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Thermal Testing of Type B Packages in Furnaces per ASTM Standard Practice E 2230

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Introduction

In the United States, the requirements for the Hypothetical Accident Conditions (HAC) Thermal Test are presented in 10 CFR 71.73 (c)(4) and state:

> *Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in) above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may 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.*

This regulatory wording was first introduced in the 1996 version of 10 CFR 71. Before that, the thermal test outlined in 10 CFR 71 was very difficult to interpret. It was not clear that a method other than an actual pool fire (such as a furnace tests) could be used when actual physical tests were being performed. The added wording in the 1996 version answered some questions, including the use of means other then a pool fire; however, it, too, had clauses which remained open to interpretation. Some limited guidance could be found in U.S. Nuclear Regulatory Commission (NRC) Guides, and in the international regulations, but a comprehensive set of guidelines regarding the performance of 10 CFR 71 thermal tests did not exist.

In 1997 Jorman Koski, then of Sandia National Laboratories, initiated the formation of the ASTM E05.13 Subcommittee on Large Scale Fire Tests under the E05 Committee on Fire Standards. Experts in the field of thermal testing of Type B shipping packages were invited to join the subcommittee based on their experience and general participation in the development of these types of tests. This subcommittee undertook the task of authoring an ASTM Standard Practice that would detail recommended practices for performing the thermal tests outlined in the NRC's 10 CFR 71. Legitimacy of the ASTM Standard was ensured by the presence and participation of a representative of the U.S. NRC. The result of this undertaking was the publication of ASTM E2230, entitled *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material* in 2002.

Overview of ASTM E2230

ASTM E2230 outlines methodologies for performing four different types of 10 CFR 71 thermal tests including pool fire, furnace, radiant heat, and analysis. For each of these test types, a section is devoted to outlining a concise process that has been employed to successfully complete these tests in the past. The standard also indicates primary candidates for each of the different types of tests and also points out any known pitfalls that need to be avoided. The standard also contains a general discussion of its applicability or scope, which amounts to a brief interpretation of the 10 CFR 71.73 (c)(4). The methodologies presented in the standard are consistent with this interpretation.

Considerations for Furnace Testing

Furnaces have been employed to perform Hypothetical Accident Conditions (HAC) thermal tests on Type B shipping packages for many years. However, prior to the 1996 revision of 10 CFR 71, it could be argued that these types of tests did not meet the regulatory requirements. When the regulations were changed in 1996 to include, "*or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C"* it was clear that furnaces could be used for these tests.

Furnace testing of Type B shipping packages has occurred in all types of furnaces including both electric and gas-fired furnaces. Typical electric furnaces lack the ability to reheat quickly once they have been opened, as is done at the beginning of a thermal test. Additionally, electric furnaces are usually closed systems such that any combustion of materials of construction during thermal testing typically results in consumption of oxygen present. Once the atmosphere becomes oxygen starved, the requirement that, *any combustion of materials of construction, must be allowed to proceed until it terminates naturally*, cannot be met. The burners of gas-fired furnaces can be set to run lean meaning excess air is pumped into the furnace, thereby ensuring the availability of oxygen to allow natural combustion of materials of construction. For both of these reasons, the ASTM standard strongly recommends the use of gas-fired furnaces over electric furnaces for HAC thermal testing of Type B shipping packages.

In both furnaces and pool fires, the primary heat-transfer mode is radiation. In the furnace, this is primarily an exchange of energy between the walls of the furnace (which make-up the largest surface area), the flames in a gas-fired furnace (which represent a varying surface area) and the package (which typically represents a comparatively small surface area). Therefore, it is vital to measure the radiative temperature of the furnace walls, as these walls are the primary source of energy being transferred to the shipping package. Since the flames in a gas-fired furnace are the heat source for the furnace walls, by definition, they must be hotter than the furnace walls. Therefore, measurement of the furnace wall temperatures demonstrates the required, "*time averaged environmental temperature of 800°C*," is met.

The requirements also state that the heat source must, "*provide an average emissivity coefficient of at least 0.9*." The emissivity of a surface can be very difficult to measure accurately and may vary depending on what wavelength is being observed and many other environmental conditions. In the case of furnace testing, the effects of surface emissivity can be rendered unimportant by choosing a properly-sized furnace. That is, the importance of emissivity is directly related to the ratio of the surface area of the package to the surface area of the radiating medium. If the radiative surface area of the furnace walls, floor, and ceiling is much, much larger than the surface area of the package being tested, then the ratio approaches zero and surface emissivity no longer effects the heat-transfer rate. Therefore, it is important to consider the ratio of the surface area of the radiating surfaces within the furnace to the surface area of the package to be tested when planning and performing HAC thermal testing of Type B shipping packages.

Another portion of the regulations that changed in 1996 was the manner in which convection needed to be considered. The new regulations stated that, "*the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified*." Because furnaces are typically perceived as having less convection than open pool fires and measurement of *in situ* convective forces is difficult and impractical, this stipulation complicates the use of furnaces in performing HAC thermal tests on Type B shipping packages. In reality, the gas flow conditions within most gas-fired furnaces are chaotic, with tremendous quantities of air being blown through the burners and tall flues creating tremendous pull. Most gas-fired furnaces have burners near the top of the chamber with flue openings near the bottom. Since normal flow of heated air would be from low to high rather than vice versa, this arrangement enhances the convective atmosphere within the furnace. However, there is no simple method for showing the level of convection for comparison to pool fire conditions.

Selection of Furnaces for Thermal Testing

Over the past eighteen months, the Transportation Technologies Group (TTG) of Oak Ridge National Laboratory (ORNL) has tested 4 different drum-type packages for the Y-12 National Security Complex. The ES-2100, DPP-2, MD-1, and ES-3100 Shipping Packages have all undergone HAC thermal testing. These tests have been conducted at remote locations including ABB Combustion Engineering in Chattanooga, TN U.S.A. (ES-2100) and Timken Latrobe Steel in Latrobe, PA U.S.A. (DPP-2, MD-1, and ES-3100). Each of these facilities were chosen based on the type of furnace offered for use, the operating personnel provided, and the staging area available near the furnace.

As discussed above, successful furnace testing requires either considerable knowledge of the emissivity of the furnace surfaces or furnace surface area that is considerably greater then the surface area of the package being tested. During the search process for appropriate industrial furnaces to use for these tests, some furnaces were eliminated from selection based on their dimensions, which were just large enough to house the package to be tested. Both of the furnaces picked for testing had interior radiating surface areas greater then 100 times the surface area of the packages to be tested.

One key to successful testing in a furnace is the ability to load and unload a hot furnace in a short period of time. If a cold furnace were used for testing, the vast majority of the energy coming from the source would be absorbed by the furnace surfaces. To ensure a radiative environment which meets that required in 10 CFR 71, the furnace surfaces must be at temperature (800°C or 1475°F) or above during the course of the thermal test. When a furnace door is opened, a massive quantity of heat is transferred to the surroundings. Therefore, it is important that the furnace door remain open for as short a period of time as possible, especially at the beginning of the test. Both of the furnaces used in these tests were loaded using a forklift with an extension arm. The forklift operators at both facilities were very experienced loading and unloading steel into hot furnaces and were well prepared for the thermal testing. Loading ability was a key factor in choosing the respective facilities used in these tests.

Another factor important for successful testing, but easily overlooked, is the area adjacent to the furnace. Ample staging area must be available for the data acquisition system, the preheat chamber, a package cooling area and, the associated personnel. Especially important is the package cooling area due to the requirement in 10 CFR 71 stating, "*Artificial cooling may not be applied after cessation of external heat input*." This means that the packages cannot be exposed to forced fan cooling or drafty conditions which may lead to them cooling faster than usual. Both of the facilities selected offered adequate accommodations adjacent to the furnace.

Preparations for Testing

In preparation for these tests, a custom data acquisition system was built specifically for measuring temperatures associated with the thermal testing. The system is PC/Windows-based and measures up to 72 different temperatures simultaneously. Data is measured continuously and is written to an Excel data file at discrete intervals (typically 15 s). The system is set up to accept Type-K thermocouples, but could easily be adjusted to accept other thermocouple types. Type-K thermocouples are chosen due to their accuracy in the range of interest, and relatively low cost. The National Instruments software Lookout 5.0 is used to interface the user and allow for data manipulation. A custom user interface was developed at ORNL which allows the user to view several different data displays including graphical histories of all channels, lowest temperature readings from a selected group of thermocouples, as well as current temperatures at selected locations. Typically, temperatures of the furnace walls, floor, test stand, door, the package surface during testing and after, as well other packages undergoing thermal test preheating, and the ambient temperature are monitored and recorded simultaneously.

Another preparation for testing was to build a test stand to cradle the package being tested. To ensure that the stand does not act as a heat sink when the package is placed on it, ASTM E2230 calls for loading the package directly onto a stand that is already inside the furnace and is already at temperature. Because the stand needed to withstand not only several days in the furnace, but also the physical abuse of loading and unloading several test packages, it was constructed of stainless steel. Additional cooling racks of the same design as the test stand, but constructed of carbon steel, were also prepared for use. This similar design guaranteed that the system used to load and unload the packages from the test stand in the furnace could also offload the hot packages onto the cooling stands.

Testing Process

Upon arriving at the test site, all packages to be tested are loaded into a preheat chamber (see Fig. 1). This chamber heats the packages to slightly over 38°C (100°F). The packages remain in the preheat chamber for several days to ensure they are thoroughly soaked at the preheat temperature. At the same time the preheat chamber is set up, the data acquisition system is initiated. Temperatures inside the preheat chamber (typically a flue temperature and a package surface temperature) are monitored throughout the preheat period and the data is kept as proof of each package's initial condition at test time.

Once the preheat chamber and data acquisitions system are functioning, the test furnace is instrumented for testing. It should be noted that the furnace is always allowed to cool for several days before the test personnel arrive. This allows the personnel to enter the furnace upon arrival to install testing hardware. Hardware for instrumenting the test furnace typically consists of a steel plate for the furnace floor, the test stand and many thermocouples. The steel plates give a solid surface for the test stand to be mounted to and also act as a thermal mass. The test stand was solidly welded to the steel plates – making the inadvertent movement of the stand during loading, which could result in the package being dropped inside the furnace – much less likely to occur.

Figure 1. Preheat chamber being used to prepare MD-1 packages for HAC thermal testing

As described above, the packages are loaded and unloaded to and from a hot furnace as quickly as possible, using a forklift, to keep the furnace as hot as possible. Therefore, after instrumenting the furnace, but prior to heating it, package loading and unloading is practiced. Often times, paint or other means are used to mark the position of forklift wheels when the package has reached the correct depth in the furnace to place the package in the test stand. Typical loading and unloading times for both of these furnaces was 50–65 s, from the initiation of the door lifting until it was fully closed.

Once the furnace is fully instrumented and practice loading and unloading has led to high level of confidence in these processes, the furnace door is closed and the burners are fired. Experience with many different industrial style furnaces has shown that it takes many hours for a furnace to fully heat soak and equilibrate. A fully heat-soaked furnace displays steadier temperatures and recovers more quickly after the door is opened. It typically takes an industrial-sized furnace about 18–24 hours to fully equilibrate at the testing temperature. All industrial furnaces display some fluctuation in their internal temperatures, and in a fully heat soaked furnace, the amplitude of these fluctuations is minimized. The graphical history displayed on the data acquisition system is used to determine when these fluctuations have stabilized, indicating the furnace is ready for use.

After the furnace has been allowed to heat soak (at least overnight), and the packages have been fully preheated (typically about 48 hours), actual HAC thermal testing is performed. The first step of the testing sequence is to remove a package from the preheat chamber and instrument it with thermocouples so that its surface temperature can be followed throughout the duration of the test. Because of some of the questions discussed above, primarily the lack of an ability to define the convective atmosphere within the furnace, a so-called steady-state method, as described in Section 7.3.4.3 of the ASTM Standard Practice, has been employed during each of the four thermal tests performed recently. In this method, the temperature of the furnace surfaces (typically 15 of 18 thermocouples) and the package surface (typically 5 of 6 thermocouples) must attain the regulatory temperature of 800° C (or 1475° F) prior to the 30-minute test period beginning. This is only possible with drum-type packages in which a thin outer shell of metal is backed by an insulating material such that the surface of the package heats rapidly. Some packages also have internal thermocouples which must be connected to the data acquisition system prior to loading the package into the furnace. The loading process must be performed both carefully, so as to not drop the package in the furnace as well quickly, to minimize heat loss from the furnace (Fig. 2). Once the package has been carefully placed on the test stand within the furnace, the furnace door is closed and the data acquisition system is closely monitored to determine when all surfaces (package and furnace) have reached temperature and the 30-minute clock is started. During these tests, packages reached the regulatory temperature in approximately 7 to 13 minutes, and were then kept in the furnace for an additional 30 minutes (per the HAC requirements). Thus, each package remained in the furnace a total of 37 to 43 minutes.

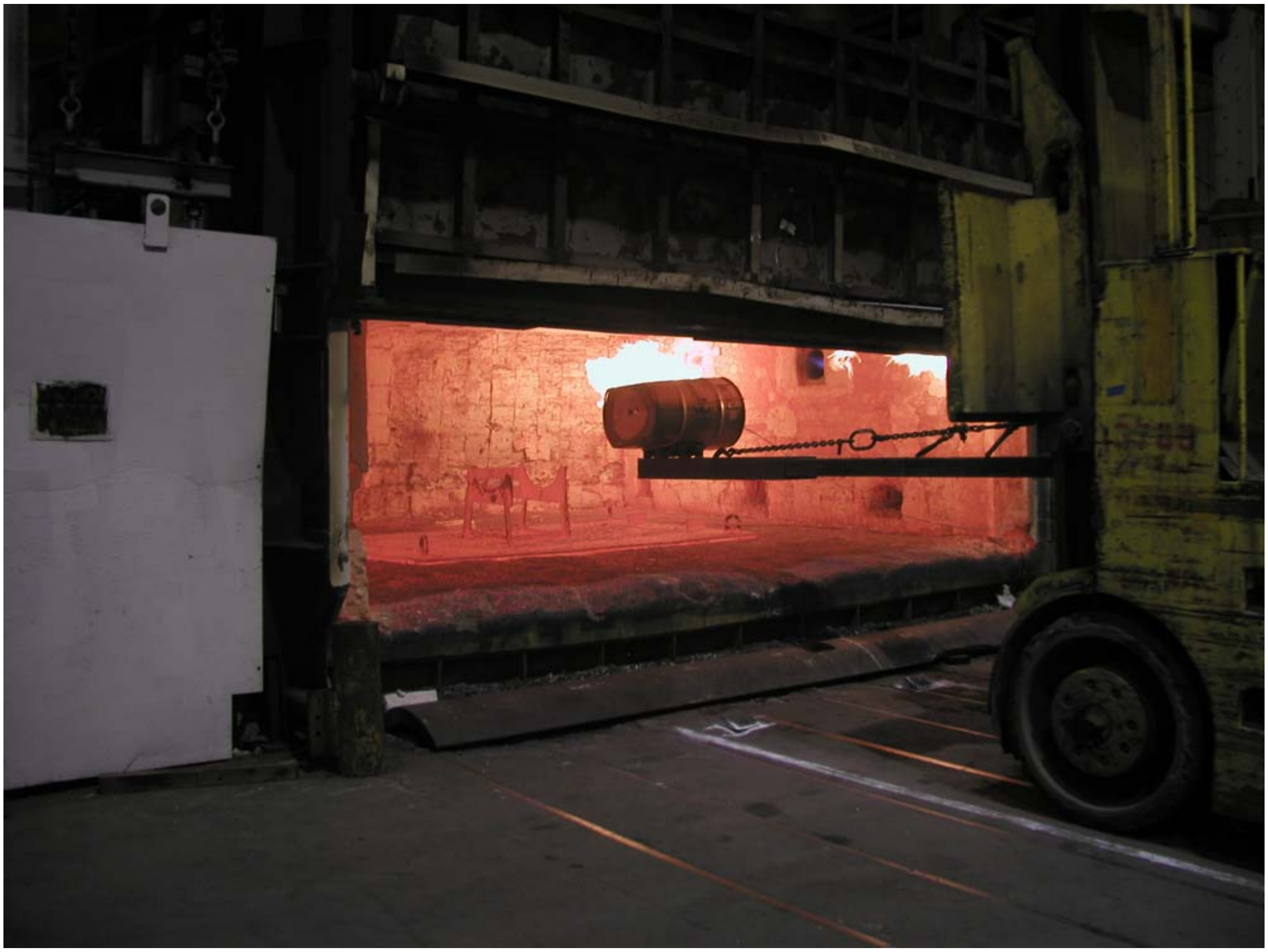

Figure 2. ES-2100 package being loaded into a furnace at the start of thermal testing

When the 30 minutes of the HAC thermal test are complete, the packages are promptly removed from the furnace (Fig. 3) and placed on cooling stands (Fig. 4). Package surface thermocouples are typically monitored for several hours after testing is complete. If the package has internal thermocouples, these are monitored for a longer period of time (up to 24 hr) so that additional data regarding internal temperatures can be recorded. As mentioned above, the cooling stands must be located so that no artificial cooling is applied. The packages must be protected from means of forced cooling such as fans and drafts that may occur in large industrial settings.

Figure 3. DPP-2 package about to be removed from the furnace at the end of a thermal test

All of the thermal data from each test is included in the test report issued to document that particular package's regulatory testing. Typically, the data is presented in graphical format with separate graphs for package temperatures and furnace temperatures. Additionally, thermal analysts working on package development or certification may wish to use the raw data, in spreadsheet form, to help formulate boundary conditions for computer simulations to help verify or adjust their analytical model.

The entire testing process must be performed under the auspices of an approved Quality Assurance Program. TTG operates its package testing program under NTRC-PRF-QAP-001, *Quality Assurance Plan for the Package Testing Program at the National Transportation Research Center Packaging Research Facility*, and the thermal test are specifically performed according to procedure TTG-PRF-13 entitled Operating Procedure for HAC Thermal testing – Testing of Radioactive Material Packages. This QA program, while based on 10 CFR 830, specifically considers the quality requirements outlined in 10 CFR 71 Subpart H – *Quality Assurance*.

Figure 4. ES-3100 package being placed on a cooling stand at the end of a thermal test

Summary

ASTM E2230, *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material* was written to provide guidance when using any of four different methods for performing the HAC thermal test outlined in 10 CFR 71.73 (c)(4). The guidance provided in the Standard Practice has been used to successfully test four different drum-type packaging designs (ES-2100, DPP-2, MD-1 and ES-3100). There are many considerations that must be dealt with when performing these tests which are a direct result of the wording of 10 CFR 71 HAC thermal test regulations. The Standard Practice offers guidance that helps to deal with each of these considerations in a manner which meets current regulatory requirements.

The ASTM E05.13 Subcommittee on Large Scale Fire Tests, which produced the Standard Practice in 1997, is currently meeting to consider revision of this standard. Under consideration is an interpretation of the Normal Conditions of Transport thermal conditions found in 10 CFR 71.71, to help better define the methods of showing compliance with these regulatory requirements.