ASTM STANDARD PRACTICE FOR THERMAL QUALIFICATION OF TYPE B PACKAGES FOR RADIOACTIVE MATERIALS

Jack Hovingh
Lawrence Livermore National Laboratory
Livermore, CA

Jorman A. Koski
Retired
Sandia National Laboratories
Albuquerque, NM

ABSTRACT

Type B quantities of radioactive materials must be shipped in packages that comply with 10 CFR 71 and IAEA TS-R-1. These packages must be subjected to a hypothetical accident prescribed in 10 CFR 71.73 and TS-R-1, Section VII, while remaining within regulatory limits for containment, shielding, and criticality.

The ASTM E05.13 Task Group 9 is developing a Standard Practice for the Thermal Qualification of Type B Nuclear Packages. The emphasis of the Standard Practice is on performing the thermal portion [10 CFR 71.73 (c)(4); IAEA TS-R-1, paragraph 728] of the hypothetical accident.

The Standard Practice focuses on thermal test methods that can be used to satisfy the regulatory requirements of 10 CFR 71.73. These tests can include either a physical test, the mathematical simulation of a physical test, or a combination of both.

The various methods for performing a physical test include a pool fire, furnaces, and a radiant heat source. The Standard Practice discusses the advantages and limitations of each method (including mathematical simulation), test preparation, test conduct, and adjustments of results for off-regulatory conditions. Instrumentation issues are also discussed in the Standard Practice.

The status of the Standard Practice will be presented.

INTRODUCTION

Type B quantities of radioactive materials must be shipped in packages that comply with 10 CFR 71 and IAEA TS-R-1. These packages must be subjected to a hypothetical accident prescribed in 10 CFR 71.73 and TS-R-1, Section VII, while remaining within regulatory limits for containment, shielding, and criticality. Differences between 10 CFR 71.73 and TS-R-1 are given in Appendix 3 of the Standard Practice.

The ASTM E05.13 Task Group 9 is developing a Standard Practice for the Thermal Qualification of Type B Nuclear Packages. The regulations cited above specify the hypothetical accident conditions that a package must withstand, but they do not contain detailed instructions on alternative test methods or criteria for evaluating results. The Standard Practice is intended to provide details of the thermal portions of the certification process that can be referenced by both package regulators and applicants during package certification. This approach is consistent with current emphasis on consensus standards as a regulatory tool in place of detailed regulations.

The emphasis of the Standard Practice is on performing the thermal portion [10 CFR 71.73 (c)(4); IAEA TS-R-1, paragraph 728] of the hypothetical accident. In ASTM parlance, a standard practice is not considered to be a standard, but rather a guide for completing a procedure or test.

The Standard Practice focuses on thermal test methods that can be used to satisfy the regulatory requirements of 10 CFR 71.73. These tests can include either a physical test, the mathematical simulation of a physical test, or a combination of both.

MOTIVATION FOR ASTM STANDARD PRACTICE/GUIDE

Several regulatory authorities exist for transport of nuclear materials depending on the nature of the shipment (foreign or domestic) and the type of nuclear material to be transported. The main advantage of the Standard Practice will be to make the package certification process more uniform, regardless of the certification authority and path.

The task group developing the Standard Practice consists of regulators, package developers and testing organizations. Over three years of regular meetings have led to development of the current draft Standard Practice. During that time several people have contributed or expressed an interest in the development of the Standard Practice.

Chris Bajwa, NRC	Arnie Justice, DOE/AL
Bode Buckley, ASTM	Mike Keane, DOE/EM
Y.S. Cha, ANL	Ned Keltner, Ktech, Inc.
Earl Easton, NRC	Felix Killar, NEI
Matt Feldman, Oak Ridge	Joe Koski, SNLA
Dan Gemeney, RJA Assoc.	Bill Lake, DOE/RW
Walt Gill, SNLA	Carlos Lopez, SNLA
Jim Griffith, SWRI	Jim Nakos, SNLA
Lou Gritzo, SNLA	Steve Nunley, DOE/AL
Dick Gromada, WSRC	Tony Patko, ATG, Inc.
Lynnette Hendricks, NEI	Dave Raske, ANL
Steve Hensel, WSRC	Ernst Schmidt, Omega Point
Glenn Hohnstreiter, SNLA	Paul Stevens, PacTec
Jack Hovingh, LLNL	

Note that the list includes a balance of people from regulatory, test, package vendor organizations, and industry trade groups.

TEST METHODS

The various methods for performing a physical test include a pool fire, furnaces, and a radiant heat source. The Standard Practice discusses the benefits and limitations of each method (including mathematical simulation), test preparation, additional information to be reported, and test conduct. Adjustments of results for off-regulatory conditions and instrumentation issues are discussed in the Appendices of the Standard Practice.

Qualification by Analysis

Mathematical simulation is often used to estimate the response of a large package containing a Type B quantity of radioactive material to a regulatory fire (10 CFR 71.73). (A large package is of a size that may challenge the capability of test facilities.) Mathematical simulation can model the decay heat rate of the package contents, a parameter not usually included in physical tests. In addition, mathematical simulation can determine the sensitivity of the package performance to off-regulatory test conditions, with the concomitant change in the thermal design margins of the package. The mathematical simulations generally use ideal geometries, tabulated material thermal and physical properties, and empirical heat transfer correlations that require knowledge of the flame and combustion products, properties, and velocities. Generally, mathematical simulation treats conduction and radiation across gaps and enclosures within the package but neglects the effects of convection in the enclosures within the package. In addition, the decomposition of the package components during and following the fire and their effect on the thermal performance of the package cannot be easily simulated.

Package Modeling. The Standard Practice discusses the following topics for preparing a package model for analysis:

- Model preparation including
- Thermophysical properties of the package materials (structural elements, impact limiters, and contents).
- Thermal conditions during normal conditions of transport and under hypothetical accident conditions.
- Example of a package model
- Additional information including temperature histories, internal pressures, thermal stresses, and post-fire, steady-state temperatures.
- Methods for conducting the mathematical simulation response of a package to the regulatory fire test.
- Quality assurance requirements for computer codes.
- Solved problems used to benchmark thermal analysis codes.

Descriptions of several thermal analysis computer codes, deemed to be representative of thermal analysis codes are given in the Appendix 4 of this Standard Practice.

Qualification by Pool Fire Test

Pool fires are used to estimate the response of a package containing a Type B quantity of radioactive material to a regulatory fire (10 CFR 71.73). A pool fire may best meet the regulations of 10 CFR 71.73 relative to the other types of test facilities. The regulatory fire invokes the radiation and convection surface heat fluxes and temperatures on the package boundaries.

Relative to mathematical simulation, the package geometry is as fabricated and as damaged from the preceding regulatory drop tests of 10 CFR 71.73. The actual package material properties and internal heat transfer mechanisms are tested. However, the decay heat rate of the package contents is usually not included in physical tests. In addition, the regulatory pre- and post-fire environment conditions such as temperature and insolation may not be achieved.

Completed procedures are presented for an actual pool fire test in Appendix 2, beginning with preparing the test unit (package) through ignition, post-test activities, and all activities between preparation and post-test.

Test Preparation. A pool fire facility is relatively simple with the flexibility to test a wide variation of package sizes. With the exception of the regulatory 1m height of the package above the pool surface, every pool fire test setup is different. The basic facility needs, in addition to a pool, a package support structure and a supply of fuel. The setup design presents common features of any pool fire test, identifies features for demonstrating conformance to the regulatory requirements of 10 CFR 71.73, and discusses additional features for ensuring conformance to 10 CFR 71.73. These additional features include the ability to add fuel to the pool during the burn, the use of wind fences to reduce the effects of wind on the fire, and methods help ensure the package is fully engulfed in flames.

Test procedures, including considerations, the elements of a test plan, and organization are described in Appendix 2 of the Standard Practice.

Test Performance. The Standard Practice addresses the test performance, including the selection of the time of day to perform the test and the package and instrumentation response. The time of day to perform the pool fire test is selected to minimize the wind effects on the fire during the 30-minute fire duration. At Sandia, the wind is usually minimized during the early morning hours when the wind shifts in direction.

Pool Fire Test Setup. The setup design presents common features of any pool fire test, identifies features for demonstrating conformance to the regulatory requirements of 10 CFR 71.73, and additional features for ensuring conformance to 10 CFR 71.73. These additional features include the ability to add fuel to the pool during the burn, the use of wind fences to reduce the effects of wind on the fire, and methods to help ensure the package is fully engulfed in flames.

The Standard Practice also addresses the test performance, including the selection of the time of day to perform the test and the package and instrumentation response. The time of day to perform the pool fire test is selected to minimize the wind effects on the fire during the 30-minute fire duration. At Sandia, the wind is usually minimized during the early morning hours when the wind shifts in direction.

The Standard Practice shows the response of (1) thermocouples placed in several locations on a test package, and (2) a thick wall passive calorimeter oriented horizontally in the same fire at the same level as the test unit. Measurements taken by the thermocouples and calorimeter demonstrate that the pool fire met or exceeded regulatory requirements of 10 CFR 71.73.

Qualification by Furnace Test

Furnaces are frequently used to estimate the response of a package containing a Type B quantity of radioactive material to a regulatory fire (10 CFR 71.73). The package is heated by thermal radiation from the furnace walls as well as by natural convection from the furnace internal atmosphere. The heat flux from natural convection may be less than from a pool fire; to compensate, the radiant heat flux may need to be increased to achieve the regulatory total heat flux on the package surface. In addition, the flow of hot "air" surrounding a cool package in a furnace test may be in the opposite direction of the flames and heated gases of a pool fire. The heat loss of the furnace facility during the insertion of the package into the facility may result in an ambiguous start time for the test.

Relative to mathematical simulation, the package geometry is as fabricated and as damaged from the preceding regulatory drop tests of 10 CFR 71.73. The actual package material properties and internal heat transfer mechanisms are tested. However, the decay heat rate of the package contents is usually not included in physical tests. In addition, the regulatory pre- and post-fire environment conditions such as temperature and insolation may not be achieved.

Test Preparation and Configuration. The Standard Practices addresses the test preparation and configuration of a furnace test. A gas-fired furnace is recommended over an electric furnace for a regulatory heat test (10 CFR 71.73) of a package for two reasons: one, the higher heat flux associated with the gas-fired furnace reduces the perturbation of the furnace environment during the loading of the test package into the furnace; two, the oxygen concentration in a gas-fired furnace may be easier to maintain such that combustion, if any, of the package materials of construction may proceed until it terminates naturally.

The Standard Practice addresses the following issues for the furnace test:

- The size of a furnace, whether gas-fired or electric, in terms of the interior surface area relative to the package size.
- Digital control systems for the regulation of the interior furnace temperatures.
- Methods for loading into and removing the package from the furnace, and supporting the package in the furnace to minimize the conduction losses and obstruction of the package view from the furnace surfaces. Loading a package into the preheated furnace and removing the package from the hot furnace following a test are keys to the successful performance of a furnace test to comply with the regulatory conditions of 10 CFR 71.73.
- Furnace preparation for the test. Emphasis is placed on the location and method of mounting thermocouples to ensure that the test can be demonstrated to meet the regulatory environment of 10 CFR 71.73.
- Data acquisition, including the time interval between data points.
- A method for maintaining and monitoring oxygen levels in a gas-fired furnace.
- Package preparation prior to the test, including methods for installing and mounting thermocouples to monitor the package surface temperature. After the test group installs the thermocouples and checks their functionality, the package is ready to be inserted into the furnace.

Test procedures, including considerations, the elements of a test plan, and organization are described in Appendix 2 of the Standard Practice.

Additional Data to be Reported. Additional data to be reported are identified. All thermocouple data must be recorded at 15- to 30-second intervals for the duration of the test. The time at which the package is inserted into the furnace, the time at which the test begins, and the time the package is removed from the furnace must be recorded. The flue gas oxygenation should be measured every 5 minutes during the test.

Conducting the Test. The Standard Practice addresses the conduct of a furnace test. The actual testing of the package is straightforward. The furnace is preheated, the furnace door is opened, and the package is loaded into the furnace. When the test is completed, the package is removed from the furnace. However, because of the depression of the furnace interior and wall temperatures from heat losses during the insertion of the package into the furnace, the determination of the time when the test starts, and hence ends 30 minutes later, is less straightforward. Methods for estimating the "start time" as well as methods for loading and unloading a test speciman into and from a furnace are given.

Adjustments of Results. Adjustments of results for differences from regulatory and initial boundary conditions are addressed in the Appendix of the Standard Practice.

Abnormal Events, Remediation. Abnormal events and their remediation are addressed. The use of "dry runs" is strongly recommended in advance of an actual furnace test to ensure that all procedures will perform as expected, and that unexpected difficulties are discovered prior to the actual test.

Qualification by Radiant Heat Test

Radiant heat facilities are used to estimate the response of a package containing a Type B quantity of radioactive material to a regulatory fire (10 CFR 71.73). The package is heated by thermal radiation from heat lamps as well as by natural convection from the facility internal atmosphere. The heat flux from natural convection may be less than from a pool fire; to compensate, the radiant heat flux may need to be increased to achieve the regulatory total heat flux on the package surface. The low thermal inertia of a radiant heat facility results in a rapid increase in radiant heat flux at the beginning of a test, as well as the ability of the facility to rapidly respond to input power changes.

Relative to mathematical simulation, the package geometry is as fabricated and as damaged from the preceding regulatory drop tests of 10 CFR 71.73. The actual package material properties and internal heat transfer mechanisms are tested. However the decay heat rate of the package contents is usually not included in physical tests. In addition, the regulatory pre- and post-fire environment conditions such as temperature and insolation may not be achieved.

Test Preparation. The Standard Practice addresses the test preparation for conducting a radiant heat test. The test preparation addresses procedures, setup, calibration, and uncertainty analysis. Procedures include the environmental documentation and safety, quality, and operational procedures necessary to perform a radiant heat test.

The Standard Practice discusses the following issues for the radiant heat test:

- Test setup, including the lamp array size needed for the specific test, the design of the test stand to support the package, the temperature profile required on the test enclosure, the required instrumentation for the test, and other tasks. These tasks include connection of water hoses, a check of the power connections and cables, the installation of safety barriers, and the setup of the data acquisition system. A "check test" is recommended using an instrumented mock package to check operation of the experimental apparatus, pre-conditioning hardware, and the enclosure uniformity. If required, modifications can be made and re-tested as necessary reusing the mock package.
- Calibration of the individual thermocouples and other transducers and an uncertainty analysis of the entire measurement system.
- A pre-test validation analysis of the expected measurements and a check of the data acquisition system.

Test procedures, including considerations, the elements of a test plan, and organization are described in Appendix 2 of the Standard Practice.

Additional Data to be Reported. Additional data to be reported include the volts, amps, and power of the power system, the electrical noise levels, and the reference junction temperature. These data are desirable to ensure that the facility is performing as expected, and the true temperatures and their fluctuations are as measured.

For quality assurance purposes, the details of the equipment used, calibration dates, etc. during the radiant heat test should be reported.

Test Conduct. The conduct of a radiant heat test is presented in a checklist form for a typical radiant heat test. Several taboos are also listed.

Abnormal Events, Remediation. Abnormal events and their remediation are addressed. An example of an abnormal event is the failure of a water hose that sprays water over the setup, that necessitate test termination.

Precision and Bias.

Package qualification is, in part, determined by leak tightness test following the entire regulatory qualification prescribed in 10 CFR 71.73, which includes drop testing, puncture testing, crush testing (if applicable) and fire testing. For this reason, the data presented in a Safety Analysis Report for Packages and other regulatory documents are intended to provide evidence that the regulatory fire environment was met or exceeded. For actual testing, the precision of these measurements must be sufficient to convince the regulatory authority that the regulatory fire conditions were met or exceeded.

Appendices

Appendices to an ASTM specification are not mandatory. The Standard Practice appendices give further information and guidance for the user.

Appendix 1 of this Standard Practice addresses the approaches of the adjustment of test results for differences of the test initial conditions as well as the test boundary conditions from the

10 CFR 71.73 regulatory prescribed initial and boundary conditions. These recommendations are dependent on the magnitude and cause of the differences.

Appendix 2 of this Standard Practice discusses test procedures. These procedures are, in general, applicable to all of the test methods (pool fire, furnace, and radiant heat) described in this Standard Practice.

Formal documentation is often required. This documentation may include information necessary to ensure the proper conduct of the test to satisfy the applicant and NRC, and may also include the internal requirements of the testing organization and other government agencies such as the EPA. For example, the internal requirements of the testing organization may require documentation showing that the test is conducted safely to meet both internal requirements and requirements from OSHA or the DOE Integrated Safety Management program. Permission to conduct a pool fire test may require approval of the EPA as well as burn permits from state and local agencies.

Documentation necessary to ensure the proper conduct of the test includes a test plan, hazards documentation, and the test procedure. The test plan includes the information necessary to facilitate communications with the interested parties including the applicant, the testing organization, and the regulatory agency. A hazards analysis is performed and supporting documentation is prepared to identify hazards for the in-house test organization as well as, if appropriate, the NEPA requirements. A test procedure identifies and formalizes the steps and procedures necessary to perform the test to the satisfaction of the applicant as well as the appropriate regulatory agency, e.g., the NRC.

Prior to the test, the test organization performs a test readiness review and presents the results to the applicant and other interested parties such as in-house health and safety groups and outside oversight groups. This review ensures that all test objectives satisfy interested stakeholders. Following the test, the test organization presents their interpretation of the outcome of the test in meeting the thermal accident requirements of 10 CFR 71.73. The quality of the data is addressed, including the occurrence of abnormal events, if any, as well as the lessons learned.

Customer	**Administration**	**Engineering**	**Operations**	**Regulators**
Initiate request	Cost estimate	Generate preliminary test plan		10 CFR 71
Supply funding	Allocate funding to resources			
Review and concur with test plan		Finalize test plan		
		Design test	Calibrate instrumentation	NIST
	File environmental documentation	Perform hazards analysis		In-house safety organization
	Obtain open burn permits			Local EPA Air Quality Board
			Implement test setup	

Customer	Administration	Engineering	Operations	Regulators
		Prepare test procedure	Walkthrough procedure	In-house safety organization
	Initiate public notification		Conduct full dress rehearsal	Local EPA Air Quality Board
Review and concur with test procedure		Conduct test readiness review		
Provide test unit	Shipping and handling		Execute test	
Review draft test data report		Draft test data report		
		Conduct post-test debriefing	Perform post-test cleanup	In-house waste management organization
Accept final report	Closeout funding account	Finalize test data report		

A test data report is generated by the test organization that ultimately becomes part of the evidence presented to the appropriate regulatory agency, e.g., the NRC. An outline of the material that needs to be included in the report is given in the Standard Practice.

The process of preparing for and performing the various tasks necessary for a pool fire test is given in Table 1, above. Role players include the applicant (customer), the testing organization including administration, engineering and operations, and the regulators. The tasks shown in the table rows are in chronological order.

Appendix 3 of this Standard Practice compares the thermal portion of the hypothetical accident prescribed by 10 CFR 71.73 (2000) with IAEA TS-R-1 (1996). Differences between the regulations are emphasized.

Appendix 4 of this Standard Practice addresses thermal analysis computer codes. The emphasis is on newer codes, including *HSTAR*, *MSC* Patran Thermal, and *TAS*. Brief descriptions of each of the codes are given.

Appendix 5 of this Standard Practice addresses instrumentation issues and primarily focuses on temperature measuring devices; more specifically, thermocouples. It covers issues, including calibration, survival in hostile environments, and heat conduction and shunting errors. Pre-test checks of thermocouples and the effects of thermocouple intrusion into a package are addressed.

CURRENT STATUS OF ASTM STANDARD PRACTICE

The concept for the Standard Practice grew from discussions held during a Symposium on Large Scale Fires sponsored by ASTM in 1997. The discussions were held in ASTM Subcommittee E05.13 on Large Scale Fire Tests. This subcommittee is a portion of the ASTM Committee E05 on Fire Standards. At a subsequent E05.13 subcommittee meeting one of the authors (Koski) was appointed as task group leader to develop the Standard Practice. Participants funded by various organizations produced draft sections: first, by presenting applications and performing tests for the initial drafting process and second, requesting the group as a whole to review and comment on the draft contents.

To date, an initial ballot on the Standard Practice has been conducted at the E05.13 Subcommittee level. Because no negative comments were received, the document was advanced for ballot to the entire E05 committee. This ballot effort will represent the first opportunity for the ASTM Fire Standards group to provide input and comments on the practice. The goal is to have a consensus standard published within one year of the initial balloting. The length of the acceptance process will depend on the number and nature of comments received.

CONCLUSIONS

The ASTM Standard Practice for Thermal Qualification of Type B Nuclear Packages is designed to help applicants for certification of Type B radioactive material transportation packages select a method for performing a thermal test in partial fulfillment of the requirements of 10 CFR 71.73. In addition, salient features of each method are described to allow the applicant to review the test issues, evaluate the test plan, and understand other procedures. This Standard Practice may be cited by an applicant as partial fulfillment of the requirements of 10 CFR 71.31(c).

ACKNOWLEDGEMENTS

The primary authors of the Standard Practice are:

Tony Patco, Qualification by Analysis

Walt Gill, Qualification by Pool Fire Test

Matt Feldman, Qualification by Furnace Test

Jim Nakos, Qualification by Radiant Heat Test

REFERENCES

Title 10, Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Material*, Jan. 1, 2000, United States Government Printing Office, Washington, D.C.

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