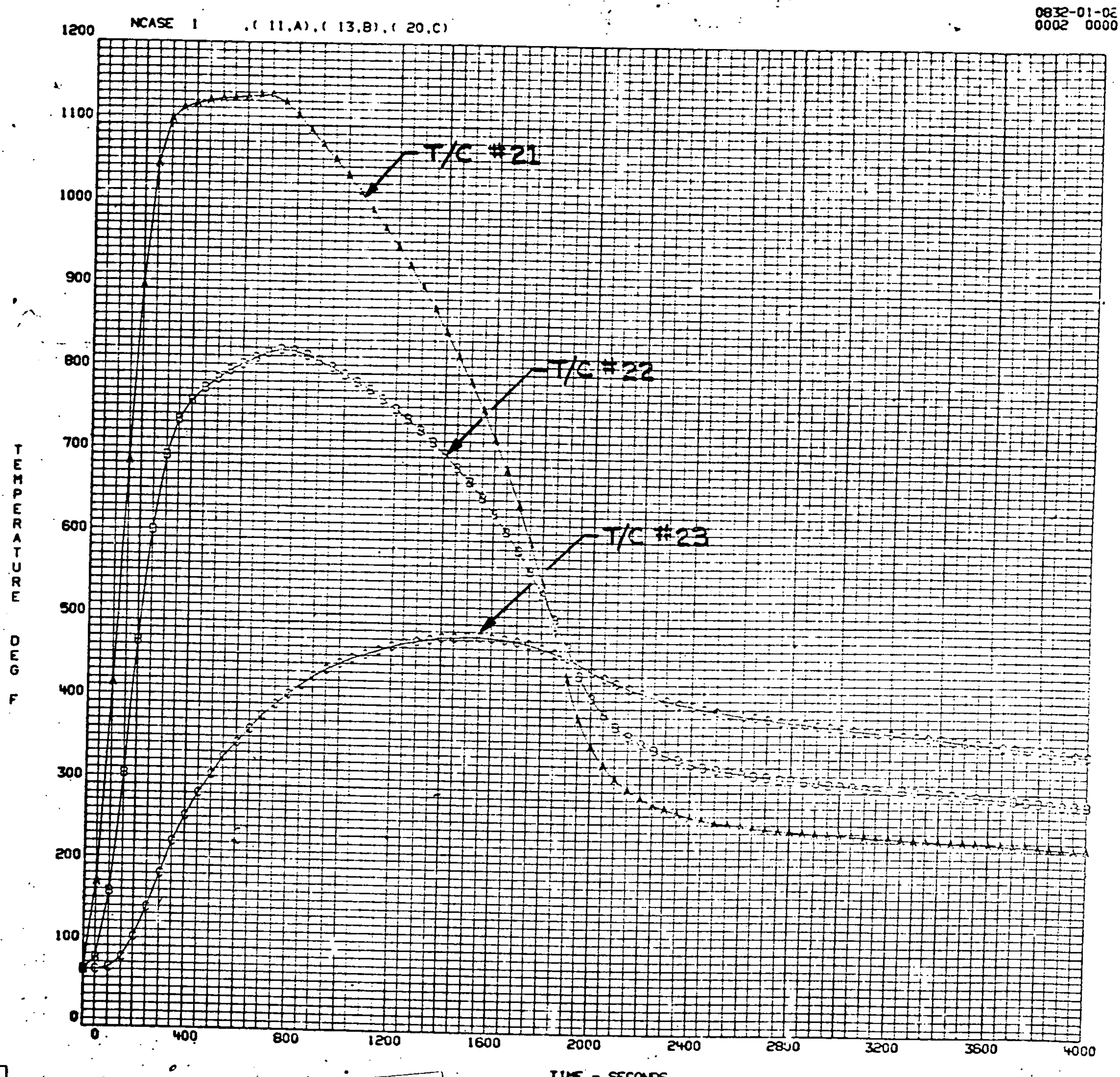

FIGURE 4(e). PRE-TEST PREDICTION OF B/AL COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

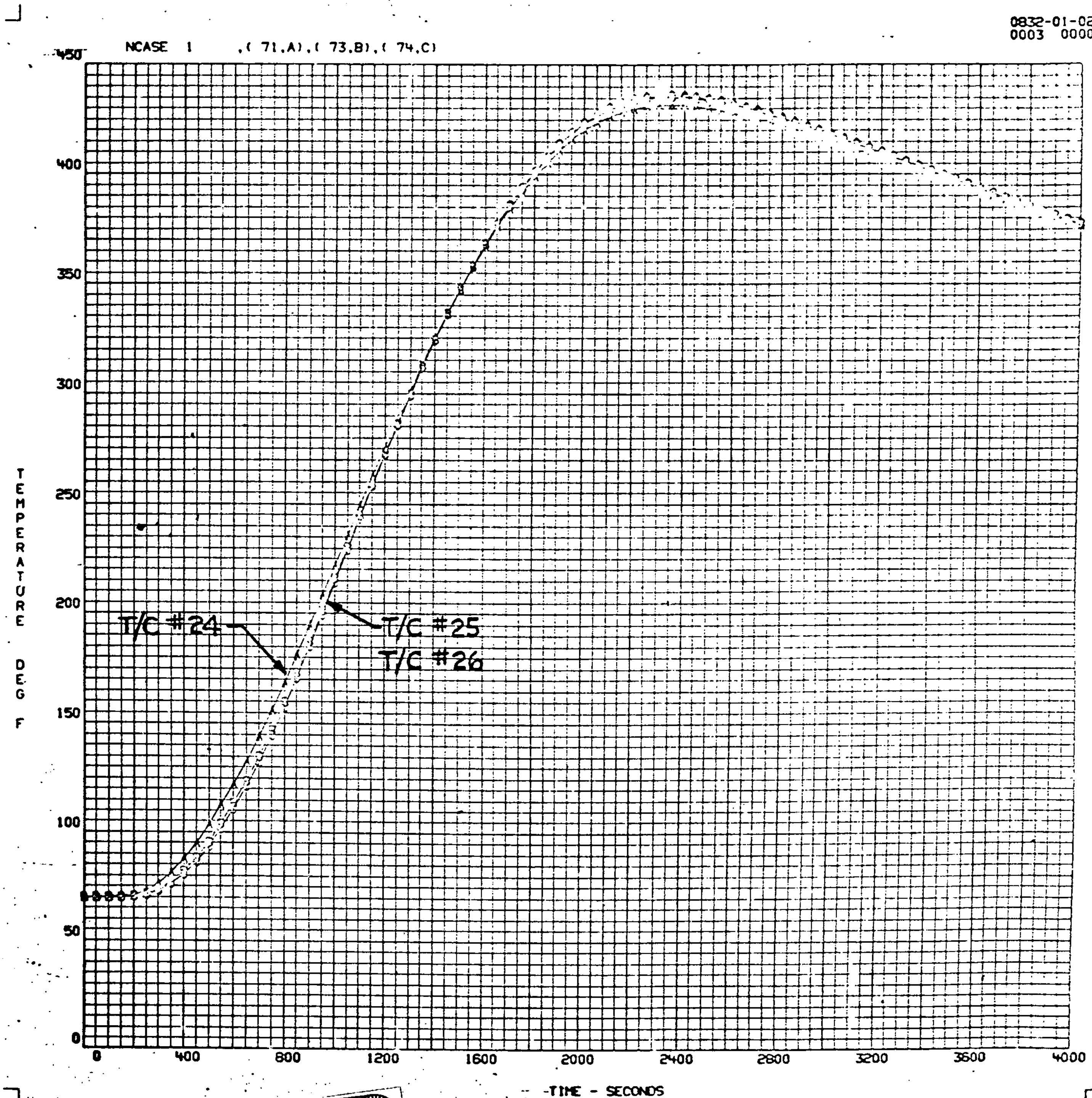

FIGURE 4(f) PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT— B/PI TEST ARTICLE

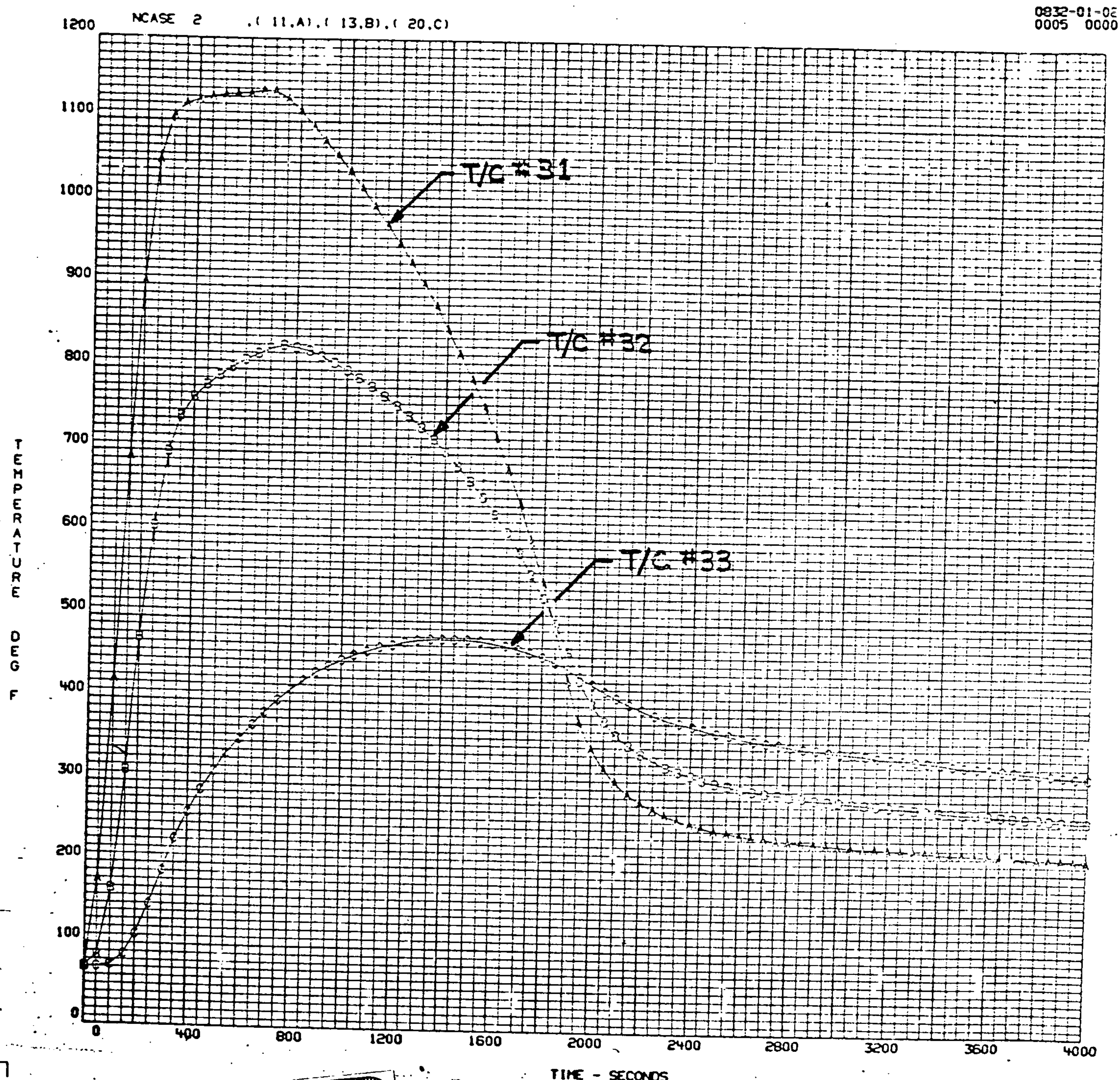

FIGURE 4(g). PRE-TEST PREDICTION OF B/PI COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

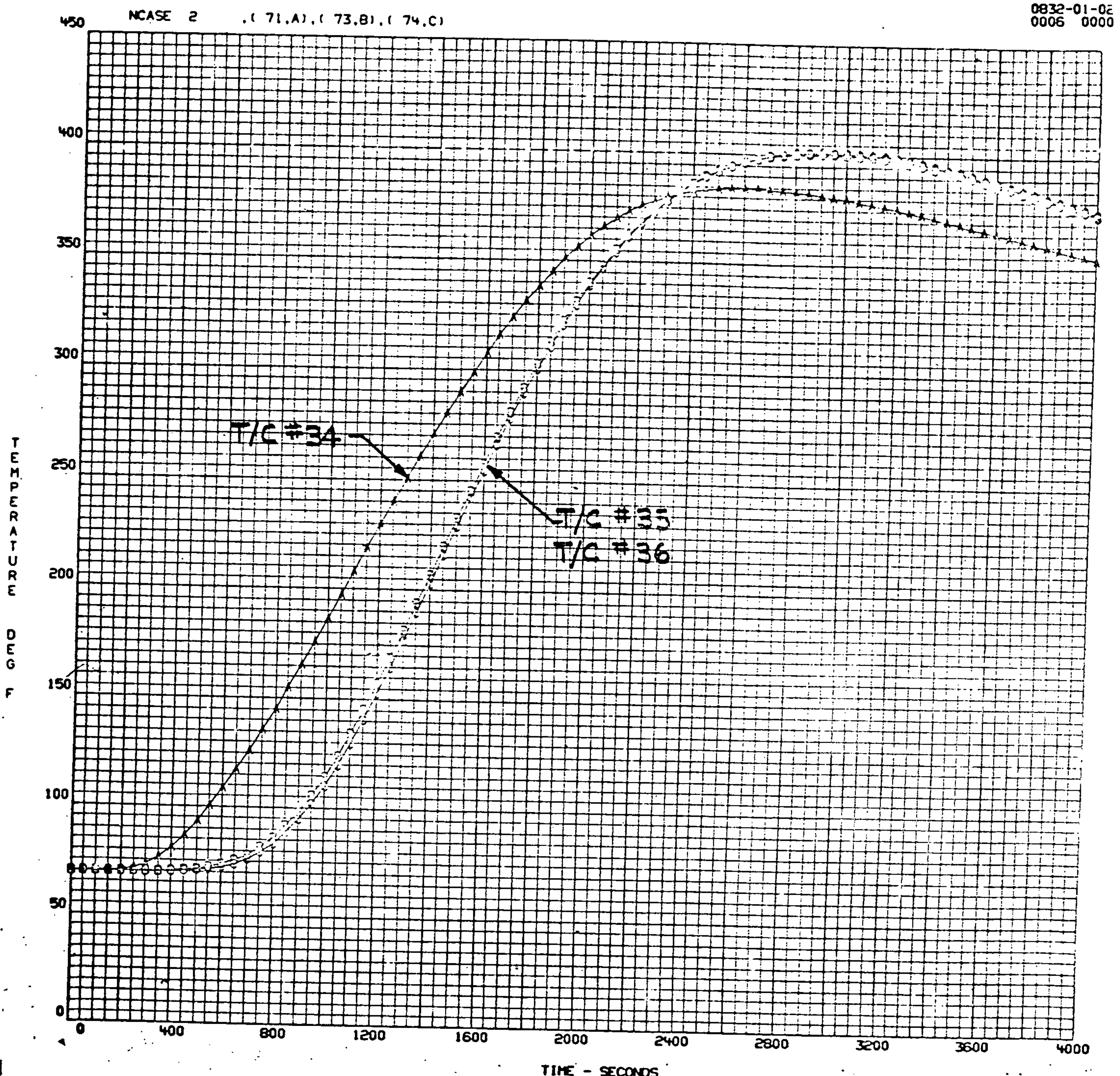

FIGURE 5(a). 1800F TEST ENVIRONMENT

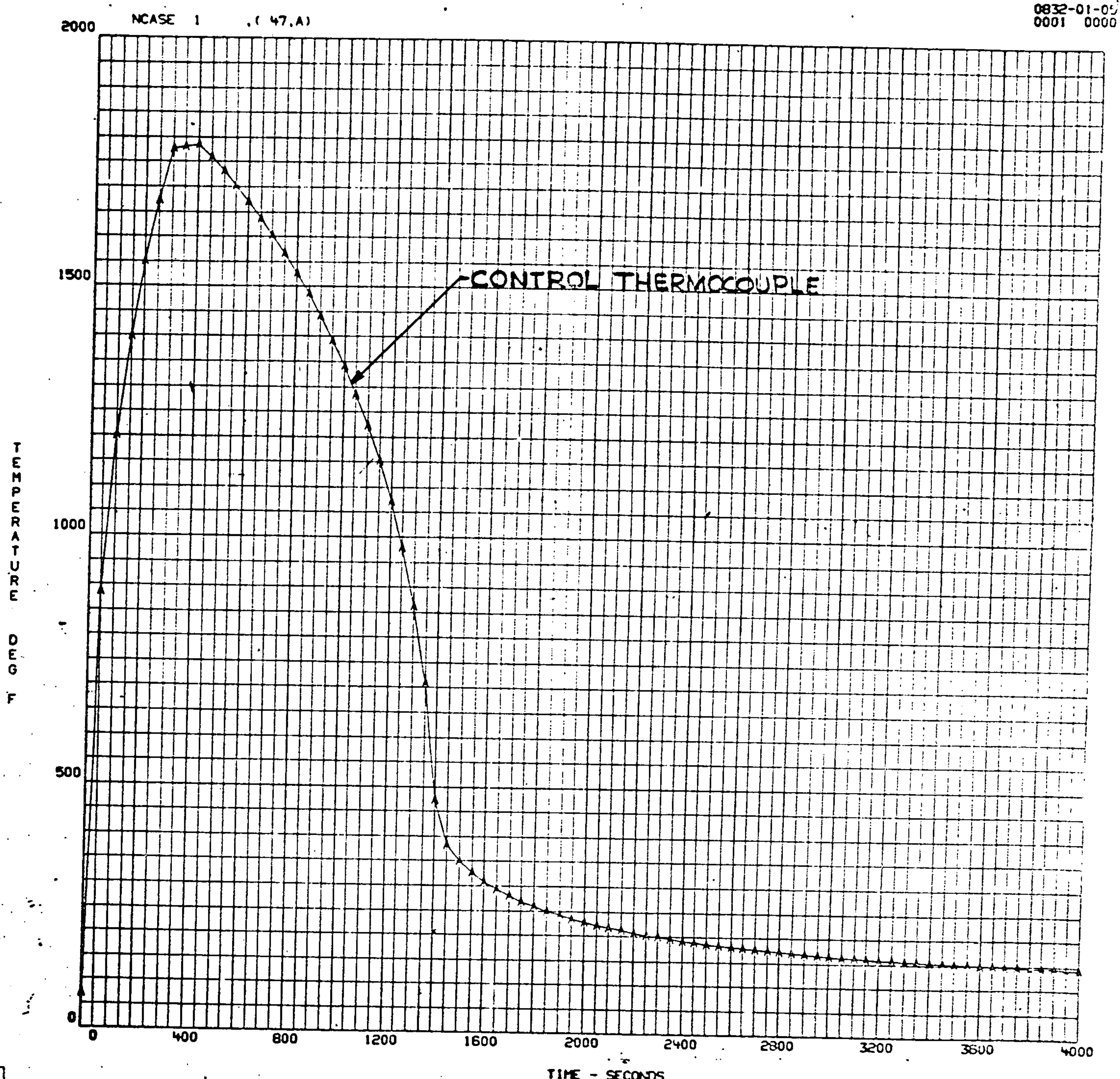

FIGURE 5(b). PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT— G/E TEST ARTICLE

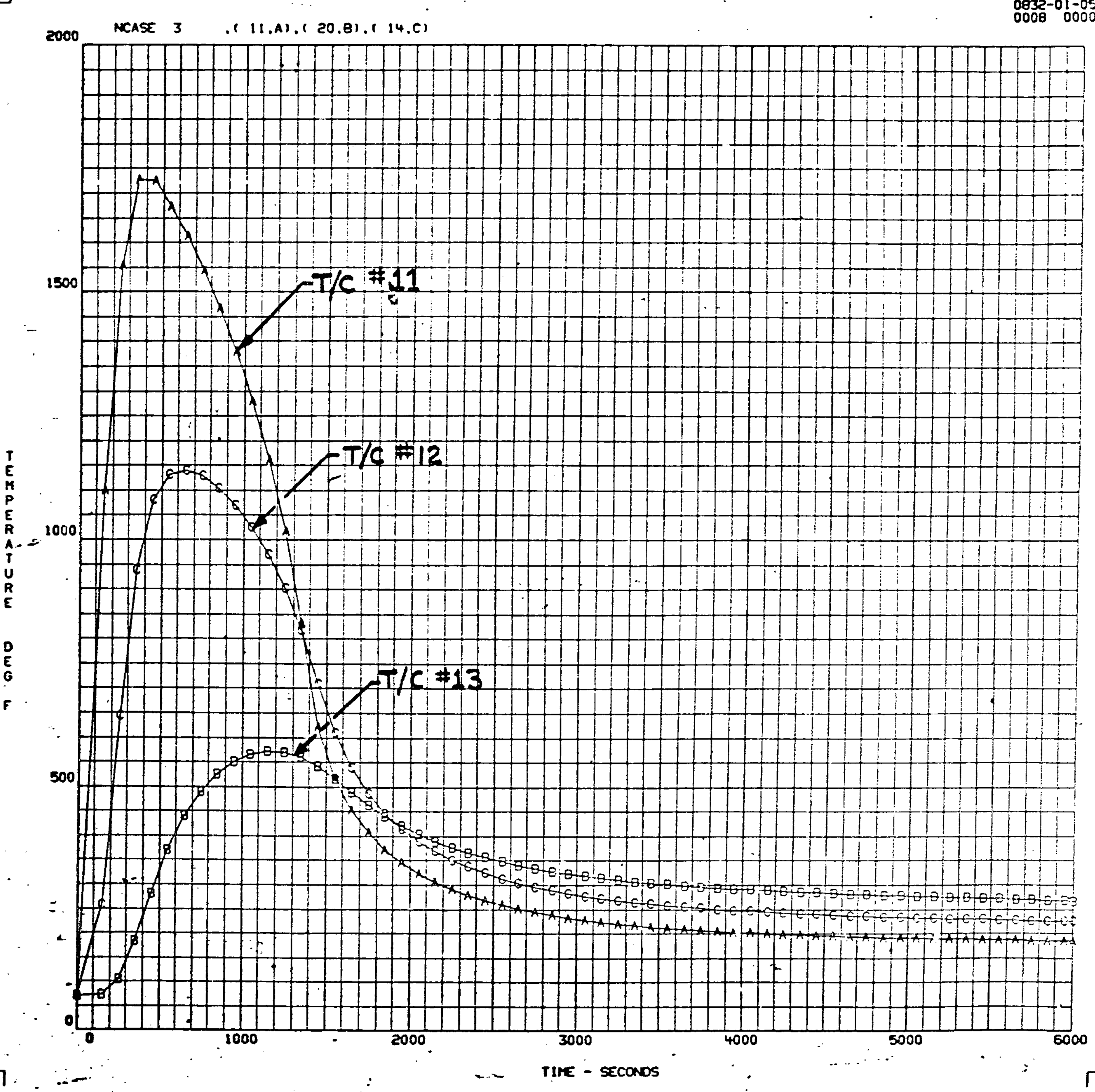

FIGURE 5(c). PRE-TEST PREDICTION OF G/E COMPOSITE PANEL THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

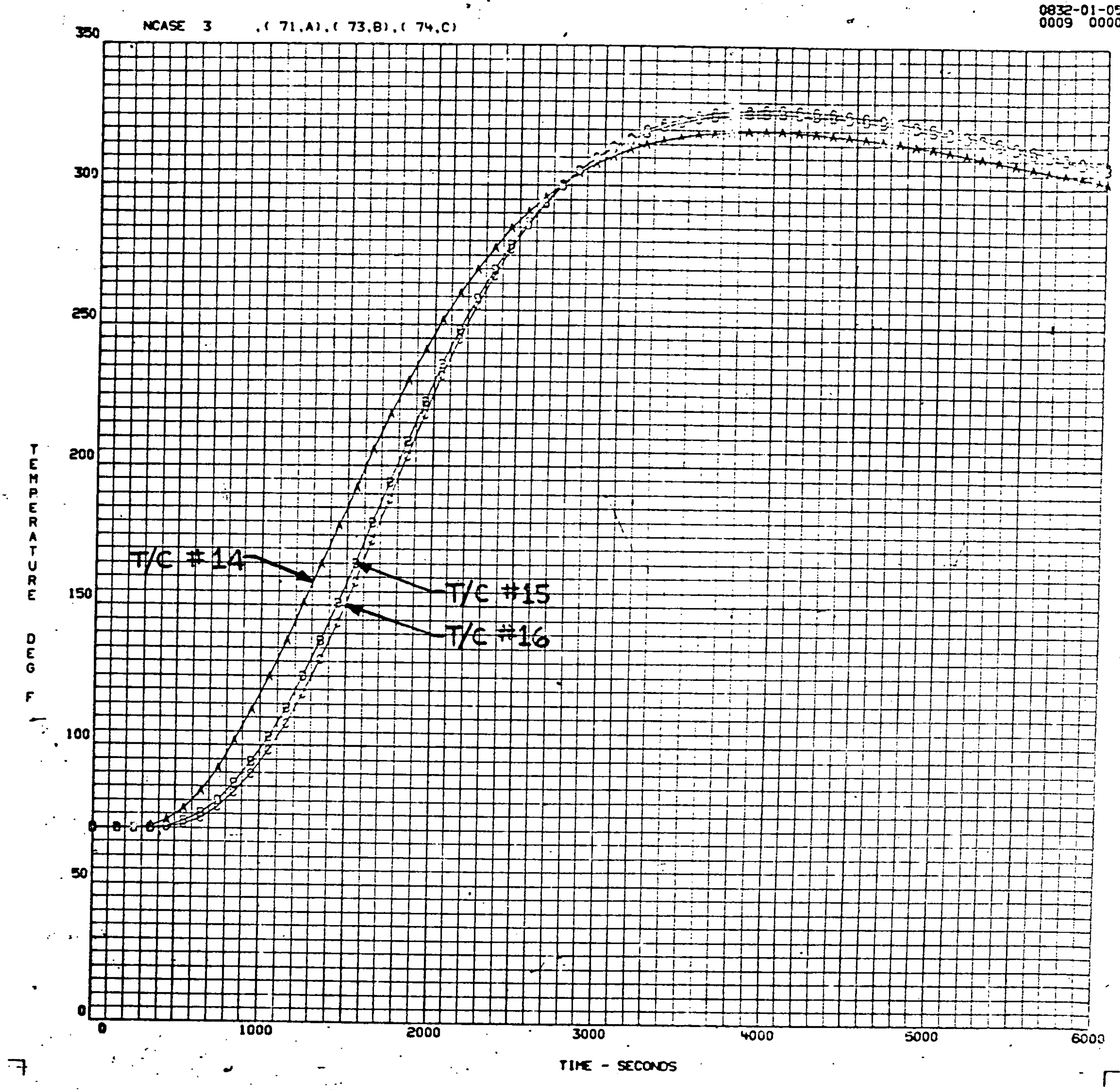

FIGURE 5(d). PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT – B/AL TEST ARTICLE

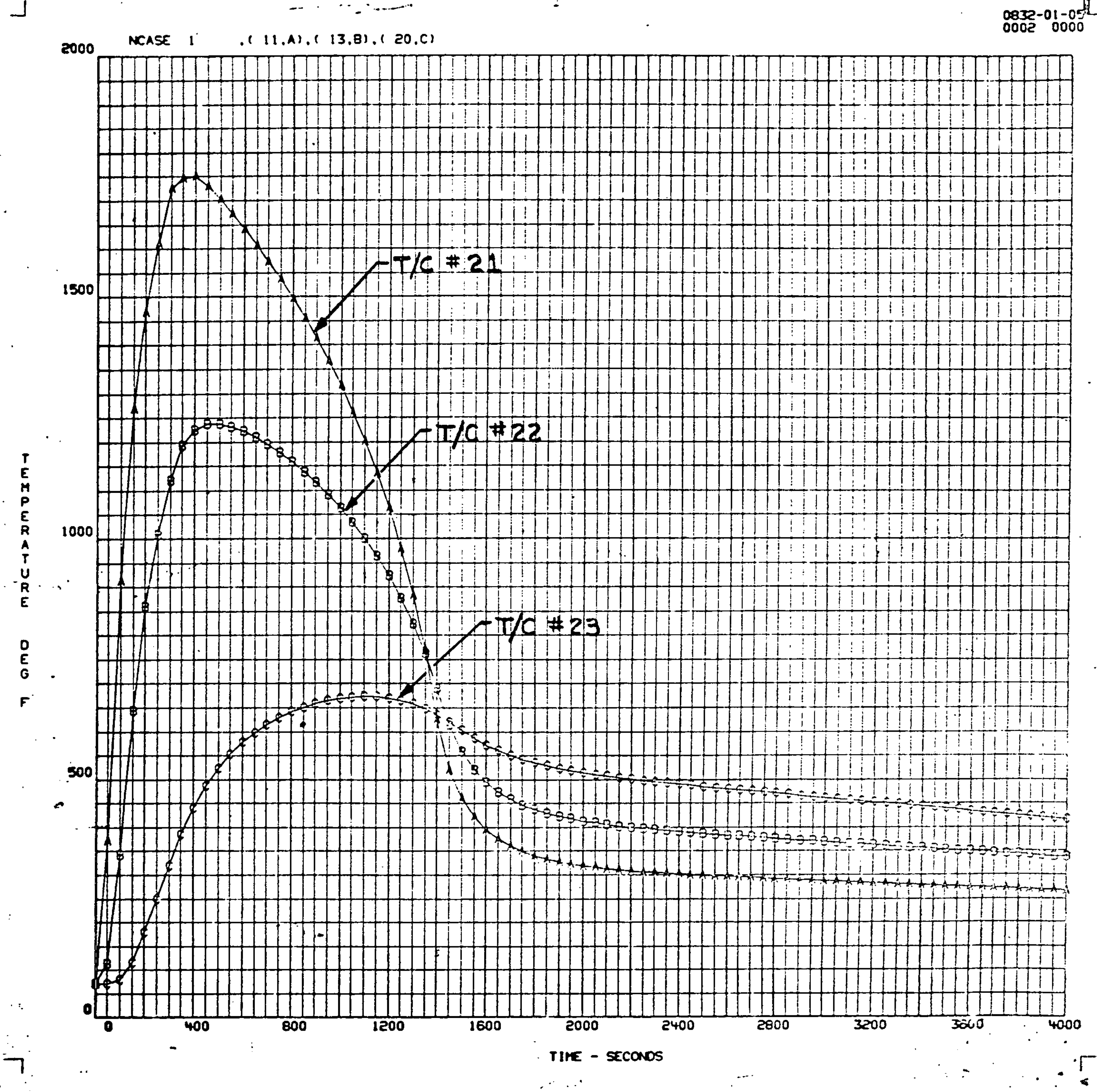

FIGURE 5(e). PRE-TEST PREDICTION OF B/AL COMPOSITE PANEL THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

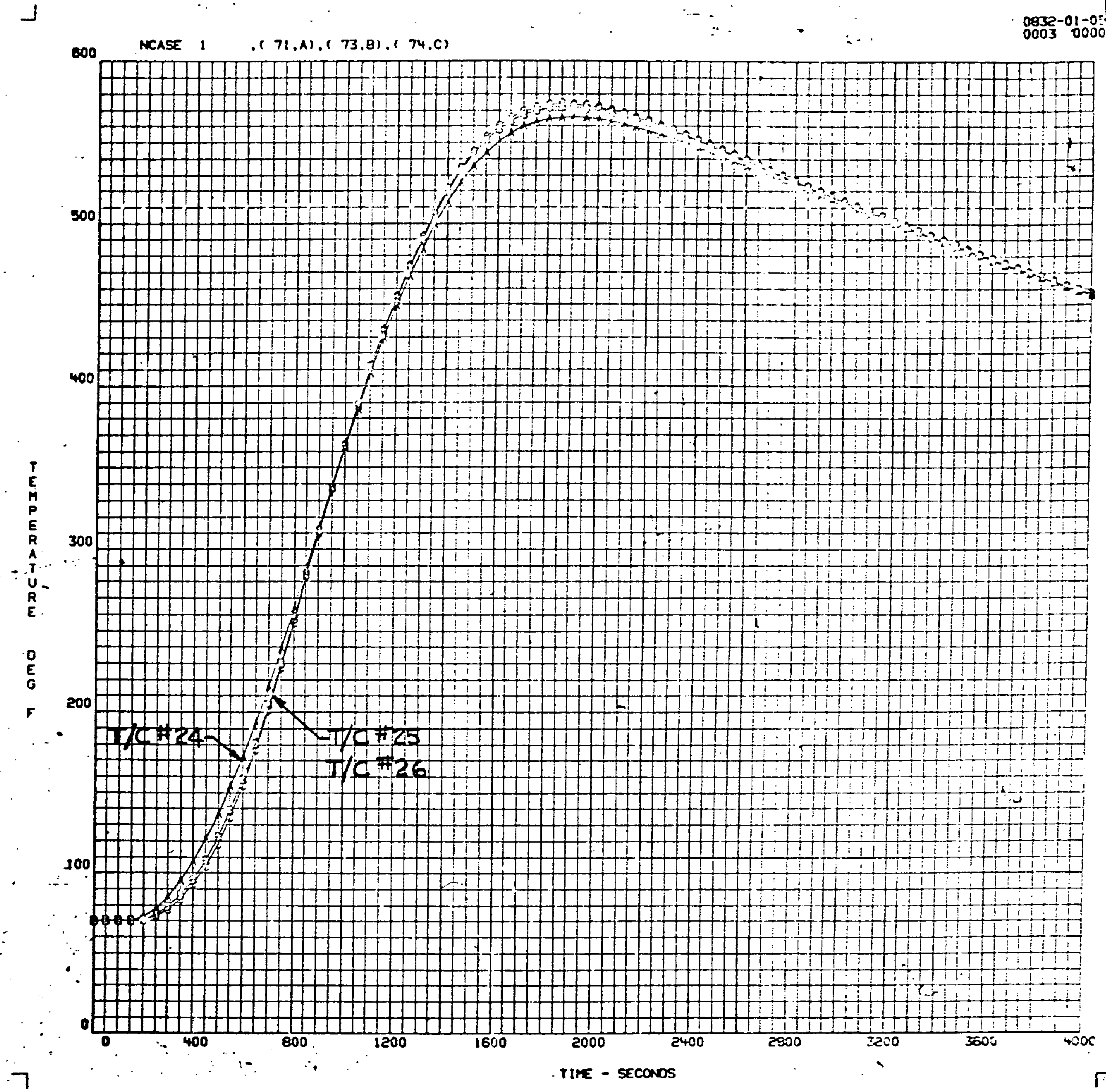

FIGURE 5(f). PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT– B/PI TEST ARTICLE

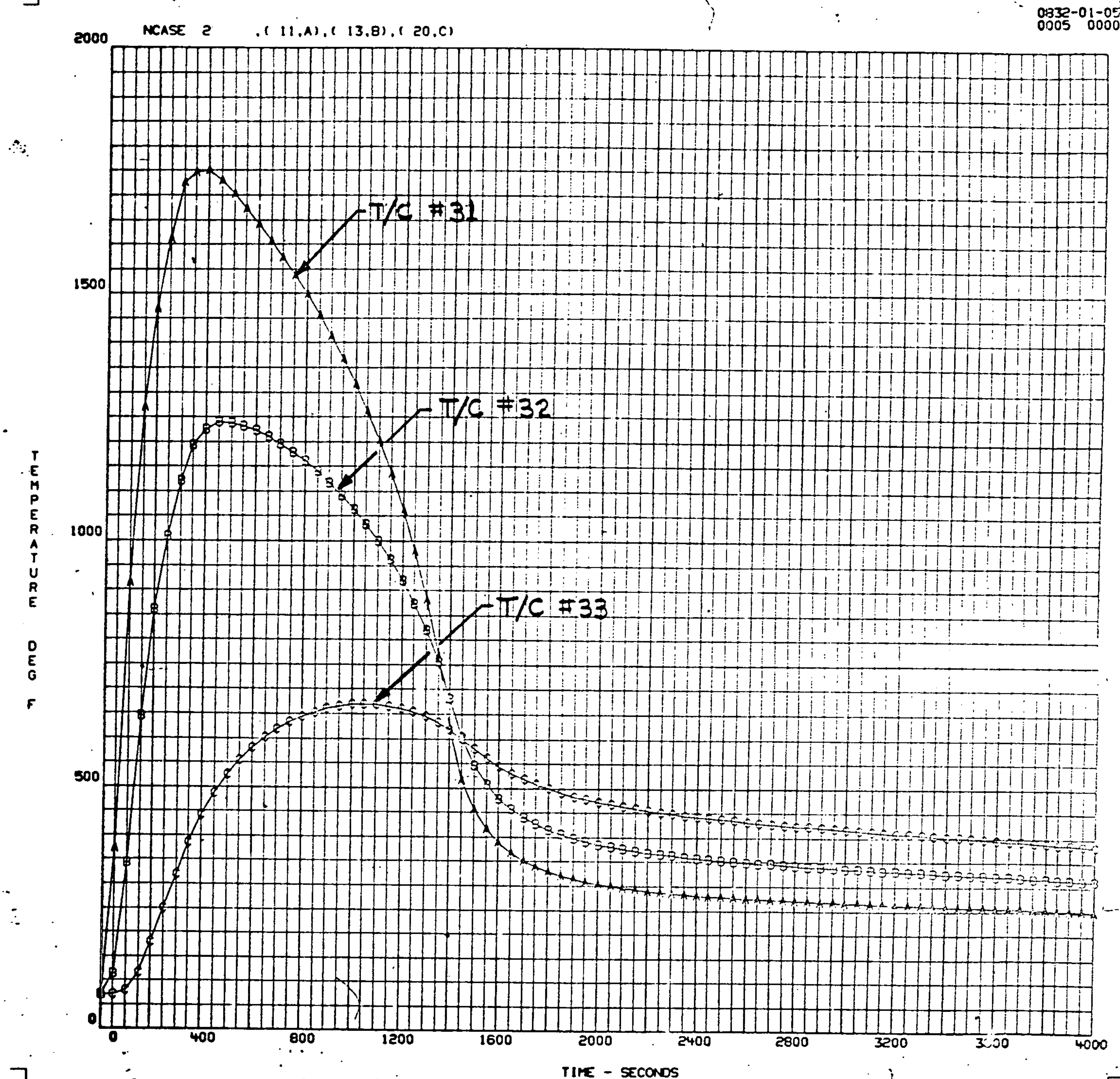

FIGURE 5(g) PRE-TEST PREDICTION OF B/PI COMPOSITE PANEL THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

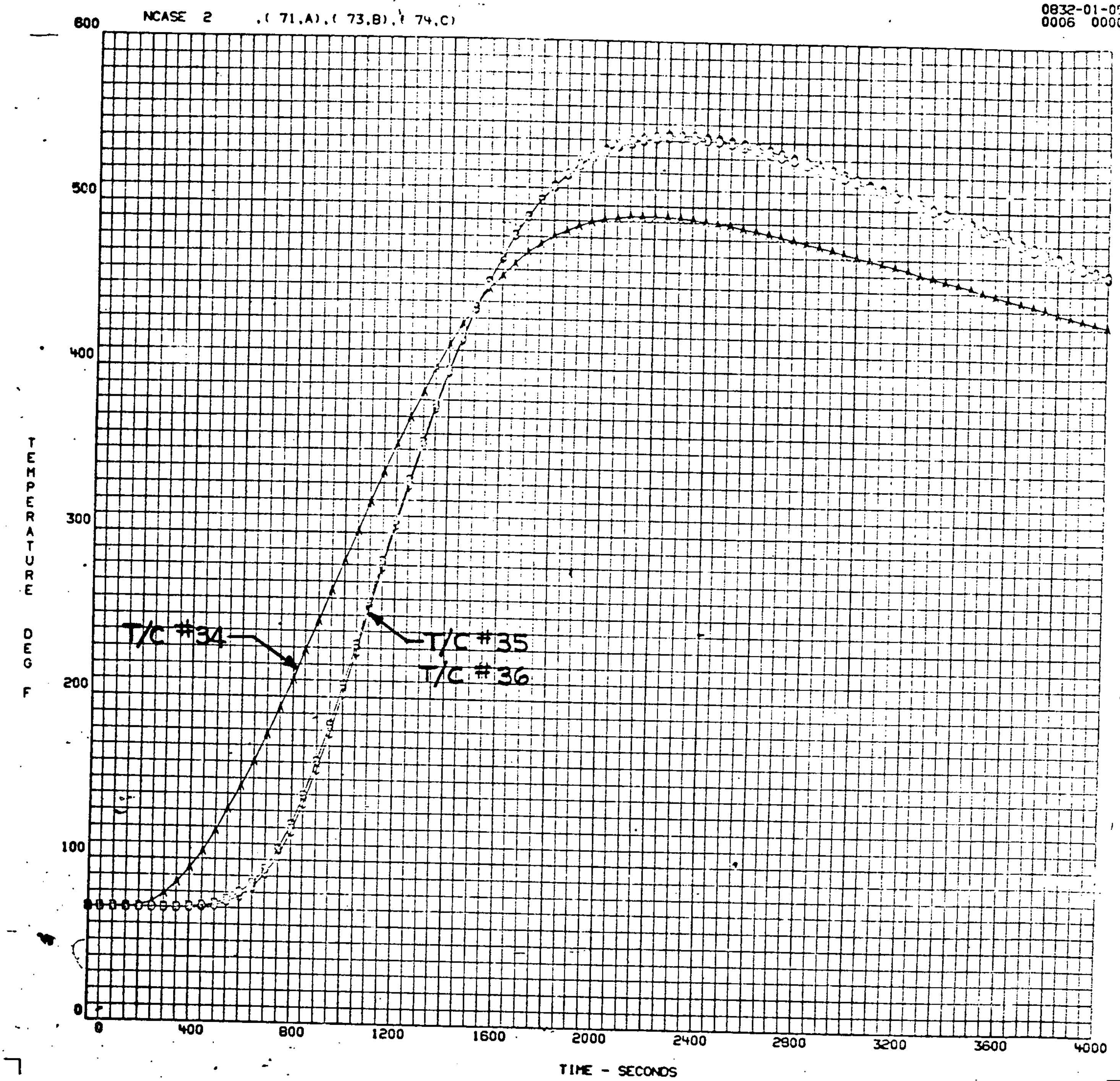

FIGURE 6(a). COMPARISON OF PLANNED AND MEASURED 1200F TEST ENVIRONMENT

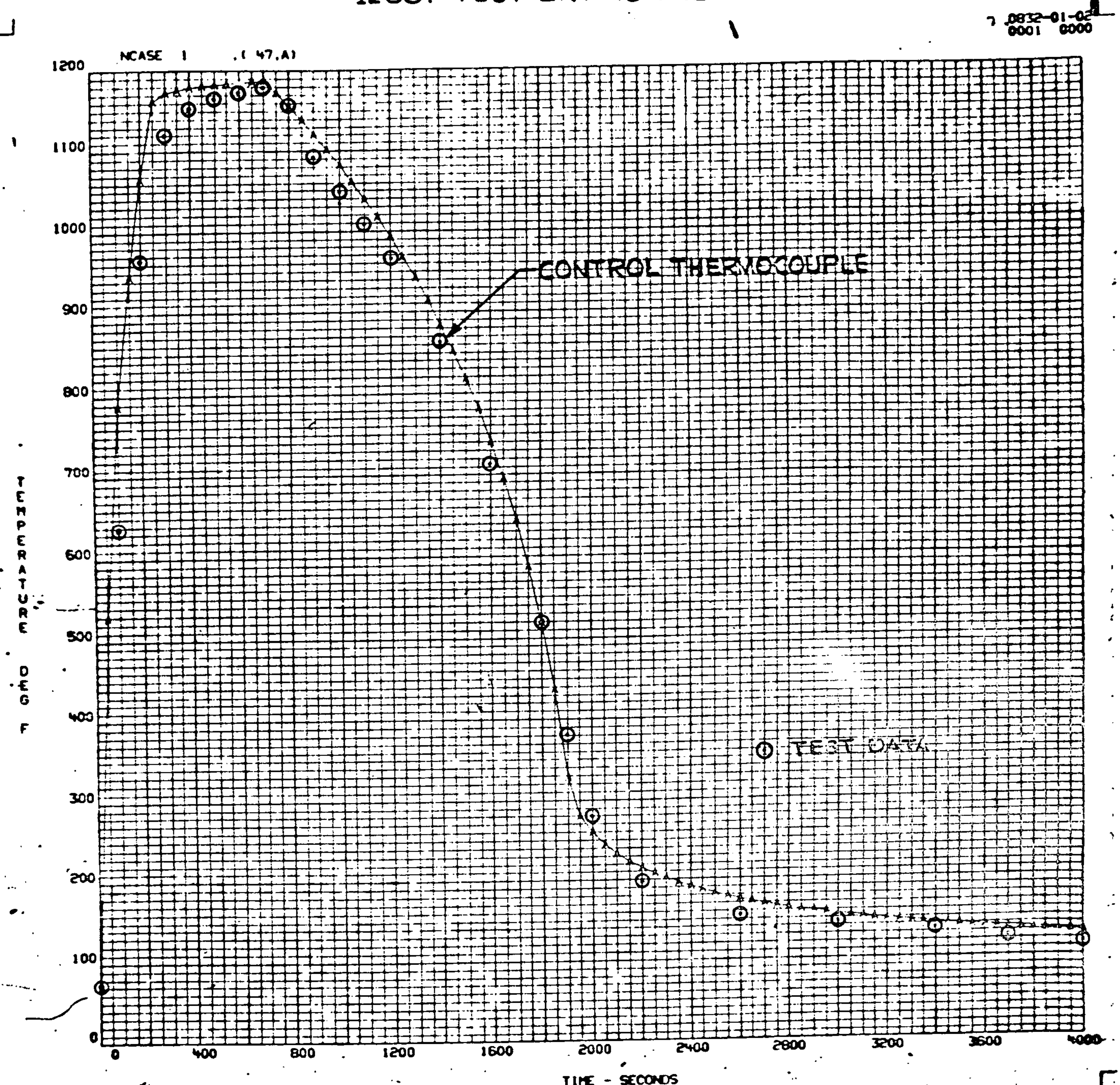

FIGURE 6(b). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT – G/E TEST ARTICLE

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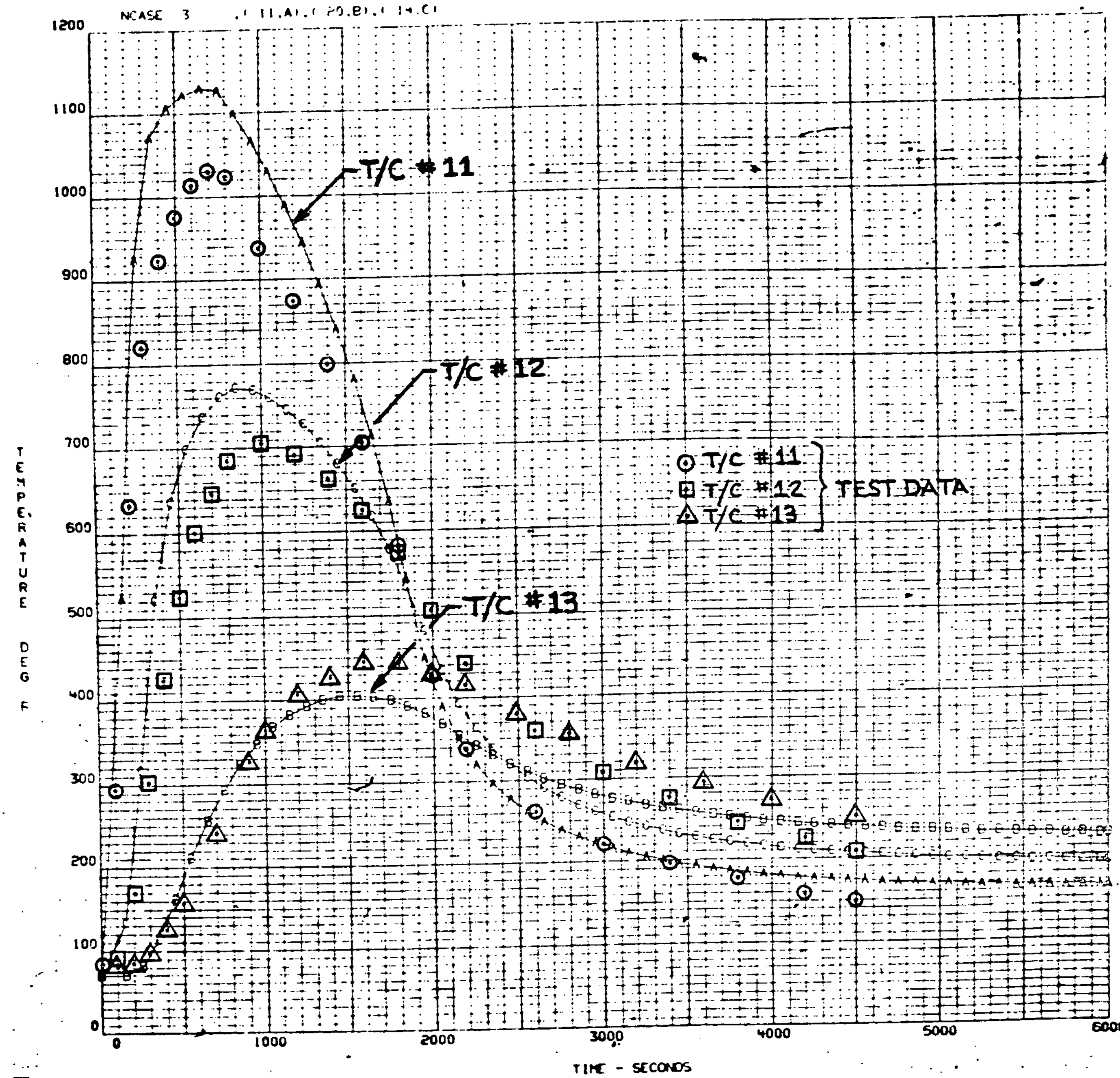


FIGURE 6(c). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF G/E COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

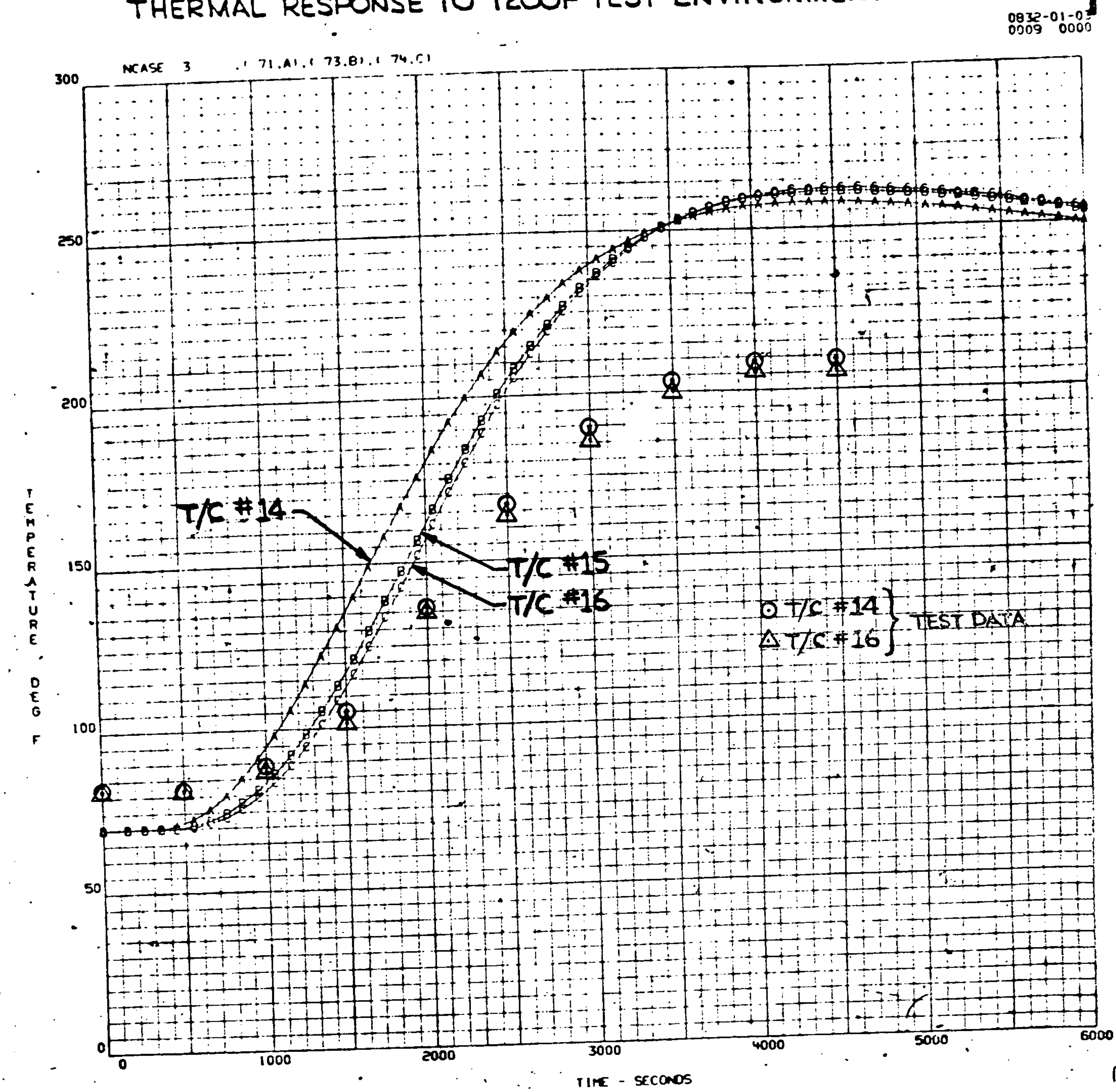


FIGURE 6(d). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT– B/AL TEST ARTICLE

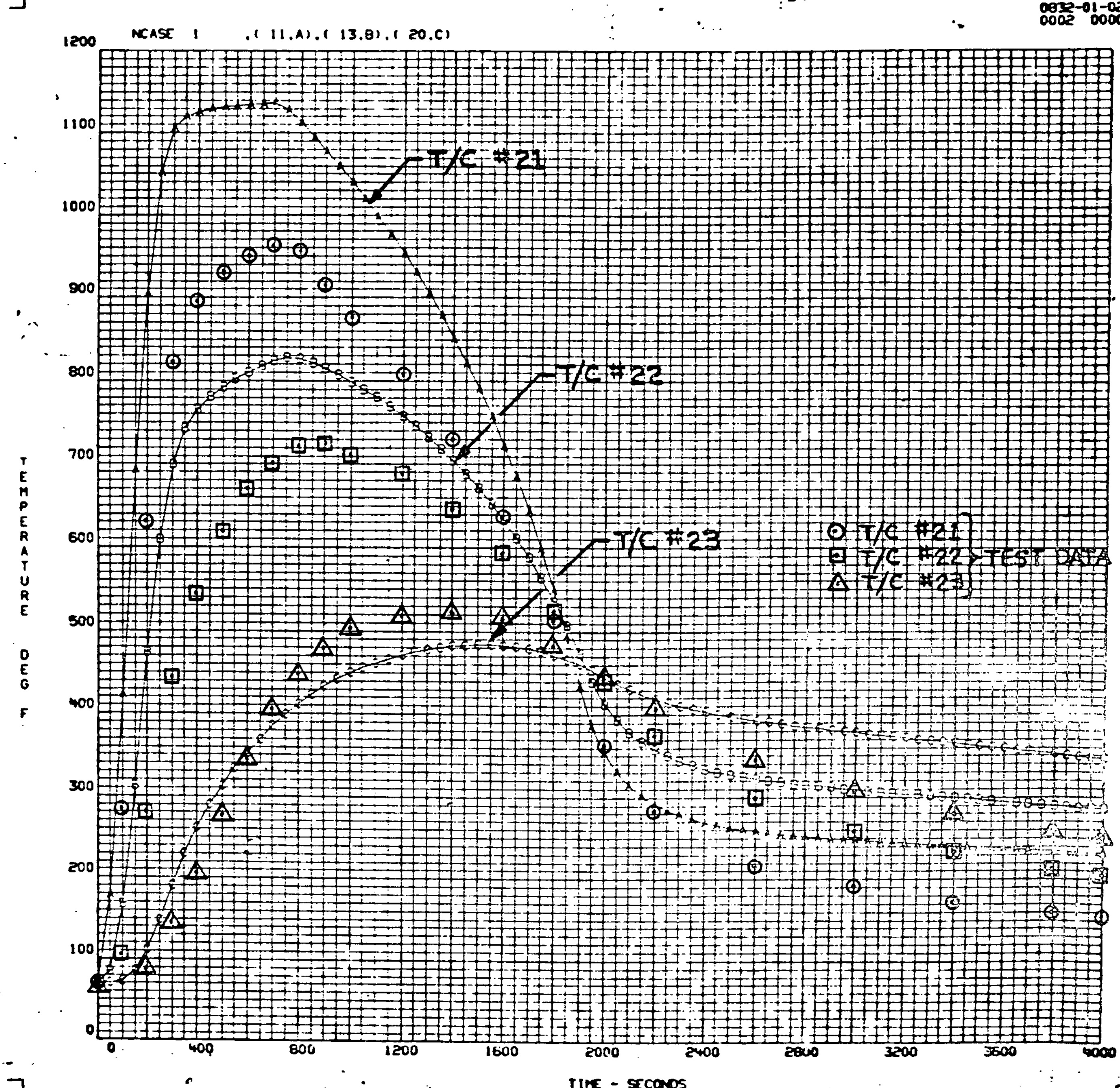


FIGURE 6(e). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF B/AL COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

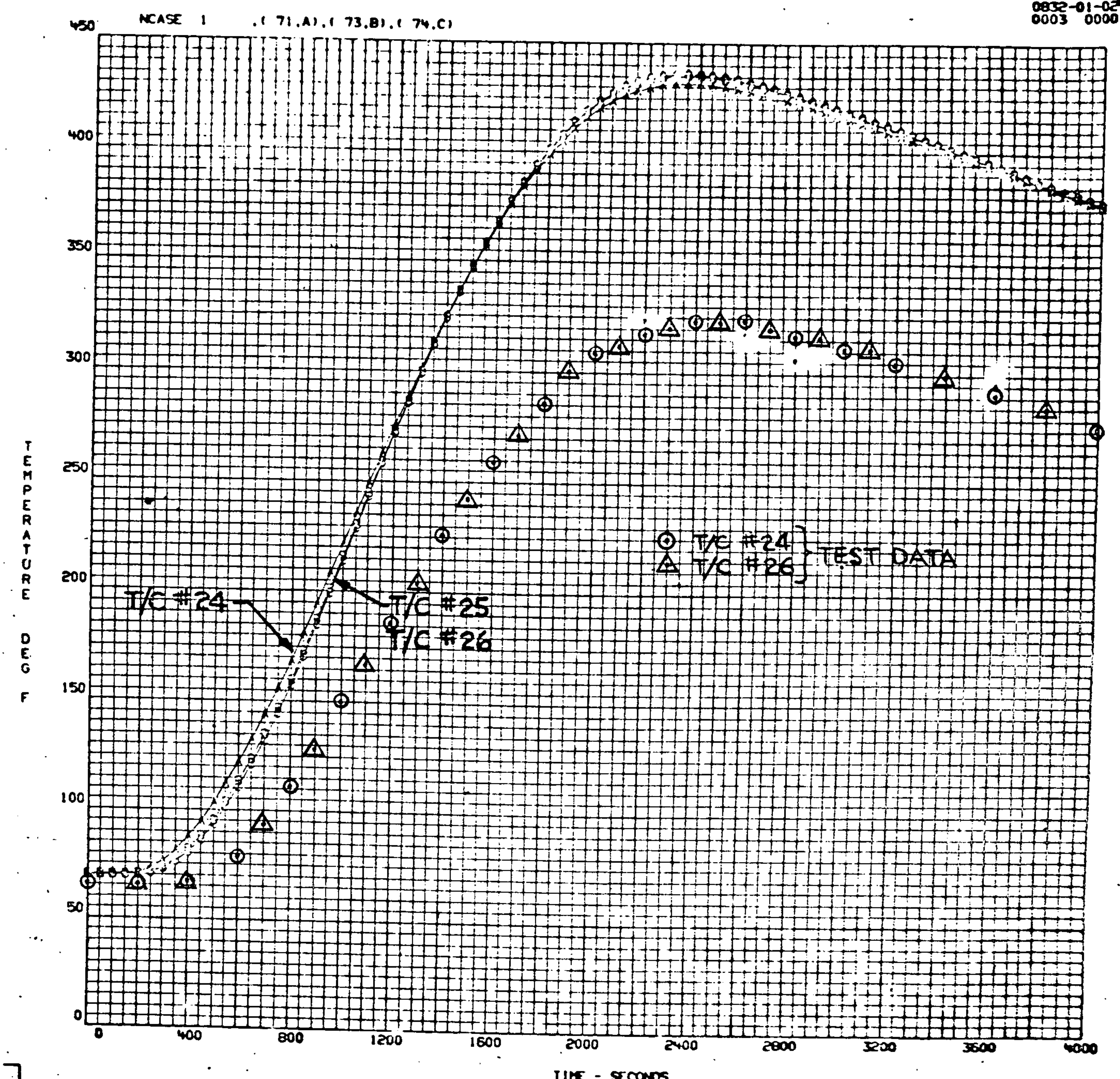


FIGURE 6(f). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1200F TEST ENVIRONMENT– B/PI TEST ARTICLE

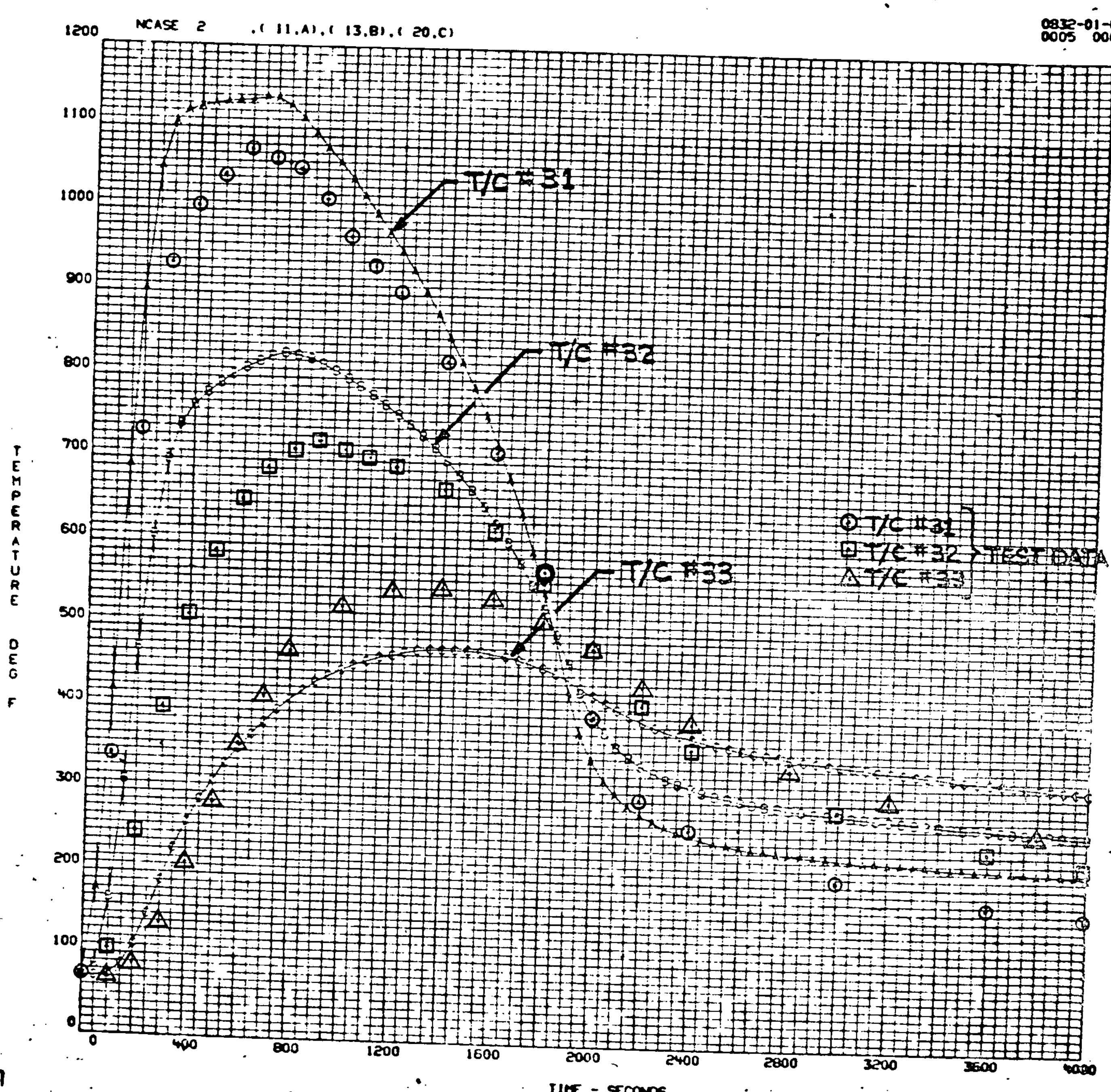


FIGURE 6(g). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF B/PI COMPOSITE PANEL THERMAL RESPONSE TO 1200F TEST ENVIRONMENT

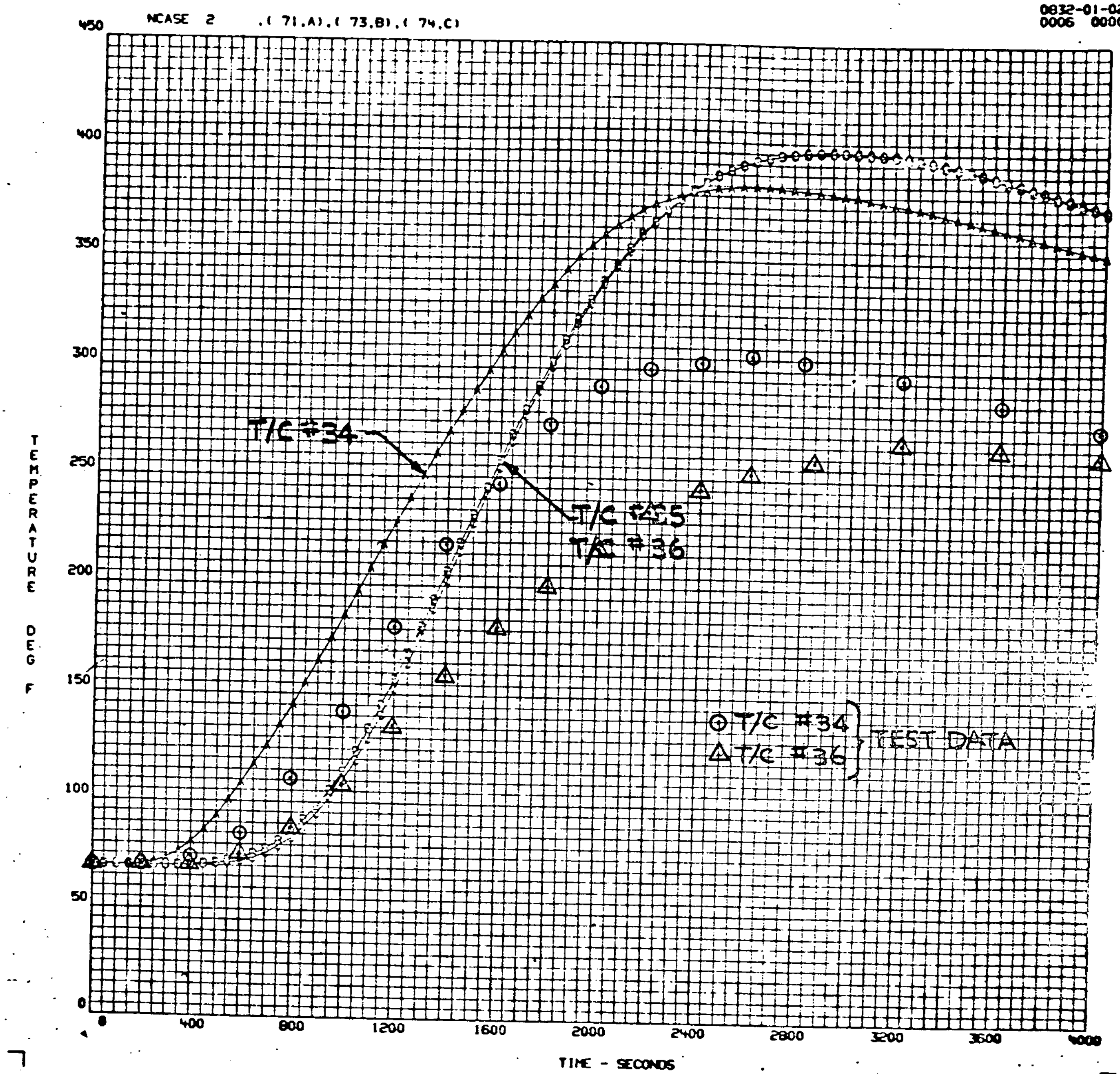


FIGURE 7(a). COMPARISON OF PLANNED AND MEASURED 1800F TEST ENVIRONMENT

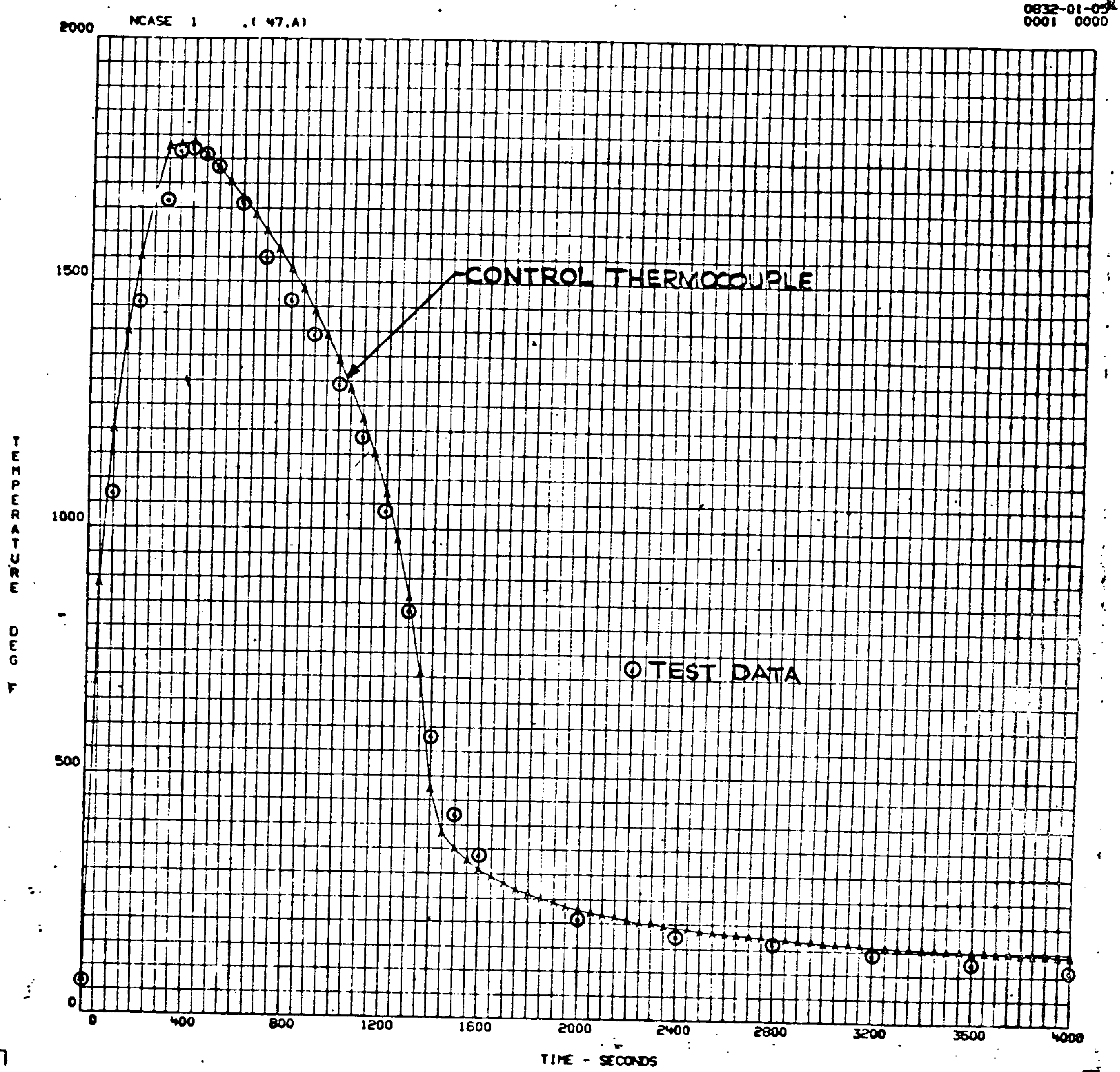


FIGURE 7(b). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT – G/E TEST ARTICLE

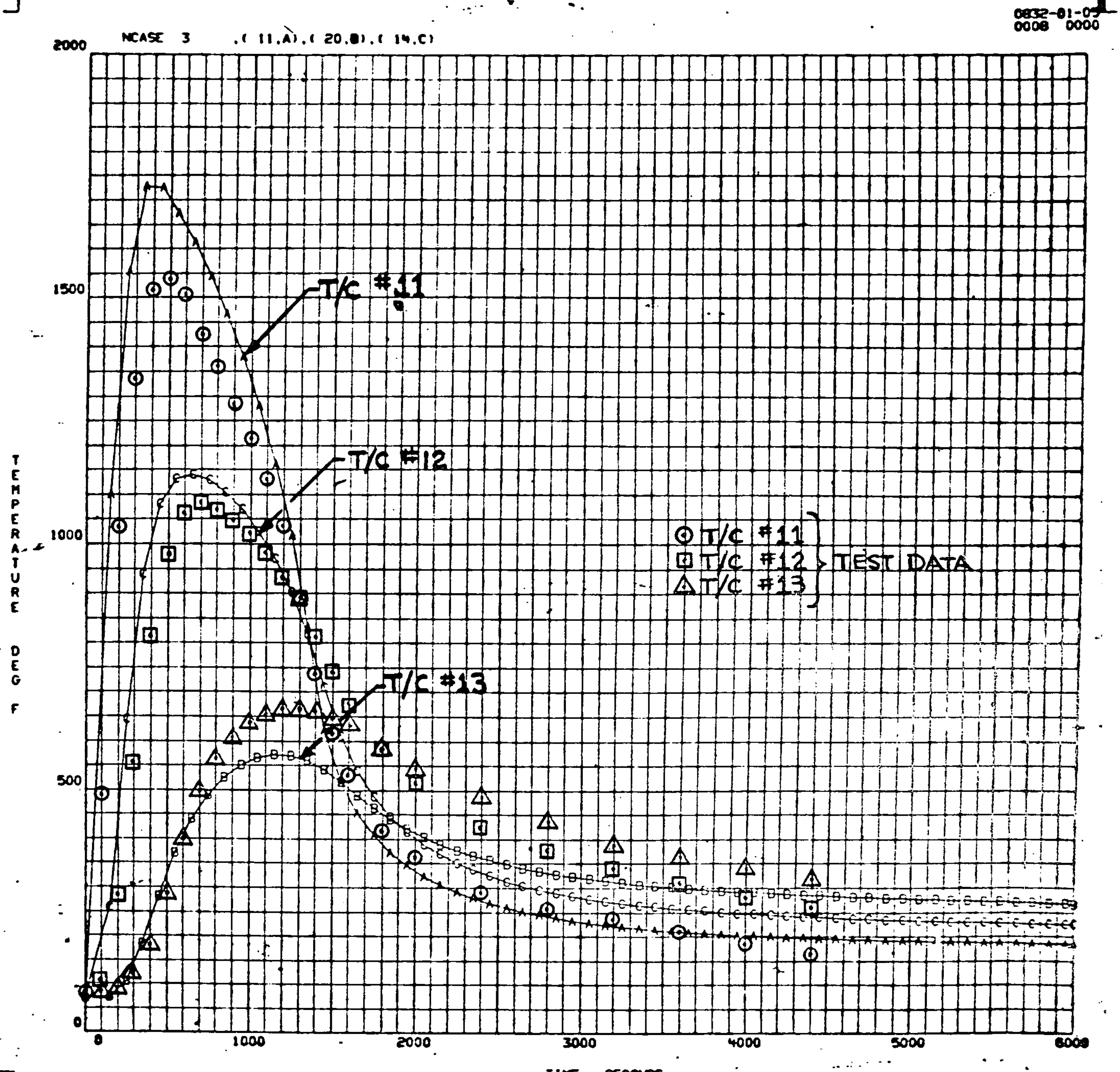


FIGURE 7(C). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF G/E COMPOSITE PANEL THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

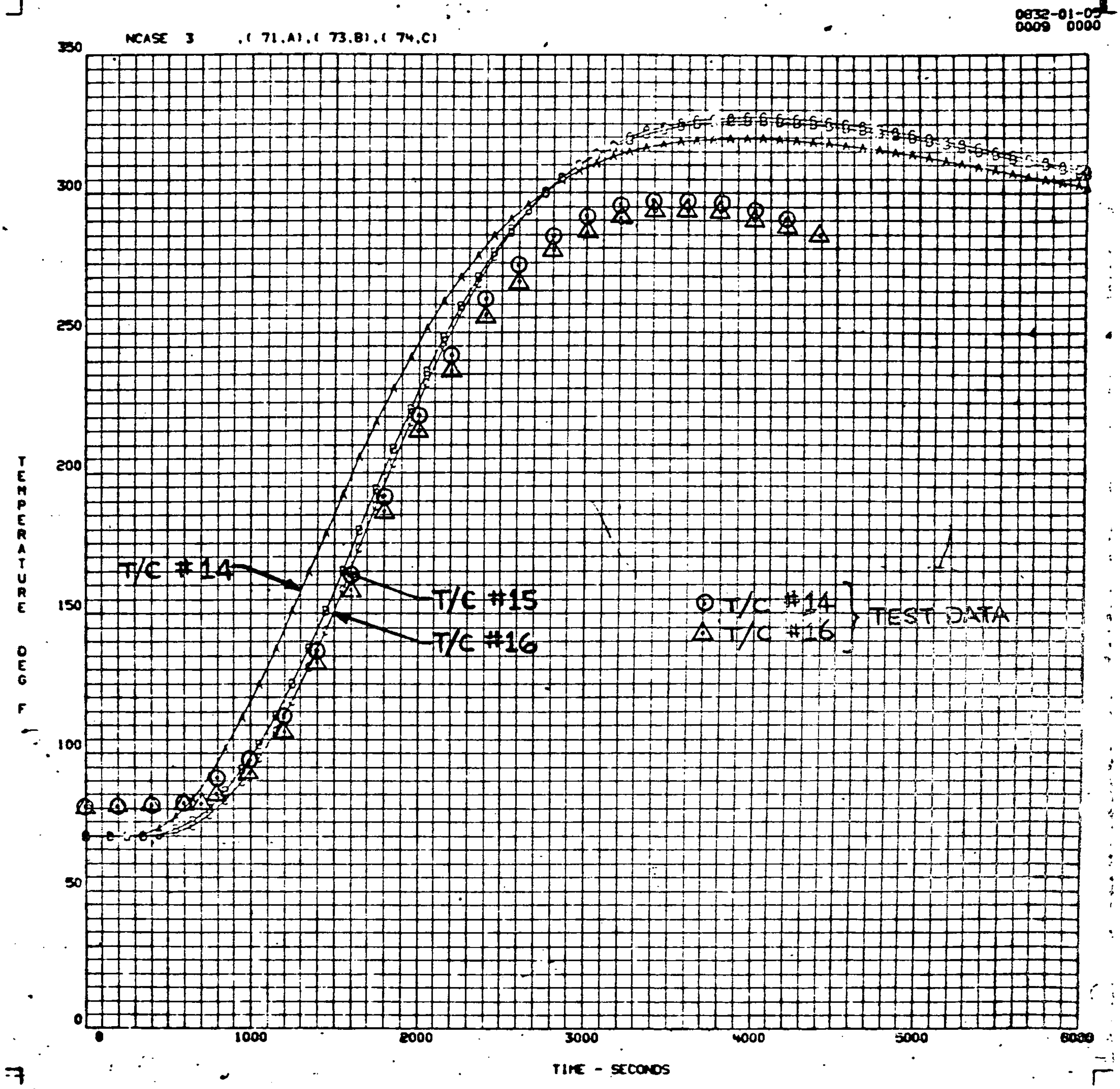


FIGURE 7(d). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT – B/AL TEST ARTICLE

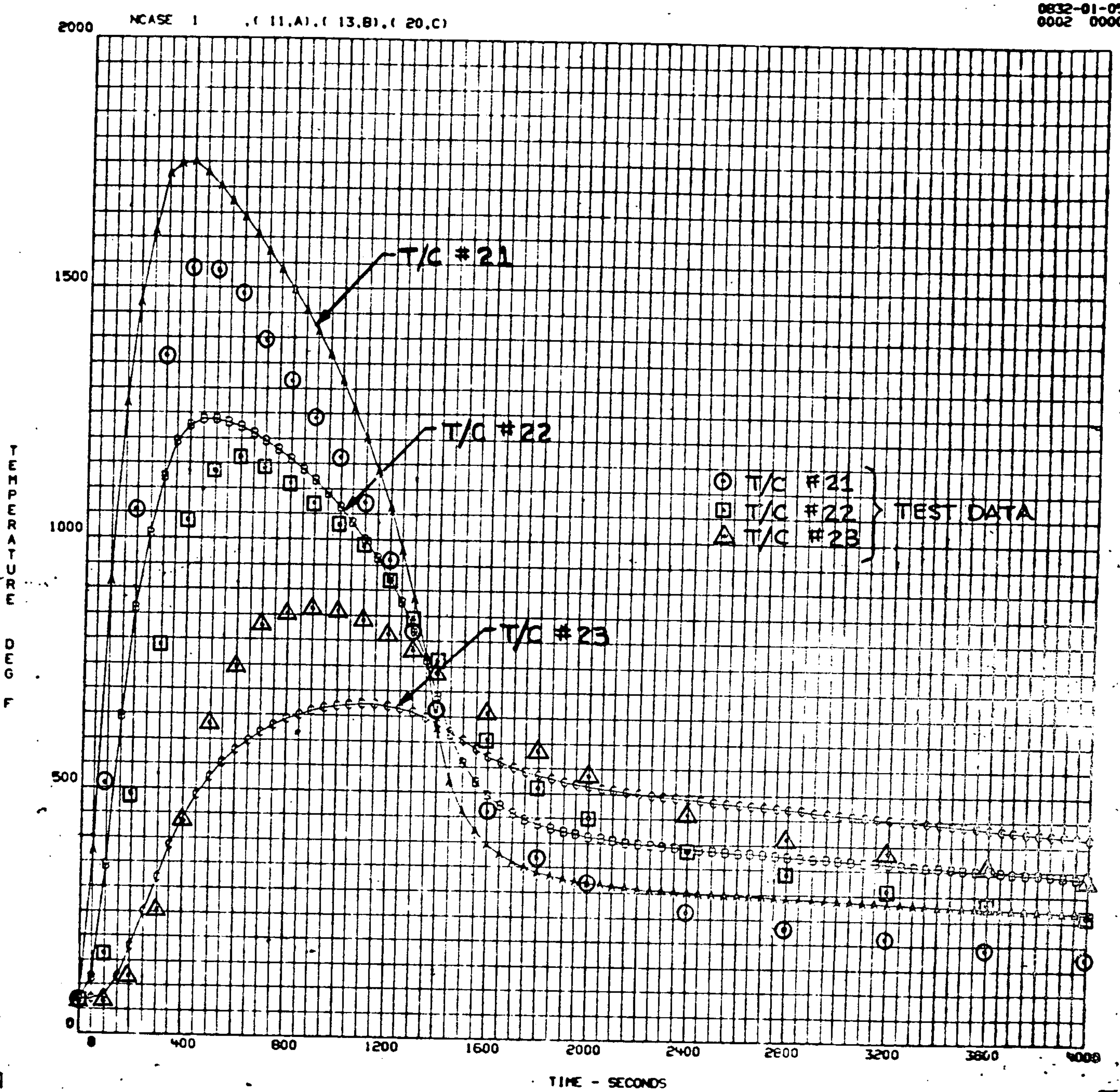


FIGURE 7(e). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF B/AL COMPOSITE PANEL. THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

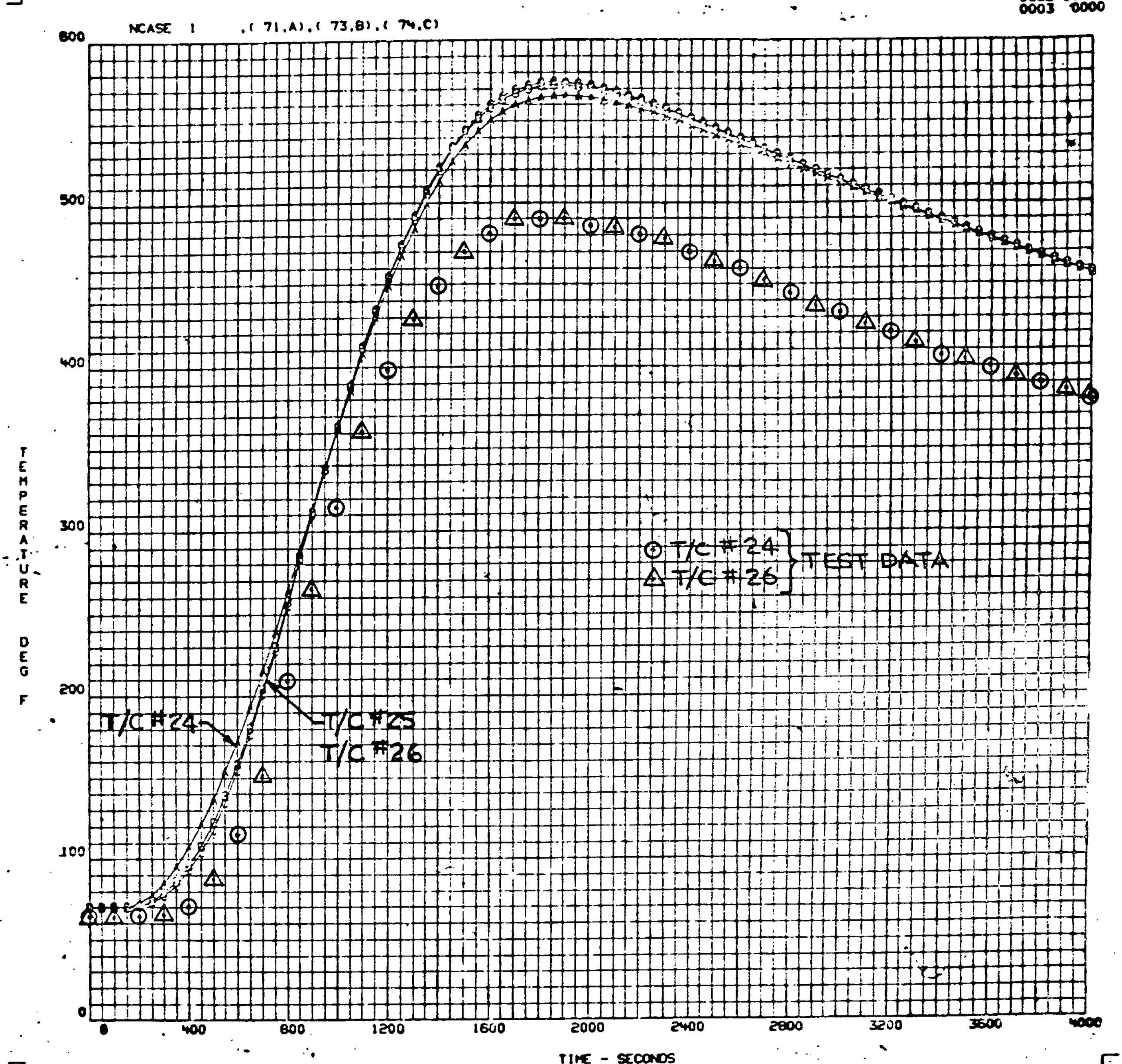


FIGURE 7(f). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF STAND-OFF THERMAL RESPONSE TO 1800F TEST ENVIRONMENT- B/PI TEST ARTICLE

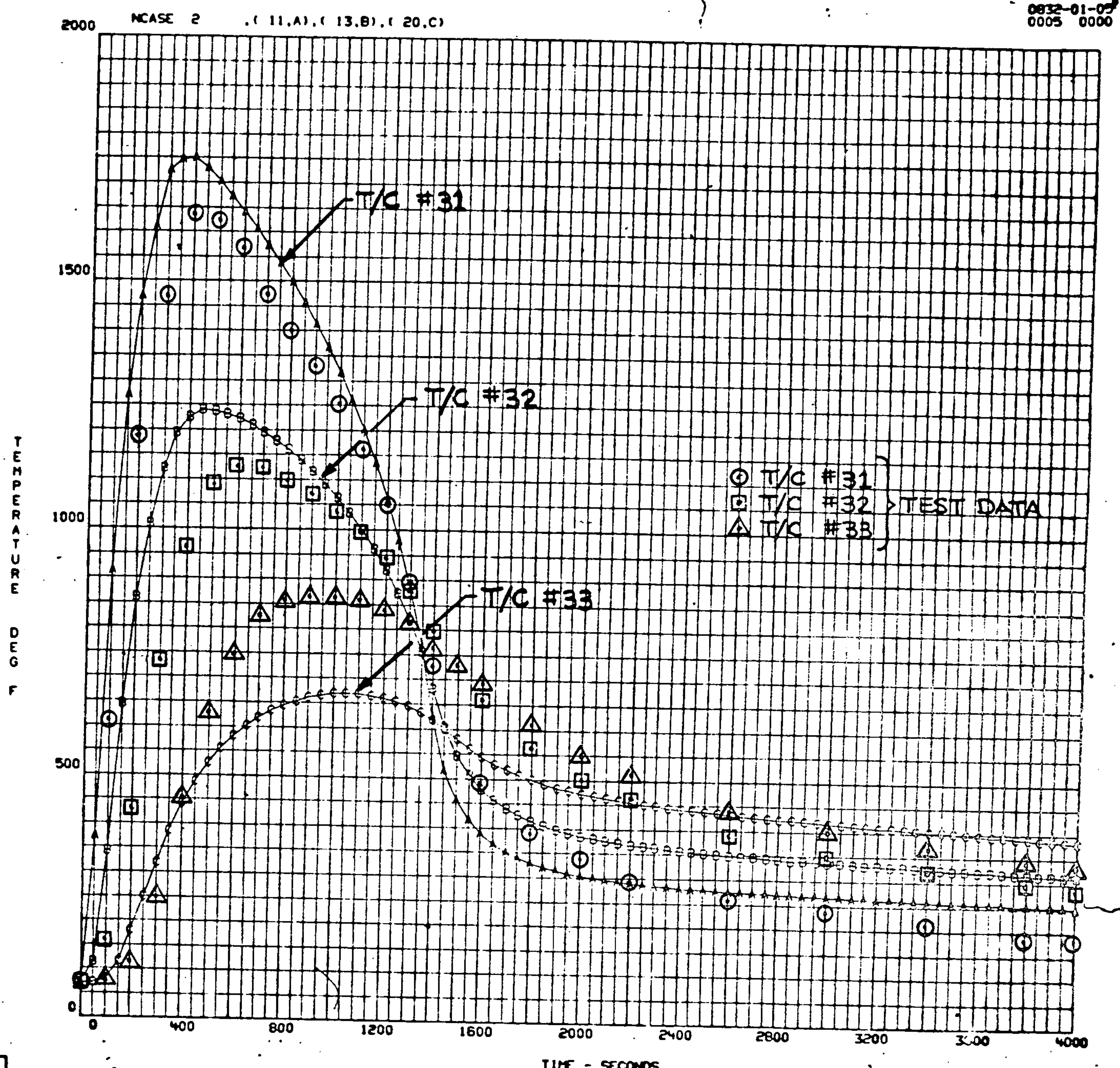


FIGURE 7(g). COMPARISON OF TEST MEASUREMENTS AND PRE-TEST PREDICTION OF B/PI COMPOSITE PANEL THERMAL RESPONSE TO 1800F TEST ENVIRONMENT

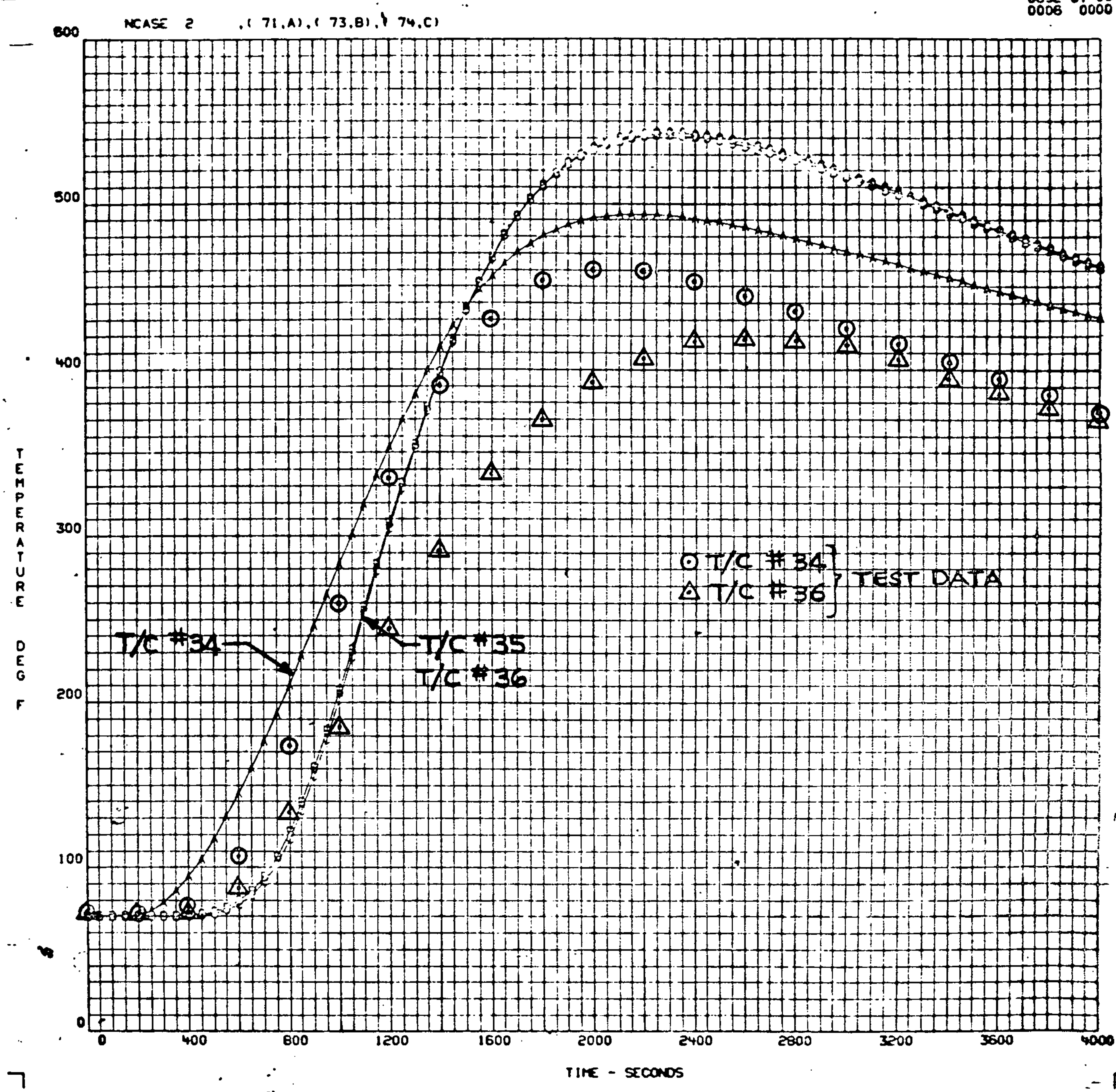


TABLE I
COMPARISON OF PRE-TEST PREDICTIONS AND THERMOCOUPLE MEASUREMENTS OF MAXIMUM TEST ARTICLE TEMPERATURES FOR 1200F MAXIMUM SURFACE TEMPERATURE CONDITION*

Thermocouple Location	Graphite/Epoxy Composite			Boron/Aluminum Composite			Boron/Polyimide Composite		
	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.
#1	11	1130F	1031F	21	1135F	962F	31	1135F	1078F
#2	12	770F	705F	22	830F	727F	32	830F	725F
#3	13	405F	444F	23	485F	526F	33	480F	554F
#4	14	260F	209F	24	430F	323F	34	385F	306F
#5	15	260F	209F	25	435F	323F	35	400F	271F
#6	16	260F	206F	26	435F	323F	36	400F	268F
#7	17	260F**	209F	27	435F**	323F	37	400F**	265F

* REFER TO FIGURE 3 FOR THERMOCOUPLE LOCATIONS

** ESTIMATED (NOT INCLUDED IN 2-D THERMAL ANALYSES)

TABLE II
COMPARISON OF PRE-TEST PREDICTIONS AND THERMOCOUPLE MEASUREMENTS OF MAXIMUM TEST ARTICLE TEMPERATURES FOR 1800F MAXIMUM SURFACE TEMPERATURE CONDITION*

Thermocouple Location	Graphite/Epoxy Composite			Boron/Aluminum Composite			Boron/Polyimide Composite		
	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.	T/C No.	Pre-Test Max.Temp. Prediction	Measured Max. Temp.
#1	11	1740F	1543F	21	1750F	1554F	31	1750F	1641F
#2	12	1140F	1084F	22	1240F	1164F	32	1240F	1131F
#3	13	570F	672F	23	675F	863F	33	670F	871F
#4	14	320F	297F	24	565F	489F	34	495F	458F
#5	15	325F	294F	25	570F	500F***	35	540F	428F
#6	16	330F	294F	26	575F	489F	36	545F	420F
#7	17	330F**	294F	27	575F**	489F	37	545F**	415F

*REFER TO FIGURE 3 FOR THERMOCOUPLE LOCATIONS

**ESTIMATED (NOT INCLUDED IN 2-D THERMAL ANALYSES)

***SUSPECT DATA AT TIME OF MAXIMUM TEMPERATURE

TEST PLAN FOR THERMAL DESIGN VERIFICATION OF HIGH TEMPERATURE TPS ATTACHMENTS TO COMPOSITE MATERIALS

TEST PLAN SCOPE

The scope of this test plan includes detailed pre-test thermal analyses, fabrication and procurement of test hardware, assembly of test specimens, test specimen instrumentation, radiant heating environment tests, and comparison of test data with analytical thermal data. Specific tasks have been coordinated with the persons indicated as follows:

Subtask 4.1	Detailed Pre-Test Thermal Analyses	G. Mauss D/190
4.2	Test Article Design and Test Requirements Definition	G. Mauss D/190
4.3	Test Hardware Procurement and Fabrication of Composite Panel	M. Nadler D/191 M. Suppanz D/098
4.4	Assembly of Test Articles	M. Suppanz D/098
4.5	Test Specimen Instrumentation	M. Suppanz D/098
4.6	Thermal Tests	M. Suppanz D/098
4.7	Test Data and Test Data Reduction	M. Suppanz D/098
4.8	Post-Test Analyses	G. Mauss D/190
4.9	Test Report	G. Mauss D/190

TEST OBJECTIVE

The object of this test program is to obtain temperature measurements for verification of thermal analysis methods and thermal property data utilized in the preliminary design evaluation of high temperature TPS attachments to composite structures per Task 4 of NAS8-27041, "Thermal Design of Composite Material High Temperature Attachments".

DETAILED PRE-TEST THERMAL ANALYSES (Subtask 4.1)

The thermal tests will consist of three composite materials (Graphite/Epoxy, Boron/Polyimide, and Boron/Aluminum) exposed simultaneously to two different radiant heating environments. Detailed 2-D thermal analyses have been performed to define the two environments (1200F and 1800F maximum surface temperatures) such that maximum temperatures of the three composite materials will not exceed design temperature limits (350F for Graphite/Epoxy, 600F for Boron/Polyimide, and 650F for Boron/Aluminum). The exposure time for the 1200F surface temperature condition is limited to that which will produce temperature increases of the composite substructure to approximately two-thirds of the design temperature limit; the exposure time for the 1800F surface temperature environment is defined analytically to produce composite structure maximum temperatures to within 90-95% of design limits. With the definition of these environments, detailed thermal analyses will be performed to establish temperature histories throughout each test specimen, including the instrumented locations on each specimen. The two environments are illustrated graphically in Figures 1(a) and 1(b).

TEST ARTICLE DESIGN AND TEST REQUIREMENTS DEFINITION (Subtask 4.2)

The general test arrangement design is presented in Figure 2. The heating area of the radiant lamp fixture is approximately 19 by 22 inches. For prevention of edge heat sink effects, the three test specimens are located such that no edge of any test article is closer than 2.5 inches to the heating area boundary and 3 inches to any other test article. Fibrous insulation (6 pcf Dynaflex) above the composite structure simulates the insulation of a design TPS system and is also provided in the test arrangement to support the test articles and insulate the composite structure panels from edge conditions and excessive heat sink effects of the test bed. A layer of Irish Refrasil Cloth over the entire heated surface provides a constant emittance surface. Fiber orientations for each 4 x 7 inch composite panel have been selected to produce temperature gradients on the lengthwise centerline of the standoff/composite panel specimens and are schematically illustrated in Figure 2 in the upper left-hand corner of each composite panel outline.

The radiant environments discussed previously will be controlled by a feedback system driven by a pre-programmed surface temperature measured by a control thermocouple located in the center of the test area (away from the influence of the test specimens). A detailed description of the components required for each test article is provided by Table I.

TEST HARDWARE FABRICATION AND PROCUREMENT (Subtask 4.3)

The components required for the tests (Table I) will be obtained from in-house stock, fabricated, or purchased. The stainless steel standoffs, which simulate the thickness to height ratio of the Haynes 188 standoffs utilized in the detailed thermal analysis (Second Quarterly Report), are to be fabricated by L&T per Figures 3(a)-1 and Figures 3(a)-2. The PBI and Chem Ceram Foam Isolators (Figures 3(b)-1, 3(b)-2, 3(b)-3) as well as the molded PI and Chem Ceram bushings [Figure 3(c)] are to be purchased from the vendor through M&P. Fabrication of the Graphite/Epoxy, Boron/Polyimide, and Boron/Aluminum composite panels will be accomplished by L&T and coordinated through M&P. The Dynaflex insulation and fasteners will be provided for the tests by L&T from in-house stock.

ASSEMBLY OF TEST ARTICLES (Subtask 4.4)

The assembly of the test components will be performed by L&T per Figures 2 and 4. Figure 2 shows the location of test specimens relative to the test bed and radiant lamp fixture, and Figure 4 illustrates the standoff/isolator/composite assembly. The basic test article assembly includes the stainless steel hat-type standoff attached to the composite panel by a machine screw (3/16" diameter) through a thermal isolator block (PBI or Chem Ceram Foam). Molded bushings (PI or Chem Ceram) fit through the leg of the standoff and the composite panel, and are fitted flush to the top and bottom of the isolator block during assembly. The bushings provide for thermal isolation of the screw from the standoff leg, and for thermal isolation of the composite material from the screw.

TEST SPECIMEN INSTRUMENTATION (Subtask 4.5)

Instrumentation of the test articles by L&T will be accomplished per Figures 2 and 4. Thermocouples will be located in the center of the standoff cap (#1), half way down the standoff height (#2), at the edge of the standoff leg (#3), on the composite panel lengthwise centerline directly below #3 (#4), along the lengthwise centerline, .75 inches from #4 (#5), along the lengthwise centerline at the edge of the panel (#6), and in the direction perpendicular to the lengthwise centerline, 1.50 inches from #4 (#7). Refer to Figures 2 and 4 for a pictorial representation of thermocouple locations. Each of the three test articles will be instrumented in the same manner.

A control thermocouple will be provided on the surface of the Refrasil Cloth in the center of the test area, as discussed previously, and will function as a feedback controller of radiant flux to the pre-programmed surface temperature, which is to be measured by the control thermocouple.

THERMAL TESTS (Subtask 4.6)

The thermal testing will be conducted in the 19 by 22 inch test fixture, utilizing the environments, test specimens, test specimen arrangement, and measurement scheme discussed. Test recording time will be determined from pre-test thermal analysis (Subtask 4.1).

TEST DATA AND TEST DATA REDUCTION (Subtask 4.7)

The test data generated shall consist of the following:

1. Dimensional measurements of test specimen assemblies and thermocouple locations.

2. Dimensional measurements of test assembly including spacing of test specimens, insulation thicknesses (both pre-test and post-test measurements), and relationship of radiant lamp bank to simulated TPS surface.

3. Temperature history recordings for test specimen thermocouples and control thermocouple.

Reduction of the test data shall be presented in a format suitable for use in analytical procedures. Format, data sample rates, and other data definition requirements will be negotiated with L&T. All test data will be reported in engineering units suitable for use in analytical procedures.

POST-TEST ANALYSES (Subtask 4.8)

Subsequent to receipt of the recorded test data, comparisons of the temperature histories predicted analytically at the thermocouple locations (pre-test analyses) will be made with the test data. The test data will be evaluated in this perspective, and any data anomalies (either analytical or test) will be assessed. Post-test thermal analyses will be performed if required for identification of possible causes of discrepancies between test and analytical results.

TEST REPORT (Subtask 4.9)

At the conclusion of the post-test data evaluation a test report will be prepared.

SCHEDULE

Figure 5 presents the planned schedule for the test and test reporting period. Significant dates include delivery of fabricated isolator blocks and bushings by January 7, 1972, completion of the tests by January 18, 1972, and completion of the test report by January 31, 1972.

FIGURE 1(a). 1200F TEST ENVIRONMENT

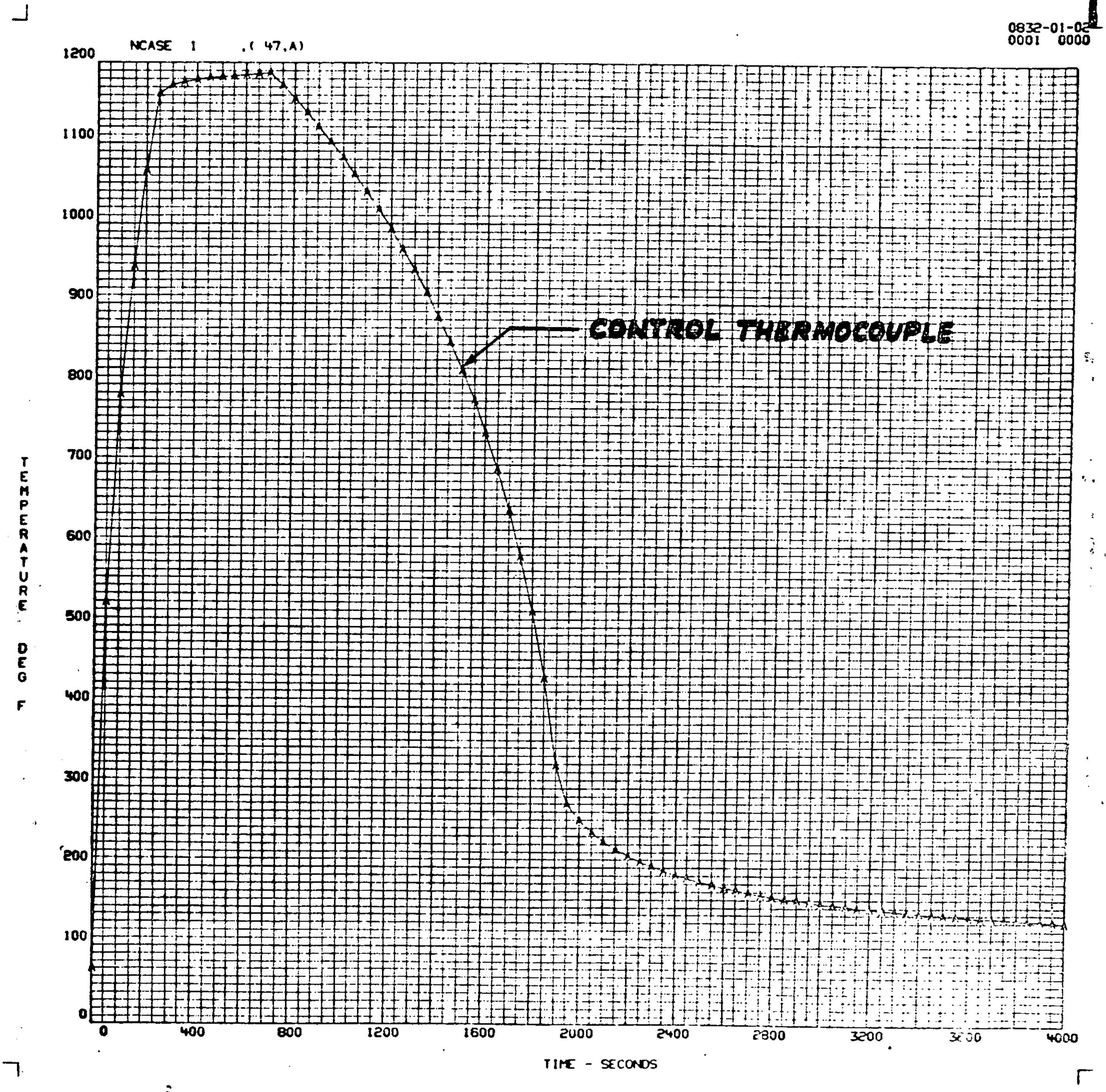


FIGURE 1 (b). 1800F TEST ENVIRONMENT

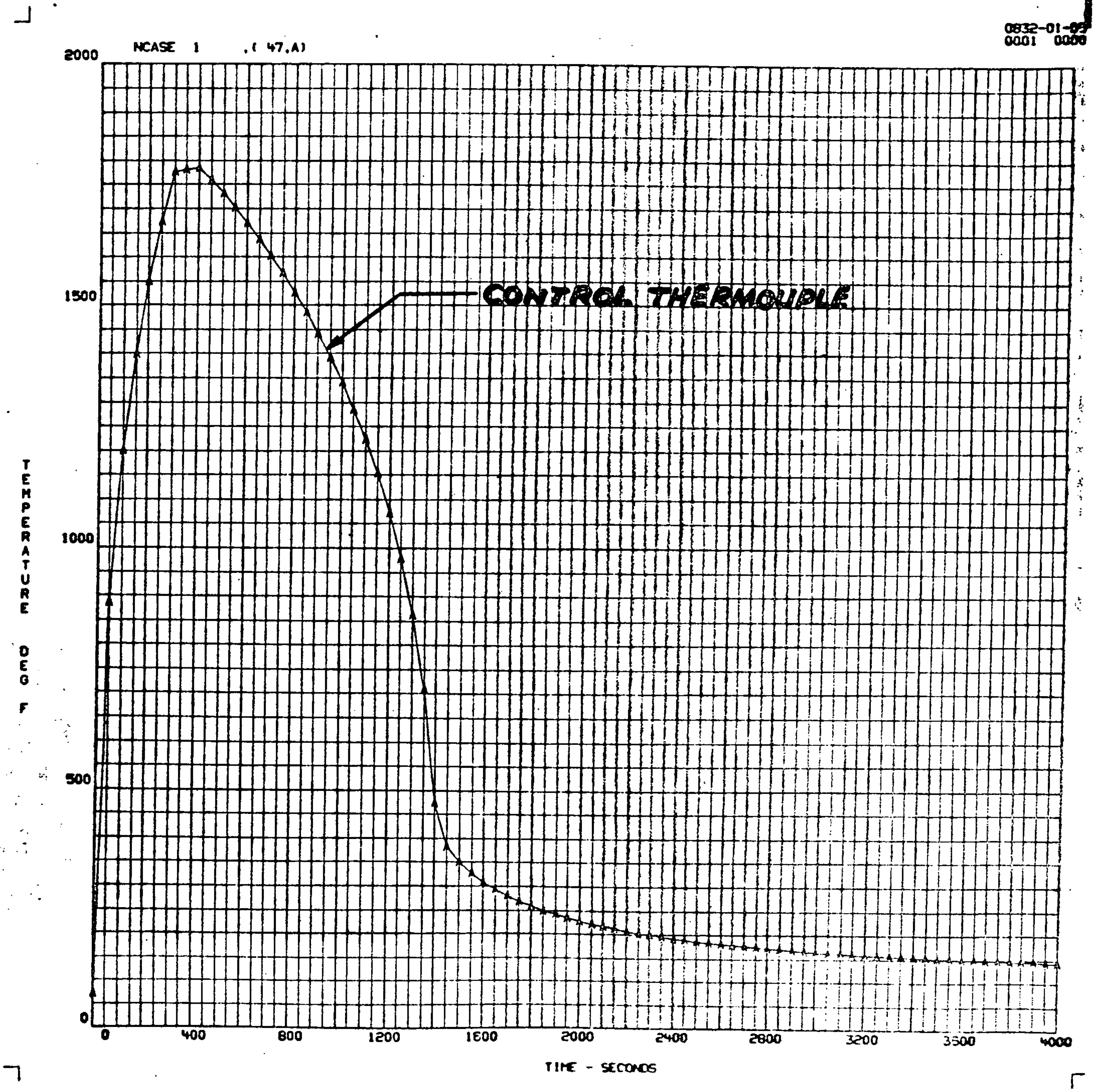


FIGURE 2. TEST ARRANGEMENT

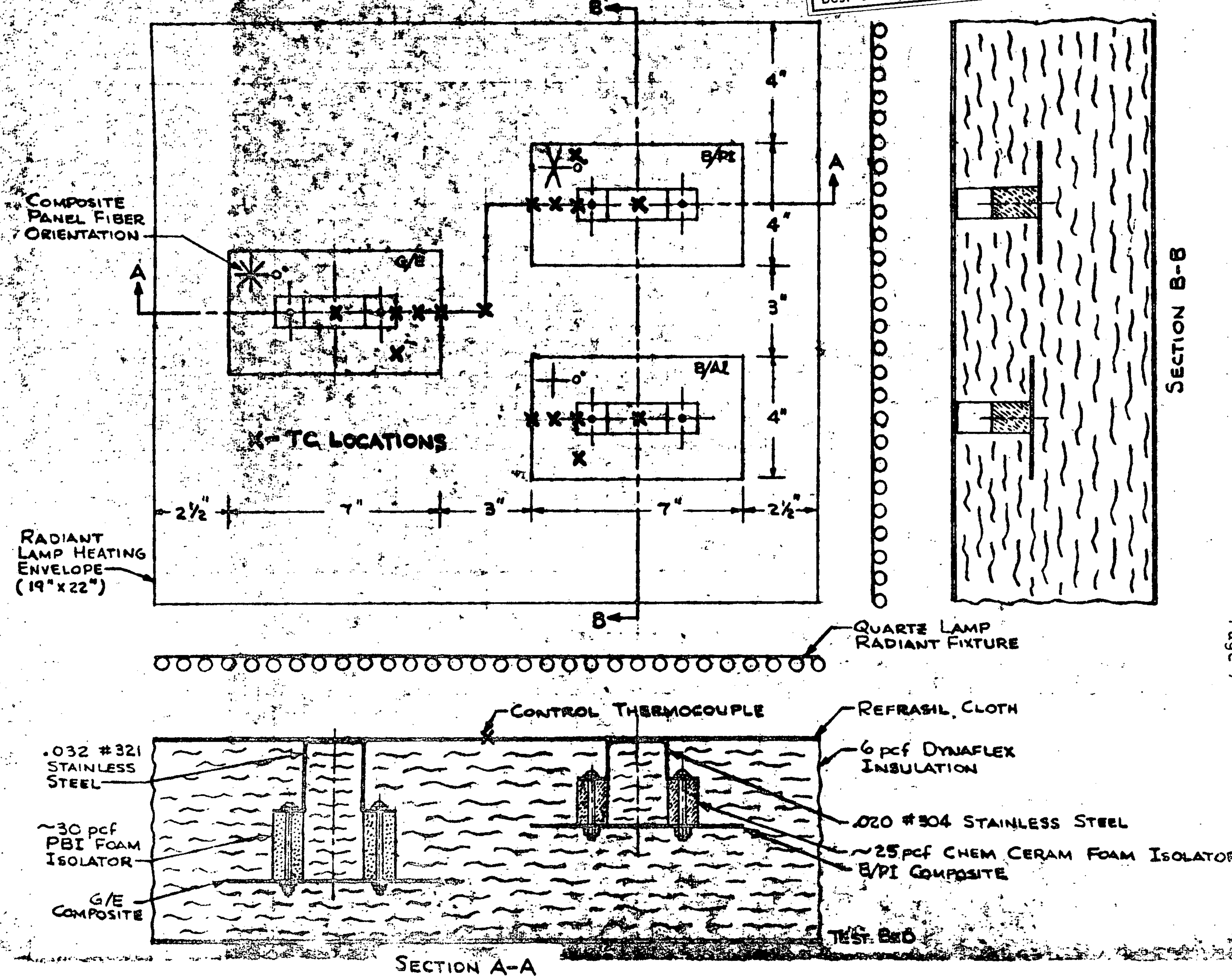
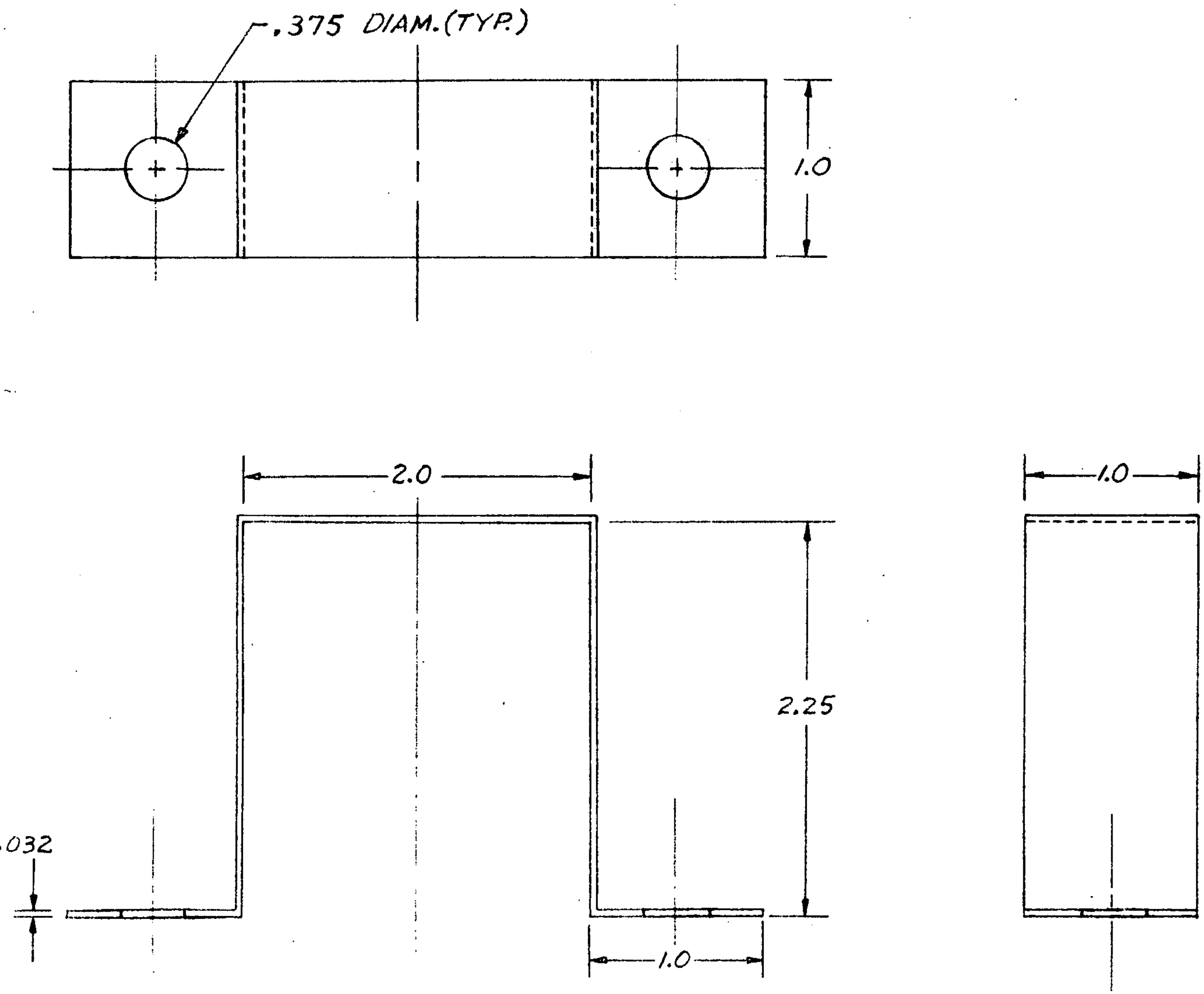


FIGURE 3(a)-1. STAINLESS STEEL STAND-OFF FOR G/E TEST SPECIMEN



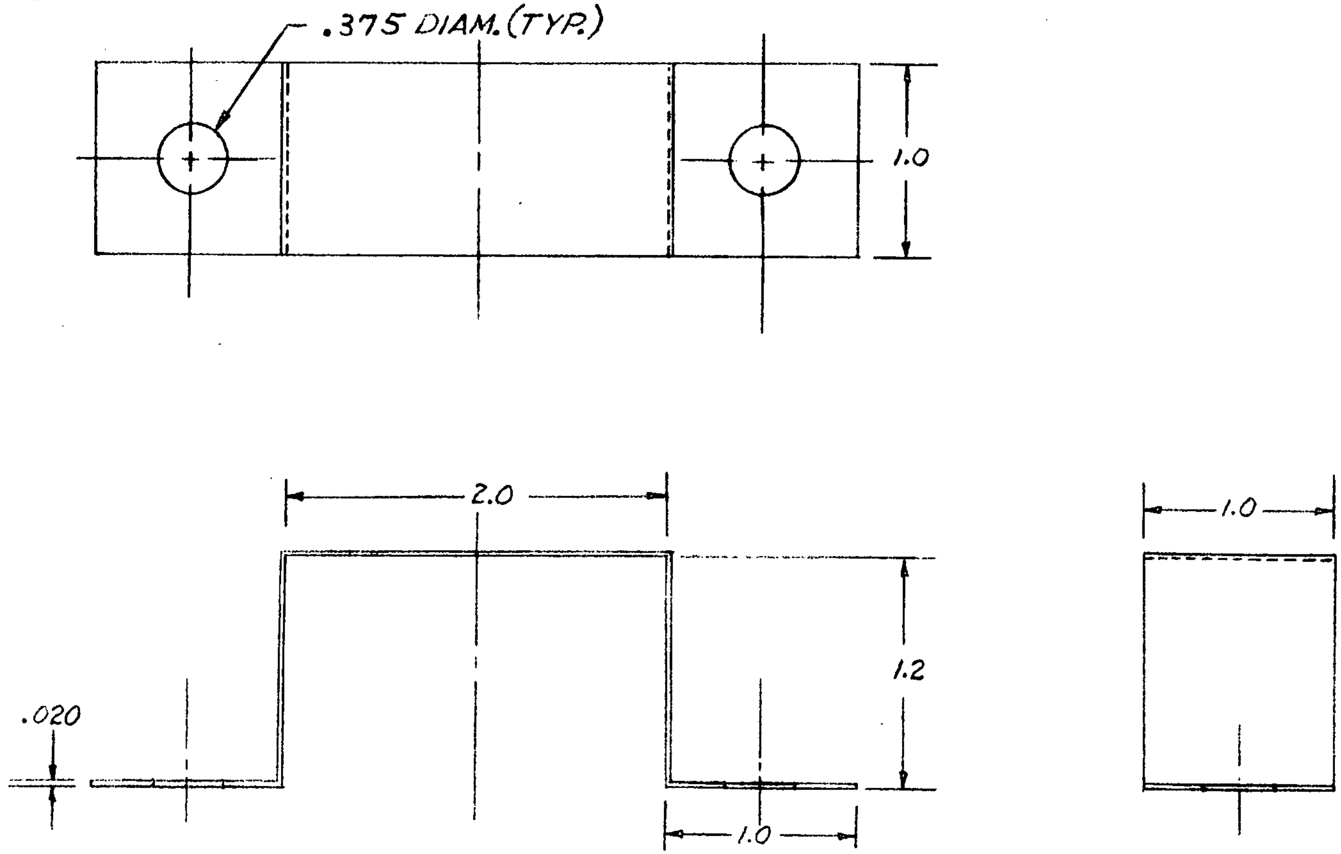
.032 #321 STAINLESS STEEL (1 REQ'D)

REVISED 12-10-71

SCALE : 1/1

GWM 12-3-71

FIGURE 3(a)-2. STAINLESS STEEL STAND-OFFS FOR B/PI AND B/AL TEST SPECIMENS

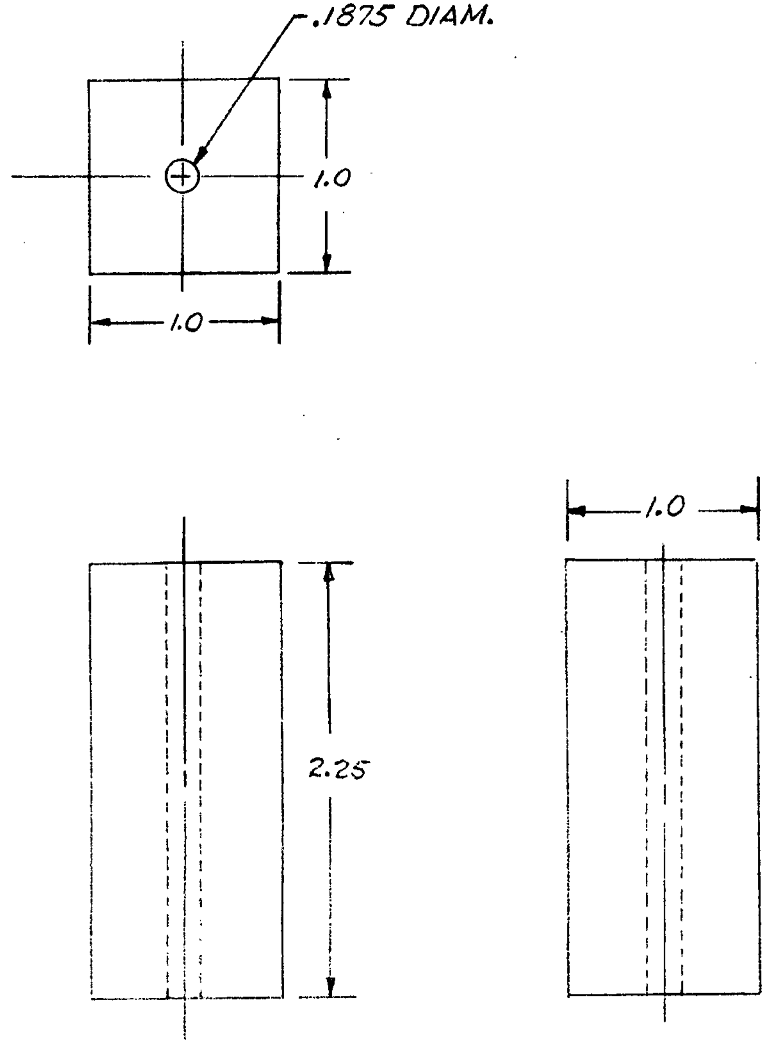


REVISED 12-10-7

.020 #304 STAINLESS STEEL (2 REQ'D)

SCALE: 1/1

FIGURE 3(b)-1. THERMAL ISOLATORS FOR G/E TEST SPECIMEN

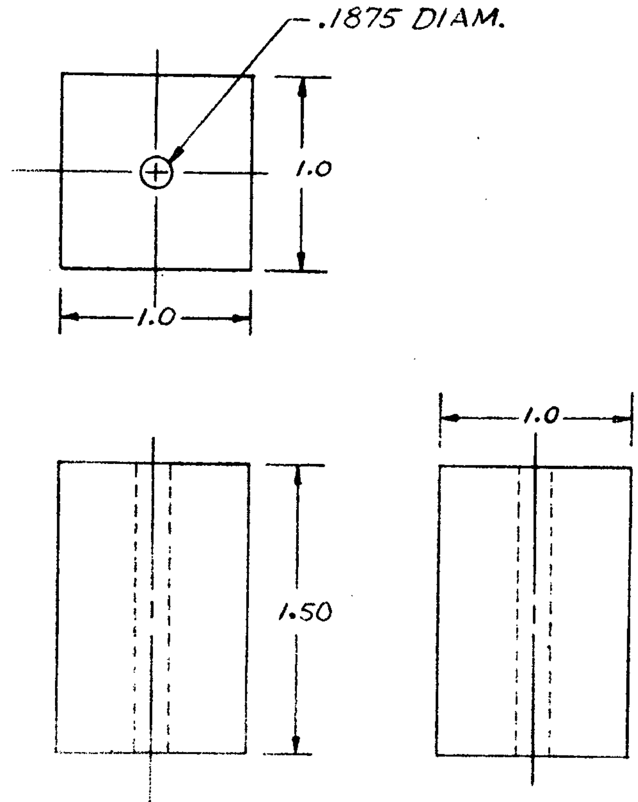


SYNTACTIC PBI FOAM (~31 PCF) BLOCK
(3 REQ'D)

SCALE: 1/1

GWM 12-3

FIGURE 3(b)-2. THERMAL ISOLATORS FOR B/PI TEST SPECIMEN

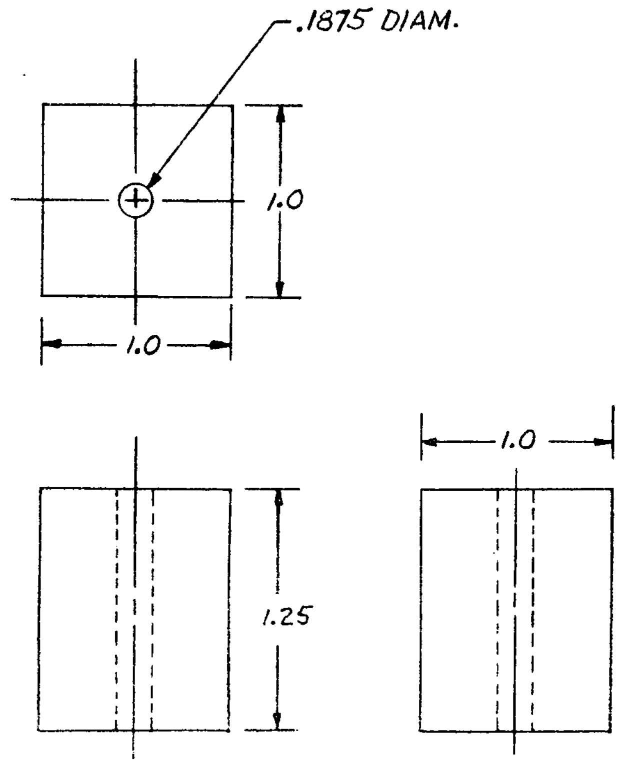


CHEM CERAM FOAM (~25 PCF) BLOCK
(4 REQ'D)

SCALE: 1/1

GWM 12-3-71

FIGURE 3(b)-3. THERMAL ISOLATORS FOR B/AL TEST SPECIMEN



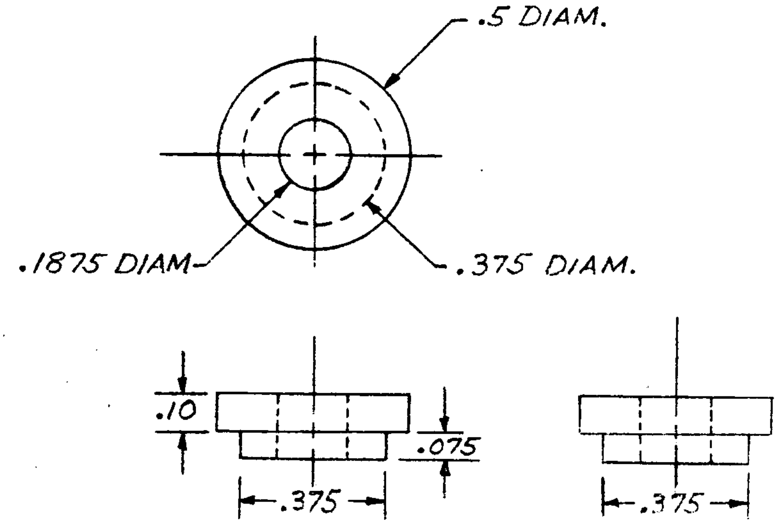
CHEM CERAM FOAM (~25 PCF) BLOCK
(4 REQ'D)

SCALE: 1/1

GWM 12-3-71

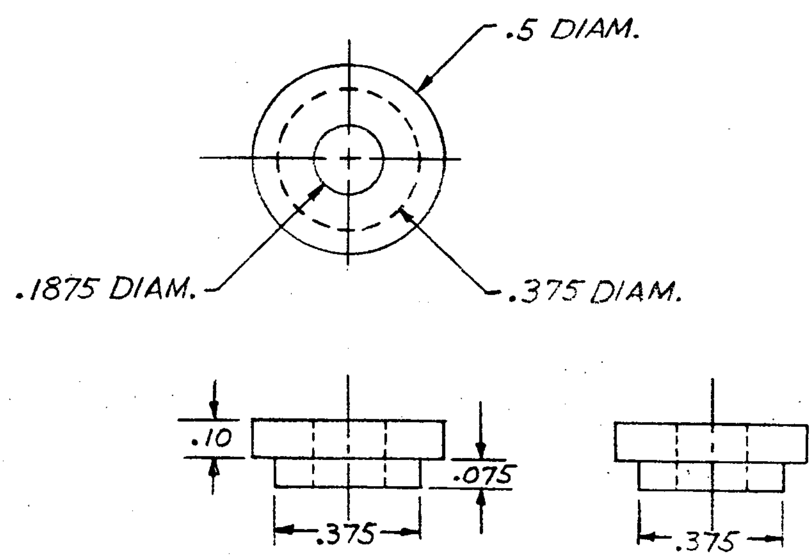
FIGURE 3(c). BUSHINGS FOR G/E, B/PI, AND B/AL TEST SPECIMENS

SCALE: 2/1



MOLDED POLYIMIDE (~120 PCF) BUSHING
(6 REQ'D)

SCALE: 2/1



MOLDED CHEM CERAM (~125 PCF) BUSHING
(12 REQ'D)

GWM 12-3-71

FIGURE 4. STAND-OFF/COMPOSITE SYSTEM ASSEMBLY AND THERMOCOUPLE LOCATIONS FOR TEST

NOTES: (1.) DYNAFLEX INSULATION NOT SHOWN

(2.) ISOLATION BUSHINGS FIT TO TEST CONFIGURATION

(3.) REFER TO FIGURE 2 FOR TEST CONFIGURATION AND COMPOSITE PANEL FIBER ORIENTATION RELATIVE TO TEST CONFIGURATION.

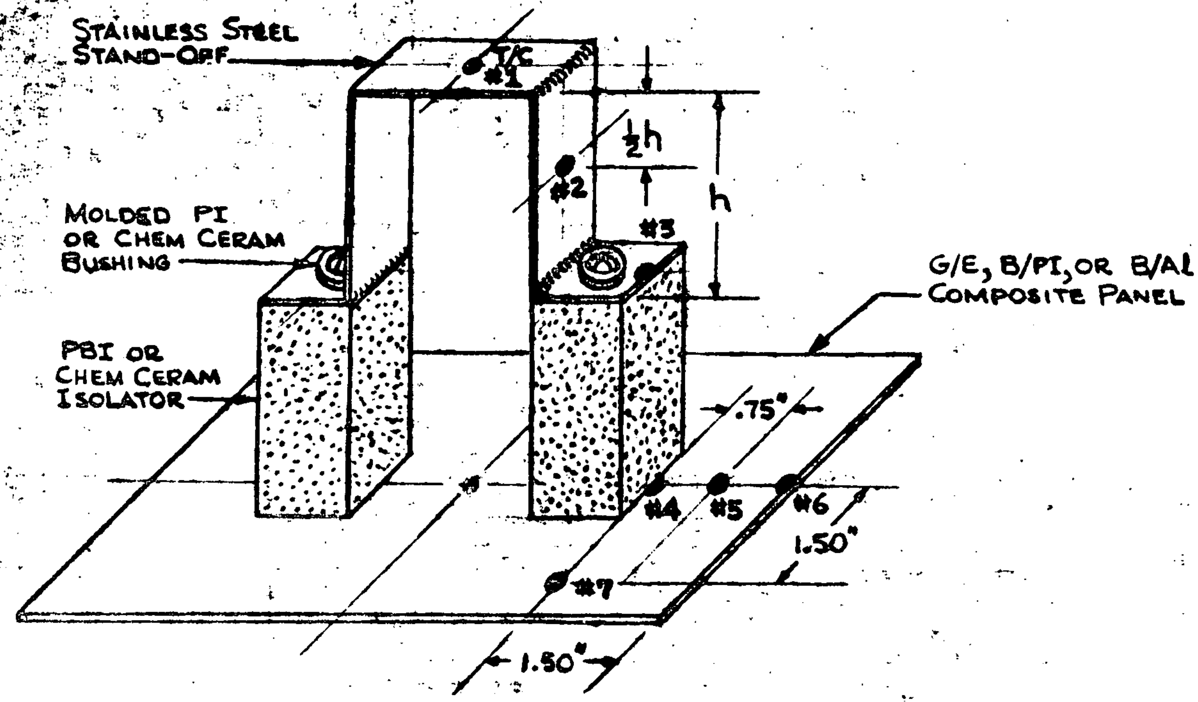


FIGURE 5. TEST PLAN SCHEDULE

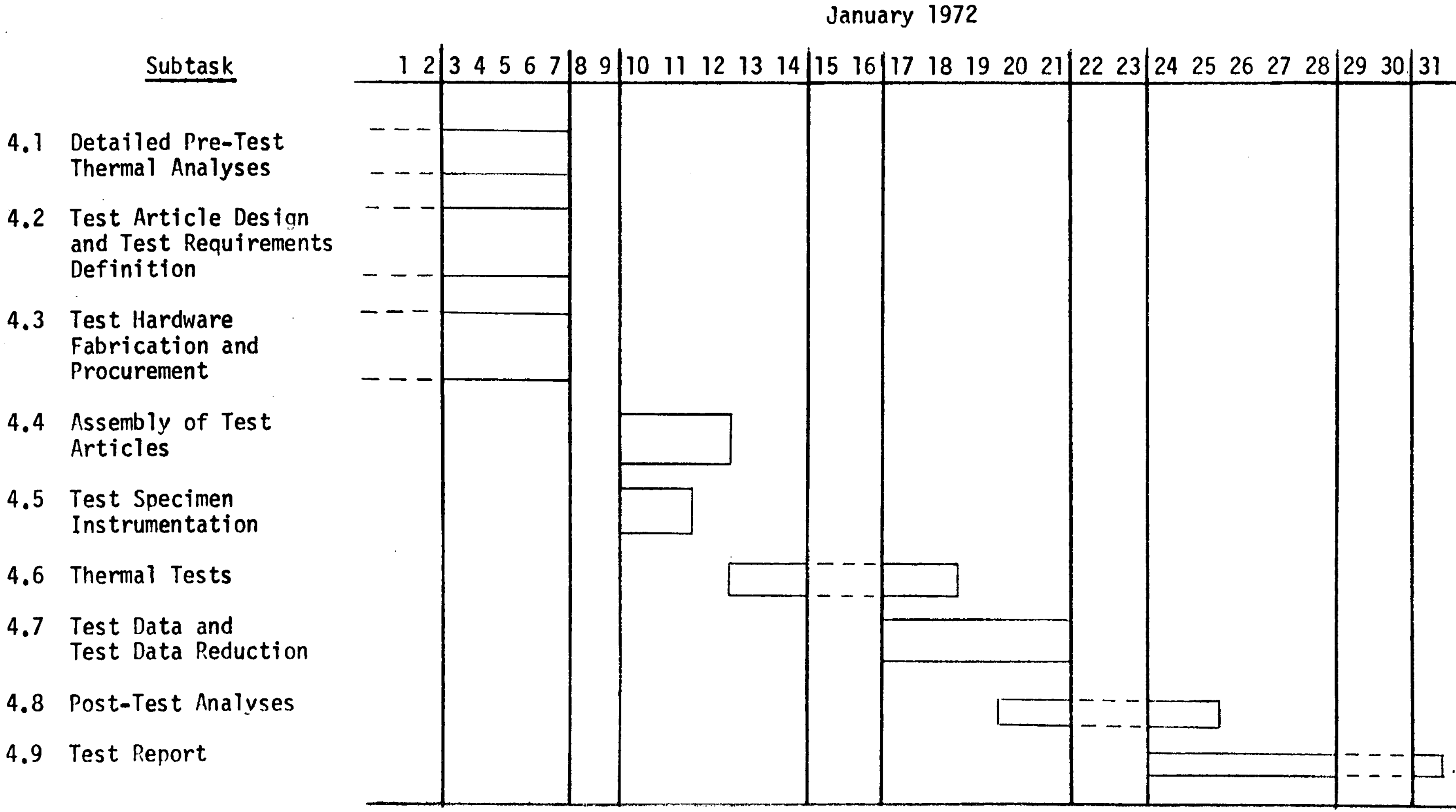


TABLE I. TEST SPECIMEN COMPONENT DESCRIPTION

	B/Al	B/PI	G/E
COMPOSITE MATERIAL STRUCTURE			
Configuration	Sheet	Sheet	Sheet
Sheet thickness (approx)	0.042"	0.04"	0.06"
Lay-up (no. of plys)	8	8	8
Fiber orientation	90°	2[0°/±45°/90°]	2[0°/±45°/90°]
Fiber content (% vol)	~ 45%	~ 50%	~ 55%
Fiber	.004D B	.004D B	.0075D HMS G
Filler	Al	P13N	3002
Sheet size	~ 4" x 7"	~ 4" x 7"	~ 4" x 7"
ISOLATOR BUSHING *			
	Molded Ceramic (~125 pcf)	Molded Ceramic (~125 pcf)	PI Molded (~120 pcf)
Diameter O.D.	4@ .5/.375	4@ .5/.375	4@ .5/.375
Diameter I.D.	3/16"	3/16"	3/16"
Thickness	.175"	.175"	.175"

TABLE I. TEST SPECIMEN COMPONENT DESCRIPTION (CONTINUED)

	B/Al*	B/PI	G/E
ISOLATOR BLOCK	Chem Ceram (~25 pcf)	Chem Ceram (~25 pcf)	PBI foam (~30 pcf)
Width/length	1"/1.25"	1"/1.5"	1"/2.25"
Depth	1"	1"	1"
Bolt Hole Diam.	3/16"	3/16"	3/16"
STANDOFF			
Material	#304 Stainless Steel	#304 Stainless Steel	#321 Stainless Steel
Thickness	.020"	.020"	.032"
Height	1.20"	1.20"	2.25"
Depth	1"	1"	1"
FIBROUS INSULATION	6 pcf Dynaflex	6 pcf Dynaflex	6 pcf Dynaflex
Thickness above composite	2.45"	2.70"	4.50"
Thickness below composite	4.0"	3.80"	2.0"
Surface Overlay Specimen	Refrasil Cloth	Refrasil Cloth	Refrasil Cloth
Number of Thermocouples	7 Total	7 Total	7 Total

* Dimensions shown are for procurement purposes.
Bushings will be fit to test configuration during assembly.