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**Martin Marietta Energy Systems, Inc.
Central Engineering Services
Technical Programs and Services**

Furnace Characterization for Horizontal Shipping Container Thermal Testing

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May 1994

**Prepared by
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MASTER

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ABSTRACT

In order to perform regulatory thermal tests required by 10 CFR 71.73(c)(3) on the newly designed Horizontal Shipping Container (HSC), it was necessary to find a company involved in the business of heat treating who was willing to allow their furnace to be used for these tests. Of the companies responding to a request for interest, Lindberg Heat Treating Company's Solon, Ohio, facility was found to be the best available vendor for this activity. Their furnace was instrumented and characterized such that these tests could be performed in a manner that would conform to the specifications contained in 10 CFR 71. It was found that Lindberg's furnace was usable for this task, and recommendations concerning the use of this furnace for the above stated purpose are made herein.

1. SUMMARY

Containers developed for shipping radioactive materials by U. S. Department of Energy (DOE) contractors must conform to the specifications outlined in the Code of Federal Regulations, Title 10, Part 71.¹ Among these specifications are various physical tests that the shipping container 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 including, but not limited to, 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 (MMES), Inc. Until recently, the B-1023 furnace located in Building 9204-4 at the Y-12 Plant had been used for all container thermal testing. Characterization of this furnace had previously taken place for the explicit purpose of ensuring that tests conformed to 10 CFR 71.^{2,3} Development of the Horizontal Shipping Container (HSC) by the Y-12 packaging group necessitated that an alternative thermal test site be located, since the HSC was too large to fit into the B-1023 furnace with sufficient clearance to the furnace walls. Lindberg Heat Treating Company, in response to a request for proposal, expressed interest in allowing one of their facilities to be used for this purpose. Discussions with Lindberg indicated that their Solon, Ohio, facility would best meet MMES's needs.

The identified furnace was then instrumented, and several experiments were undertaken to determine the ability of this furnace to be used for regulatory testing of the HSC. It was found that, indeed, the regulatory testing could be performed in the Lindberg furnace. Based on the results of these experiments, recommendations concerning the procedure to be used during regulatory testing are made. It is believed that adherence to these recommendations will result in regulatory testing which meets the conditions specified in 10 CFR 71.73(c)(3).

2. INTRODUCTION

2.1 BACKGROUND

Over the past several years, the Y-12 Packaging Program has been involved in efforts to assure that hypothetical thermal accident regulatory tests performed for radioactive material shipping packages explicitly meet the federal regulations. During that time, these tests had been performed exclusively in the B-1023 furnace located at the Y-12 Plant in Oak Ridge, Tennessee. More recently, the Y-12 Packaging Program has undertaken the design and certification of a new container, the Horizontal Shipping Container (HSC). This container is too large to be thermally tested in the B-1023 furnace; thus, it was necessary to locate alternative thermal test sites.

The effort to locate alternative test sites began in June 1992. Initially these efforts consisted of contacting several different individuals who had a working knowledge of the heat treating industry. It was hoped that these individuals could then contact others in the business who may have an interest in hosting such tests. A total of four possible vendors were identified and visits were made to each of their locations. It was found that of the four, three of the businesses, Lindberg Heat Treating in Solon Ohio, Cooperheat in Baton Rouge, Louisiana, and ABB Combustion Engineering in Chattanooga, Tennessee, actually had the equipment, know-how, and manpower necessary to do the job. A specification for the job was then written and the job was placed out for bids in August 1992.

The successful bidder for this job was Lindberg Heat Treating Company (LHTC). It was determined that the furnace located at their Solon, Ohio, facility would best suit the needs of the HSC thermal test. In mid-September 1992, the characterization process was initiated at this facility.

2.2 PROJECT OBJECTIVES

The primary objective of this effort was to characterize a furnace that would be used for hypothetical thermal accident tests on HSC for container certification in accordance with 10 CFR 71.73(c)(3), which states:

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.

Because a similar effort had been completed earlier on the Y-12 Plant B-1023 furnace, the method of furnace characterization was well understood.^{2,3} But, while the previous characterization had taken a year to complete, it was necessary to finish this effort in one month. Additionally, unlike the first characterization project, a gas-fired furnace was being used for this effort. It was anticipated that the dynamics of the surface temperatures in the gas-fired furnace would significantly differ from the electric furnace previously studied. Thus, it was very important that the task be carefully planned to avoid delays.

3. EXPERIMENTAL

3.1 EXPERIMENTAL APPARATUS

All experiments were performed using the Sauder Tip-Up Box Furnace Number 152 located at Lindberg Heat Treating Company's Solon, Ohio, facility. It is a gas-fired furnace with working area dimensions of 50 inches high x 288 inches long x 72 inches wide, and is primarily used for heat treating of long metal bars and ingots. The furnace is a large inverted box which sits on a refractory flooring. It is opened by being tipped back such that the front face of the furnace lifts up, while the rear of the furnace rotates in place. This opening action is performed by two angled rods (one at each end of the furnace) which are hydraulically raised causing the furnace to tilt open. The furnace is heated by eight gas burners which are stagger-mounted on the furnace sidewall and roof (4 on each surface); the total rated output of these burners is 7,500,000 Btu/hr. The arrangement of these burners is such that a convective swirl is set up within the furnace which promotes uniform heating throughout the furnace. Furnace control is provided by a Barber Coleman 570/560 control system which regulates the furnace in two separate zones. All five inner surfaces of the inverted box (four side walls and the ceiling) are lined with 6.5 inches of pyro-block alumina refractory cloth. The floor is made of a castable alumina refractory. The furnace is rated for heat treating jobs requiring temperatures up to 2300°F.

Under normal circumstances, the furnace has 19 ceramic piers spaced evenly across the length of the floor. These piers are used as supports for the object being heat treated. To allow the floor of the furnace to radiate directly to HSC, it was necessary to remove most of the piers which would have been under (and touching) the HSC (Fig. 1). All but two of the piers were removed in the area directly below the container. The two that remained were braced to handle the weight of the HSC. Loading the furnace is accomplished by using an automated loading device. This device, which is the same length as the furnace interior, has 20 tines that are used for loading and unloading the furnace. Prior to loading, the item(s) to be loaded into the furnace rests upon the tines. During loading, the tines slide into the furnace between and slightly above the ceramic piers. When the part being loaded has been maneuvered to the correct depth into the furnace, the tines are slowly lowered below the piers and the load is transferred onto the piers. The loading device is then reversed, pulling the tines out of the furnace, and the furnace is then closed. Unloading of the furnace is the same process in reverse. To accommodate the HSC container, extensive rework of the tines on the loading machine had to be performed. The forklift pockets at the bottom of the HSC did not coincide with tine location on the loading device. Thus, several tines had to be removed and two new tines were fabricated. The new tines line up with the HSC's forklift pockets.

To facilitate the thermal testing, and to help demonstrate compliance with 10 CFR 71.73(c)(3), the furnace was instrumented with a total of 21 thermocouples. These were in addition to the thermocouples already present inside the furnace that are used by the furnace temperature controller. The 21 thermocouples were distributed throughout the furnace to monitor the temperatures of all six surfaces in the furnace. To monitor furnace floor temperatures, it was necessary to cut 1 to 2 inch deep trenches in the castable refractory flooring, then place thermocouples in these trenches. The thermocouple leads were laid in the bottom of the trenches,

Fig. 1. Furnace floor showing thermocouple and pier locations during furnace characterization experiments.

and a 90° bend was put in the thermocouple lead near the thermocouple junction. In this manner, the thermocouple junctions were set within 0.10 inch of the top of the trench (furnace floor level). The trenches were then recast with refractory material and allowed to harden. This made it possible for the temperature of the castable refractory flooring to be monitored during thermal testing. A total of five thermocouples were imbedded in the furnace floor in various locations under the package's position (see Fig. 1). Additionally, one thermocouple was imbedded into each of the ceramic piers on which the packages being tested were placed.

The walls and ceiling of the furnace were covered with an alumina refractory cloth approximately 6.5 inches thick, so it was necessary to place thermocouples on these surfaces in a manner quite different from the thermocouples placed in the floor of the furnace. For each thermocouple to be located on either a wall or ceiling surface, a hole was drilled (approximately 3/4 inch diameter) in the outer wall (or roof) of the furnace. A thermocouple well was then placed into each of the holes. Thermocouple wells are shaped like a test tube, and are similar to a thermocouple sheaths, only larger, and act to protect the unsheathed thermocouples which are placed inside. Thermocouples were then placed into wells. The wells were adjusted such that their ends were flush with the edge of the cloth refractory lining. The thermocouple wells were made of an alumina refractory material similar to the wall material. The thermocouple wells were approximately 0.30 inches thick; thus, the temperature indicated from these thermocouples was equivalent to a temperature slightly below the surface of the furnace wall. This was a conservative method of measuring furnace wall temperatures since the temperature was measured below the actual surface of the furnace work area. Three of these thermocouples were mounted on each of the four walls (Figs. 2 and 3) of the furnace, and two more were mounted in the ceiling (Fig. 4). Mounting locations were directly adjacent to where the package would be placed since these areas would have the greatest radiative exchange of energy with the package.

To characterize the furnace, it was necessary to test the furnace under conditions representative of those found in a regulatory test. For this purpose, a "mock" HSC (MHSC) unit was built. The idea behind the MHSC was to test the furnace with a thermal load on it similar to the thermal load the furnace would experience during an actual regulatory test. This would cause the furnace to react the same as when the actual HSC unit was tested. The MHSC is constructed of 0.1875 inch thick 304 stainless steel (similar to the HSC). The shape of the MHSC is an open ended right cylinder 96 inches long and 38 inches in diameter. The open end was flanged and an end-piece cover, also constructed of 0.1875 inch thick stainless steel, attached to the unit at this flange (Fig. 5). The MHSC was loaded with Celotex™ fiberboard in a manner similar to that found in the HSC. Vent holes similar to those found on the HSC were drilled in the MHSC: 4 rows of 3 holes each at 90° offsets around the body of the shell (exactly like the HSC) and 4 on each end (unlike the HSC which has no vent holes on the end). The MHSC had forklift pockets located at the bottom and, by coincidence, these pockets were at a width which matched the original pitch of the tines on the loading machine. Thus, only minor changes to the loading machine had to be made for the characterization experiments. The MHSC was instrumented with a total of 13 thermocouples: two on each end, and nine spread across the body of the package (Figs. 5 and 6). The thermocouples used to monitor the temperature of the MHSC were 18-gauge type K Alumel-Chromel with a 0.125 inch diameter stainless steel sheath

Δ -- FRONT WALL THERMOCOUPLES

● -- REAR WALL THERMOCOUPLES

Fig. 2. Front and rear wall thermocouple locations during furnace characterization experiments.

Fig. 3. Right and left side wall thermocouple locations during furnace characterization experiments.

● — ROOF THERMOCOUPLES

Fig. 4. Ceiling thermocouple locations during furnace characterization experiments.

Fig. 5. Side view of mock horizontal shipping container showing thermocouple locations during furnace characterization experiments.

Fig. 6. End view of mock horizontal shipping container showing thermocouple locations during furnace characterization experiments.

with Magnesium Oxide used as an insulator. These thermocouples were attached to the MHSC by thermocouple lugs that were welded to the MHSC surface.

All thermocouple leads (with the exception of furnace control thermocouples) were attached to a Leeds and Northrup Speedomax 25000 Series Hybrid Multipoint Recorder. This recorder was then interfaced to a DEC Micro VAX 2000 computer. Through this interface, it was possible for the data from the Leeds and Northrup Data Recorder to be directly written to a computer disk. These data were then turned over to MMES personnel on a computer floppy disk along with the original analog data from the Leeds and Northrup recorder.

3.2 EXPERIMENTAL PROCEDURE

The purpose of this effort was to characterize Lindberg Heat Treating Furnace Number 152 prior to its use for regulatory thermal testing. Thus, experimental procedures were set up to simulate an actual thermal test. After some consideration of the alternatives, it was determined that the simplest method of regulatory compliance would be to follow the steady-state method of compliance as outlined in Section 2.2.1 of A Combination Test/Analysis Method Used To Demonstrate Compliance To DOE Type B Container Thermal Test Requirements (30 Minute Fire Test).⁴ This method requires that both the surface of the container being tested and the testing medium (i.e., the furnace surfaces) reach the regulatory testing temperature (1475°F) before the 30-minute test minute period begins. Additionally, it requires that this temperature be maintained on all of these surfaces (package and furnace) throughout the duration (30 minutes) of the test.

The furnace was preheated for a length of time such that interior furnace surface temperatures had stabilized for a minimum of 2 hours. For Characterization Experiment 1, the furnace temperature was adjusted to a set-point temperature of 1650°F, and for Characterization Experiment 2 a set-point temperature of 1575°F was used. For both experiments, a fully instrumented MHSC was placed on the loading machine and moved until it was directly in front of the furnace. Next, the leads of the thermocouples attached to the exterior of the MHSC to be tested were plugged into the temperature recording unit. The MHSC was then loaded into the furnace as quickly as possible while maintaining the safety of the workers and the integrity of the MHSC.

After the MHSC was placed in the furnace and the furnace closed, the temperatures of both the MHSC and the furnace surfaces were closely monitored. When all measured temperatures had reached 1475°F, the experiment time count began. When the time count reached 30 minutes, the MHSC was removed as quickly as possible. The MHSC was then allowed to cool directly in front of the furnace (with the furnace closed) for about 1/2 hour. Cooling away from the furnace would have been preferable; however, to transport the package away from the furnace the loading machine would have passed over an open oil quench tank. There would have been some danger of igniting the quench oil if a flaming package had been transported over the tank. When the MHSC was judged to be cool enough to move, it was transported away from the furnace to a loading stand at the end of the bay.

After each characterization experiment, the package used continued to smolder for some time. Eventually, it was necessary to place each unit outside so the smoke would not bother workers inside the building. Because these units were simply mock units and not actual test units, it was permissible to allow them to cool via an artificially accelerated means (i.e., in the wind) not permitted in 10 CFR 71.73(c)(3) for actual regulatory tests. It should be kept in mind that the purpose of the mock units was simply to characterize the furnace and not simulate a complete thermal accident test (i.e., no artificial cooling followed by a leak test).

Since only one MHSC unit was constructed for these experiments, some refurbishment was required between characterization experiments. About 24 hours after the Characterization Experiment 1, the Celotex™ was removed from the MHSC. The shell was then sand blasted to remove any soot that had accumulated during Characterization Experiment 1. The sand blasting returned the MHSC to a finish similar to that found on the MHSC prior to the first test. This finish was also representative of the finish on an actual HSC. The MHSC was then reloaded with new Celotex™ and resealed prior to Characterization Experiment 2.

4. RESULTS AND DISCUSSION

The two characterization experiments performed using furnace Number 152 located at Lindberg Heat Treating Co.'s Solon, Ohio, plant indicate that this furnace can be used for hypothetical thermal accident testing. It was found that it will be possible to meet the regulations stipulated in 10 CFR 71.73(c)(3). Specific results from each of these experiments are presented below.

The furnace was preheated and then operated at a set-point temperature of 1650°F for Characterization Experiment 1. Average furnace surface temperatures for Characterization Experiment 1 are shown in Fig. 7 and the MHSC surface temperature is shown in Fig. 8. Only average temperatures are presented for discussion in this portion of the text; however, a complete graphical listing of all temperatures monitored during these experiments is presented in Appendix A. The lower solid line on Figs. 7 and 8 indicate the regulatory temperature of 1475°F while the upper solid line shows the furnace set-point temperature (1650°F). As expected, during the first few minutes after the package was loaded, furnace surface temperatures dropped below 1475°F. The recovery was rapid such that all surface temperatures were back above 1475°F within 8 minutes. The MHSC took about 12 minutes to reach the regulatory temperature. Thereafter, all temperatures remained above 1475°F for the duration of the test. The temperatures all leveled out and remained nearly constant between 1550 and 1650°F for the rest of the test. At the 44 minute mark, the furnace was opened and the package was removed. There was a 32 minute time period when all surface temperatures were at least 1475°F; thus, this test would have qualified this experiment under the steady-state option outlined in section 2.2.1 of A Combination Test/Analysis Method Used To Demonstrate Compliance To DOE Type B Container Thermal Test Requirements (30 Minute Fire Test).⁴

The results obtained from Characterization Experiment 1, using a furnace set-point temperature of 1650°F, indicate that the regulatory thermal test could be performed in this furnace. Some temperatures were significantly above the 1475°F temperature required by 10 CFR 71.73(c)(3). Thus, it was decided a second experiment would be conducted using a somewhat lower furnace set-point temperature. In general, it appeared that furnace temperatures could most likely be lowered at least 50°F. However, there was only one opportunity to make an additional mock run, so it was decided to lower the furnace set-point temperature by 75°F to 1575°F.

Figures 9 and 10 show average temperatures from the individual furnace surfaces and the MHSC package surface, respectively, during Characterization Experiment 2. Similar to the Characterization Experiment 1, all furnace surface temperatures initially fell below the regulatory temperature of 1475°F but then recovered quickly. The recovery time for Characterization Experiment 2 was longer than for Characterization Experiment 1 (11 minutes versus 8 minutes). However, the MHSC took 13 minutes to reach the regulatory temperature which is only one more minute than in Characterization Experiment 1. All average temperatures remained above regulatory temperature until the package was unloaded at 46 minutes. It is important to note that temperatures shown on Figs. 8 and 9 are average values for entire surfaces. For regulatory tests the actual individual temperatures would need to be considered. The data from the individual thermocouples are presented in Appendix A. During Characterization Experiment 2, some

Fig. 7. Average furnace surface temperatures vs time for Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. 8. Average package surface temperature vs time for Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. 9. Average furnace surface temperatures vs time for Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. 10. Average package surface temperature vs time for Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

furnace side wall thermocouple locations fell below the regulatory temperature; thus, this experiment would most likely not qualify under the steady-state provision of the document governing these tests.⁴

It is interesting to note that, by the end of each of these experiments, the highest temperatures monitored were those on the package, not on the furnace walls. Thus, the package eventually acts as a source of heat to the furnace surfaces. There are two possible explanations for this. It is known that the decomposition of CelotexTM is an exothermic process, and it may be that the heat from this process is heating the MHSCs. However, a more likely explanation is that the temperature of the gases within the furnace is actually warmer than the walls of the furnace. The highly convective nature of the work zone within the furnace causes the package surface to heat to the temperature of the gases. The furnace controller is actuated by a thermocouple which measures the gas temperature within the furnace, so the gas temperature is very close to the set-point temperature. Noting that in both characterization experiments the MHSC equilibrated at almost exactly the furnace set-point temperature suggests that the latter process was responsible for the excessive heating of the MHSCs. Regardless of the cause, the cooling of the furnace surfaces will need to be monitored very closely during regulatory test to ensure that they do not fall below 1475°F.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The Lindberg Heat Treating Furnace Number 152, located at their Solon, Ohio, facility can be used to perform regulatory thermal tests on the Horizontal Shipping Container. It will be possible to meet all of the requirements of 10 CFR 71.73(c)(3). It will be necessary to take great care in the actual performance of these tests to ensure that all of the regulations are met. The system to monitor furnace temperatures which was constructed for these characterization experiments, is adequate to meet 10 CFR 71.73(c)(3). For the HSC testing, scheduled for the fall of 1992, this set-up will be left in place and should be used "as is" for the regulatory testing. For any subsequent testing of the HSC container [or other containers required to conform to 10 CFR 71.73(c)(3)], instrumentation should be installed in the same manner as has been done for this characterization project.

The temperatures measured in Characterization Experiment 1 (set-point temperature 1650°F) met and exceeded the required temperature (1475°F); the temperatures reached in Characterization Experiment 2 (set-point temperature 1575°F) met the regulatory requirements in all but a few instances. The temperatures which did fall below 1475°F in Characterization Experiment 2 did so by only a few degrees. Thus, it is recommended that a furnace set-point temperature of 1600°F be used during the regulatory tests. Using the data from both characterization experiments, the responses of both the furnace surfaces (Fig. 11) and the HSC surface (Fig. 12) have been predicted for a regulatory thermal test using a set-point temperature of 1600°F. Furnace surfaces are predicted to reach regulatory temperature within about 10 minutes and should remain above 1475°F for the remainder of the test. In both characterization experiments, the furnace side wall temperatures were the lowest measured temperatures. Therefore, it will be necessary to monitor these temperatures especially closely. The HSC should reach 1475°F in about 12 or 13 minutes. If the prediction is accurate, it will be necessary to leave the HSC in the furnace for approximately 43 minutes. It is expected that the package's surface temperature will eventually level out very near to the furnace set-point temperature (1600°F) and remain there until the conclusion of the test.

This recommendation assumes that the HSC will react in a manner similar to the MHSC used in these experiments. If this is not the case, it will become obvious during the initial HSC thermal test, and it will then be necessary to use a different set-point temperature during subsequent regulatory tests. If it is necessary to vary from this recommended set-point temperature during the first test, it should be possible to make adjustments during the test (i.e., adjust the temperature control upward if package, furnace, or both temperatures are too low) to ensure regulatory compliance. Further, it is recommended that the steady-state method of compliance⁴ be used for these test procedures.

Fig. 11. Predicted average furnace surface temperatures vs time for HSC regulatory thermal test with 1600°F furnace set-point temperature. Note: Upper solid line indicates furnace set-point temperature (1600°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. 12. Predicted average package surface temperature vs time for HSC regulatory thermal test with 1600°F furnace set-point temperature. Note: Upper solid line indicates furnace set-point temperature (1600°F) and lower solid line indicates regulatory temperature (1475°F).

5.2 RECOMMENDATIONS

1. Testing should be closely coordinated with Lindberg Heat Treating Company personnel. Tests should be run only when the furnace can be dedicated to this job for a minimum of 2 days (starting from a cold furnace).
2. Prior to any heat being applied to the furnace, personnel who will be present during the test should practice the loading and unloading procedures to be used during the test. Any pier relocation that must take place for the tests should be performed at this time.
3. Instrumentation (i.e., thermocouples) should be placed within the furnace as outlined previously in this report when the furnace is cool. This includes three thermocouples on each of the four walls, two on the ceiling, five on the floor and one on each of the piers used to support the package being tested. These thermocouples should be placed in the same (or as near as possible) locations as they have been for these characterization experiments.
4. After practice has been fully completed and the operators and the test manager are familiar with the manner in which the tests will be performed, the furnace should be sealed and turned on by setting the furnace controller to the intended furnace set-point temperature. Data recordings should be initiated at this time, with readings taken at least every hour. The furnace should be allowed to heat for at least 8 hours.
5. Thermocouples internal to the furnace to be used during the test should be attached to a data recorder prior to initial heating of the furnace. When the furnace is first turned on, the readings from these thermocouples should be observed to ensure that they are functioning properly. If this is not done until the furnace has fully heated, it will take longer for the furnace to cool enough for problems to be located and fixed.
6. During the test, thermocouple data should be recorded at least every minute.
7. For consecutive tests to be performed on the same day, at least 2 hours should be required between test to allow the furnace to thermally equilibrate. This 2-hour period should begin when the furnace is closed after removal of the initial test unit and the furnace should not be opened again until the initiation of the next test. If for some reason it becomes necessary to open the furnace between runs, 2 hours should be allowed to pass after the furnace has been closed before the initiation of the next test.
8. For a test to be considered complete all the requirements outlined in Section 2.2.1 of A Combination Test/Analysis Methods Used to Demonstrate Compliance to DOE Type B Container Thermal Test Requirements (30 Minute Fire Test)⁴ must be met.

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Appendix A
PRESENTATION OF EXPERIMENTAL DATA

Appendix A

PRESENTATION OF EXPERIMENTAL DATA

All thermocouple data taken during the course of the experimental work discussed herein are organized by individual experiment and presented in graphical format. For each of the two experiments six graphs are used to present the data (Figs. A.1-A.6 for Characterization Experiment 1 and A.7-A.12 for Characterization Experiment 2). Each graph contains data from several different thermocouples and all recorded thermocouple data are presented. Thermocouple malfunctions are noted in the caption under the graph that would have contained the data from these thermocouples. For clarification refer to Figs. 2 through 6 to identify thermocouple locations.

Fig. A.1. Temperature vs time for furnace floor locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.2. Temperature vs time for furnace front and rear wall locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.3. Temperature vs time for furnace left and right side wall locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.4. Temperature vs time for furnace ceiling and pier locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.5. Temperature vs time for various package surface locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.6. Temperature vs time for various package surface locations during Characterization Experiment 1. Note: Upper solid line indicates furnace set-point temperature (1650°F) and lower solid line indicates regulatory temperature (1475°F). Package thermocouple 35 did not function during this experiment.

Fig. A.7. Temperature vs time for furnace floor locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.8. Temperature vs time for furnace front and rear wall locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.9. Temperature vs time for furnace left and right side wall locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.10. Temperature vs time for furnace ceiling and pier locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.11. Temperature vs time for various package surface locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

Fig. A.12. Temperature vs time for various package surface locations during Characterization Experiment 2. Note: Upper solid line indicates furnace set-point temperature (1575°F) and lower solid line indicates regulatory temperature (1475°F).

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