10/2-24-92 JS (1)

MARTIN MARIETTA

ORNL/ENG-10

Characterization of the B-1023 Furnace for Use in Hypothetical Thermal Accident Testing of Shipping Containers in Accordance with 10 CFR, Part 71

M. R. Feldman

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/ENG-10

ORNL/ENG--10

DE92 007781

Martin Marietta Energy Systems, Inc., Engineering
Process Engineering

Characterization of the B-1023 Furnace for Use in Hypothetical Thermal Accident Testing of Shipping Containers in Accordance with 10 CFR, Part 71

M. R. Feldman

Date Published—January 1992

MARTIN MARIETTA ENERGY SYSTEMS, INC.
Oak Ridge, Tennessee 37831
managing the
Oak Ridge National Laboratory
Oak Ridge Y-12 Plant
Oak Ridge K-25 Site
Paducah Gaseous Diffusion Plant
for the
U. S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Page

LIST OF FIGURES (continued)

ACKNOWLEDGMENTS

The author acknowledges the help and influence of several individuals who aided in the preparation of this document. J. C. Anderson and W. R. Williams of Engineering Analysis were especially instrumental in providing original ideas, support, and comments as this work progressed. As always, G. H. Llewellyn, also of Engineering Analysis, acted as counsel throughout the project.

During the course of the experimental phase of this work, the workers in the metal preparation area at Building 9204-4 at the Oak Ridge Y-12 Plant made the experiments a success. Without their diligent effort, the project would have failed. The members of the Energy Systems Independent Review Group committee and the Packaging Group of the Y-12 Plant Systems Safety Engineering Division and the Weapons Support Group of the Mechanical Design Division were most helpful throughout this project. E. Stumpfl of the Y-12 Packaging Program and S. D. Moses of the System Safety Engineering Division gave continuous input as well as support during this project. M. E. Boren and R. A. Vines of the ORNL Instrumentation and Controls Division assisted in the installation of furnace wall thermocouples.

This project was performed at the request of and was funded exclusively by the Y-12 Packaging Program.

ABSTRACT

The B-1023 furnace, located in Building 9204-4 at the Oak Ridge Y-12 Plant in Tennessee, is used for hypothetical thermal accident (HTA) testing of shipping containers that carry radioactive materials, in accordance with 10 CFR, Pt. 71.73(c)(3). This code requires a specific radiant (and convective) thermal environment during HTA tests. Experiments were performed to determine the furnace surface temperatures during these tests, which thus determine the radiant thermal environment. Several conclusions drawn from these experiments are presented. It is possible to perform conforming HTA tests in this furnace if a specific test routine is carefully followed. Recommendations concerning the procedure to be used during future tests are made.

1. SUMMARY

Containers developed for shipping radioactive materials by U.S. Department of Energy (DOE) subcontractors must conform to specifications outlined in the Code of Federal Regulations, Title 10, Part 71.[1] Among these specifications are various physical tests that the shipping containers must be able to withstand without sacrificing container integrity. One test, the hypothetical thermal accident [10 CFR 71.73(c)(3)], can be performed in a number of ways: analytical modeling, furnace testing, pit burning, or a combination of these.

Currently, furnace testing is the primary method of thermal exposure for radioactive material shipping containers being developed at Martin Marietta Energy Systems, Inc. The Energy Systems Independent Review Group (ESIRG) questioned the validity of furnace thermal tests, as they relate to 10 CFR 71.73(c)(3), being performed by the Y-12 Packaging Group. This project was undertaken to investigate the furnace environment and to determine the validity of tests previously performed as well as to make recommendations for future tests.

Tests conducted before the initiation of this study did not maintain the environment required by 10 CFR 71. However, the results from those tests are not useless, because those thermal assaults closely mimic the assault that would be provided in the required environment of a valid test. The use of analytical methods and extrapolation via engineering judgment can most likely be applied to justify certification of these containers without retesting.

Future tests will be carried out in a manner somewhat different from the previous tests, and new procedures will ensure 10 CFR 71 compliance. This report outlines not only explicit new test procedures but also a new approach that should make the furnace testing process both more reliable and more documentable.

2. INTRODUCTION

2.1 BACKGROUND

Over the past several years, DOE has reevaluated the certification process for containers that are to be used for transporting radioactive materials. These shipping containers (packages) have had to meet the specifications set forth in 10 CFR 71 since its enactment, but recently, the explicit wording of this document has been followed to a much greater extent. Thus, both physical tests and analytical methods used in documenting the ability of a shipping container to meet 10 CFR 71 are under much closer scrutiny. When this project was first initiated, a commonly heard remark was, "but this is how we've done it for thirty years." Rather than justifying the testing methods that were used, this statement simply underscores the need to address the issues.

ESIRG was assembled in accordance with DOE Order 1540.2 to technically evaluate safety analysis reports for packaging (SARPs) and related materials presented by Martin Marietta Energy Systems, Inc., to DOE in the pursuit of packaging certification. The focus of the ESIRG review is to determine whether said materials present adequate evidence that the packaging meets applicable regulations, guides, and DOE orders. Several issues have been raised by ESIRG, and most were easily resolved. One issue was raised initially in November 1989 and a year later (November 1990), the issue had not been satisfactorily settled. At that time the Engineering Analysis Section of the Central Engineering Organization was asked to look into the problem as a disinterested third party.

ESIRG questioned the thermal environment present during the physical testing of packages for the hypothetical thermal accident. Title 10 CFR 71.73(c)(3) states the following requirements:

> Exposure of the whole specimen for not less than 30 minutes to a heat flux not less than that of a radiation environment of 800°C (1475°F) with an emissivity coefficient of at least 0.9. For purpose of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to a fire or 0.8, whichever is greater. In addition, when significant, convective heat input must be included on the basis of still ambient air at 800°C (1475°F). Artificial cooling must not be applied after cessation of external heat input and any combustion of materials of construction must be allowed to proceed until it terminates naturally. The effects of solar radiation may be neglected prior to, during and following the test.

Thermal tests used for DOE certification are performed in the B-1023 furnace located in the metal preparation area of Building 9204-4 at the Oak Ridge Y-12 Plant in Tennessee. This furnace is controlled by a single thermocouple located in the center of the furnace ceiling that hangs down approximately 30 cm (1 ft). A backup thermocouple, about 30 cm behind the control thermocouple and mounted closer to the ceiling, acts as a safety mechanism; if the control thermocouple malfunctions and the temperature in the furnace is significantly higher than the reading from the control thermocouple, power to the furnace will be shut off. Unfortunately, these thermocouples measure ambient air temperatures in the furnace, and 10 CFR 71 mandates a specific radiant environment which requires that the walls, floor, and ceiling surfaces maintain a specific temperature. ESIRG noted that the placement of the control thermocouple (approximately directly above the package being tested) would make it possible for flames from combustion of the Celotex™ packaging material to influence the readings obtained from the control thermocouple. In turn, these readings would affect the power supplied to the furnace (up to and including complete shutoff of furnace power), which then would possibly affect the furnace interior surface temperatures. ESIRG was also concerned that no attempt was made to monitor furnace surface temperatures even though such temperatures are the primary regulatory control for the required heat flux.

Another issue of concern to ESIRG was that, in several tests, the package was placed on a cold slab-type fixture and then the entire unit was placed in the furnace. Using this method of testing leaves little doubt that the bottoms of packages do not receive the heat flux required in 10 CFR 71.73(c)(3).

2.2 PROJECT OBJECTIVES

Simply stated, the objective of this project is to characterize the thermal environment in the B-1023 furnace when hypothetical thermal accident tests are performed for certifying radioactive material shipping packages. Once this objective is met, several other matters can then be addressed. These matters can be broken into two separate groups: those pertaining to future thermal tests and those pertaining to previous tests.

Careful characterization of the furnace will indicate the proper recommendations to be made concerning future thermal tests. Though these recommendations will be based entirely on data received from physical experimentation, the newly recommended process will not be a simple "cookbook recipe" for thermal testing. Rather, a new approach to these tests will be encouraged which includes close coordination with workers in the metal preparation area and careful planning of test procedures to ensure smoothness of operation. Even some experimental procedures will be practiced with a cold furnace such that procedural characteristics unique to the tests of each individual package can be anticipated. In this manner, it will be possible to run tests that unequivocally comply with 10 CFR 71. While this approach may cause the tests to be somewhat more difficult, the positive results, in the long run, will greatly outweigh these difficulties.

Several series of tests for qualifying packages under 10 CFR 71 were run prior to the initiation of this project. For each test, only minimal data were taken, so in many instances, it was difficult to determine the extent of the thermal assault to the package and how this assault compared with that required by 10 CFR 71. Undoubtedly, some of these tests do not meet the requirements of 10 CFR 71, but I believe that the damage caused by placing the packages in the hot furnace is similar to the damage that would result if the packages were exposed to the required thermal environment. Thus, though these tests were not in full compliance, their results may still be valuable. Possibly, with the aid of some analysis, compliance can be certified without further destructive testing to costly packages.

2.3 PROJECT DEVELOPMENT

When this project was first initiated, it was apparent that some experimentation would be necessary to determine the radiant environment present within the furnace during testing procedures. The B-1023 furnace in which these tests were run is equipped with heating element elements on all four inside walls (including the door) and the ceiling, but the floor has no heating elements. Therefore, it was believed that the lowest temperatures in the furnace would be found on the floor.

A method of measuring floor temperatures was devised and tested. The results from these experiments were used to outline a new test procedure that was then used for actual compliance testing of the DT-18 packages in February 1991. As part of this planned procedure, infrared photography was used in an attempt to determine the temperatures of the various surfaces in the furnace immediately after the door of the furnace was raised at the end of the test. Unfortunately, the time necessary to properly focus and activate the camera was on the order of 30 min after the furnace door had been opened. Clearly, after the furnace door was open for that length of time, infrared pictures would not be able to approximate various surface temperatures *during* the test. But, the infrared pictures taken did reveal that 30 min after the test, the walls of the furnace were significantly cooler than the floor.

Further investigation revealed that the firebrick of the furnace floor was approximately three to four times denser than the firebrick of the walls and ceilings. The data gathered to this point allowed us to estimate wall temperatures, but without direct measurement, these temperatures could not be exactly quantified. Thus, a decision was made to fully thermocouple the walls, ceiling, and floor of the furnace.

A method was developed for installing surface thermocouples directly on the inside walls and ceiling of the furnace. After some initial setbacks (e.g., destruction of thermocouples), the method was modified, and acceptable results were obtained.

3. EXPERIMENTAL

3.1 EXPERIMENTAL APPARATUS

All experiments were performed in the B-1023 furnace located in the metal preparation area of the 9204-4 Building at the Oak Ridge Y-12 Plant. The B-1023 furnace is a Flinn and Dreffein electric car-bottom preheat furnace. The furnace is controlled by a proportional controller, and its recommended useful temperature range is from 370–1150°C (700–2100°F). The walls and ceiling of the furnace are lined with (2300°F) IFB (firebrick), and the floor is lined with 60% alumina refractory. The heating elements are Driver-Harris Nichrome V in rod overbend construction. These elements are evenly distributed on the furnace walls (including the door), and elements are also hung from the ceiling in a slightly less concentrated manner. The total power rating to the coils is 450 kW.

For the measurement of floor surface temperatures, a mild steel plate measuring ~2.4 m × 1.5 m × 2.5 cm (8 ft × 5 ft × 1 in.) was centered on the floor of the furnace (see Fig. 1). Five 3.2-mm-diam, <6.4-mm-deep (1/8-in.-diam, <1/4-in.-deep) holes were drilled in the plate. The holes were filled with liquid-metal setting compound, and a thermocouple was then pressed partway into each of the holes. The compound was then allowed to set. The installation of thermocouples was expected to allow for a good approximation of the actual surface temperature of the plate because the plate (as well as the liquid-metal setting compound) has a high thermal conductivity, which tends to prevent severe thermal gradients. The thermocouples used for the measurement of floor temperatures, provided by the Process Maintenance Department in Building 9204-4 at the Oak Ridge Y-12 Plant, were type K Chromel-Alumel[2] with a stainless steel 316 sheath.

The measurement of wall and ceiling surface temperatures was achieved by mounting thermocouples directly on these surfaces. The thermocouple wires were anchored into the furnace surfaces with metal staples made of a thin welding rod. A kink was made near the end of the thermocouple wire such that the tip of the thermocouple was pressed against the furnace surface. A slight depression [typically <1.6 mm (1/16 in.)] was made in the surface at the point where the thermocouple junction intersected it. A small quantity of liquid-metal setting compound was then hand-applied (irregularly dabbed) around the surface-junction interface. The thermocouples used for wall and ceiling surface temperature measurements were identical to those used for the floor, type K Chromel-Alumel[2] with a stainless steel 316 sheath. These thermocouples were fabricated and tested by the Instrumentation and Controls Division of Oak Ridge National Laboratory.

Fifteen surface thermocouples were mounted in this manner, three on each of the north and south walls, one on the east wall, one on the ceiling, and seven on the door. More precise locations of these thermocouples are shown in Figs. 2 and 3. (These figures are also provided as a foldout at the end of this document so that they can be referred to while looking at other figures that reference them.)

Two 12-channel Beckman Industrial Doric Minitrend 205 digital data recorders, capable of logging data at a maximum rate of once every minute, were used to record the temperatures of the 20 mounted thermocouples discussed above.

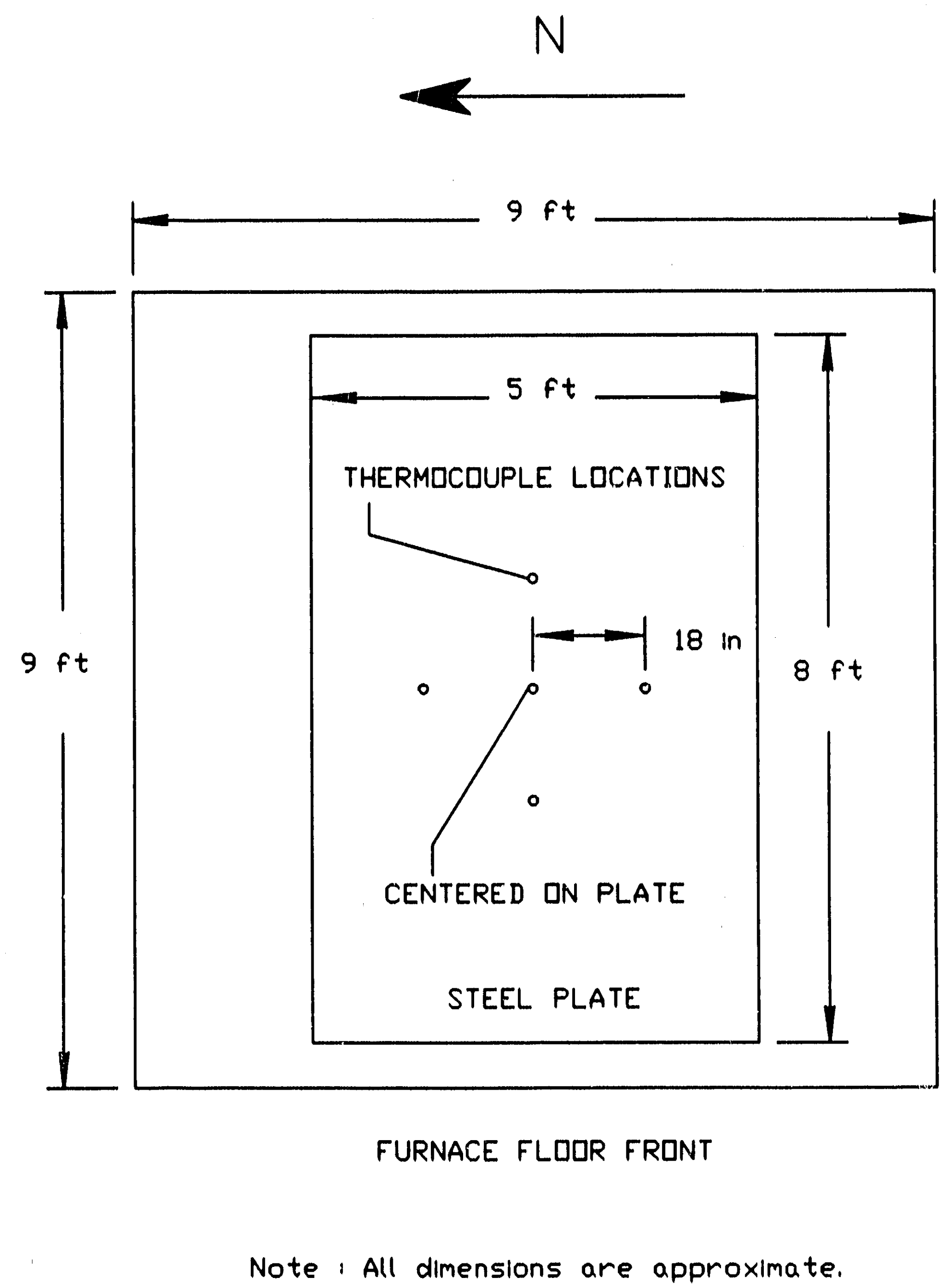


Fig. 1. Steel plate in furnace.

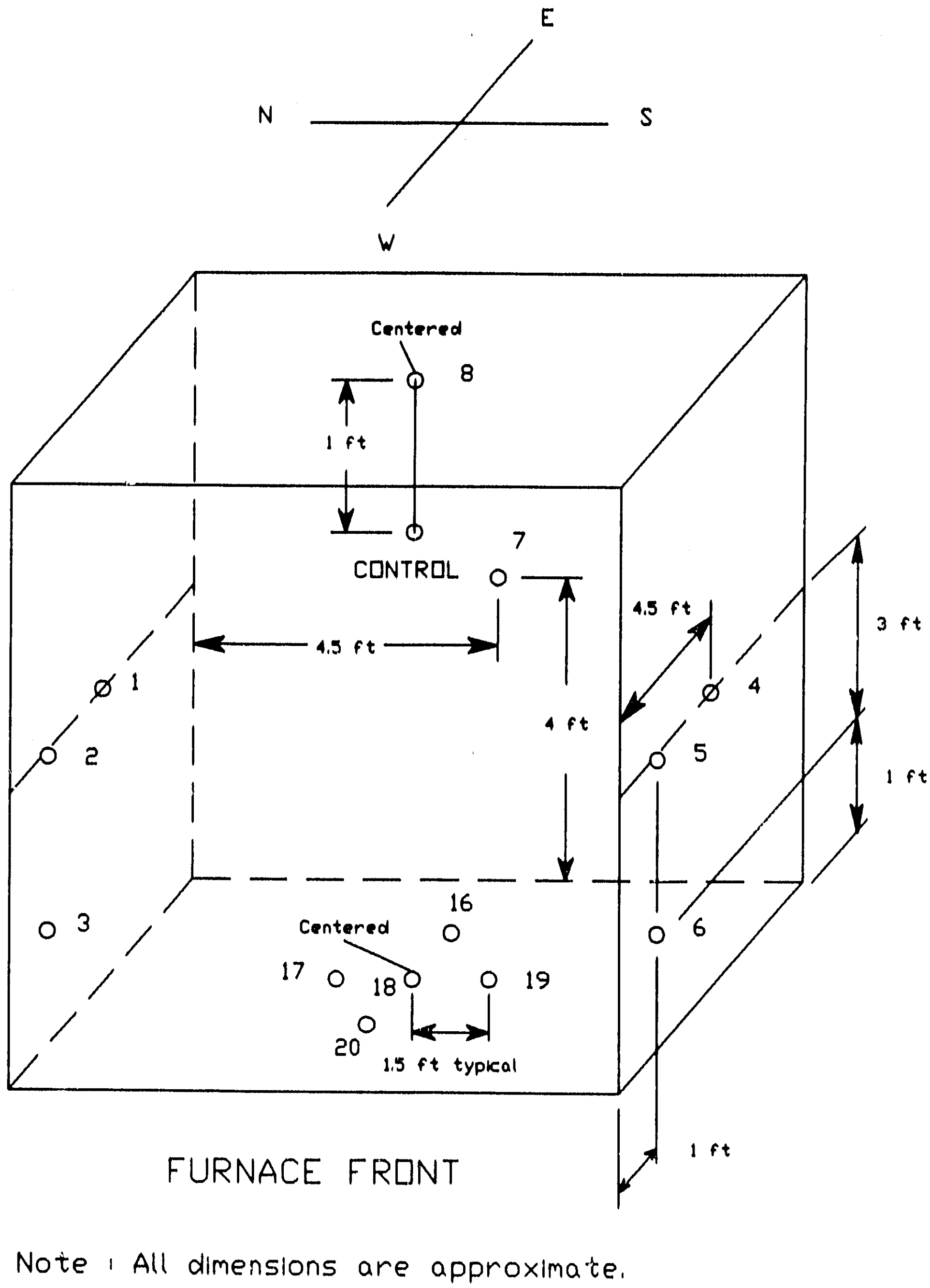


Fig. 2. Approximate interior furnace thermocouple locations.

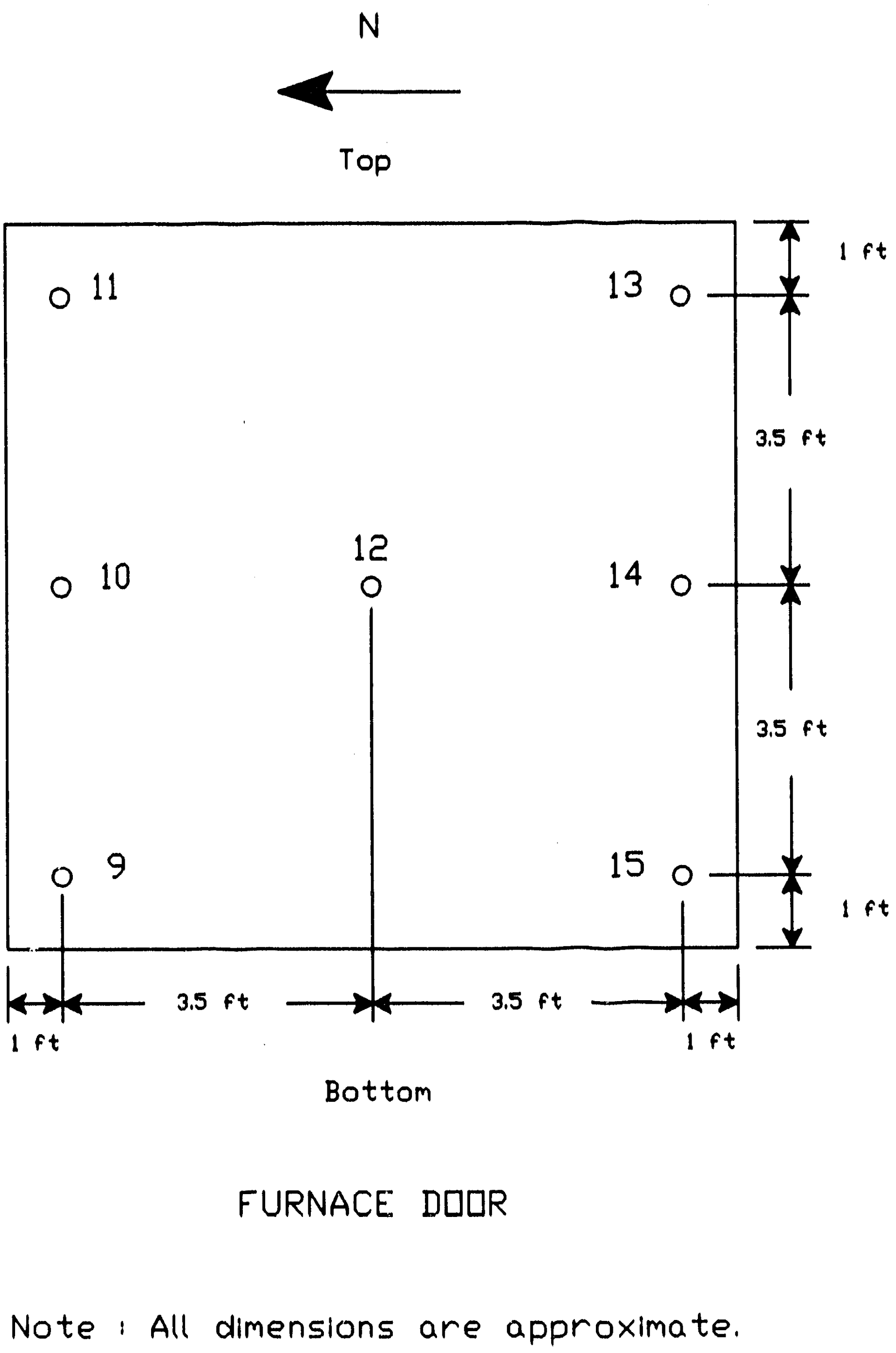


Fig. 3. Furnace door thermocouple locations.

The thermocouple referred to herein as the *control thermocouple* is permanently mounted in the furnace and is the thermocouple through which the proportional controller measures furnace temperature. This thermocouple hangs ~30 cm (1 ft) from the ceiling and measures the temperature of the thermocouple at that location. This thermocouple's reading is displayed digitally as well as continuously recorded on a strip-chart recorder. Other instrumentation included with the furnace and used here are three ammeters and three voltmeters which indicate the quantity of power being delivered to the furnace at a given time.

3.2 EXPERIMENTAL PROCEDURE

Several experiments were performed in an attempt to characterize the B-1023 furnace at temperatures at or near those used for hypothetical thermal accident physical testing. These experiments ranged from a simple heatup of the furnace from ambient temperatures (to help determine the length of time necessary to preheat the furnace prior to thermal testing) to the actual physical testing of DT-18 packages that had been accidently damaged in previous routine use. Each experiment performed is briefly described in Table 1 and is more thoroughly discussed below.

With the exception of Experiment 8, all experiments detailed in this report were performed with the furnace temperature control mechanism set at 835°C prior to the experiment. This temperature choice was based on previous observations, which had shown that floor plate temperatures could be kept above 800°C during a hypothetical thermal accident (HTA) test. On February 8 and 9, 1991, actual thermal HTA tests on DT-18 packages were performed using this furnace set-point temperature. It was hoped that information gathered during the experiments detailed in this report would help to verify that all surface temperatures in the furnace were at least 800°C—not just that of the floor plate during those 1991 February tests. Experiment 8 was performed with a set point of 800°C in an attempt to determine the extent of the thermal assault that had been administered to packages tested prior to the initiation of this investigation.

Some terms used to describe experimental procedures need to be explicitly defined. A *stable* or *stabilized* furnace refers to a furnace that has remained closed in the operating mode for not less than 2 h and the temperature at each of the mounted thermocouples and the control thermocouple has not varied by more than 2°C in the 15 min prior to the initiation of the test. A *fully heat-soaked* furnace refers to a furnace that either (1) was cold to begin with and has remained at a specific set point with the door sealed for at least 24 h or (2) was stable at or above the set-point temperature prior to being opened for less than 15 min and then was sealed and stabilized.

Experiment 1. Initial Heatup

A cold furnace that had not been operated for at least 3 d was sealed, the data recorders were set to record temperatures of all mounted thermocouples every 5 min, the control thermocouple strip-chart recorder was turned on, the furnace temperature control point was set to 835°C, and power to the furnace was turned on. The furnace was allowed to operate in this manner for 24 h.

Table 1. Brief summary of experiments

Experiment	Objective	Date of experiment	Time of experiment	Furnace condition	
				Preexperiment[a]	During
1	Determine heatup curve of furnace surfaces for empty furnace	4/4–5/91	14:00–14:00	Ambient	835°C set point
2	Determine cooling rate of furnace surfaces for empty furnace with door open	4/5/91	14:00–15:30	835°C set point	No power; door open
3	Determine cooling rate of furnace surfaces for empty furnace with door closed	4/8/91	12:10–14:10	835°C set point	No power; door closed
4	Determine effect on furnace surface temperatures of opening door for 1 min, then reclosing and applying power	4/11/91	10:37–11:07	835°C set point	835°C set point
5	Determine effect on furnace surface temperatures of opening door for 2 min, then reclosing and applying power	4/9/91	15:17–15:47	835°C set point	835°C set point
6	Same as for Experiment 4, but no power applied	4/11/91	11:56–12:26	835°C set point	No power; door closed
7	Simulate hypothetical thermal accident testing of upright DT-18 package on test stand to determine furnace surface temperatures for 835°C set point	4/10/91	8:28–9:00	835°C set point	835°C set point
8	Simulate hypothetical thermal accident testing of upright DT-18 package on test stand to determine furnace surface temperatures for 800°C set point	4/10/91	13:24–13:56	800°C set point	800°C set point

[a]Exact preexperiment conditions specified in text.

Experiment 2. Open-Door Cooldown

After the furnace had been allowed to stabilize (empty), having been operated at an 835° C set point for 24 h (initially cold), the furnace door was fully raised and kept up for the duration of the experiment. All mounted thermocouple readings were recorded every 5 min for 1.5 h. A strip-chart recording of the control thermocouple was also made.

Experiment 3. Closed-Door Cooldown

The furnace (empty) was allowed to stabilize at a set point of 835° C; then the power to the furnace was cut off while the door remained closed. The cooling of the furnace was then recorded. All mounted thermocouple readings were recorded at 5-min intervals, and a strip-chart recording of the control thermocouple response was made. The experiment was allowed to proceed for 2 h.

Experiment 4. Furnace Recovery with Power Restored, 1 min Open

The furnace (empty) was allowed to stabilize at a set point of 835° C. Power to the furnace was cut off, and the furnace door was fully opened simultaneously. The door was left open for 1 min, then shut. The time count began when the door started to lift, and 60 s later the door started to shut. The door takes 5 to 10 s to be closed and sealed. Power to the furnace was immediately resupplied, and temperatures in the furnace were then recorded for the next 29 min. Mounted thermocouple readings were recorded at 1-min intervals, and the control thermocouple reading was recorded on a strip-chart recorder.

Experiment 5. Furnace Recovery with Power Restored, 2 min Open

The furnace (empty) was allowed to stabilize at a set point of 835° C. Power to the furnace was cut off, and the furnace door was fully opened simultaneously. The door was left open for 2 min, then shut. The time count began when the door started to lift, and 120 s later the door started to shut. Power to the furnace was immediately resupplied, and the temperatures in the furnace were then recorded for the next 28 min. Mounted thermocouple readings were recorded at 1-min intervals, and the control thermocouple reading was recorded on a strip-chart recorder.

Experiment 6. Furnace Recovery without Power Restored

Because of the error of the experimentalist, the furnace was not heat-soaked for this experiment in the same manner as for the other experiments. The furnace had been opened for a 1-min period 78 min prior to the initialization of this test. Before this 1-min opening, the furnace had been operating for more than 20 h in a sealed manner with a set point of 835° C. Of the 21 monitored temperature readings within the furnace, 13 were the same as before the door was opened for 1 min, two thermocouples (2 and 17) were 1° C higher, four thermocouples (8, 10, 18, and 19) were 1° C lower, and one thermocouple (9) was 2° C lower (thermocouple 15 was monitored but did not operate during this experiment). Thus, although the furnace was not fully heat-soaked, it is believed the results of this experiment were not influenced significantly by this omission. Power to the furnace (empty) was cut off, and the furnace door was fully opened simultaneously. The door was left open for 1 min, then shut.

The time count began when the door started to lift, and 60 s later the door started to shut. Power to the furnace was not resupplied, and the temperatures in the furnace were then recorded for the next 29 min. Mounted thermocouple readings were recorded at 1-min intervals, and the control thermocouple reading was recorded on a strip-chart recorder.

Experiment 7. Test Package Burn at 835° C

A previously damaged (accidently during routine use) DT-18 package was placed in the furnace, which had been fully heat-soaked and had stabilized at 835° C. This experiment was meant to simulate the DT-18 thermal tests performed on February 8 and 9, 1991.

The package used in this test had 12 thermocouples attached to it such that additional data could be gathered for use in separate studies. Six of these thermocouples were attached to the outside of the outer container (one each on the top and bottom and four mounted at the midheight of the container every 90°). Additionally, six more thermocouples were attached to the outside of the inner container in similar locations.

A stand specifically constructed for DT-18 package thermal tests (see Fig. 4) was placed inside the furnace the day before the experiment. A forklift with a pincher lifting device was used to lift the package by pressing against the sides of the package. When the forklift had successfully lifted the package and it was ready to be loaded into the furnace, the furnace door was opened (nearly all the way) and the package was placed on the stand. A thermocouple wire from the package shell became slightly tangled in the forklift pincher assembly but was disentangled after ~30 s of effort. This event caused the furnace door to be opened ~30 s longer than would usually be necessary for this exercise (usually the door is open for between 35 and 50 s), in this case for 65-80 s. As soon as the forklift was clear of the furnace, the door was shut and power to the furnace was restored.

The package used in this experiment was a DT-18 container that consisted of a mild steel outer drum, Celotex™ packing between the outer drum and the inner container, and a sealed inner container that was empty (no parts within the package). The seal on the inner container was not checked either before or after the mock thermal test, and no other hypothetical accident condition scenarios were simulated for this experiment (e.g., drop test, water submersion test). This package had sustained damage (during previous routine use) in the outer shell/lid interface area resulting in a 2.5- to 5.1-cm (1- to 2-in.) deformation on one side of the shell/lid interface. No attempt was made to seal this interface in the hope that some flaming of the Celotex™ inside the container would occur. (Flaming has been noted during previous thermal tests, and the effects of this flaming on the control thermocouple, and in turn the thermal environment within the furnace, has been questioned.) The package was placed in an upright position on the stand with the damaged area as near the control thermocouple as the experimental setup would allow. To help determine the effect of any flaming and to further quantify the events that occurred in the furnace during the thermal test, the amount of power to the furnace during the experiment was recorded by reading the three ammeters and the three voltmeters each minute during the experiment.

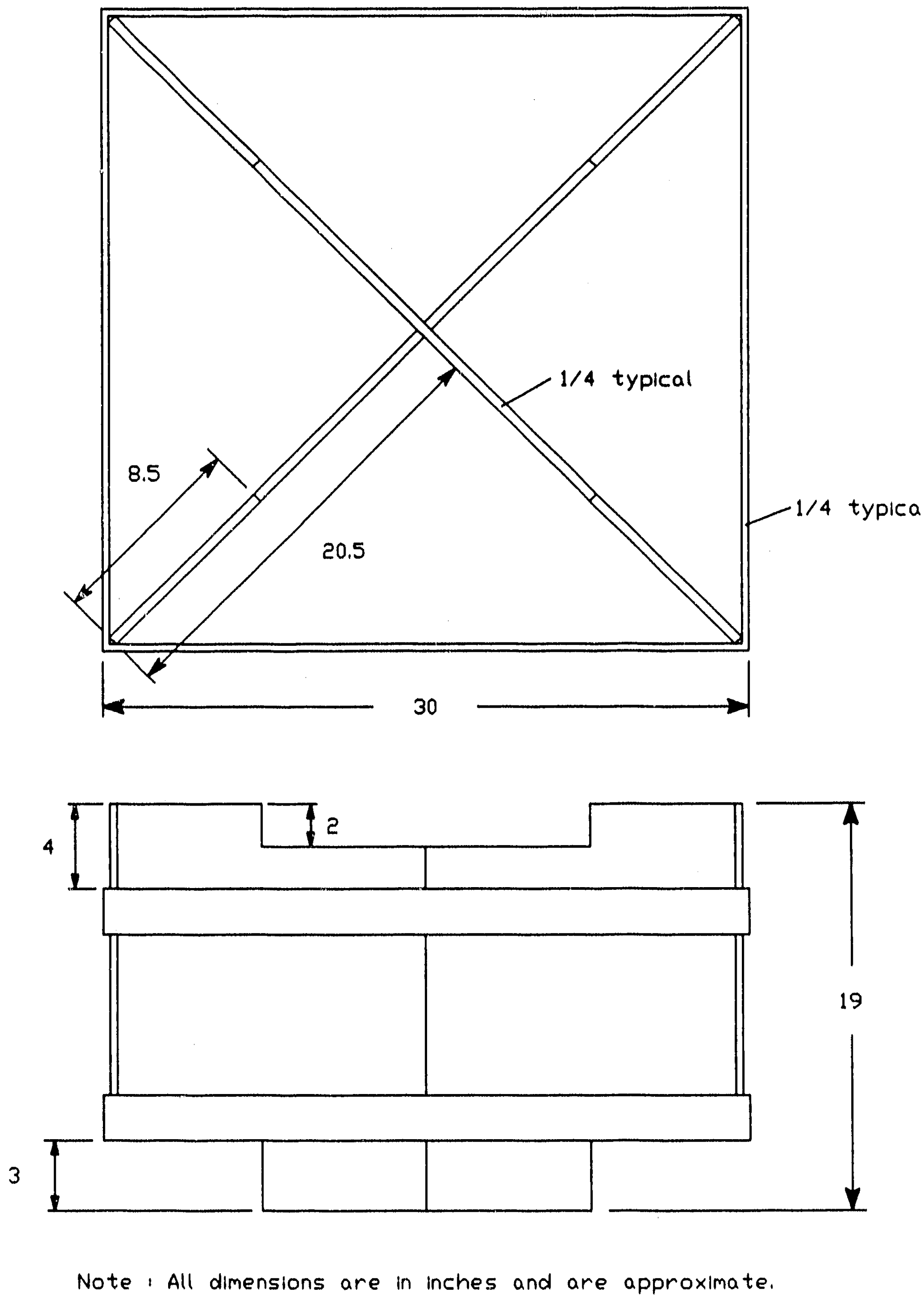


Fig. 4. DT-18 test stand top (upper) and side (lower) views.

Experiment 8. Test Package Burn at 800° C

Experiment 8 was the same as Experiment 7 except that the furnace was heat-soaked at 800° C instead of 835° C and a different but similarly equipped and damaged DT-18 package was used. Also, the test stand used was placed in the furnace after Experiment 7, prior to which it had been preheated in a separate furnace at 800° C for longer than 4 h. No interference from thermocouple wires was experienced when the package was loaded, so the furnace door was not open an extra time, as in Experiment 7 (i.e., <60 s). The package used in this experiment had damage very similar to that of the package used in Experiment 7. The package was also placed in the furnace in the upright position on the test stand, as in Experiment 7.

4. RESULTS AND DISCUSSION

Because of the large number of individual experiments undertaken for this study, it is not possible to simply state an explicit result. The point of the exercise was to determine methods of thermal testing which would ensure that the regulatory stipulations governing these tests are met. To that end, nearly all of the experiments performed revealed some information which can be applied to the development of procedures that will guarantee complete compliance or, at the very least, define the degree of compliance. The results of each experiment are presented below with a brief discussion of the important aspects therein, followed by an in-depth discussion of the proposed method for future testing.

For each experiment undertaken, 21 data points were available each time data were taken. These data were collected from the 7 thermocouples on the door, 3 on each of the two side walls, 1 on the rear wall, 1 on the ceiling, 5 on the steel plate on the floor, and 1 control thermocouple, for a total of 21. To clarify, the control thermocouple readout is a strip chart that continuously records the temperature of the control thermocouple junction, unlike the mounted thermocouples attached to a data logger. The data loggers give a continuous visual readout of the thermocouple temperatures but record temperatures for these thermocouples only at discrete points set by timed intervals (e.g., 1 min). The control thermocouple strip-chart data were then read by the author so that control thermocouple data were reported in the same manner as those for the other thermocouples. That is, the analog output from the strip-chart recorder was discretized into specific data points corresponding to the times at which the mounted thermocouple data were recorded. These steps were taken to aid in displaying the data in the figures in this report. All of the data reported here have been placed in archives at the Y-12 Plant.

So as not to overwhelm the reader, only portions of the data are presented in the main body of the report. A comprehensive listing of all thermocouple data, in graphical format, taken during these experiments is provided in Appendix A. For each experiment, data from 7 of the 21 thermocouples are shown. Data from the control thermocouple along with thermocouples 1, 3, 7, 8, 12, and 18 (see Figs. 2 and 3), are reproduced on each figure. Each thermocouple was chosen for a specific reason. The control thermocouple is unique because it is the only monitored thermocouple that measures other than surface temperature. It is also important because it controls the power to the furnace. Thermocouple 1 is on the center of the north sidewall; it was found that the north and south walls were very symmetric and thus only one is shown. Thermocouple 3 is on the north wall approximately 1 ft above the floor and 1 ft in from the door. This location was consistently the coldest spot measured in the furnace. Several other thermocouples consistently had almost the same reading as thermocouple 3. For example, thermocouple 6 is on the south wall in the same position as thermocouple 3, and thermocouples 9 and 15 are mounted on the door approximately 1 ft above the floor and 1 ft in from the side walls. Thermocouple 7, which represents the only data taken from the rear wall, is centrally located on that wall. Likewise, thermocouple 8 represents the only data taken concerning the ceiling surface temperature and is presented for that reason. Thermocouple 12 is at the center of the door, and thermocouple 18 is at the center of the floor plate. The only unique positions not represented in the main body of the text are on the side walls and doors, 1 ft in from the edge of the surface and at the midheight of the surface (thermocouples 2, 4, 10, 14). These thermocouple readings were always very close to those at the center of the wall (or door) to which they were attached, and it is believed that they did not represent any especially enlightening information. Again, all of the data taken are presented in Appendix A, and the reader is encouraged to look there to verify the reasoning presented above for displaying the specific data in the body of the text.

It should also be noted that some minor difficulties were encountered with certain thermocouples during some experiments. Thermocouples 14 and 15 sometimes gave either no readings or readings that clearly were not representative of the temperatures within the furnace. Thermocouple 7 had a short in its quick-connect plug that was corrected about 18 h into Experiment 1, after which the thermocouple responded correctly for the remainder of the experiments. Thermocouple 17, mounted on the floor plate closest to the front of the furnace, consistently responded differently from thermocouples on the plate. No large thermal gradients were expected on the plate and, other than thermocouple 17, were not seen. After the experiments were completed, inspection revealed that thermocouple 17 had pulled from its drilled hole on the floor plate. Thus, its readings were not the same as those of the surface, but rather a measure of the temperature a stainless steel object would be subjected to slightly above the plate. Otherwise, all thermocouples functioned normally for the duration of the experiments.

Experiment 1. Initial Heatup

Experiment 1 dealt with the initial heatup of the furnace. Figures 5 and 6 indicate the temperature response during this experiment in various locations throughout the furnace (Fig. 6 is simply a blowup of a portion of Fig. 5). The control thermocouple was seen to heat up the quickest, indicating that the furnace atmosphere heats more quickly than the various surfaces within the furnace. The furnace control thermocouple attained its set-point temperature within about 2 h. Other temperatures continued to rise well after the set-point temperature was attained. In particular, the temperature of the plate on the floor of the furnace was slow to stabilize at temperature. Obviously the lack of heating elements on the floor contributed to this phenomenon, but the large thermal capacity of both this plate and the floor refractory, which is as much as four times denser than the wall refractory, also contributed. Although wall temperatures almost completely stabilized after 12 h, floor temperatures continued to rise slowly for ~8 h more (20 h total). After the furnace was allowed to heat-soak for 24 h, a slight thermal gradient existed from floor to ceiling. All temperatures within the furnace were within 15°C of one another, with the floor being the coolest and the ceiling being the warmest. Only a small gradient occurred from the midheight of the furnace to the ceiling. The manufacturers of the furnace state that a "heat zone" in the furnace begins ~1 ft off the floor and extends to the ceiling. They recommend using this area of the furnace for all heat-treating activities because of the lack of large thermal gradients in this zone. The results of this experiment suggest that this zone does exist but, at this temperature (835°C), the gradients are not extremely severe anywhere in the furnace.

That near-total stabilization was attained in 20 h does not necessarily indicate that the furnace was fully heated. For the furnace to be considered fully heated, the temperature profile through the various refractories would have to be fairly flat. That is, temperatures within the brick should be close to those of the inner surfaces. The experimental apparatus used was not capable of measuring interior temperatures, so it was necessary to allow the brick to soak at temperature after all the walls attained their equilibrium temperature. During the final 4 hours of this experiment, very little temperature change occurred on the

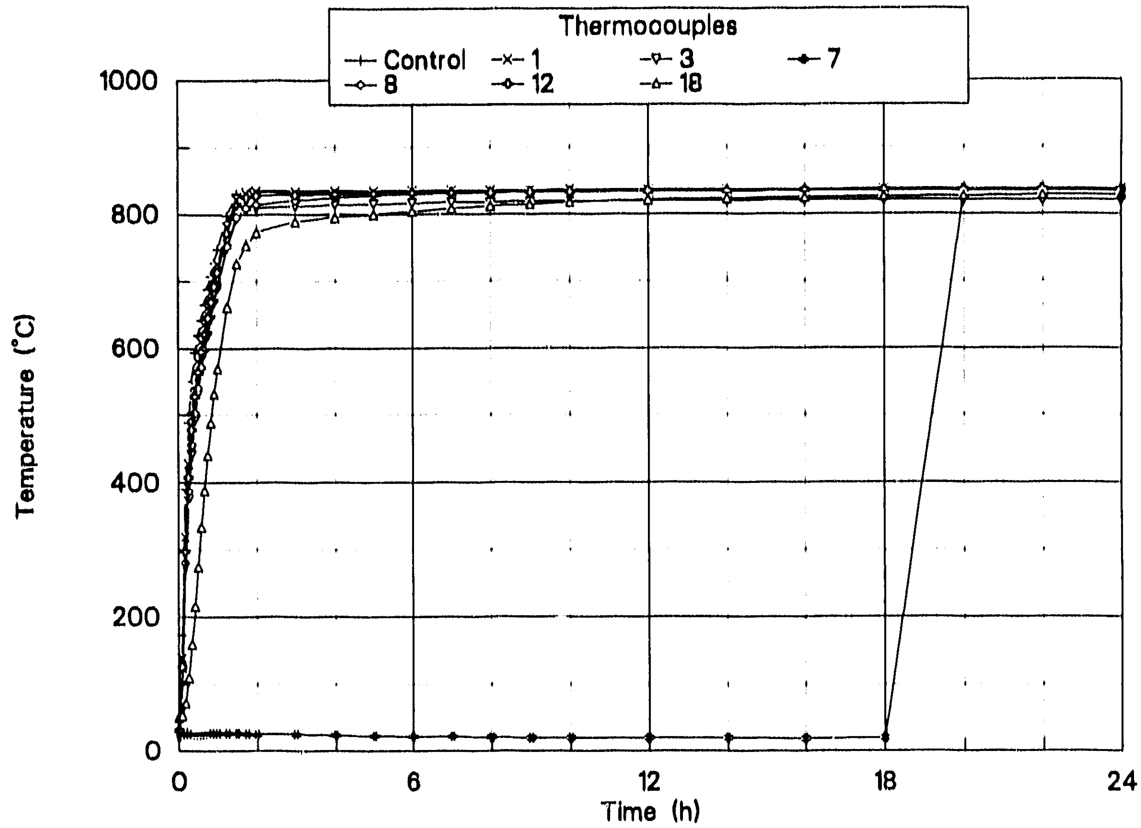


Fig. 5. Temperature vs time for various furnace surface locations during Experiment 1, furnace heatup to set point of 835° C from cold start. Note: Thermocouple 7 had a short circuit which was corrected ~18 h into the experiment.

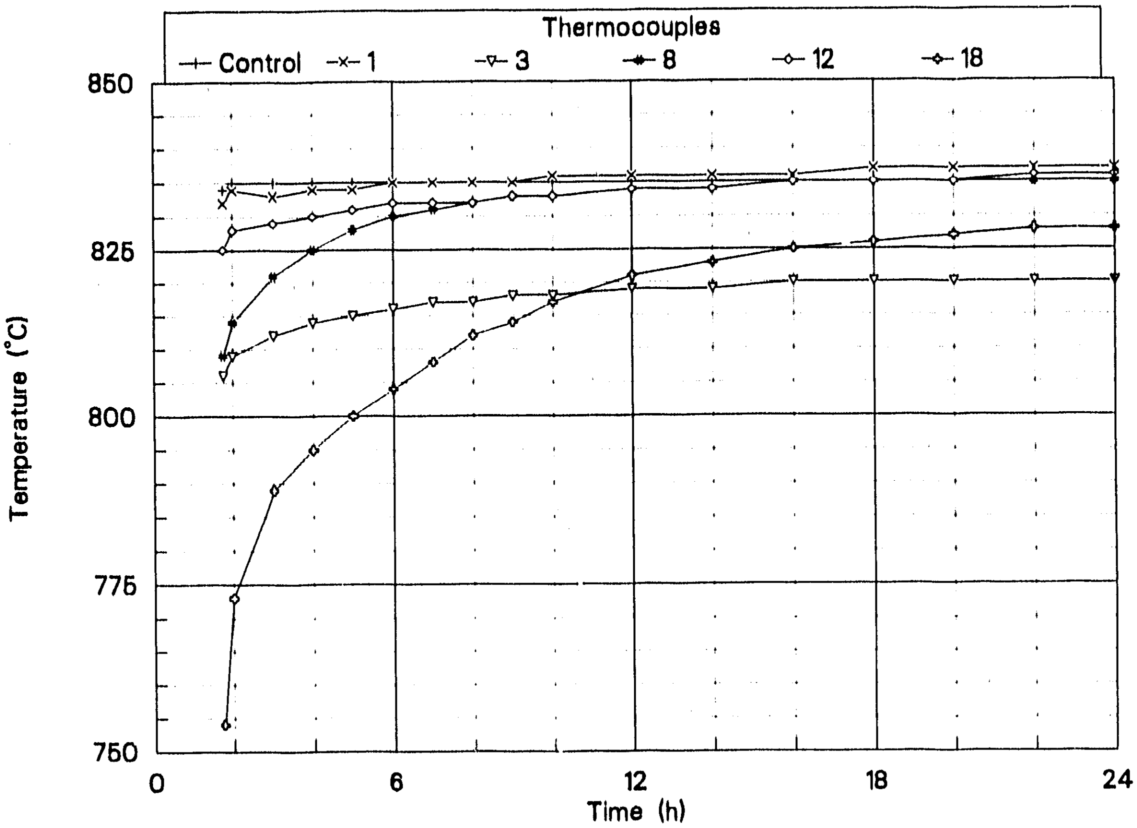


Fig. 6. Closeup of temperature vs time for various furnace surface locations during Experiment 1, furnace heatup to set point of 835° C from cold start. Note: Thermocouple 7 is not shown in this figure.

interior surfaces of the furnace, but undoubtedly temperatures in the refractory continued to climb. When the furnace is opened for the insertion of a package during a real hypothetical thermal accident test, it will be very important that furnace interior materials of construction be appropriately heat-soaked to allow those surfaces to recover to near their preopening temperatures much more quickly.

Experiment 2. Open-Door Cooldown

Experiment 2 was a very simple determination of the cooling curve for the furnace with the door wide open. The furnace had been heat-soaked at 835°C for 24 h (from a cold start). One reason for running this experiment was because of some data obtained during an actual DT-18 thermal test performed in February of 1991. At that time the floor plate was being used to detect floor temperatures. Because the floor was not directly heated by coils, it was assumed that the lowest temperatures within the furnace would be on this surface. To verify that this area was the coolest, an attempt was made to make an infrared photograph of the furnace interior just after the package was removed. Because of the intense and dynamic thermal environment in the furnace when the door was opened at the end of the test, the infrared camera could not be focused to reflect any temperature contours until the furnace had been open for approximately 30 min. The temperature contours then photographed showed that the plate was as much as 200°C hotter than other surfaces in the furnace. These results, coupled with the fact that during some of the DT-18 tests the furnace power was not restored during much of the test, raised serious questions as to what the wall and ceiling temperatures had been during the tests. In some ways, this experiment reenacted the above scenario but this time data concerning other surface temperatures were recorded.

Figure 7 shows how various furnace surfaces reacted after the door was opened and they were allowed to cool. As in the infrared photograph discussed above, 30 min after the door was opened, the floor plate was significantly hotter than any of the other surfaces. A couple of factors caused this phenomenon. First, the brick used to form the wall and ceiling refractory is only ~25% as dense as the brick used to form the floor refractory. The heat capacities of these two types of brick are very similar, but the total quantity of heat per volume of brick is about four times greater for the brick on the floor than it is for the brick on the walls and ceiling. In addition, the amount of heat held by the plate itself is quite significant. Because the plate sits on top of the denser brick and all of these materials were fully heat-soaked, it is not surprising that after a long period of time (~30 min), the plate temperature was significantly higher than that of the surrounding surfaces. Thus this experiment did agree with findings from earlier tests. It also gives insight as to the significance of these previous findings.

After 30 min of open-door cooling, wall and ceiling temperatures ranged from 240 to 400°C, while the plate was much hotter at ~565°C. This difference fully explains the findings of the infrared camera. Note also that after 5 min, plate temperatures dropped only ~60°C while other surface temperatures dropped between 150 and 400°C. For the hypothetical thermal accident tests of interest though, the importance of this experiment is the significance of the temperature drop in the first couple of minutes. Although it is obvious from the data that the other surfaces do lose temperature faster than does the plate on the

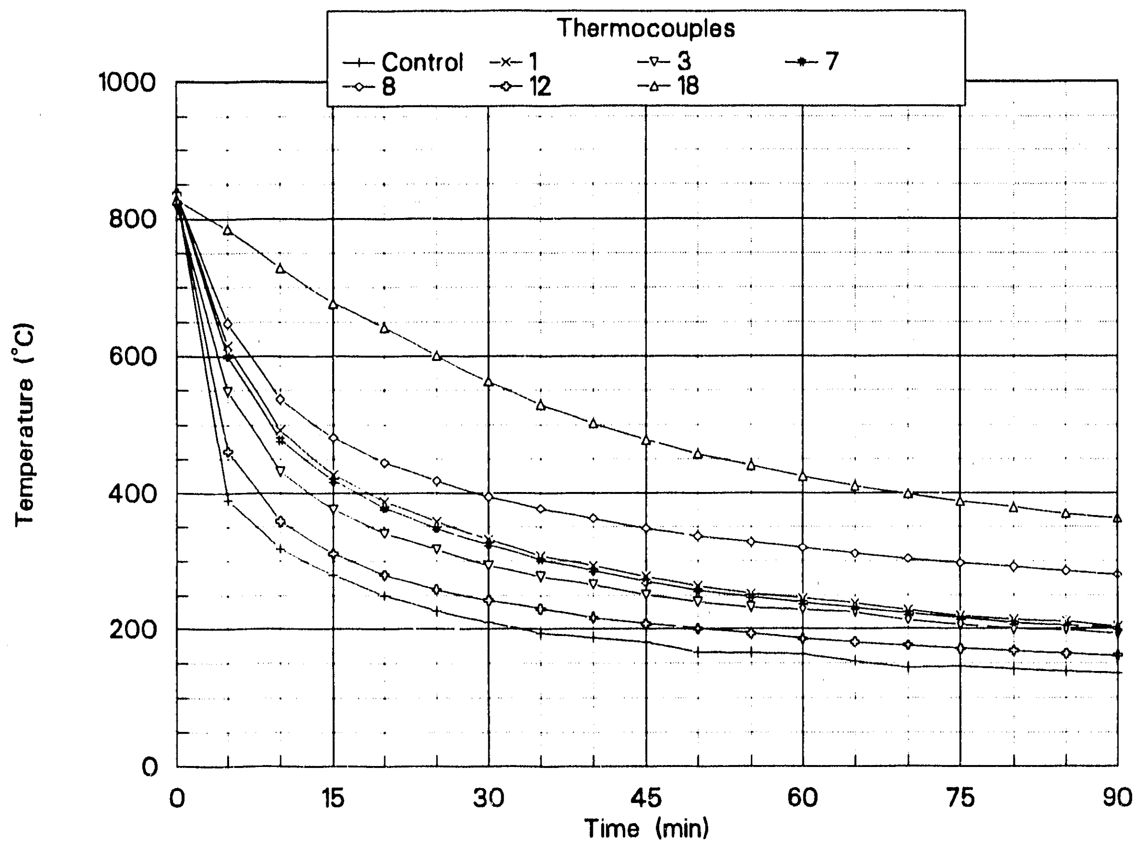


Fig. 7. Temperature vs time for various furnace surface locations during Experiment 2, open-door cooldown from set point of 835° C.

floor, it should be noted that during an actual thermal test, the door is open with the power off for only between 0.5 and 1.5 min. The door is then shut and power is reapplied (though sometimes the power stays on for only a short time). Temperature drops during this first 2-min period are significant, and other surface temperatures drop more than those of the floor plate, but a difference of 200° C, as shown previously by the infrared camera, does not occur at this early time.

This experiment showed very clearly the need to open and shut the furnace door as quickly as possible when a package is loaded during an actual thermal test. Furthermore, it indicated that knowing prior to the test how long it would take to load the package (or a reasonable approximation) would ensure that the proper furnace temperature setting could be used for the heat-soak prior to the test. When loading a package takes longer than anticipated, furnace surface temperatures drop very quickly. In such cases it may not be possible to return the surface temperatures to the proper range fast enough. The results would be either an undertest where the radiant environment is not that required by 10 CFR 71 or an overtest where, while the package is in the furnace being heated, the time clock has not started because the thermal environment does not meet the regulatory requirements. Thus it is important that before the furnace is heat-soaked for a thermal test, the loading procedure be practiced to ensure that the test procedure is well understood by all involved and that no delay in the procedure will cause the door to be open longer than necessary.

Experiment 3. Closed-Door Cooldown

Experiment 3 was a determination of the closed-door cooling curve for the B-1023 furnace. The furnace was heat-soaked at 835° C and then the power was turned off. This experiment was performed in an attempt to quantify the effect of previous qualitative observations. The furnace is controlled by a single thermocouple that hangs from the center of the furnace ceiling. If flaming occurs when a package is placed in the furnace, the flames and/or the combustion gases rise. This rise can greatly affect the reading of the control thermocouple which, in turn, affects the furnace environment. That is, if the thermocouple is heated to a high temperature by the combustion process, the furnace controller senses that the temperature in the furnace is actually this hot; thus no power is delivered to the furnace, and the radiant environment is not known. Another reason for this test was to determine the possibility of performing all (or some) future tests with no power supplied to the furnace. If the furnace had enough thermal mass, it could be heat-soaked at a specific temperature, the door could be opened and closed while the package is loaded, and the thermal test could be carried out without having to apply power to the furnace during the test. This method of powerless testing would be easily reproducible and would therefore satisfy many questions previously asked concerning testing procedures.

Figure 8 shows the rate of cooling for various surfaces in the furnace and the control thermocouple. Initially all surface temperatures are very near 840° C except for the floor plate surface, which is near 830° C, and wall locations within 1 ft of the floor and within 1 ft of the door (bottom front edge of the wall), which are near 820° C. When the power supply is cut off, wall surfaces and the control thermocouple appear to lose heat at about the same rate. The steel plate temperature initially stays more stable than the other locations for the

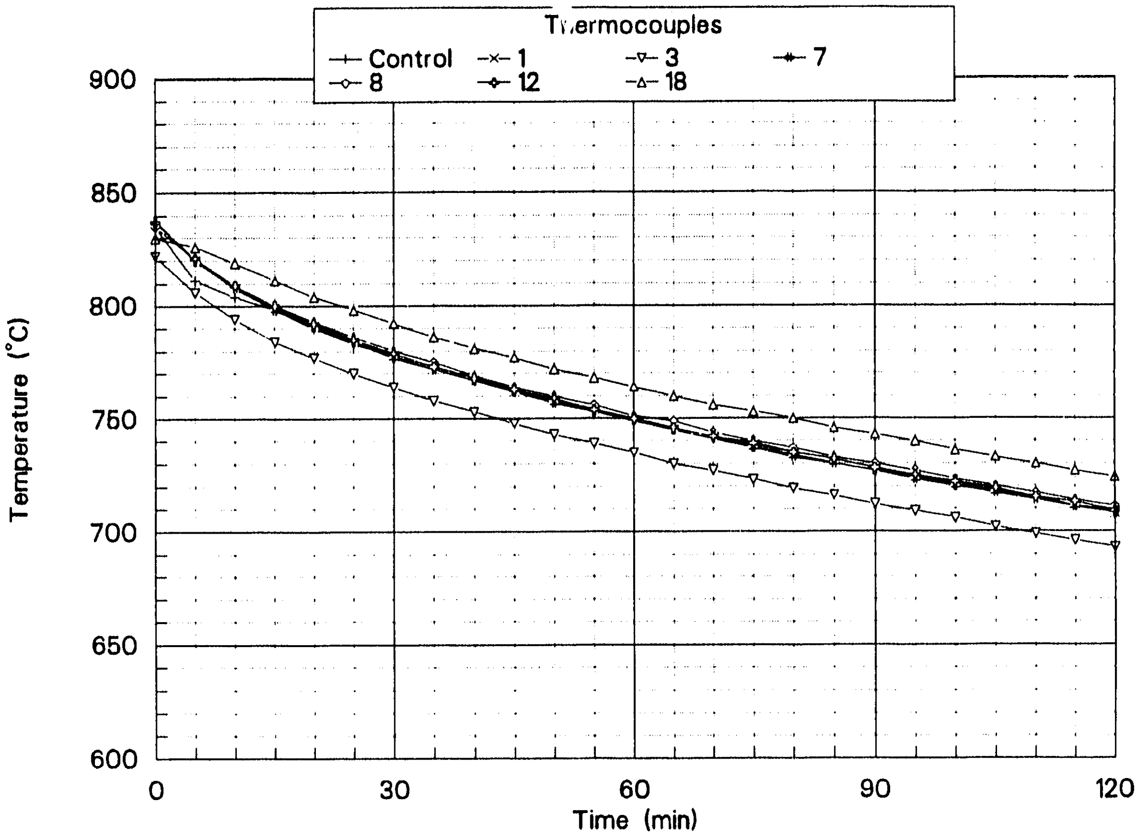


Fig. 8. Temperature vs time for various furnace surface locations during Experiment 3, closed-door cooldown from set point of 835° C.

first 5 min but thereafter falls at the same rate as those of the other surface. The temperature difference between the plate and walls remains constant at about 10 to 12°C during the final 10 min of the experiment. These data indicate that when the furnace acts as a closed system, the rate of temperature drop is nearly constant for all surfaces. The rate of temperature drop during the early part of the experiment can be explained by the density differences of the various materials that make up the surfaces. Natural convection occurs at about the same rate on all surfaces (actually a little faster on the floor than elsewhere), so that the rate of heat transfer from each of these surfaces is about the same. But because the brick on the floor and the ceiling is ~25% as dense as that on the floor, the temperatures of the wall and ceiling fall much faster than the temperatures of the floor. After a short time, the temperature difference between the floor and the other surfaces is great enough to drive radiant heat exchange between all these surfaces. The consequence is that all of the surfaces lose temperature at about the same rate. In other words, it is most likely that the walls lose considerably more heat via conduction and convection than does the floor, but the floor then radiates to these surfaces, which have cooled somewhat, and the overall effect is that the temperatures of all of these surfaces fall at about the same rate when the furnace is acting as a closed system.

As mentioned earlier, performing thermal tests in a furnace that does not have power supplied to it has some merits, but it is apparent from this test that testing of this sort is most likely not possible in the B-1023 furnace. The temperature in the furnace drops fairly rapidly after the power is turned off, though the rate of temperature drop does curtail with time. Nonetheless, a temperature drop of about 60°C is seen from some surfaces within 30 min. A package would have to act as a vigorous heat source for the furnace temperature not to fall significantly during the test.

Experiment 4. Furnace Recovery with Power Restored, 1 min Open

Experiment 4 was an attempt to test the ability of the furnace to recover heat after the door had been open for a short time. In this experiment the door was open for 1 min and then reclosed, then the power was restored. One of the reasons for running this experiment was to measure the quantity of temperature overshoot that can be expected in the furnace when it is recovering in this manner. During some past thermal tests, control thermocouple temperatures rose to well above the set point shortly after a package was inserted into the furnace, the door was shut, and the power was restored. It has been surmised that two factors cause this temperature rise. First, hot offgases rising from the package (most likely, the first burst of hot offgases that affect the control thermocouple is from the burning of the package's exterior finish) are actually hotter than the set point of the furnace. When these offgases impinge on the control thermocouple, the temperature of this thermocouple rises to well above the furnace set-point temperature. The other possible reason is that when the door is open for a short time, the temperature of the air in the furnace falls much more than do the surface temperatures because of the high rate at which air from outside the furnace flows into the furnace (almost like a chimney effect) when the door is open. Because the proportional controller for the furnace (connected to the control thermocouple) receives information that the temperature is well below the set point, the amount of restored power apportioned is very high. At the same time, the surfaces in the furnace have not lost as much heat as the atmosphere has so these surfaces immediately begin heating the atmosphere (via free convection) and the control thermocouple (via radiation). Therefore, the possible result of this scenario is an overshoot of the set-point temperature by the furnace controller. That is, the proportional controller apportions more power than the furnace needs to reach the set-point temperature. In both cases it is clear that during an overshoot, the control thermocouple temperature is not a good indication of the radiant thermal environment in the furnace.

Figure 9 shows how thermocouples at various locations in the furnace reacted to this experiment. As in the previous experiments, plate temperatures were not affected initially as much as were other surface temperatures. While the door was open, wall and ceiling temperatures fell rapidly, and the control thermocouple fell even faster. Upon closing the furnace door, recovery of these thermocouples was also very rapid. However, the anticipated overshoot was not observed because most thermocouples returned to within 1°C of their preexperiment temperature. This fact represents concrete evidence that flaming or offgasing from the package can have a strong effect on the control thermocouple because overshoot temperatures as high as 60°C above the set point have been observed during previous tests.

The other worthwhile observation made from the data presented here is the rate at which each of the furnace surfaces reheat. The 835°C set point used in this experiment has been used for previous thermal tests and is based on the belief that this set point will allow radiant surfaces in the furnace to be at least 800°C soon after the package is placed inside the furnace. With the exception of locations at the bottom and very near the door, all temperatures are >800°C approximately 3 min after the door has been shut. If the power is restored during a true thermal test, this same response can be expected. The only time that such recovery would not be guaranteed would be when power to the furnace is not restored, which might be the case if the package flamed or offgased in the direction of the control thermocouple. Even if offgasing did occur in this direction, it would be very unlikely that the furnace power would not be restored for at least a short time and at a high rate because, regardless of how much the package flames, the control thermocouple would have been exposed to air at a much lower temperature while the door was open and its temperature reading would have dropped significantly. It is apparent that the burst of energy received in the furnace from the controller is great enough to reheat the furnace very quickly.

Experiment 5. Furnace Recovery with Power Restored, 2 min Open

Experiment 5 was similar to Experiment 4 except that the furnace door was left open for 2 min instead of 1 min. Figure 10 shows the results of this experiment. The responses of various thermocouples located throughout the furnace were similar to those in Experiment 4. With the exception of the thermocouples in the floor plate, each of the monitored thermocouples dropped about 80°C more than in the previous experiment. These locations were at their coldest when the door was first shut but began recovering almost immediately. After 9 min, with the exception of the lower edges near the door, these locations attained a temperature of 800°C. The floor plate responded less rapidly; its coldest temperature occurred 6 to 8 min into the experiment. This portion of the furnace recovered to 800°C at the 12-min mark. If a real thermal test were to require that the door be open for 2 min, most likely it would not be acceptable to wait for 12 min to start the time clock; it would be necessary to raise the heat-soak temperature prior to the test. All important thermocouples read at least 785°C within 6 min (i.e., 4 min after the door was shut), and the

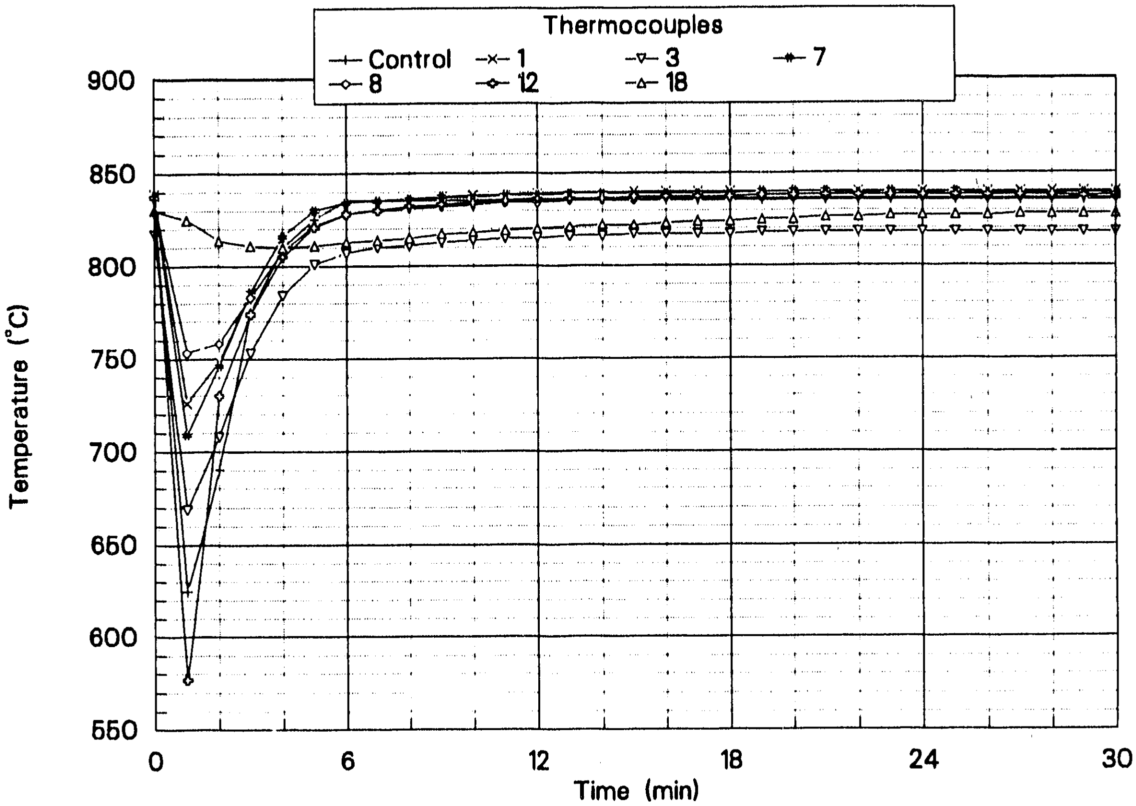


Fig. 9. Temperature vs time for various furnace surface locations during Experiment 4, door open 1 min, then shut, and power restored with a furnace set point of 835° C.

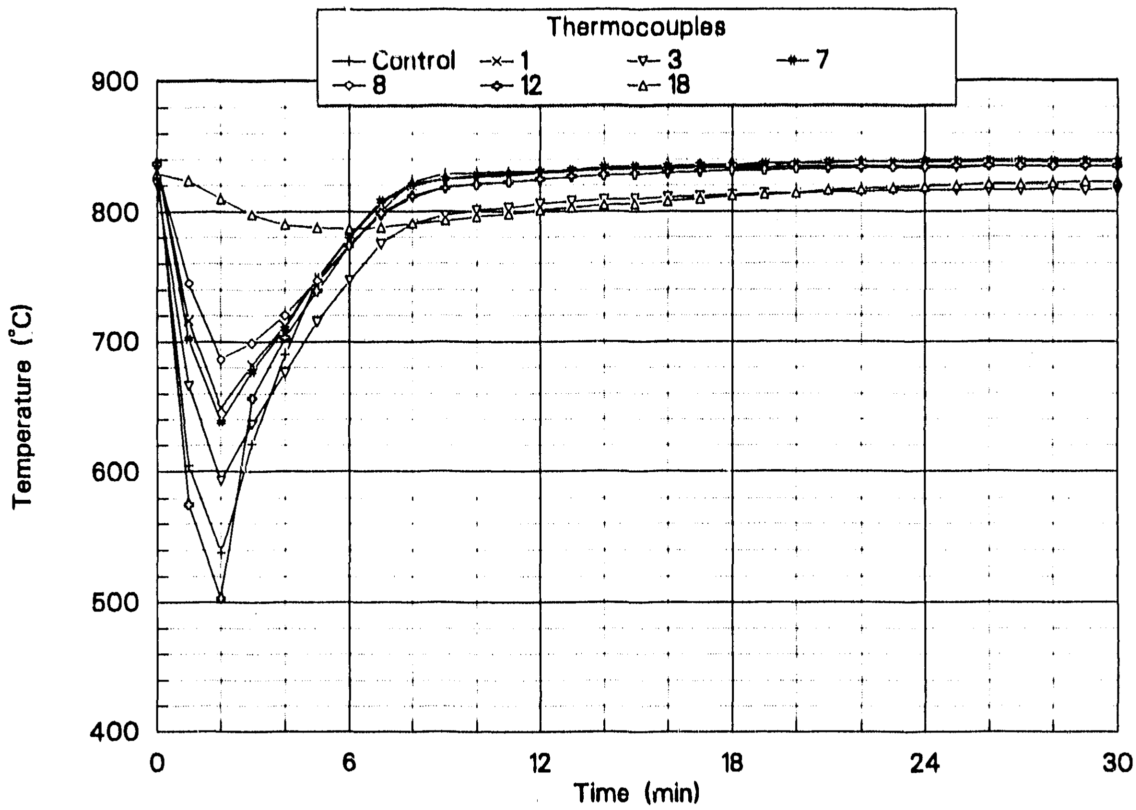


Fig. 10. Temperature vs time for various furnace surface locations during Experiment 5, door open 2 min, then shut, and power restored with a furnace set point of 835° C.

floor plate thermocouple never fell below this mark. So a heat-soak setting of 850°C followed by a control setting of 835°C during the test would be the best solution if a test procedure required that a door be open for 1.5 min or more.

Experiment 6. Furnace Recovery Without Power Restored

It has been surmised that the worst possible case for a thermal test would be one in which offgasing or flaming from the package is so intense that power to the furnace is not restored when the door is shut. It is hard to imagine such a situation. Nonetheless, it does represent a bounding scenario for thermal tests performed in the furnace. This being the case, an experiment was performed to monitor the recovery and eventual cooldown of the furnace when the furnace was heat-soaked at 835°C, the door opened for 1 min, then shut, but power was not restored.

Figure 11 shows how thermocouples in various locations responded during this experiment. The temperatures initially dropped in the same manner as they had in the previous experiment. When the door was initially shut, temperatures rebounded, but they never approached their initial reading. Except for thermocouples near the lower edge of the door and on the floor plate, all the surface thermocouples responded in the same manner as the control thermocouple. The recovery of all of these points was very close to 750°C, with the lower edge position ~10°C lower. The floor plate, as in the previous experiments, did not initially drop in temperature as did the rest of the surface thermocouples. But over time, the plate radiated to all the other surfaces within the furnace, and while the temperature of these other surfaces remained nearly constant after the first 4 min, the temperature of the plate continued to drop faster until it was ~15°C warmer than the other surfaces at ~15 min into the test. From this point until the end of the test, all surface temperatures dropped at about the same rate, indicating that radiant heat transfer between these various surfaces ensures that all surface temperatures within the furnace, excluding the lower edge near the door, stay within 20°C of one another except during the most severe conditions.

All of the above experiments were performed while the furnace was empty. The data gathered during these experiments are therefore highly idealized. That is, these data were gathered in a very "calm" atmosphere. When actual thermal tests are performed, the interior of the furnace experiences very different conditions, especially during the first few minutes. When the package is loaded into the furnace, a tremendous amount of heat is transferred to the package in the first few minutes, mainly by radiation from the surrounding surfaces but also by natural convection. As quickly as the package skin is heated, Celotex™ begins to decompose and, in some cases, combust. Also, the finish on the outside of the package decomposes. Each of these processes produce gases that cause an increase in the pressure in the furnace, which in turn forces some gas out of the furnace. The processes taking place are such that, currently, a complete heat balance on the package cannot be rendered. Evidence, however, suggests that, initially, the package acts overall as a heat source. Modeling activities are proposed that will enable us to define the package's role more precisely. For now it is sufficient to understand that the atmosphere is thermally chaotic during thermal testing in the B-1023 furnace.

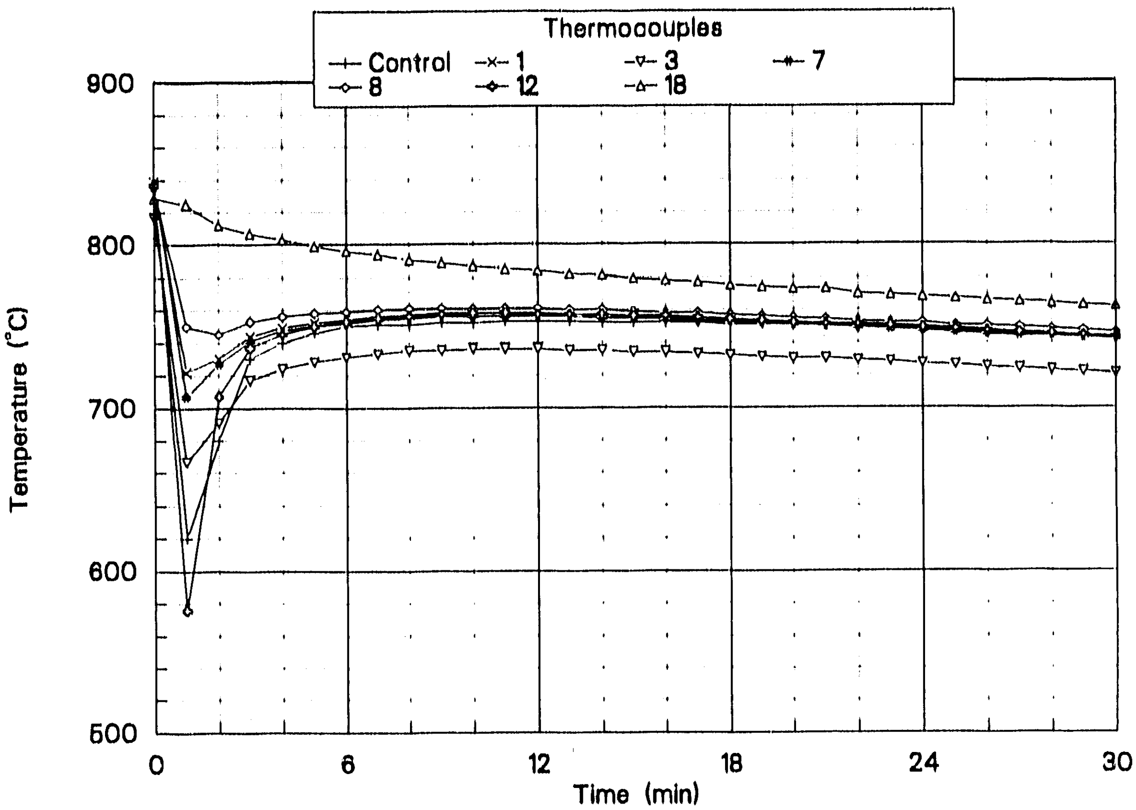


Fig. 11. Temperature vs time for various furnace surface locations during Experiment 6, door open 1 min, then shut, and power NOT restored with a furnace set point of 835° C.

Regardless of how much data are gathered in a calm furnace, some data must be gathered in an actual thermal test situation. For this reason, two DT-18 packages previously damaged during routine use were used for simulated thermal tests. For the first of these tests the furnace was heat-soaked at 835°C, and for the second, heat-soaking was performed at 800°C. Except for this difference, the two experiments were identical. The packages were placed upright on a DT-18 test stand (see Fig. 4), with the damaged area at the top. It was hoped that flaming and offgasing from the package would affect the control thermocouple, and, although the effect was not as great as has been seen in some earlier DT-18 tests, the desired result was achieved. For each package, the furnace control thermocouple reading became high enough that the controller mechanism cut off the power to the furnace. During these periods of no power delivery, furnace surface temperatures did not fall, as may have been expected from the results of Experiment 3 (closed-door cooldown), indicating that the heat of the Celotex™ reaction makes a significant contribution to the overall heat balance within the furnace.

Experiment 7. Test Package Burn at 835°C

Figure 12 shows the response of various surface thermocouples to the mock thermal test after a furnace heat-soak at 835°C. Figure 13 shows the total power delivered to the furnace vs time for the duration of the test. Ammeters readings 1 min after the door was closed were not recorded. It is believed that the largest power deliverance to the furnace occurred during that time. The controller proportions both the voltage and the amperage to the furnace, and 1 min after the test began, peak readings for the voltage were recorded. In the second thermal mock test, similar values for voltage were recorded 1 min into the test, and the amperage readings were made. Thus the second test power curve (described later) is probably more representative of both tests in the first few minutes than is that shown in Fig. 13. After this early data miscue, the power was seen to drop quickly to zero wattage, where it remained until about the middle of the test. The power was then restored, but at a level somewhat lower than was necessary to maintain the heat-soak temperature prior to the experiment (the value at −5 min in Fig. 13). Interestingly, a significant drop in furnace surface temperatures did not result from this power outage. Indications are that the package flamed for ~5 min because the control thermocouple fluctuated instead of steadily increasing or decreasing. After the flame died, steadier control thermocouple readings were obtained, and the readings began to fall slowly. Because of offgasing and flaming, the ceiling surface was heated significantly above other surfaces in the furnace, and this surface temperature nearly duplicated that of the control thermocouple. All other surface locations, except for those low and near the door, recovered to above 800°C within 6 min, and most recovered to above this point within 4 min. These temperatures then remained stable for the rest of the test. As seen in previous experiments, the floor thermocouples were not affected as much as the other surface thermocouples at the initiation of the test, but as the test progressed, the floor temperature slowly fell while the surrounding surface temperatures rose. At 9 min into the test, the floor became the coldest surface and remained so for the rest of the test. This was yet another experiment where the floor temperature and the temperature of other surfaces surrounding the floor initially reacted quite differently to "open-door stimulus," but once the door was closed, heat exchange between these separate surfaces occurred and all their respective temperatures equilibrated to within 10 to 15°C of one another in minutes.

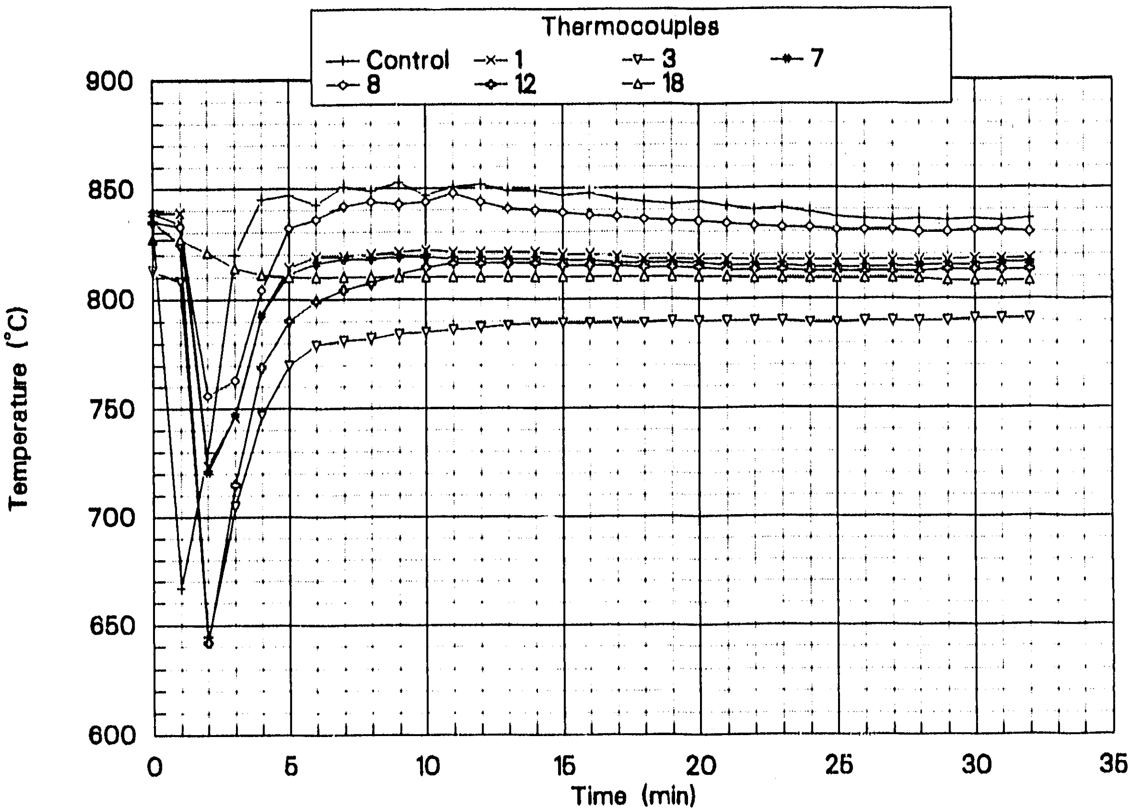


Fig. 12. Temperature vs time for various furnace surface locations during Experiment 7, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 835° C.

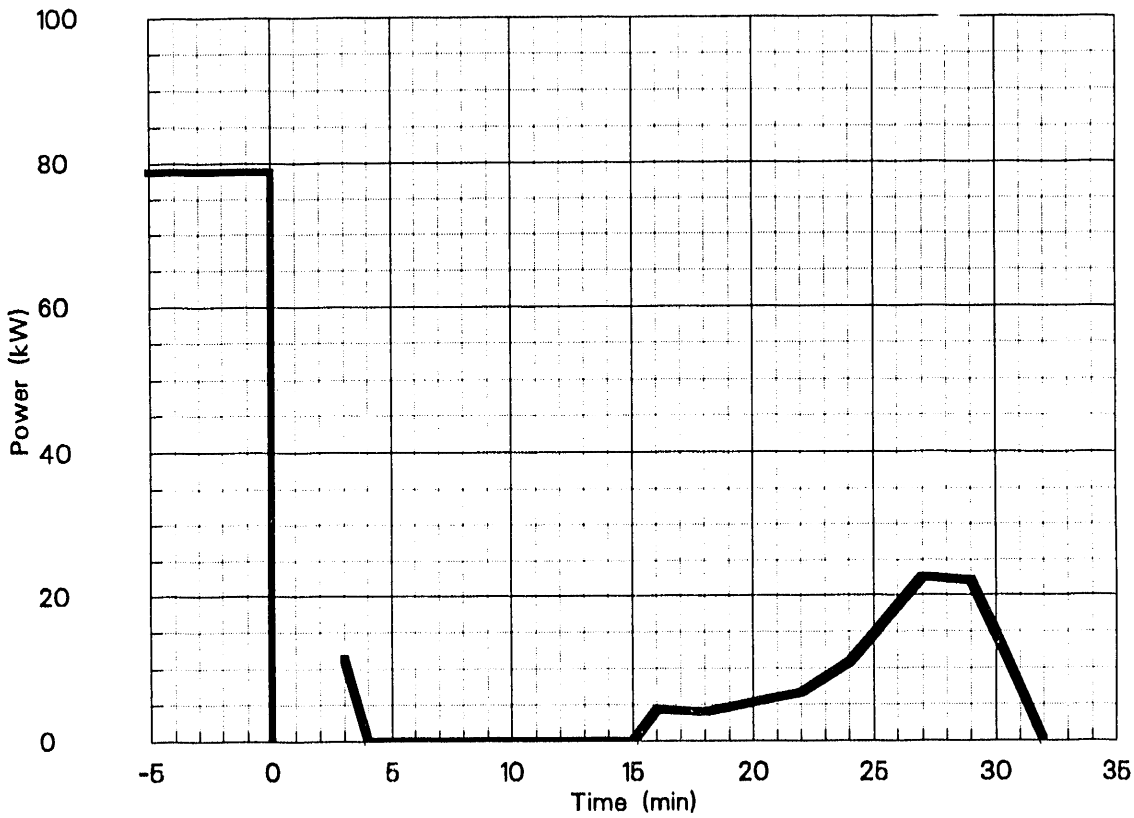


Fig. 13. Power to furnace vs. time during Experiment 7, mock hypothetical thermal testing of DT-18 container with a furnace set point of 835° C.

The proportional control of the furnace has several characteristics which indicate that the control scheme is well designed. The furnace begins to use small amounts of power 16 min into the test, even though at this point the control thermocouple registers more than 10°C above the furnace set point of 835°C. The controller must sense the control thermocouple's response over time, detect that the temperature is falling, then attempt to apply the amount of power that will allow the furnace temperature to fall slowly to the set point without dropping well below it. When the control thermocouple reaches the intended set point (26- to 27-min range) the furnace assumes a constant power input, but not the same constant power input that was necessary to keep the empty furnace at the same temperature prior to the experiment. This action shows that the furnace is constantly considering thermocouple data in a timed response manner. Both of these observations are indicative of a well-conceived control plan.

Experiment 8. Test Package Burn at 800°C

The second mock thermal test of a DT-18 package was performed in the same manner as the first except that the furnace was heat-soaked and operated at 800°C rather than 835°C. Figure 14 shows how thermocouples located in various positions throughout the furnace responded during this experiment, and Fig. 15 represents the power supplied to the furnace during the same time. This experiment was an attempt to simulate the tests carried out prior to 1991. During previous thermal tests, before any questions were raised as to the validity of the tests carried out in the furnace, the furnace temperature was set to 800°C (805 or 810°C in some cases). It was assumed that an ambient temperature reading would certify the surrounding radiant environment. Data taken before the initialization of this thermal test indicated that the wall temperatures and ceiling were very close to 800°C after a thorough heat-soak at that temperature. The floor was within 10 to 20°C of 800°C. However, these temperatures were reached prior to the opening of the furnace door for package insertion. As observed in Experiment 7, the surface temperatures within the furnace were not likely to rebound to their pretest levels during the actual test. The temperature responses of the various surfaces and the control thermocouple were very similar to responses during the earlier test, except that they were about 35°C lower. Offgasing and flaming occurred during this experiment, and both the control and the ceiling thermocouple were affected. Both reached 800°C within 5 min and then remained at or above this temperature for the remainder of the test. Side wall surface temperatures (excluding those low and near the door) returned to 790°C within 5 min, but the door required 9 min to reach 790°C. These temperatures then remained at or above 790°C for the remainder of the test. The floor plate responded in the same manner as for the previous test. A slow drop in floor temperature was recorded, with stabilization between 775 and 780°C.

The power delivered to the furnace (see Fig. 15) was somewhat similar to that of the first test, except that the power did not turn completely off for as long a time (only about 4 min). With all the data available (as opposed to the first test), the sharp spike in power directly after the door was closed was readily apparent as the input reached nearly 400,000 W. It should be noted that a similar spike occurred during the first test burn, but it occurred so quickly that the ammeter reading was not recorded and thus cannot be shown in Fig. 13. This spike lasted less than 1 min, after which the power use slowed to 20,000 W or less for the remainder of the test, with most of the test (minutes 5 through 21) at <10,000 W. Although

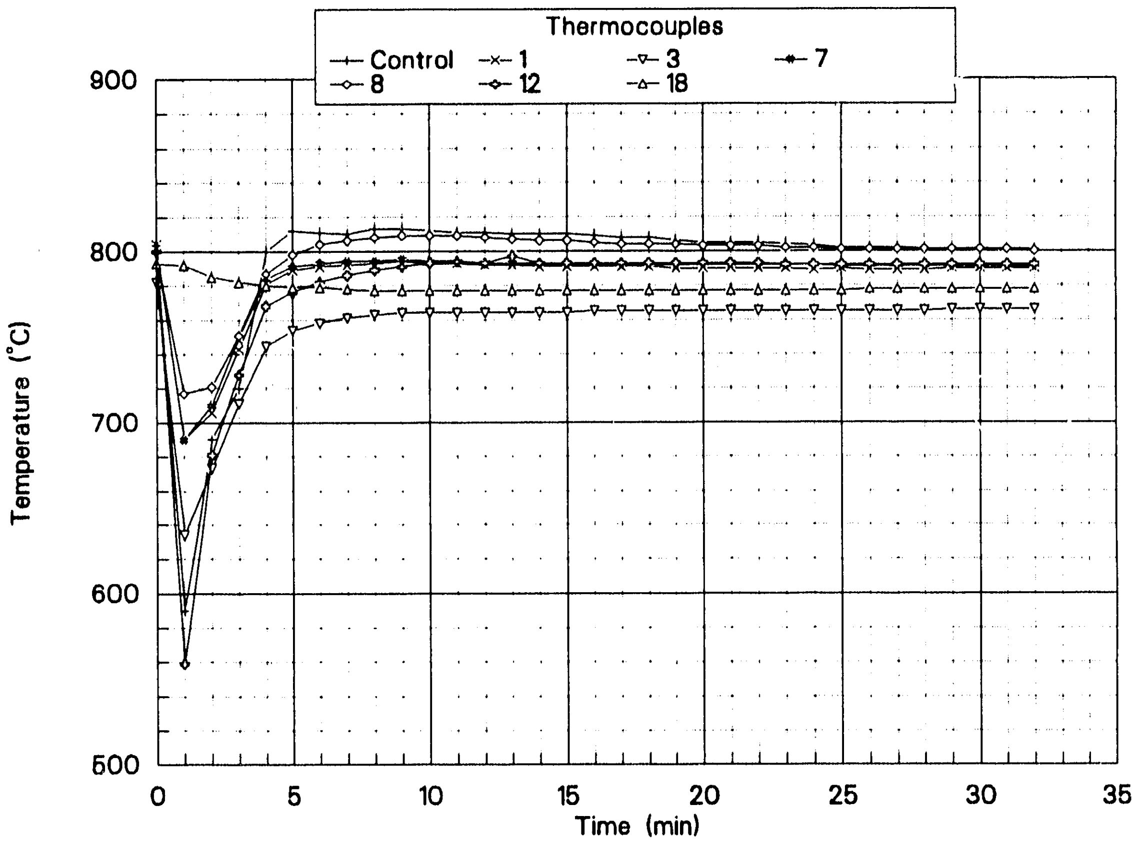


Fig. 14. Temperature vs time for various furnace surface locations during Experiment 8, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 800° C.

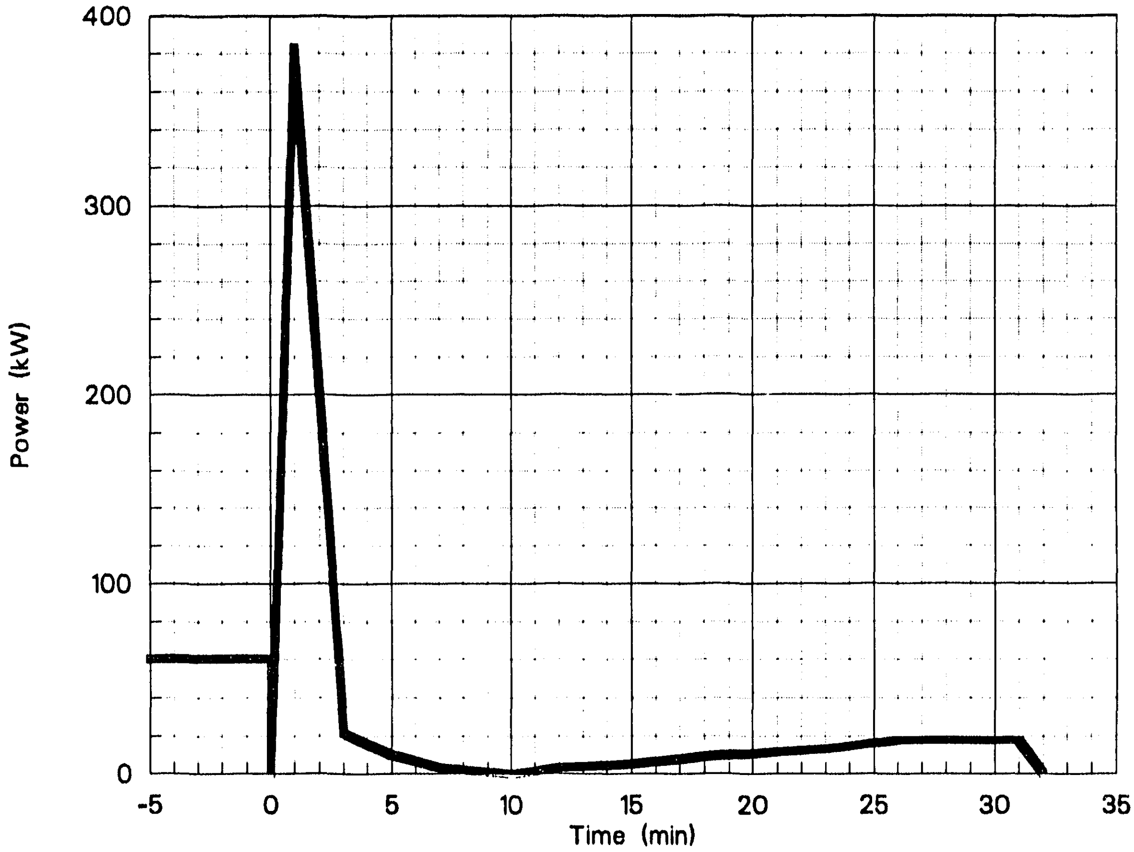


Fig. 15. Power to furnace vs time during Experiment 8, mock hypothetical thermal testing of DT-18 container with a furnace set point of 800° C.

at first glance the power used during these two tests seems quite unsimilar, closer inspection shows they are very close. During the second test burn, the furnace did not shut off for a long time, but a span occurred when the power usage was very low. After the 15-min mark in both experiments, the power began to build; between 25 and 30 min, the power in each test was about 20,000 W. In both cases, no marked change occurred in various surface temperatures corresponding to changes in the power consumption (except at the initiation of the test). That is, one cannot determine when the power consumption rate changed by reading the surface temperatures after the first 5 min of the test.

5. CONCLUSIONS

The findings of this investigation indicate that it is possible to perform hypothetical thermal accident tests as specified by 10 CFR 71.73(c)(3) in the B-1023 furnace located in Building 9204-4 at the Oak Ridge Y-12 Plant. Therefore, it is recommended that testing continue at this facility. It should also be recognized that obtaining and documenting the required thermal environment for these tests will take careful planning and execution on the part of the testing committee. The manner in which these tests are conducted may have to be refined to reflect findings contained in this report. If the following guidelines are followed, then testing in the B-1023 furnace should be sufficient to meet 10 CFR 71.73(c)(3) requirements.

Throughout all of the testing performed with the furnace door shut, little variation in temperature occurred from surface to surface, so it may not be necessary to monitor the temperature of more than one surface during future testing. The steel plate on the furnace floor makes it convenient to measure surface temperatures there because it is not necessary to actually mount these thermocouples on a part of the furnace (i.e., the plate is not part of the furnace). On the other hand, these tests do not include any data where the flame from a package directly impinges on the plate. Most likely when the flame impinges on the floor, the offgases are well distributed throughout the furnace and their effect on the control thermocouple is mirrored throughout the furnace. That is, the surrounding surfaces are probably as affected as the control thermocouple is by these vapors. But without definitive evidence, it is impossible to be sure that this conclusion is correct. The possibility of flaming from both ends of a package does exist. Also, the floor plate does not respond during the initial loading of the package in the same manner as the walls and ceiling do. Thus it will be necessary to monitor the temperature of the floor plate and at least one side wall. Data show no tangible difference between the temperatures of the various walls. This being the case, it will be necessary to instrument at least one of the furnace walls with two or three thermocouples. A minimum of two thermocouples should be permanently mounted on the back wall of the furnace in approximately the same place as thermocouple 7 was positioned during these tests. If at all possible, during future tests, special care should be taken to orient the package such that the top does not face this monitored wall. To help account for unexpected flaming or other occurrences, it is recommended that two walls be instrumented with three thermocouples each. This setup will ensure consistent furnace surface temperature measurement.

Along with the need for wall thermocouples goes a need to revise these test procedures. In the past, these tests have been performed as quickly as possible after the drop test procedures. In the future, these tests should be more carefully approached. It will still be possible to conduct these tests immediately after the drop test, but only when the necessary preliminary setup for the thermal test has been done. The set point of the furnace should be 835°C if the package can be loaded in 1.5 min or less. For a package requiring more than 1.5 min to load but less than 3 min, the furnace should be heat-soaked at 850°C. This furnace set point should be used for the heat-soak prior to the test, but during the test itself, the furnace set point should be 835°C. If packages are encountered that require more than 3 min to load, further testing will be required to determine furnace heat-soak and set point temperatures.

The next step should be a determination of exactly how the test is to be performed. This decision includes the exact placement of any stand in the furnace. Both the orientation and the position of the stand are important when determining its location within the furnace. The position of the stand should be such that the package placed on it is as close as possible to the center of the furnace. Unless package size dictates otherwise, the package should be centered between the north and south walls (side walls) of the furnace. Centering between the back wall and the door will be contingent on how deeply into the furnace the package can be loaded. Some packages are loaded by using a pincher mechanism attached to the front of a forklift, and the pincher mechanism is not long enough to load the package on a stand placed too far back in the furnace. Thus it may be necessary to place the stand slightly in front of the center of the furnace. The standard procedure is to load the package onto a hot stand to begin the test, but when the test is finished, the stand and package are removed as a single unit. Then it is necessary to load another stand into the furnace prior to the next burn. The stands are typically loaded (and unloaded) by a forklift with tines attached to the front. These tines are somewhat longer than the pincher attachment, which means that it is possible to place the stand too deeply into the furnace for the package to be loaded onto it. Special care and preparation must be taken to avoid this situation.

The foreman in Building 9204-4 metal preparation area should designate two or three workers to operate the furnace and handle the loading and unloading of the package. These workers should be available at least 2 d prior to the test so that they can practice the test procedure. This practice includes loading the stand, loading the package, and unloading the entire unit. After the best procedure for these maneuvers has been agreed upon, the loading of packages should be timed to determine how long it will take to load the package. Efforts should be made to keep the loading time under 1.5 min. The timed quantity should be that required from when the door is initially lifted until the door has been fully shut and power restored to the furnace. When this time is greater than 1.5 min, it will be necessary to heat the furnace to a higher temperature, so efforts to keep this process under 1.5 min should be exercised. The amount of time used in loading the package should be recorded and kept as part of the official test record.

The furnace should be heat-soaked at the proper temperature for at least 24 h prior to the first test. The stand should be placed inside the furnace prior to heating the furnace. A record should be kept to show that the furnace has been preheated for the required time. The strip-chart recorder connected to the control thermocouple should be turned on during the heatup period. Also, a record of the readings of all thermocouples mounted in the furnace should be kept. Recording these temperatures each hour during the heatup period should suffice. All of these temperature recordings should be kept as part of the official test record.

The stands upon which the packages are placed for testing should have thermocouples so that their temperature can be recorded. To monitor the temperature of these stands, a minimum of two thermocouples should be placed on each test stand; I recommend placing three or four thermocouples on each stand. These thermocouples should be monitored in the same fashion as those on the floor plate, and the same criteria for functionality should be used.

When the furnace is first started, special care should be taken to ensure that each thermocouple responds correctly. Surface temperatures other than those on the floor should respond almost as quickly as the control thermocouple; those on the floor plate will be somewhat slower (see Fig. 5). Once the heat-soak begins, the furnace should not be opened until the first package is inserted. If for some reason it becomes necessary to open the furnace for <15 min, 2 h should be added to the heat-soak time. If the furnace is opened for >15 min, a full 24-h reheat-soak will be required. Very few reasons could require the furnace to be open >15 min, but in those few cases, it would be wise to fully heat-soak the furnace again.

Successive tests require a 2-h wait between tests. This 2-h period should start after the stand for the next test has been inserted and the furnace has been resealed. After this 2-h period, all measured temperatures in the furnace should be within 15°C of the furnace set point. If this is not the case, the next test should be delayed until the proper temperatures are reached. It may be necessary to increase the furnace set point until all temperatures are within 15°C of the original furnace set point. (In some cases, thermocouples will not function properly. A specific method for determining when to judge a thermocouple as "nonfunctioning" is given in Appendix B.)

Once the package has been loaded into the furnace, it should remain there until all functioning furnace surface thermocouples (including control, wall, and floor) register at or above 800°C for a continuous 30-min period, or for 35 min, *whichever is longer*.

The key to keeping test time to a minimum is to not allow the floor plate to drop below 800°C. If this drop does occur, recovery time could be long because of the slow response of the plate to thermal changes. It should be required that all temperatures monitored within the furnace be within 15°C of the intended furnace set point before the package is loaded. The intended furnace set-point temperature is 835°C for packages that can be loaded in 1.5 min or less and 850°C for packages that require 1.5 to 3 min for loading. If monitored temperatures are not at this level after the proper heat-soak has been applied, it may be necessary to increase the pretest furnace set-point temperatures until the proper surface temperatures are reached. In any case, the furnace set point should be returned to 835°C when the package is loaded and should be maintained at this level for the duration of the test.

All surface temperatures recorded in the furnace should be logged at least once every minute during the test, and the strip-chart recorder should record the control thermocouple temperature continuously. The temperatures in the furnace should not only each 800°C but should remain at or above this temperature for the duration of the test. Though not previously observed, flame impingement on the control thermocouple could allow other portions of the furnace to cool because the flames keep the furnace from turning on. If the temperatures are falling such that it appears that they may fall below the necessary value prior to the end of the test, the furnace set point should be increased manually until some power is delivered. If these guidelines are carefully followed, that case will be unlikely; however, test operators must be aware of the possibility.

As soon as the package is removed, the furnace door should be closed. The furnace should not be left open after the package has been removed and another test stand is being retrieved. Rather, the furnace door should be closed immediately after the package has been removed, then reopened when the next stand is placed in the furnace, and reclosed as quickly as possible. After the next stand has been placed in the furnace, the door shut, and the power started, the 2-h heatup period should begin. Again, the 2-h period is a minimum. Heat-up time should be longer if all measured surface thermocouple temperatures are not within 15° C of the intended furnace set point. The time at which the stand is placed in the furnace and the furnace resealed with power on should be entered into the official test record.

As long as temperature measurements are being made as specified above, recording the power input to the furnace should not be required. However, for thoroughness, it is recommended that these measurements be recorded each minute during the test. The three ammeters and three voltmeters should be monitored if test personnel are available to do so. All information recorded should be retained as part of the official test record. The faces of these six meters are highly nonlinear and are difficult to read with accuracy. The possibility of directly measuring the power input on a strip-chart recorder should be investigated. If these measurements can be recorded, a peak such as the one missed in Experiment 7 would not be missed in future tests.

Although not required, the following change would allow for a simpler testing procedure: If the furnace power could be controlled by thermocouples mounted on the various surfaces, rather than by a thermocouple that measures the ambient temperature within, testing procedures would be simplified. Any significant change to the furnace such as this one, however, would have to be made very carefully. As shown earlier, the proportional controller is sensitive and has been developed for use in exactly the manner in which it is currently deployed. To suddenly plug this controller into thermocouples, mounted on various surfaces in the furnace, that do not respond as quickly as the current control thermocouple could lead to unexpected results. Such a change would have to made only after consultation with the designers of the original control system. In addition, a change such as this could not be permanent, because the furnace is used primarily as a heat treat furnace in which ambient temperature is more important than wall temperatures.

6. RECOMMENDATIONS

1. Testing should be closely coordinated with Metal Preparation personnel. Tests should be run only when the furnace can be dedicated to this job for a minimum of 2 d (starting with a cold furnace); however, 3 d is preferred. The furnace floor and the mild steel plate should be cleaned of scale and debris that may have accumulated.

2. The morning of the first day should be a time to practice the procedures to be used during the test. Any stand to be used during the first test should be placed in the furnace prior to the 24-h heat-soak. Any thermocouples internal to the furnace to be used during the test should be attached to a data recorder at this time. When the furnace is first turned on, the readings from these thermocouples should be observed to ensure that they are functioning properly.

3. Five thermocouples should be placed in the mild steel plate on the furnace floor. One thermocouple should be placed in the center of the plate; the other four thermocouples should be placed one each 45 cm (1.5 ft) to the left, right, rear, and forward of the center thermocouple. The thermocouples should be attached to holes in the plate, which are 3.2 mm (1/8 in.) in diameter and a maximum of 6.4 mm (1/4 in.) deep. The holes should be filled with a liquid-metal setting compound. Each thermocouple should then be pressed into a hole, and the liquid-metal compound should be allowed to set.

   Furnace wall thermocouples should be used to determine furnace wall temperatures. At least two thermocouples should be located near the midpoint of the rear wall and should be monitored in the same manner as thermocouples on the floor plate (every minute for the duration of the test). At least two thermocouples should also be mounted on either the north or the south side wall near the midpoint. It is recommended that three thermocouples be placed on either the north or the south wall and three additional thermocouples be placed on the back wall. Each of these thermocouples will be monitored in the manner discussed in recommendations 6 and 8.

   Thermocouples that are herein referred to as "furnace surface thermocouples" include those that are mounted on the floor plate within the furnace as well as those that are mounted on the furnace walls.

4. Thermocouples placed on the test stand are *not* considered furnace surface thermocouples and therefore are *not* included in the requirements that are stated here for furnace surface and control thermocouples. Nonetheless, the use of thermocouples on the test stand is a good idea. Therefore, the stands upon which the packages are placed for testing should be thermocoupled such that their temperatures can be recorded. To monitor the temperatures of these test stands, a minimum of two thermocouples should be placed on each stand. It is recommended that three or four thermocouples be placed on each stand, that they be monitored in the same fashion as those on the floor plate, and that the same criteria for functionality be used (see Appendix B).

5. If practice loading determines that the package can be loaded in 1.5 min or less, the furnace heat-soak temperature should be 835°C, and if the package requires between 1.5 and 3 min to be loaded, the heat-soak temperature should be 850°C. The set-point temperature determined here is defined as the "intended furnace set-point temperature" and will be referred to as such throughout these recommendations. If the package requires longer than 3 min to load, additional testing will be necessary to determine the heat-soak temperature. In any case, the furnace should be set to 835°C after the package has been loaded into the furnace. The only time, after the package has been loaded into the furnace, that the set point should be higher than 835°C is when the control thermocouple is artificially heated by offgases and it appears that monitored furnace surface temperatures may not reach or may fall below 800°C. In this case, the furnace operator should adjust the furnace controls until the furnace power turns on and the desired temperatures are reached. This operation will have to be done strictly by operator judgment with the concurrence of the test manager. Any adjustments made during testing should be entered into the official test log.

6. After practice has been fully completed and the operators and the test manager are comfortable with the manner in which the test will be performed, the furnace should be sealed and turned on by setting the furnace controller to the intended furnace set-point temperature as determined in recommendation 5. Data recordings should be initiated at this time, and these data should be retained as a part of the official test record. Recording the temperature each hour at this point will be satisfactory. The furnace should be allowed to heat for a full 24 h.

7. Before a package is loaded into the furnace, all functioning (see Appendix B for determination of nonfunctioning thermocouples) monitored furnace surface thermocouples should register within 15°C of the intended furnace set-point temperature. If, after the heat-soak requirements have been met (i.e., 24 h for initial test and 2 h for subsequent tests), and all functioning furnace surface thermocouples are not within 15°C of the intended furnace set-point temperature, it will be necessary to increase the furnace set-point temperature. The furnace set-point temperature should be increased until all functioning furnace surface thermocouples register within 15°C of the intended furnace set-point temperature.

   When all functioning furnace surface thermocouples have attained readings that are within 15°C of the intended furnace set-point temperature and all heat-soak requirements have been met, the package can be loaded into the furnace.

8. During tests, data should be recorded at least every minute. Data concerning the power being supplied to the furnace should be included if they are deemed necessary.

9. For a test to be considered complete, the following criteria should be met: (1) The package should be left in the furnace for a minimum of 35 min, and (2) all of the functioning (see Appendix B for determination of functioning thermocouples) furnace surface thermocouples and the furnace control thermocouple should register at or above 800°C for a consecutive 30-min period during the time the package is in the furnace.

10. For consecutive tests, at least 2 h should be required between tests to allow the furnace and test stand to thermally equilibrate. Stands to be used for tests other than the first of the day should be heat-soaked in another furnace. The 2-h period will begin after the stand for the next test has been placed in the B-1023 furnace, the B-1023 furnace has been sealed, and the B-1023 furnace power has been restored. All functioning monitored furnace surface temperatures in the furnace should be within 15°C of the intended furnace set-point temperature before the package is loaded (see recommendation 5). With a 2-h wait between tests, it may not be possible to complete more than three tests during a single shift of operator time. Thus, it may be necessary either to practice with members from two different shifts or have operators from a single shift work overtime when more than three packages are to be burned (or testing could resume the following day). It is recommended that operators be requested to work overtime, thereby ensuring consistency in the manner in which the job is performed without prolonging the process.

11. Data that should become part of the official test record include furnace temperature readings that show the length of the heat-soak prior to each test, all temperature readings taken during each test, data concerning the amount of power to the furnace during each test, and the length of time each test lasted. The temperature readings should include those of the control thermocouple, those of the steel plate at the bottom of the furnace and those of the monitored furnace wall thermocouples. If available, temperature readings from the test stand should be included in the official test record.

REFERENCES

1. *Code of Federal Regulations*, Title 10, Part 71, Washington, D.C., Jan. 1, 1991.

2. *Manual on the Use of Thermocouples*, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1970.

Appendix A

PRESENTATION OF EXPERIMENTAL DATA

Appendix A

PRESENTATION OF EXPERIMENTAL DATA

All temperature data taken during the course of the experimental work discussed in this report are organized by individual experiments and presented in graphical format. For each experiment, three graphs are used to present the data in Figs. A.1–A.24. Each graph contains data from seven different thermocouples such that all 21 thermocouples are represented. Thermocouple malfunctions are noted in the caption under the graph that would have contained these data. For each experiment, figures are labeled "wall locations"; "door locations"; and "floor, ceiling, and control locations." The wall location figures include three temperature histories from each of the side walls and an additional temperature history from the rear-wall thermocouple. The door location figures simply contain temperature histories from all seven thermocouples located on the door of the furnace. The floor, ceiling, and wall location figures include five temperature histories from the floor plate along with temperature histories from the control thermocouple and the surface-mounted thermocouple on the ceiling.

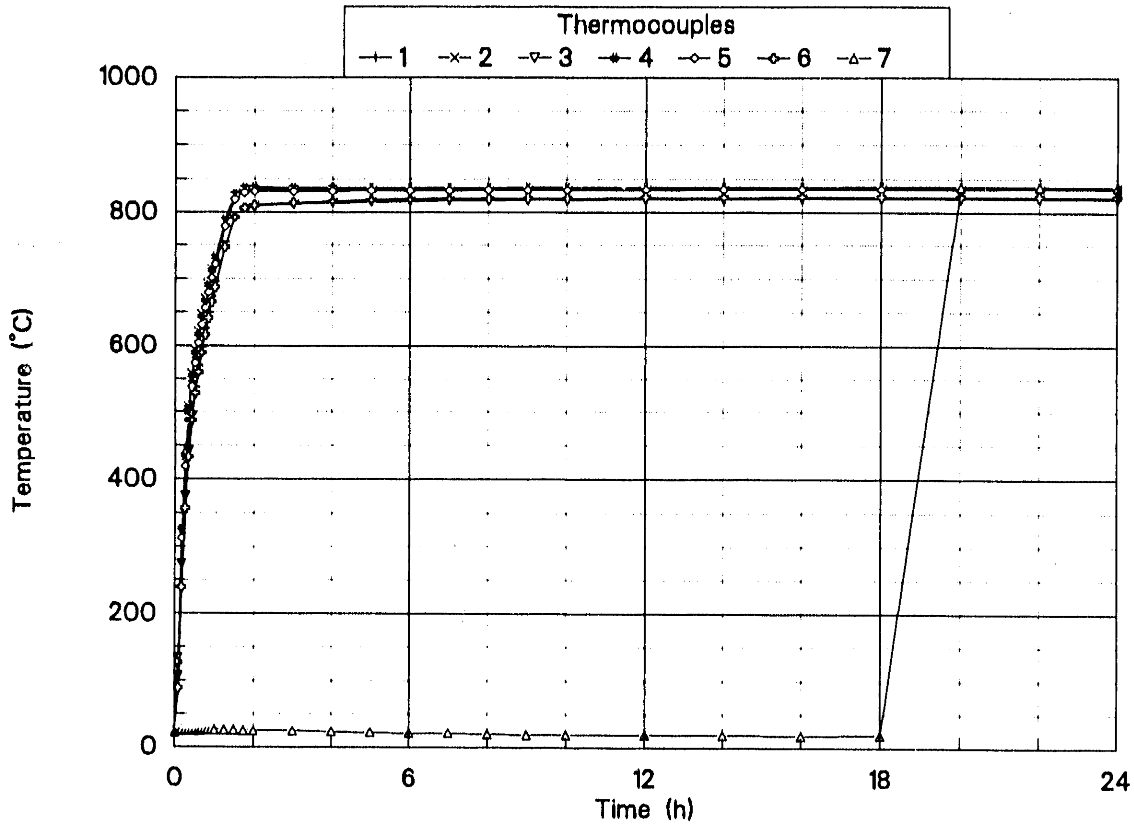


Fig. A.1. Temperature vs time for furnace wall locations during Experiment 1, furnace heatup to set point of 835° C from cold start. Note: Thermocouple 7 had a short circuit which was corrected ~18 h into this experiment.

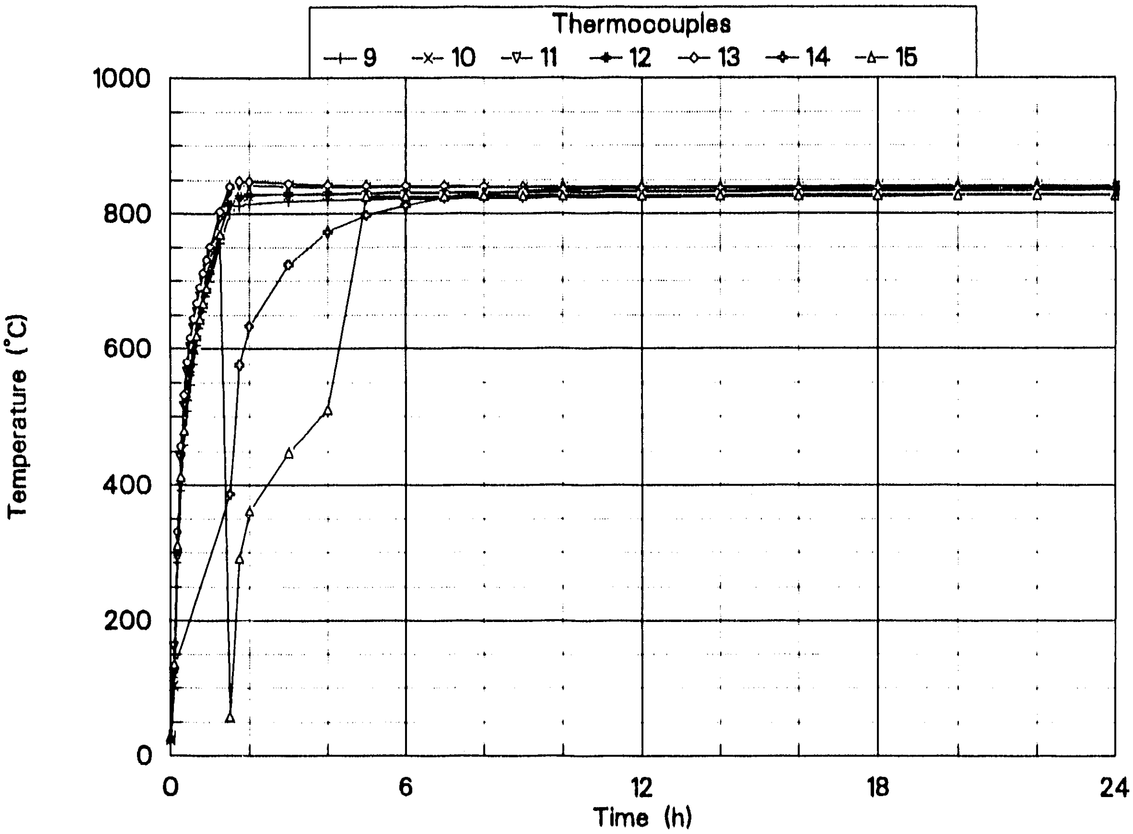


Fig. A.2. Temperature vs time for furnace door locations during Experiment 1, furnace heatup to set point of 835°C from cold start. Note: Thermocouples 14 and 15 were malfunctioning for the first 6 h of this experiment.

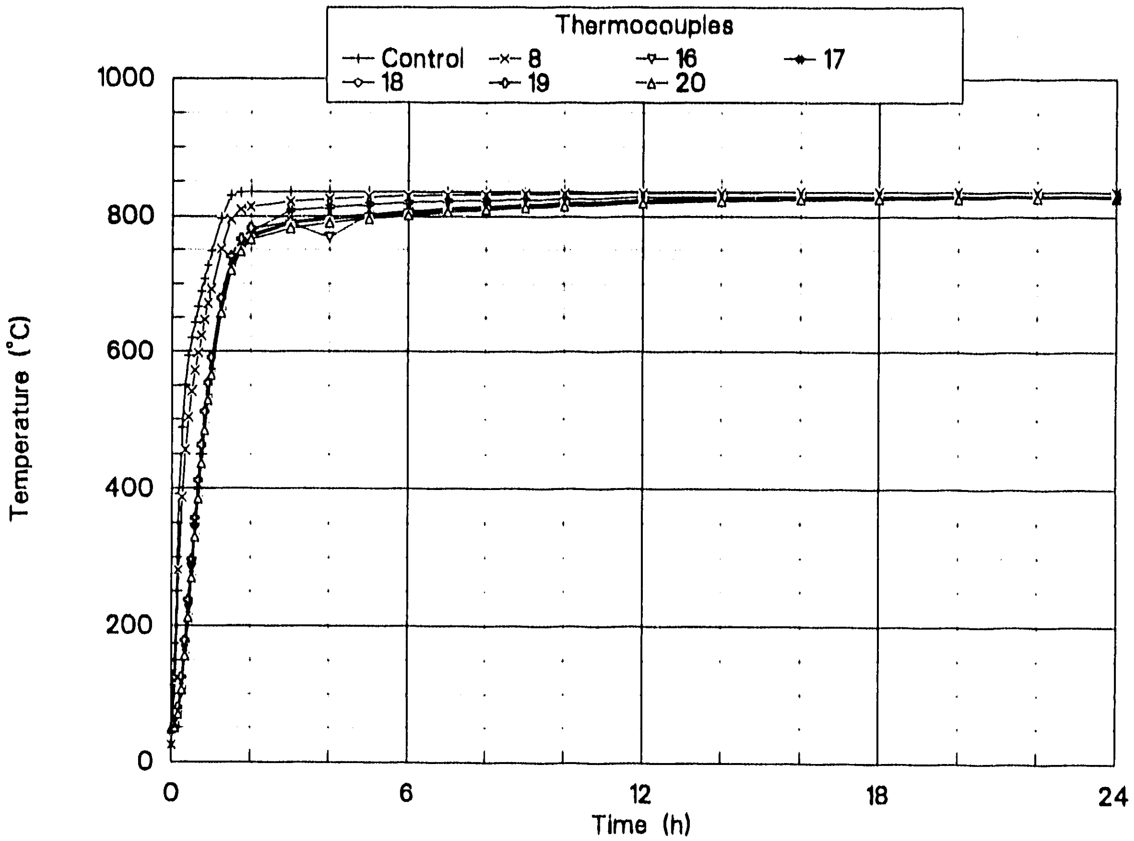


Fig. A.3. Temperature vs time for furnace control, ceiling and floor locations during Experiment 1, furnace heatup to set point of 835° C from cold start.

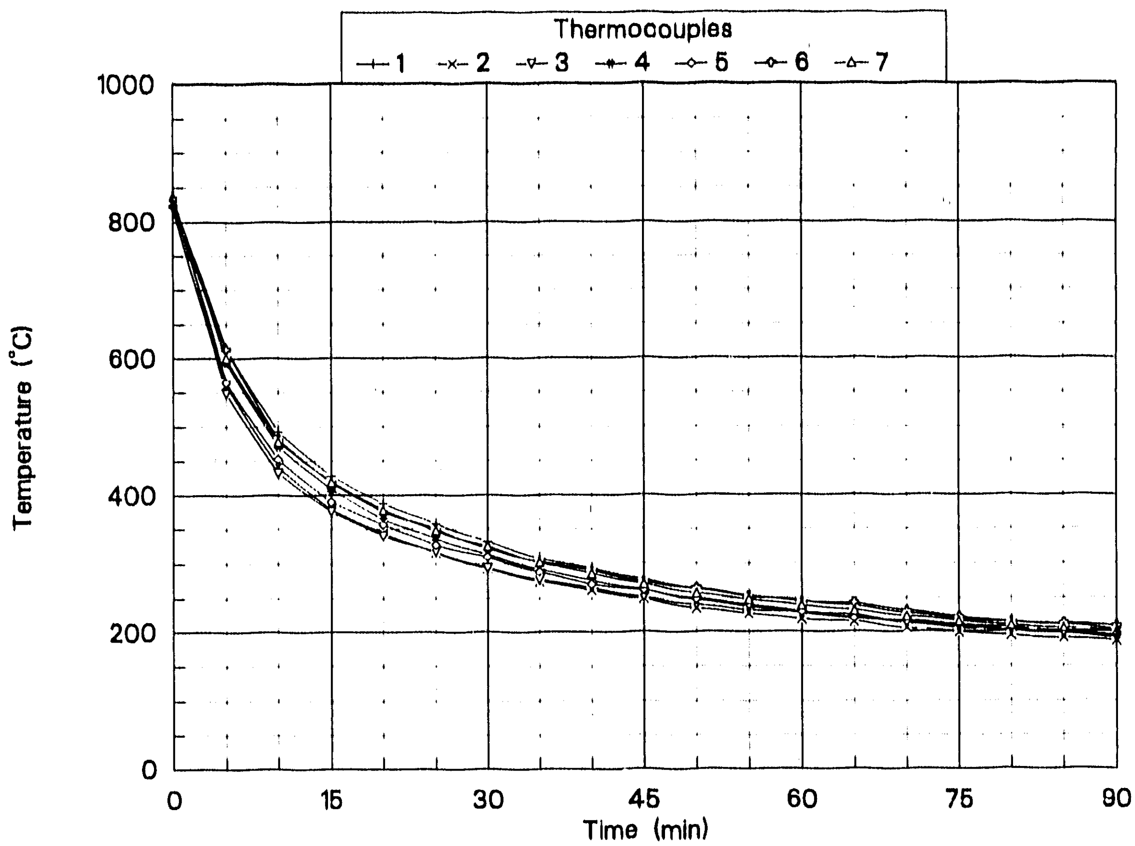


Fig. A.4. Temperature vs time for furnace wall locations during Experiment 2, open-door cooldown from set point of 835° C.

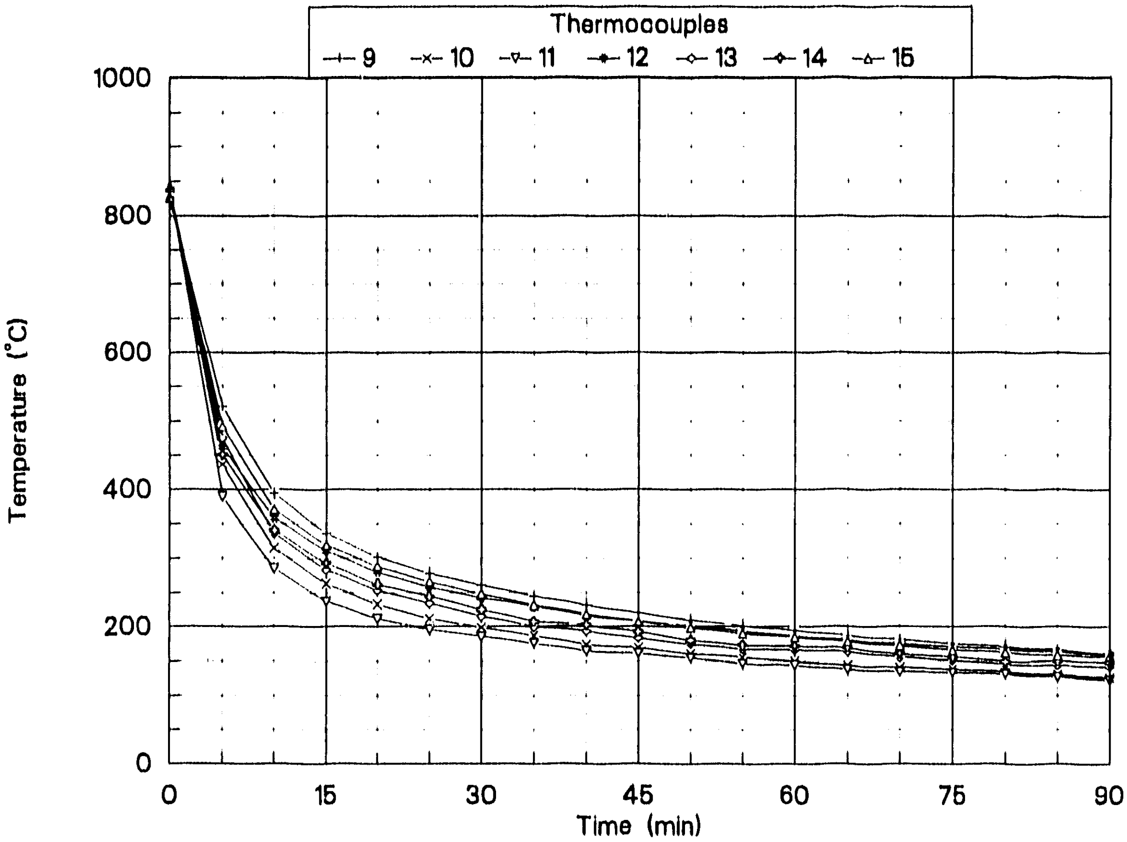


Fig. A.5. Temperature vs time for furnace door locations during Experiment 2, open-door cooldown from set point of 835° C.

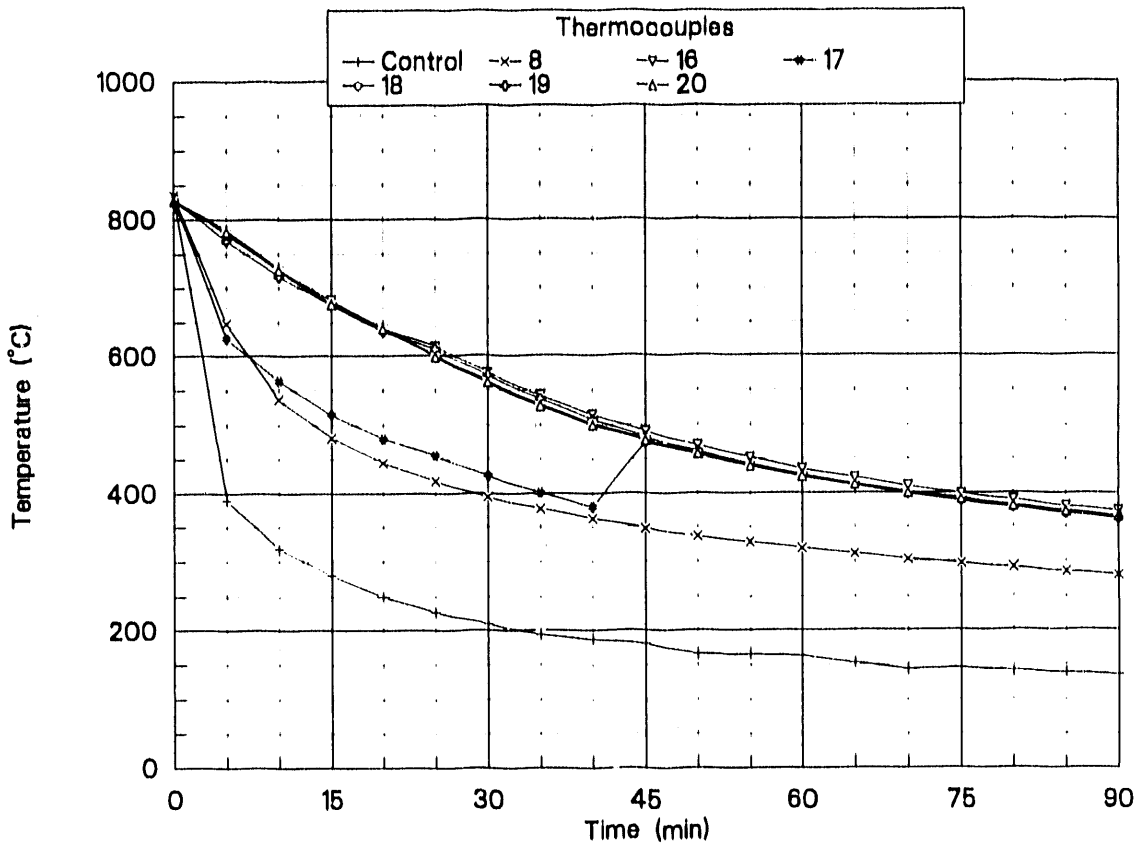


Fig. A.6. Temperature vs time for furnace control, ceiling and floor locations during Experiment 2, open-door cooldown from set point of 835° C.

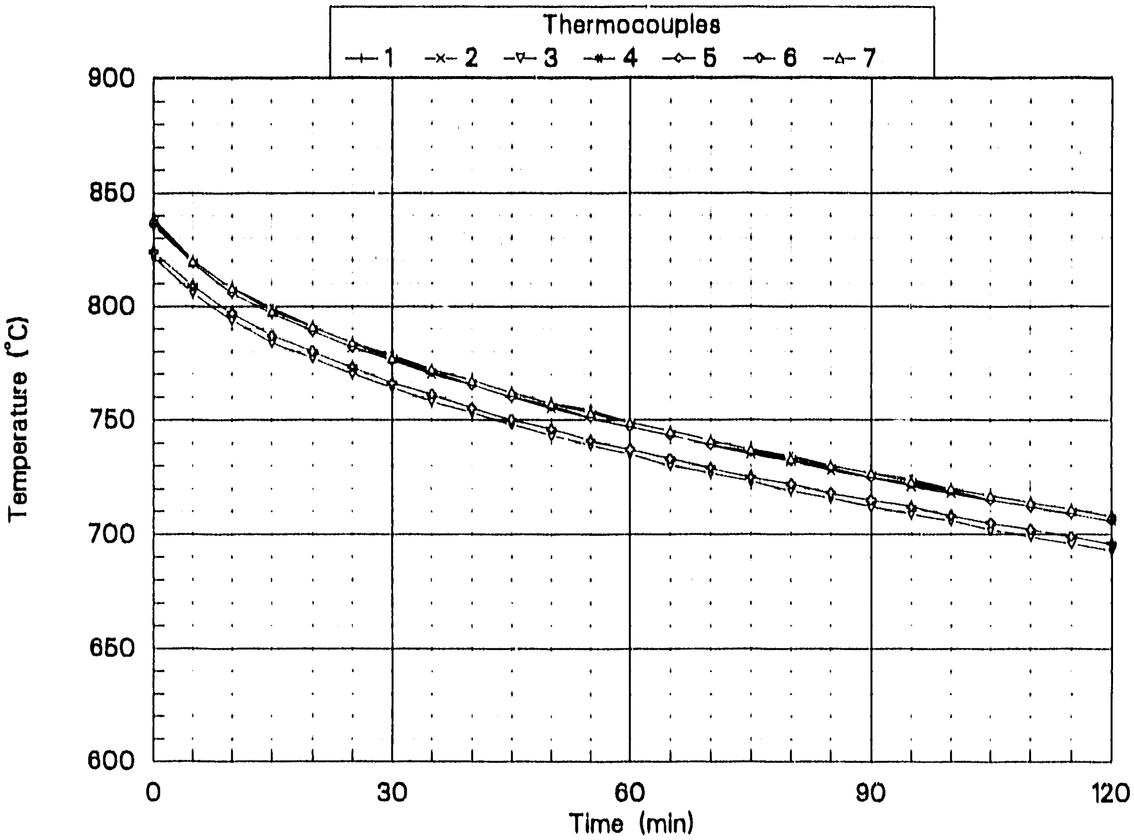


Fig. A.7. Temperature vs time for furnace wall locations during Experiment 3, closed-door cooldown from set point of 835° C.

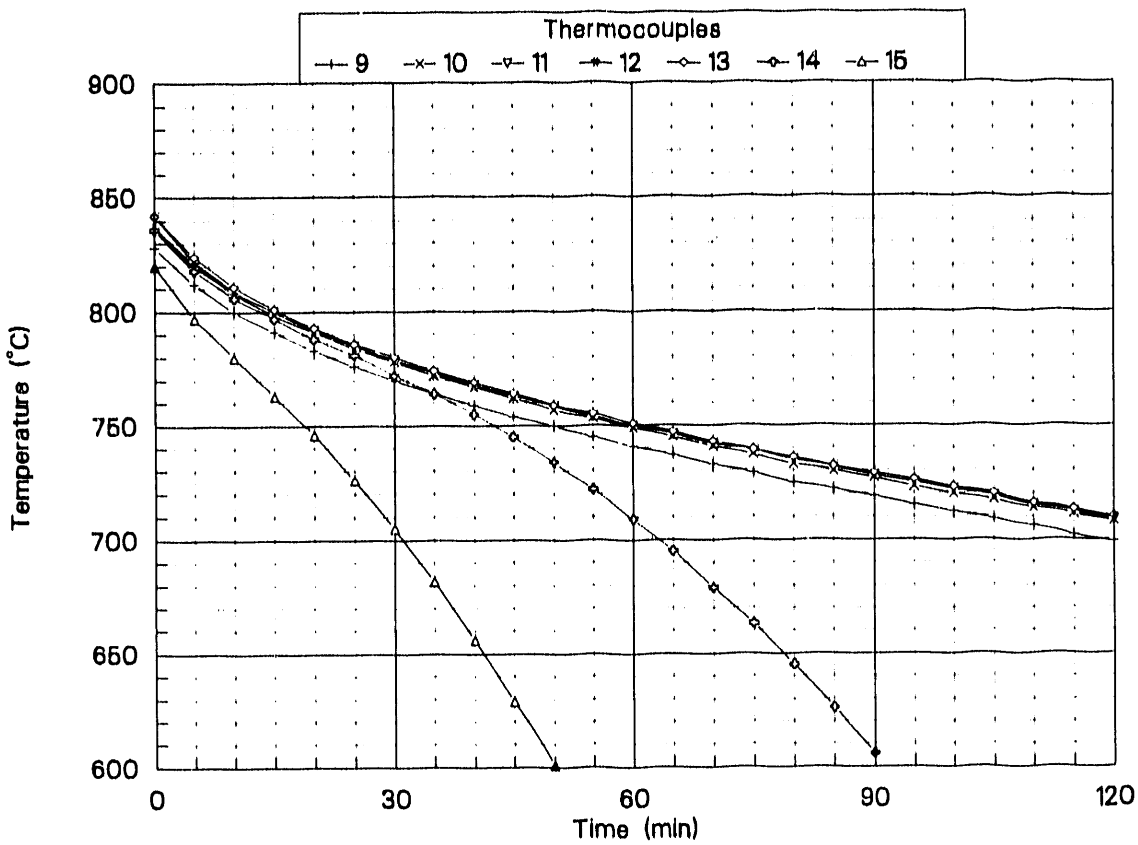


Fig. A.8. Temperature vs time for furnace door locations during Experiment 3, closed-door cooldown from set point of 835° C. Note: Thermocouples 14 and 15 malfunctioned during this experiment.

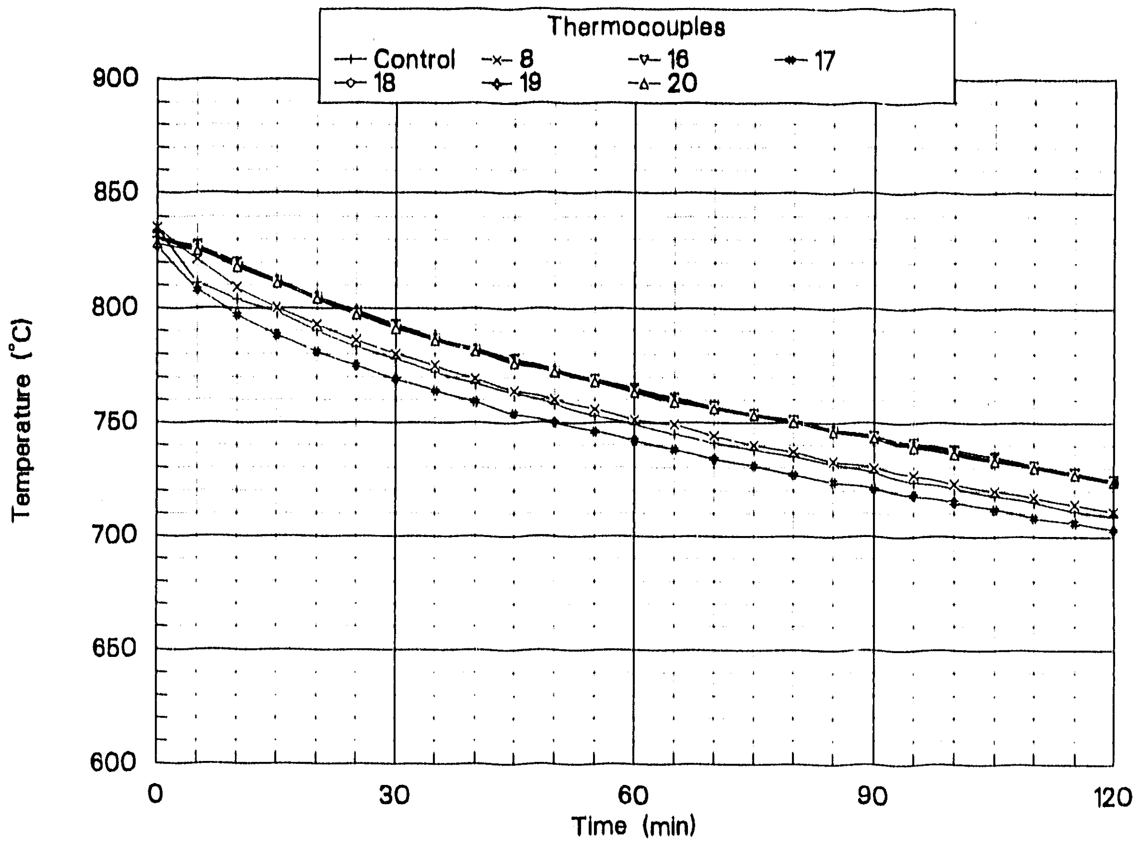


Fig. A.9. Temperature vs time for furnace control, ceiling and floor locations during Experiment 3, closed-door cooldown from set point of 835° C.

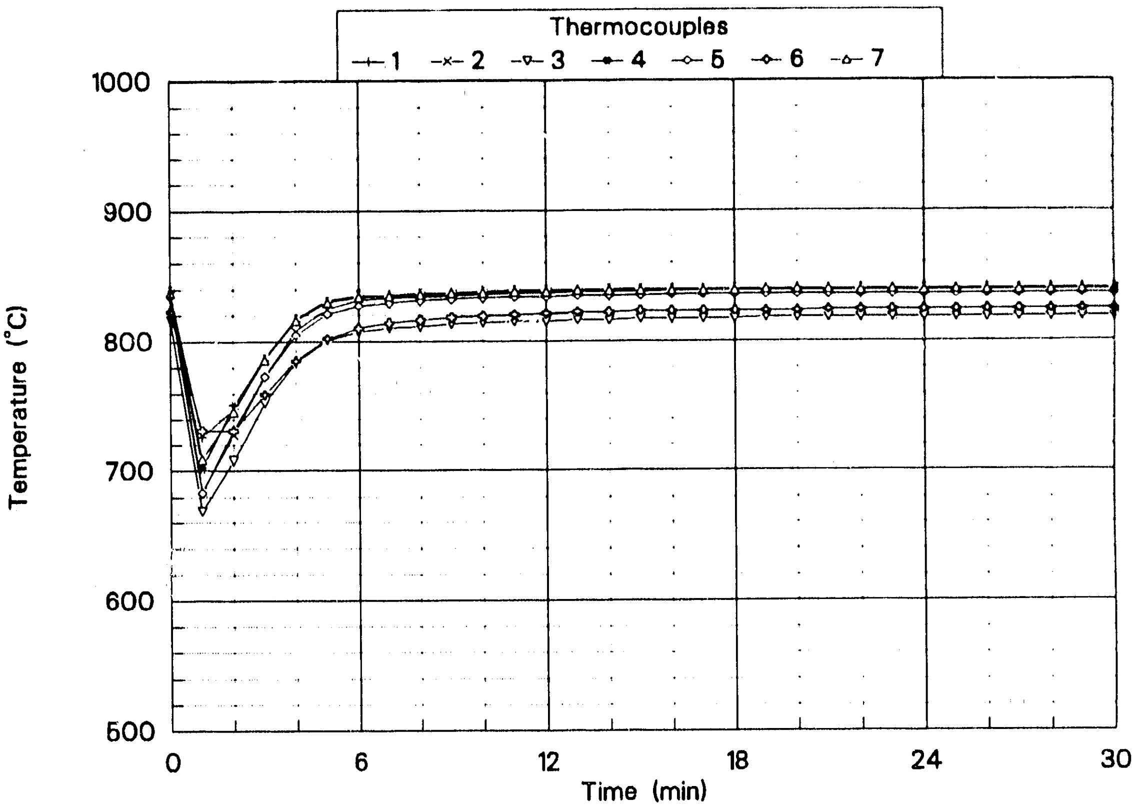


Fig. A.10. Temperature vs time for furnace wall locations during Experiment 4, door open 1 min, then shut, and power restored with a furnace set point of 835° C.

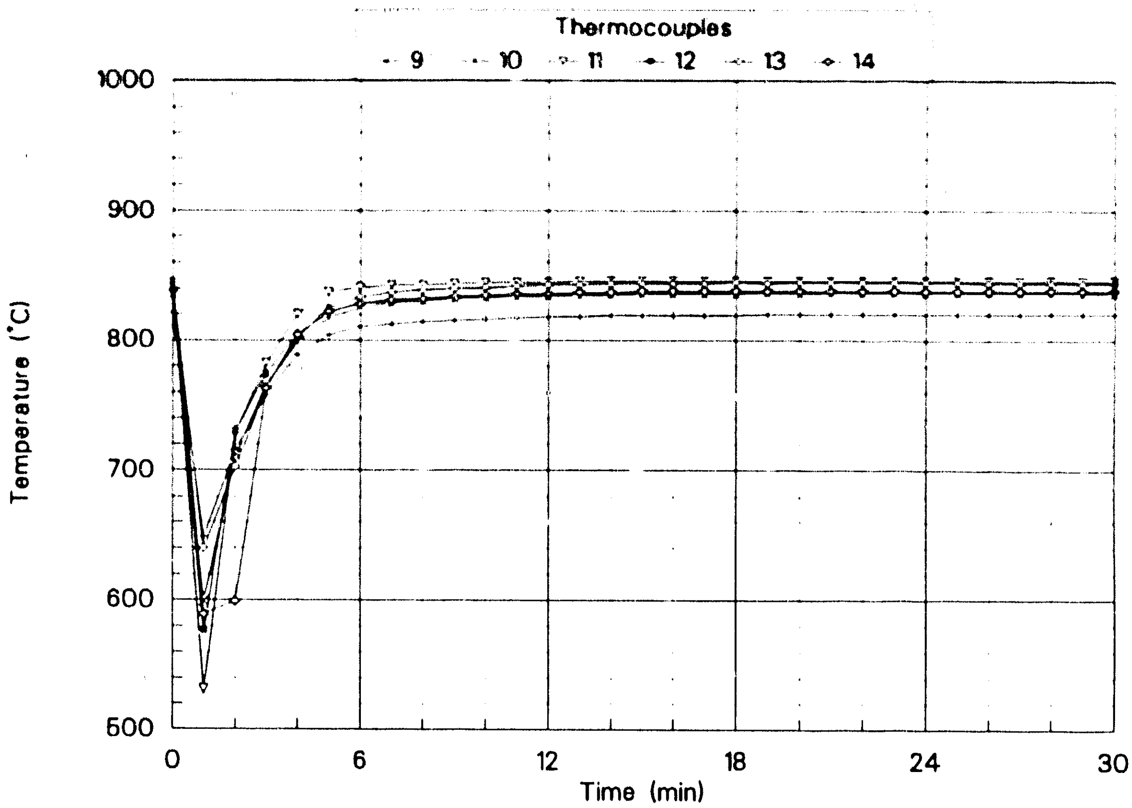


Fig. A.11. Temperature vs time for furnace door locations during Experiment 4, door open 1 min, then shut, and power restored with a furnace set point of 835° C.

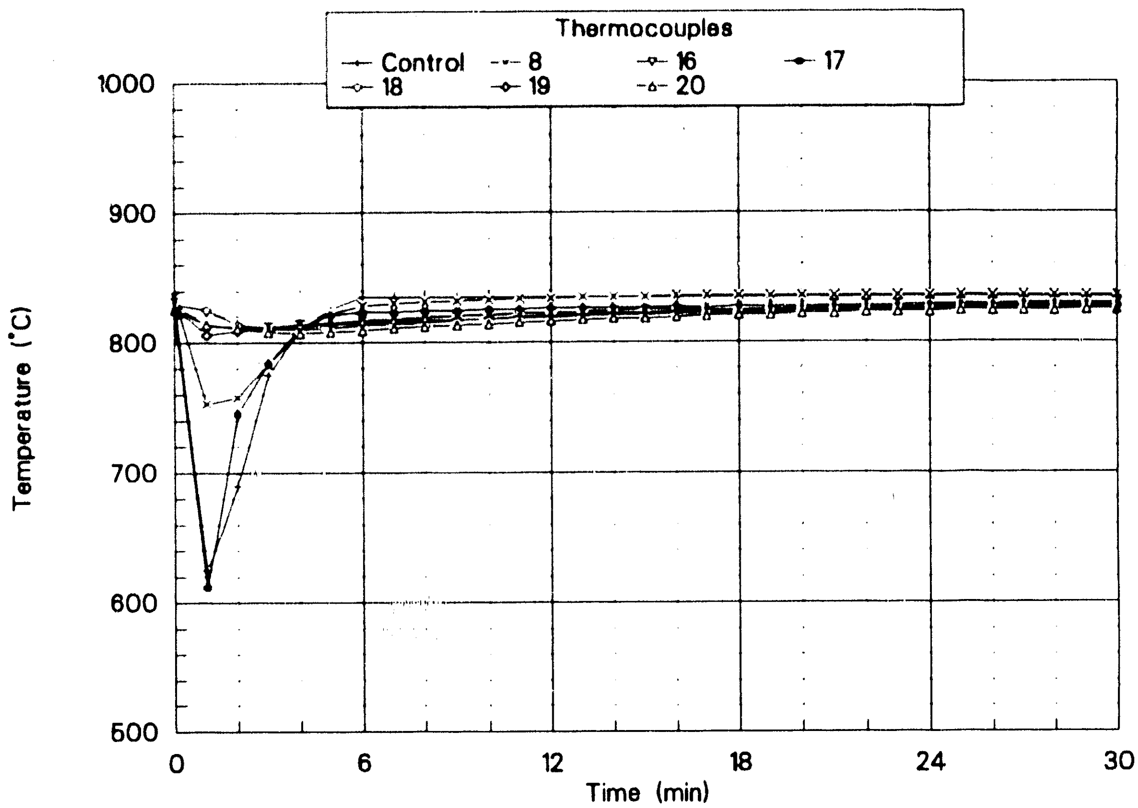


Fig. A.12. Temperature vs time for furnace control, ceiling and floor locations during Experiment 4, door open 1 min, then shut, and power restored with a furnace set point of 835° C.

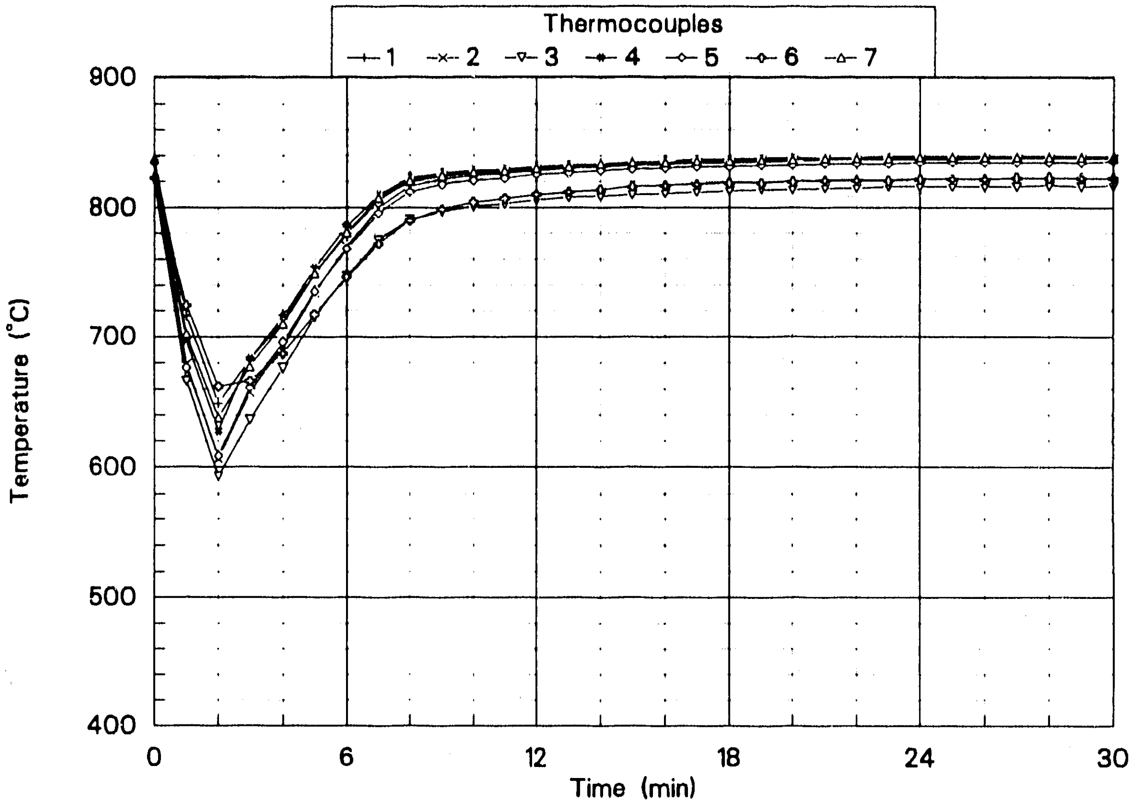


Fig. A.13. Temperature vs time for furnace wall locations during Experiment 5, door open 2 min, then shut, and power restored with a furnace set point of 835° C.

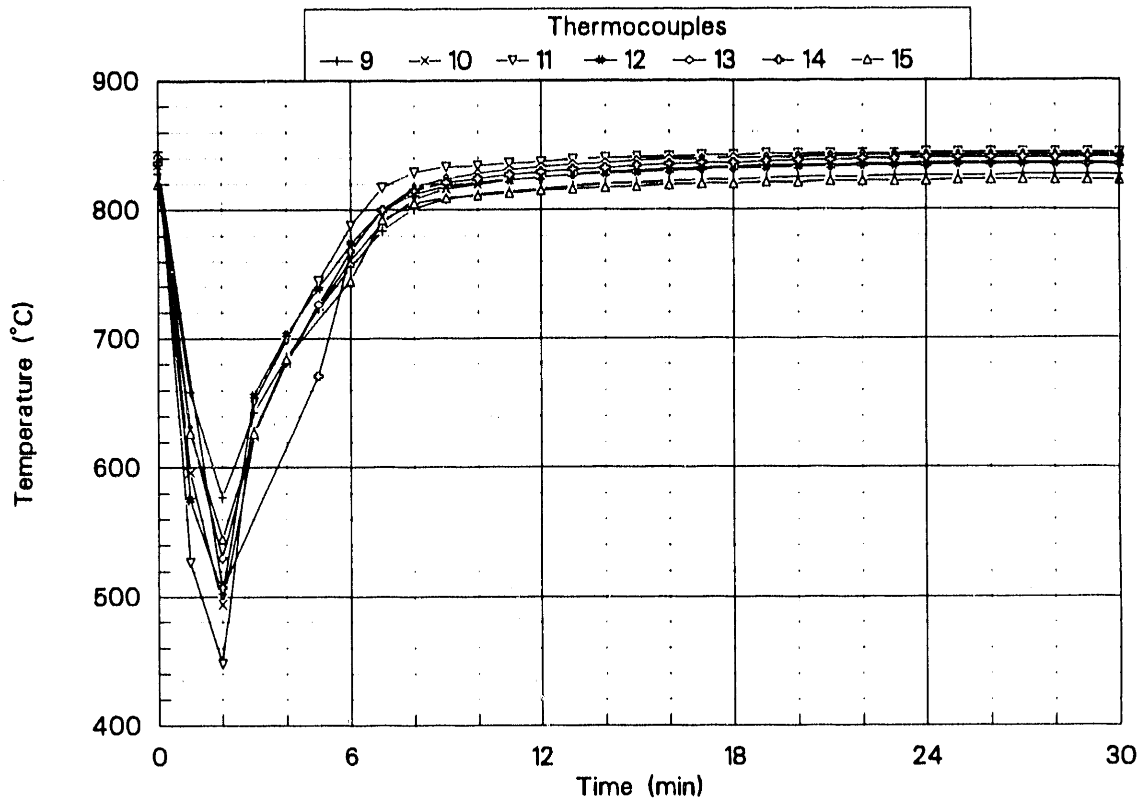


Fig. A.14. Temperature vs time for furnace door locations during Experiment 5, door open 2 min, then shut, and power restored with a furnace set point of 835° C.

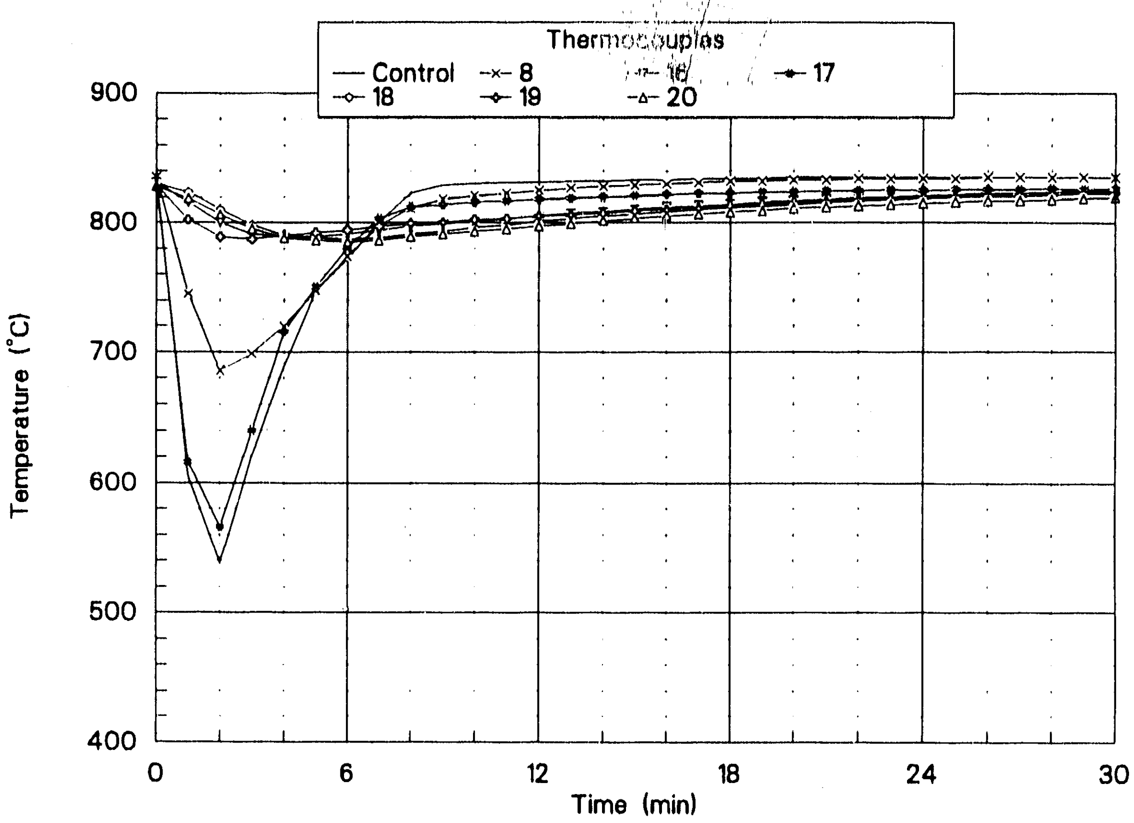


Fig. A.15. Temperature vs time for furnace control, ceiling and floor locations during Experiment 5, door open 2 min, then shut, and power restored with a furnace set point of 835° C.

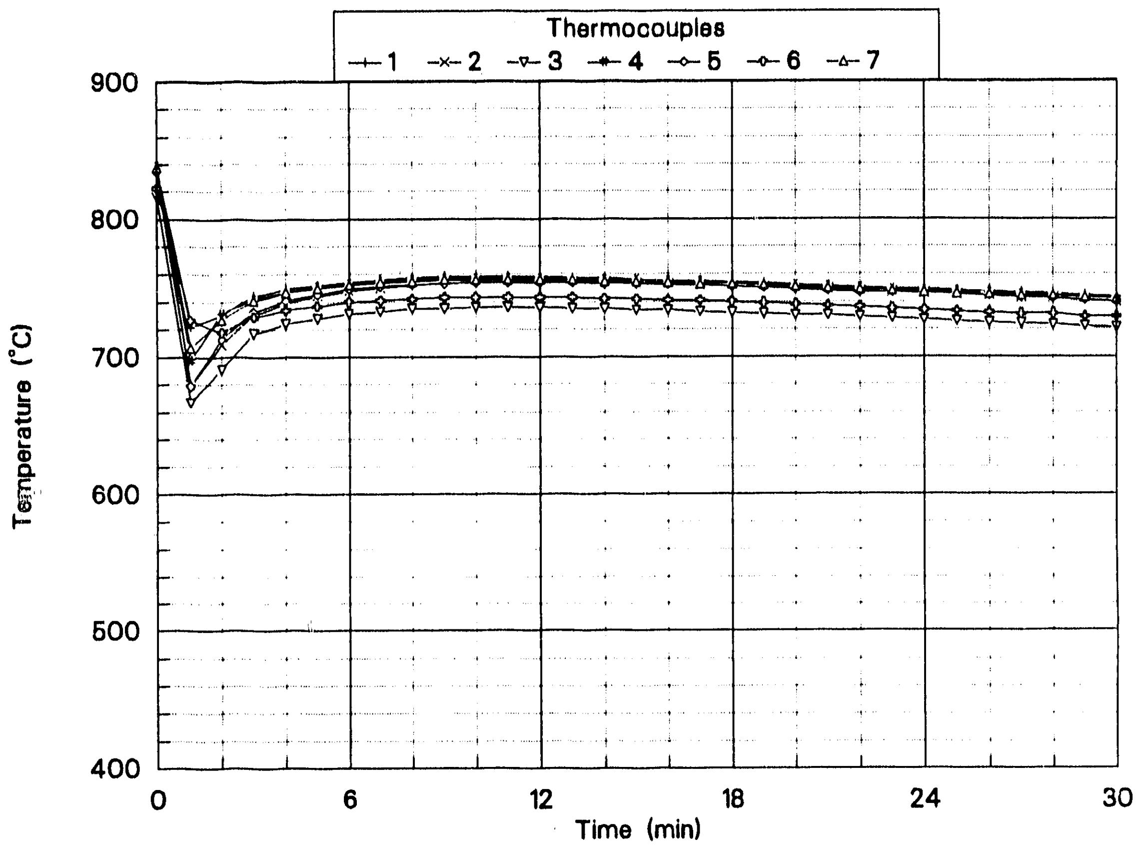


Fig. A.16. Temperature vs time for furnace wall locations during Experiment 6, door open 1 min, then shut, and power NOT restored with a furnace set point of 835° C.

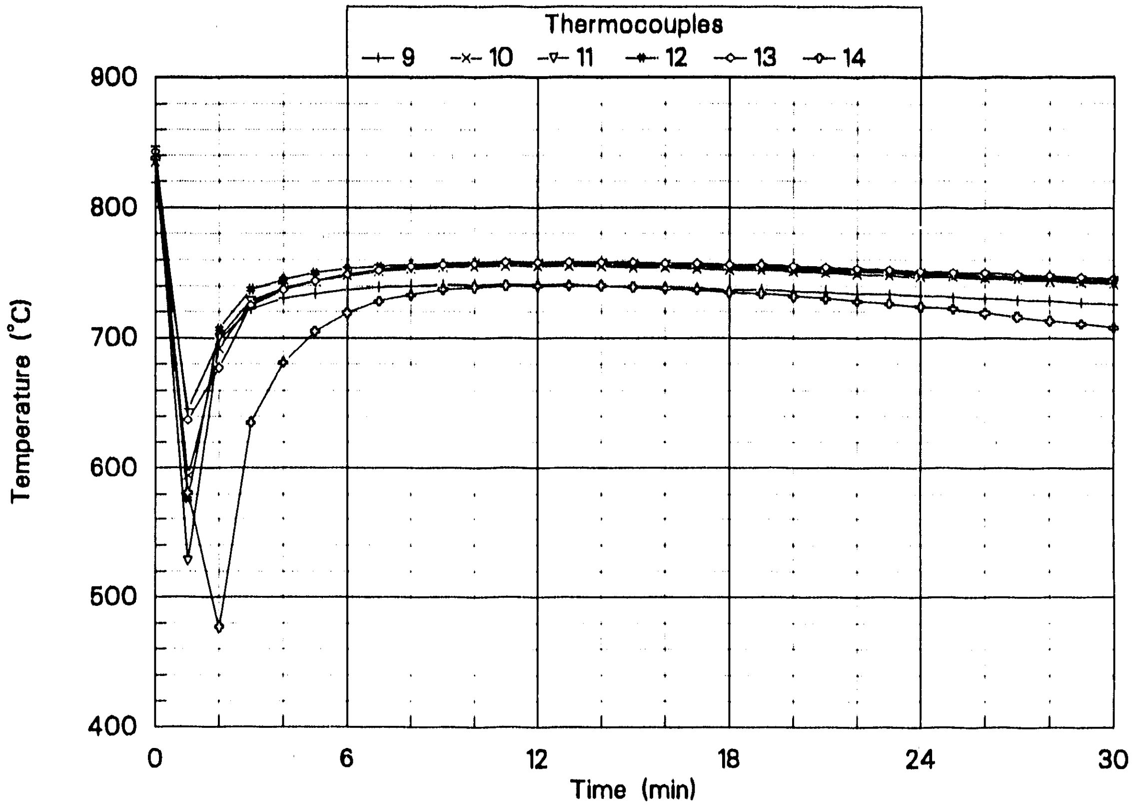


Fig. A.17. Temperature vs time for furnace door locations during Experiment 6, door open 1 min, then shut, and power NOT restored with a furnace set point of 835° C. Note: Thermocouple 15 was not functioning during this experiment.

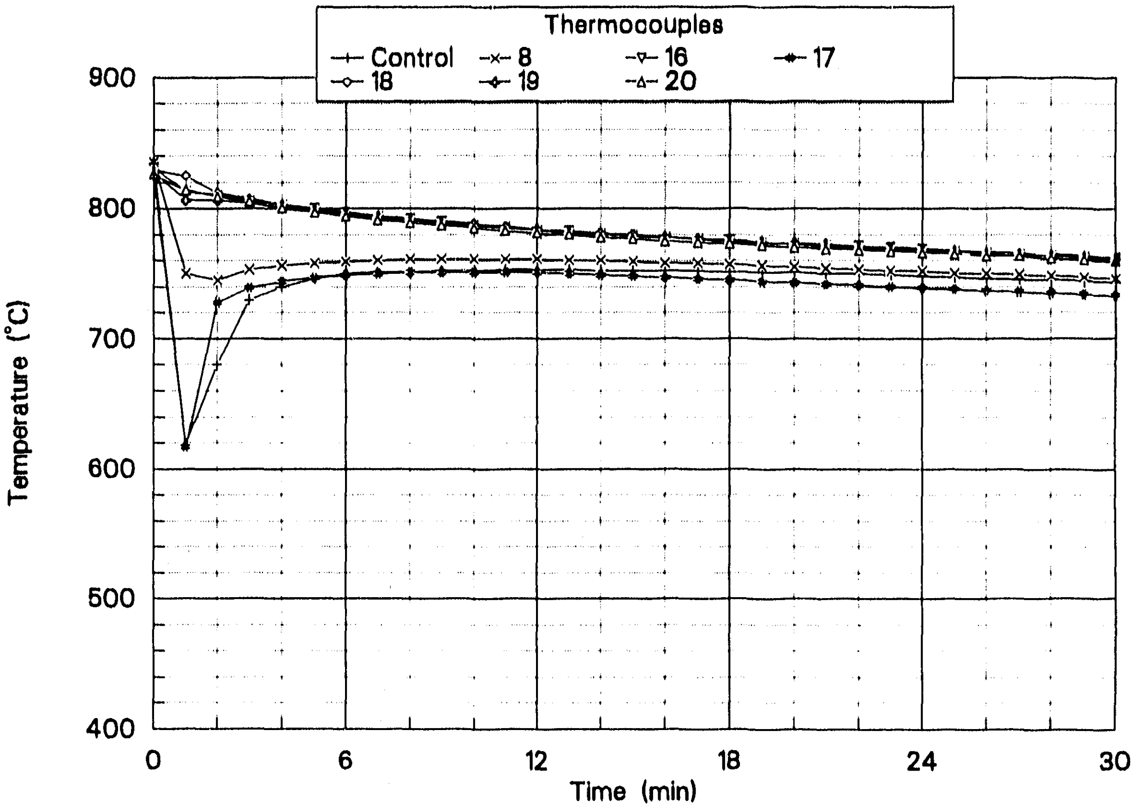


Fig. A.18. Temperature vs time for furnace control, ceiling and floor locations during Experiment 6, door open 1 min, then shut, and power NOT restored with a furnace set point of 835° C.

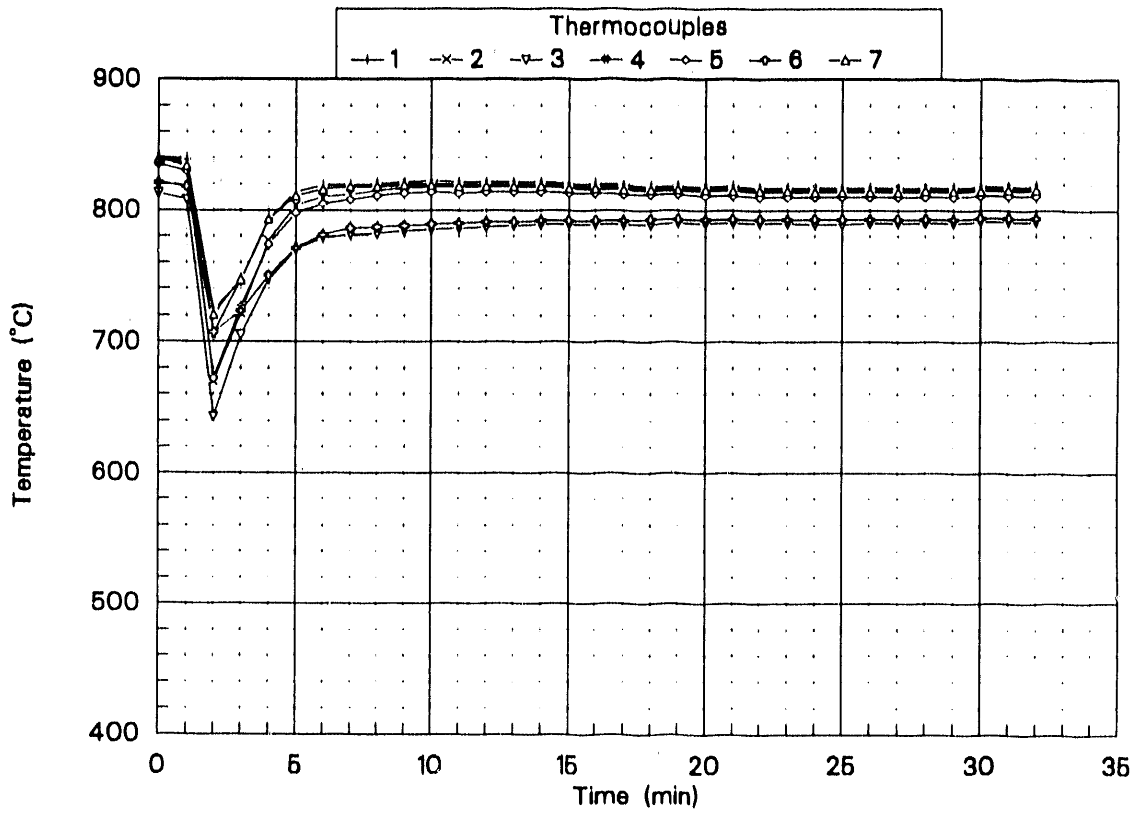


Fig. A.19. Temperature vs time for furnace wall locations during Experiment 7, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 835° C.

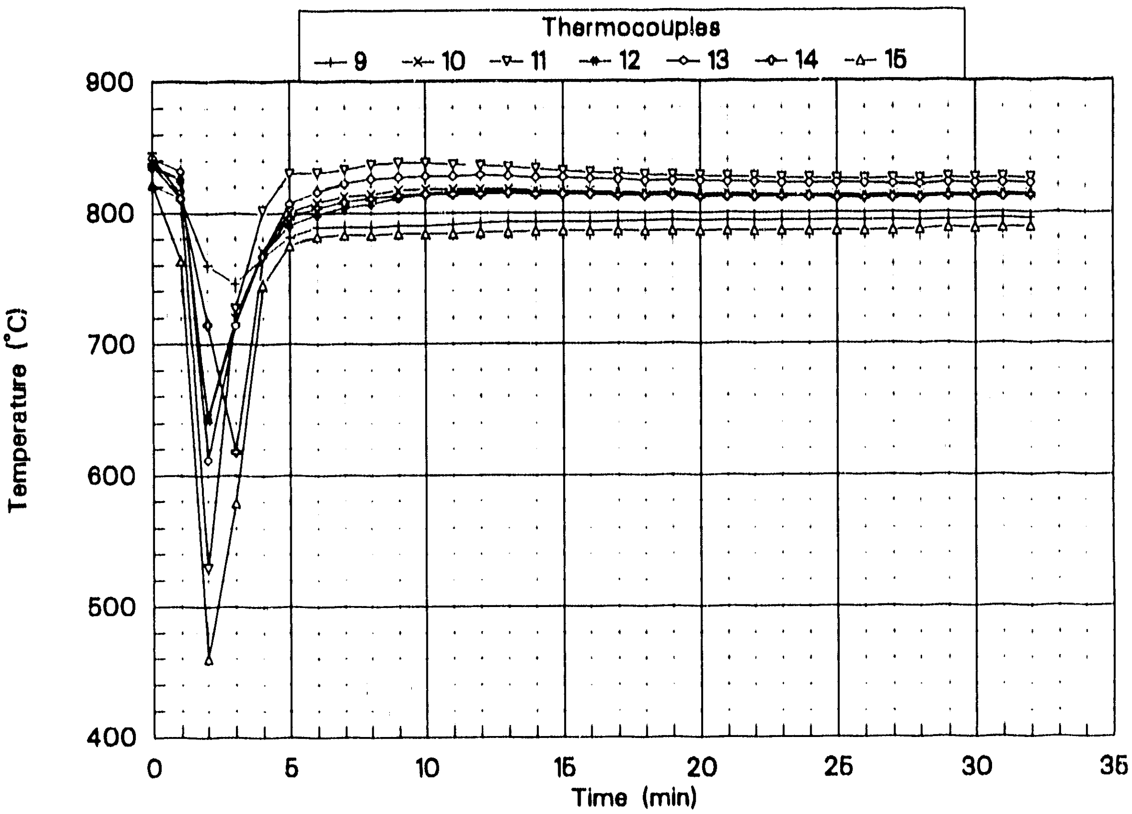


Fig. A.20. Temperature vs time for furnace door locations during Experiment 7, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 835° C.

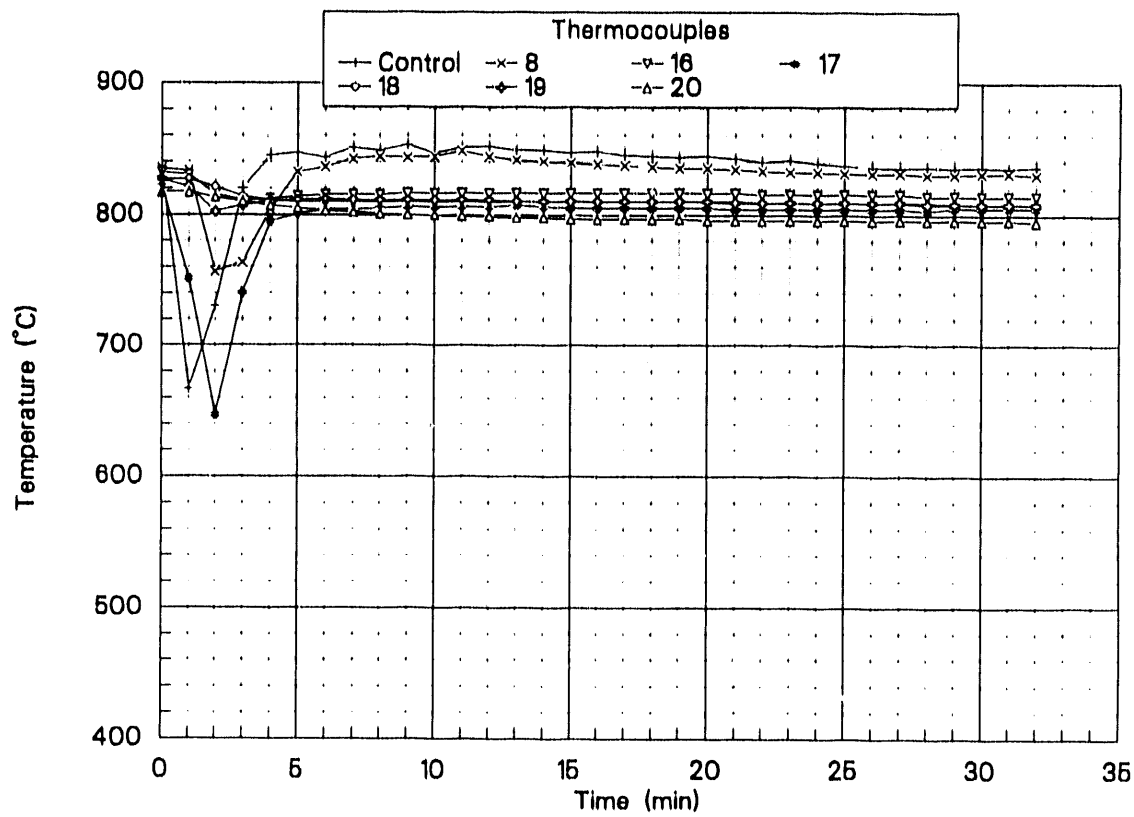


Fig. A.21. Temperature vs time for furnace control, ceiling and floor locations during Experiment 7, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 835° C.

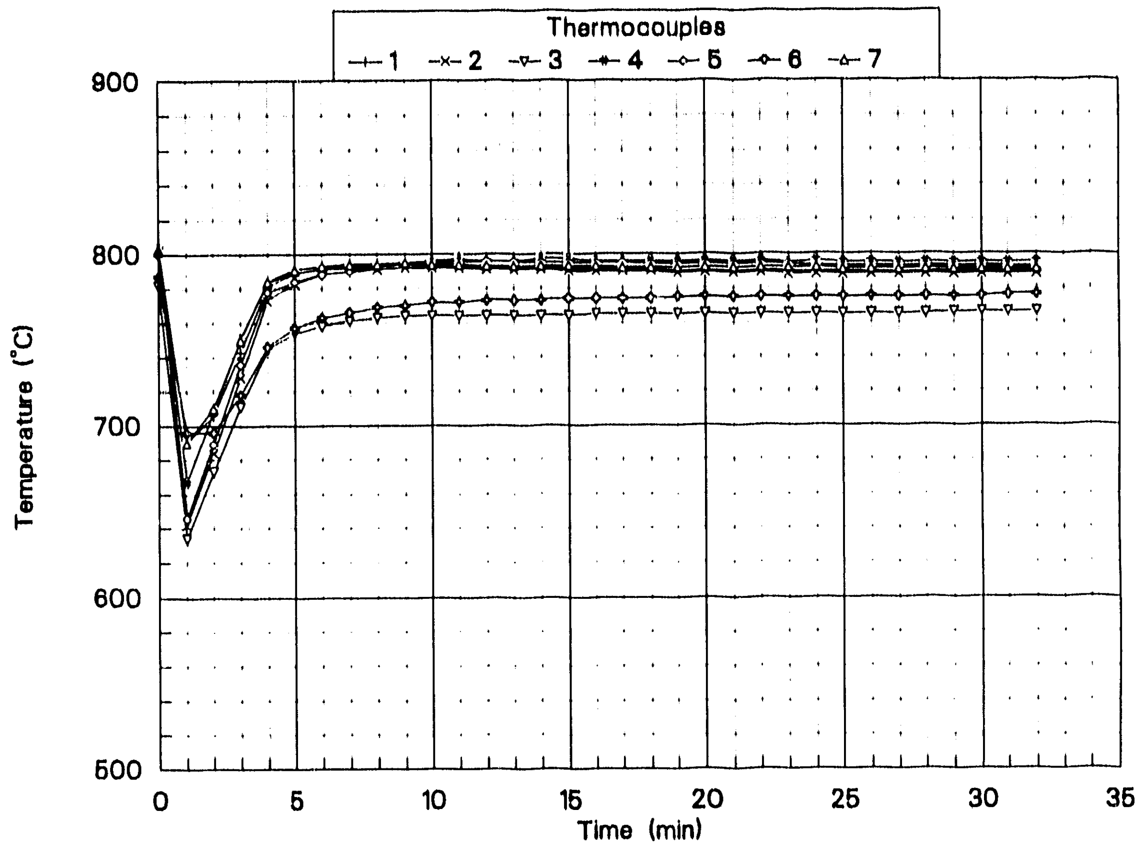


Fig. A.22. Temperature vs time for furnace wall locations during Experiment 8, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 800° C.

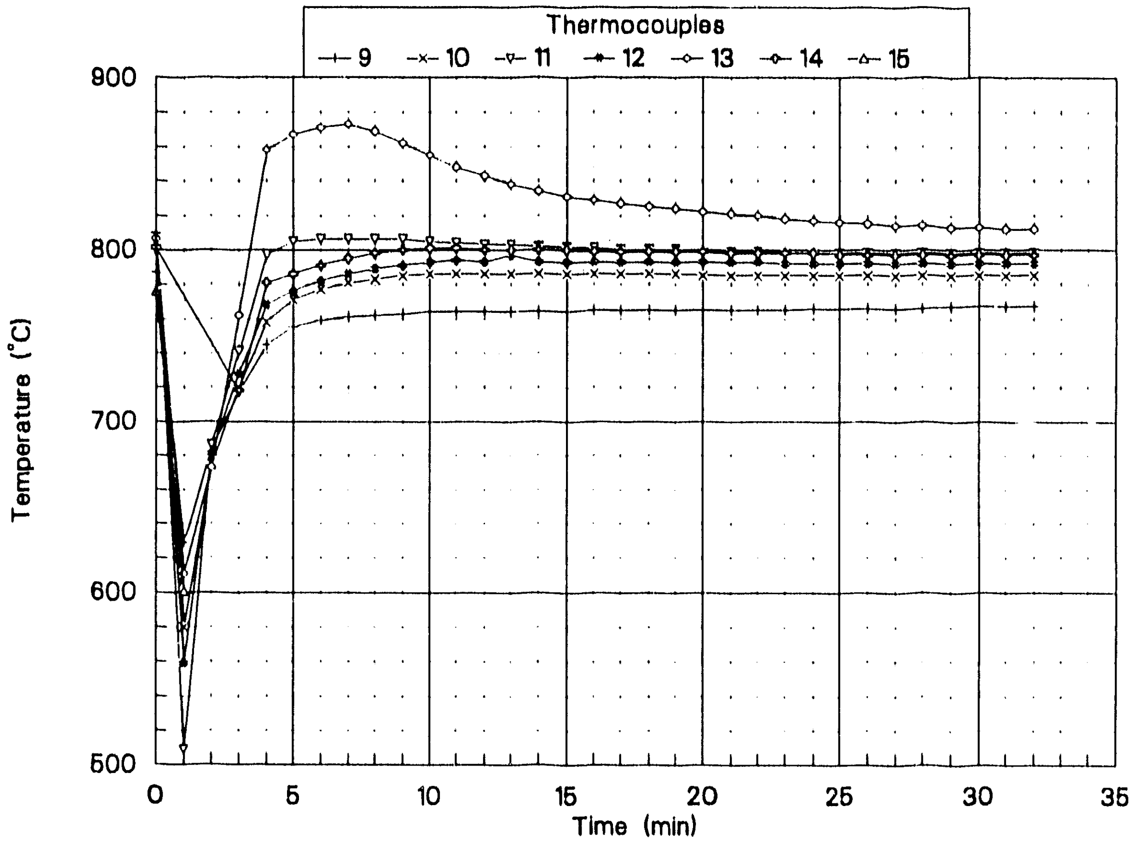


Fig. A.23. Temperature vs time for furnace door locations during Experiment 8, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 800° C.

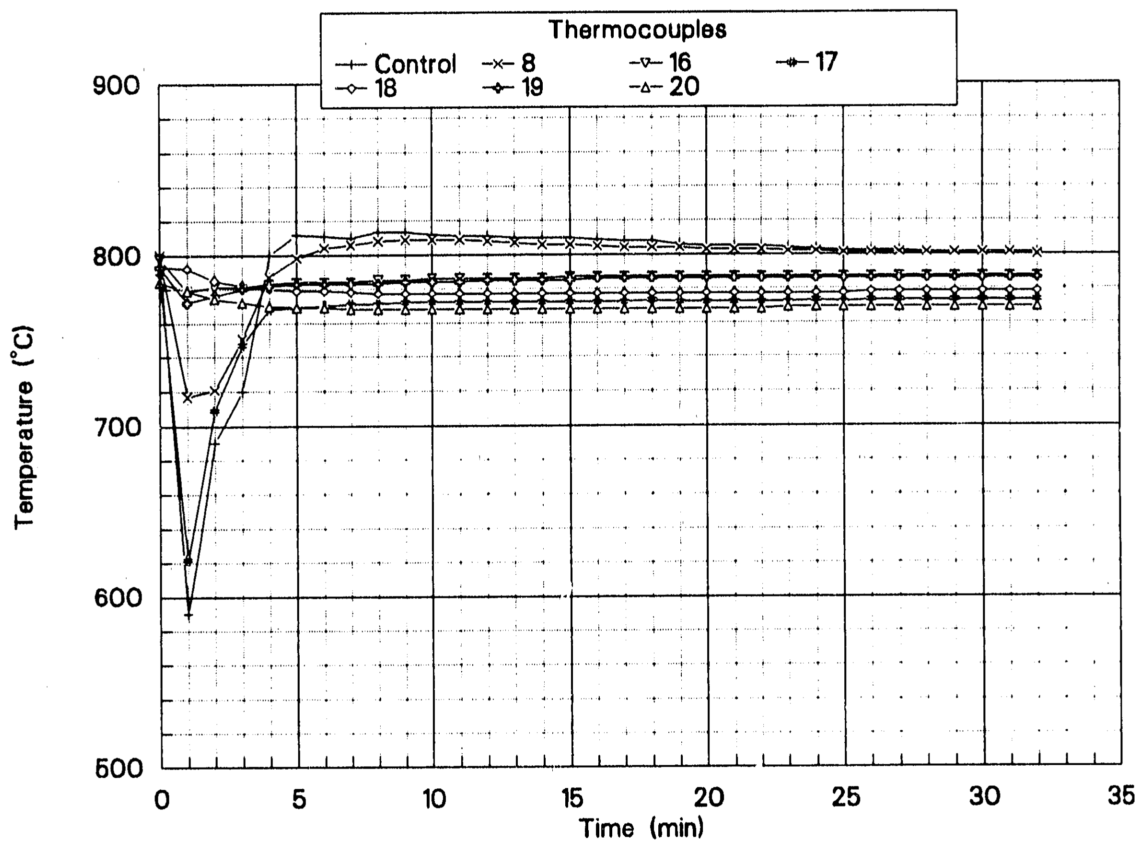


Fig. A.24. Temperature vs time for furnace control, ceiling and floor locations during Experiment 8, mock hypothetical thermal accident testing of DT-18 container with a furnace set point of 800° C.

Appendix B

DETERMINATION OF NONFUNCTIONING THERMOCOUPLES

Appendix B

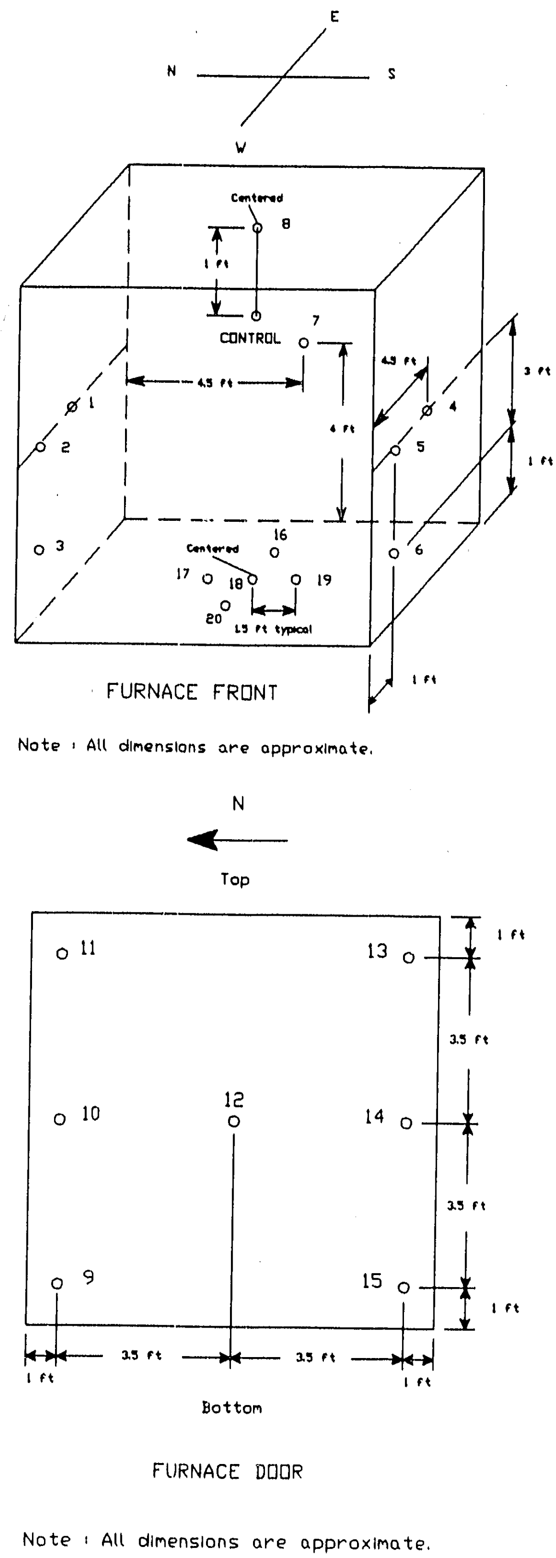
DETERMINATION OF NONFUNCTIONING THERMOCOUPLES

A thermocouple located on the furnace wall shall be considered to be nonfunctioning if its readings are 50° C below the readings of all other monitored furnace thermocouples for a period of more than 3 min.

A thermocouple on the steel plate shall be judged to be nonfunctioning if its temperature readings differ by more than 30° C from those of all other monitored thermocouples on the plate.

(a)

(b)



Thermocouple locations on (*a*) furnace interior and (*b*) furnace door.

INTERNAL DISTRIBUTION

1.	J. C. Anderson	31.	R. D. Poor
2.	H. C. Beeson	32.	J. C. Salyers
3.	J. P. Belk	33.	W. C. Stoddart
4.	R. W. Bieniek	34.	E. Stumpfl
5.	B. B. Bowden	35.	A. J. Szady, Jr.
6.	J. R. Dixon	36.	P. A. Tabor
7.	D. A. Dyslin	37.	D. A. Tollefson
8.	B. F. Elam	38.	M. S. Walker
9-13.	M. R. Feldman	39.	J. C. Walls
14.	C. P. Frew	40.	D. E. Welch
15.	R. W. Glass	41.	W. R. Williams
16.	R. F. Holdaway	42-43.	Central Research Library
17.	K. G. Kahl	44.	Y-12 Technical Reference Section
18.	C. D. Liles	45.	Y-12 Plant Records
19-28.	S. D. Moses	46.	Laboratory Records
29.	W. O. Nobles	47.	Laboratory Records - Record Copy
30.	T. W. Pickel	48.	ORNL Patent Section

EXTERNAL DISTRIBUTION

49. Assistant manager for Energy Research and Development, DOE-OR, P.O. Box 2001, Oak Ridge, TN 37831-8600

50. James F. Leonard/EM-321, U. S. Dept. of Energy, RM G-134/GTN, Washington, D. C. 20545

51. Roger W. Carlson, Lawerence Livermore National Laboratory, P. O. Box 808, Mail Code L-197, Livermore, CA 94551

52. Larry E. Fischer, Lawerence Livermore National Laboratory, P. O. Box 808, Mail Code L-197, Livermore, CA 94551

53. James H. VanSant, Lawerence Livermore National Laboratory, P. O. Box 808, Mail Code L-197, Livermore, CA 94551

54-65. Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831

END

DATE
FILMED
3 / 16 / 92