INTERNATIONAL

Designation: E2230 – 22

Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material[1]

This standard is issued under the fixed designation E2230; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice defines detailed methods for thermal qualification of "Type B" radioactive materials packages under Title 10, Code of Federal Regulations, Part 71 (10CFR71) in the United States or, under International Atomic Energy Agency Regulation SSR-6. Under these regulations, packages transporting what are designated to be Type B quantities of radioactive material shall be demonstrated to be capable of withstanding a sequence of hypothetical accidents without significant release of contents.

1.2 The unit system (SI metric or English) used for thermal qualification shall be agreed upon prior to submission of information to the certification authority. If SI units are to be standard, then use IEEE/ASTM SI-10. Additional units given in parentheses are for information purposes only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.*

1.5 *Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E176 Terminology of Fire Standards

IEEE/ASTM SI-10 International System of Units (SI) The Modernized Metric System

2.2 *Federal Standard:*

Title 10, Code of Federal Regulations, Part 71 (10CFR71), *Packaging and Transportation of Radioactive Material*, United States Government Printing Office, October 1, 2004

2.3 *Nuclear Regulatory Commission Standards:*

Standard Format and Content of Part 71 Applications for Approval of Packaging of Type B Large Quantity and Fissile Radioactive Material, Regulatory Guide 7.9, United States Nuclear Regulatory Commission, United States Government Printing Office, 1986

2.4 *International Atomic Energy Agency Standards:*

Regulations for the Safe Transport of Radioactive Material, No. SSR-6 (IAEA SSR-6 Revised) International Atomic Energy Agency, Vienna, Austria, 2018

Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), No. SSG-26, (IAEA SSG-26) International Atomic Energy Agency, Vienna, Austria, 2014

2.5 *American Society of Mechanical Engineers Standard:*

Quality Assurance Program Requirements for Nuclear Facilities, NQA-1, American Society of Mechanical Engineers, New York, 2001

2.6 *International Organization for Standards (ISO) Standard:*

ISO 9000:2000, Quality Management Systems—Fundamentals and Vocabulary, International Organization for Standards (ISO), Geneva, Switzerland, 2000

ISO 13943 Fire Safety – Vocabulary, International Organization for Standards (ISO), Geneva, Switzerland, 2017

[1] This practice is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.13 on Spent Fuel and High Level Waste.

Current edition approved Jan. 1, 2022. Published April 2022. Originally approved in 2002. Last previous edition approved in 2013 as E2230 – 13. DOI: 10.1520/E2230-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method refer to the terminology contained in Terminology E176 and ISO 13943 (Fire Safety – Vocabulary). In case of conflict between Terminology E176 and ISO 13943, the definitions given in Terminology E176 shall prevail.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hypothetical accident conditions, n*—a series of accident environments, defined by regulation, that a Type B package must survive without significant loss of contents.

3.2.2 *insolation, n*—solar energy incident on the surface of a package.

3.2.3 *normal conditions of transport, n*—a range of conditions, defined by regulation, that a package must withstand during normal usage.

3.2.4 *regulatory hydrocarbon fire, n*—a fire environment, one of the hypothetical accident conditions, defined by regulation, that a package shall survive for 30 min without significant release of contents.

3.2.5 *thermal qualification, n*—the portion of the certification process for a radioactive materials transportation package that includes the submittal, review, and approval of a Safety Analysis Report for Packages (SARP) through an appropriate regulatory authority, and which demonstrates that the package meets the thermal requirements stated in the regulations.

3.2.6 *Type B package, n*—a transportation package that is licensed to carry what the regulations define to be a Type B quantity of a specific radioactive material or materials.

4. Summary of Practice

4.1 This document outlines four methods for meeting the thermal qualification requirements: qualification by analysis, pool fire testing, furnace testing, and radiant heat testing. The choice of the certification method for a particular package is based on discussions between the package suppliers and the appropriate regulatory authorities prior to the start of the qualification process. Factors that influence the choice of method are package size, construction and cost, as well as hazards associated with certification process. Environmental factors such as air and water pollution are increasingly a factor in choice of qualification method. Specific benefits and limitations for each method are discussed in the sections covering the particular methods.

4.2 The complete hypothetical accident condition sequence consists of a drop test, a puncture test, and a 30-min hydrocarbon fire test, commonly called a pool fire test, on the package. Submersion tests on undamaged packages are also required, and smaller packages are also required to survive crush tests that simulate handling accidents. Details of the tests and test sequences are given in the regulations cited. This document focuses on thermal qualification, which is similar in both the U.S. and IAEA regulations. A summary of important differences is included as Appendix X3 to this document. The overall thermal test requirements are described generally in Part 71.73 of 10CFR71 and in Section VII of SSR-6. Additional guidance on thermal tests is also included in IAEA SSG-26.

4.3 The regulatory thermal test is intended to simulate a 30-min exposure to a fully engulfing pool fire that occurs if a transportation accident involves the spill of large quantities of hydrocarbon fuels from a tank truck or similar vehicle. The regulations are "mode independent" meaning that they are intended to cover packages for a wide range of transportation modes such as truck and rail.

5. Significance and Use

5.1 The major objective of this practice is to provide a common reference document for both applicants and certification authorities on the accepted practices for accomplishing package thermal qualification. Details and methods for accomplishing qualification are described in this document in more specific detail than available in the regulations. Methods that have been shown by experience to lead to successful qualification are emphasized. Possible problems and pitfalls that lead to unsatisfactory results are also described.

5.2 The work described in this standard practice shall be done under a quality assurance program that is accepted by the regulatory authority that certifies the package for use. For packages certified in the United States, 10 CFR 71 Subpart H shall be used as the basis for the quality assurance (QA) program, while for international certification, ISO 9000 usually defines the appropriate program. The quality assurance program shall be in place and functioning prior to the initiation of any physical or analytical testing activities and prior to submittal of any information to the certifying authority.

TEST METHODS

6. General Information

6.1 In preparing a Safety Analysis Report for Packaging (SARP), the normal transport and accident thermal conditions specified in 10CFR71 or IAEA SSR-6 shall be addressed. For approval in the United States, reports addressing the thermal issues shall be included in a SARP prepared according to the format described in Nuclear Regulatory Commission (NRC) Regulatory Guide 7.9. Upon review, a package is considered qualified if material temperatures are within acceptable limits, temperature gradients lead to acceptable thermal stresses, the cavity gas pressure is within design limits, and safety features continue to function over the entire temperature range. Test initial conditions vary with regulation, but are intended to give the most unfavorable normal ambient temperature for the feature under consideration, and corresponding internal pressures are usually at the maximum normal values unless a lower pressure is shown to be more unfavorable. Depending on the regulation used, the ambient air temperature is in the –29 °C (–20 °F) to 38 °C (100 °F) range. Normal transport requirements include a maximum air temperature of 38°C (100°F), insolation, and a cold temperature of –40 °C (–40 °F). Regulations also include a maximum package surface temperatures for personnel protection of 50 °C (122 °F). See Appendix X3 for clarification of differences between U.S. and international regulations.

6.2 Hypothetical accident thermal requirements stated in Part 71.73 or IAEA SSR-6, Section VII call for a 30 min exposure of the entire container to a radiation environment of 800 °C (1475 °F) with a flame emissivity of 0.9. The surface emissivity of the package shall be 0.8 or the package surface value, whichever is greater. With temperatures and emissivities stated in the specification, the basic laws of radiation heat transfer permit direct calculation of the resulting radiant heat flux to a package surface. This means that what appears at first glance to be a flame or furnace temperature specification is in reality a heat flux specification for testing. Testing shall be conducted with this point in mind.

6.3 Two definitions of flame emissivity exist, and this causes confusion during the qualification process. Siegel and Howell, 2001, provide the textbook definition for a cloud of hot soot particles representing a typical flame zone in open pool fires. In this definition the black body emissive power of the flame, σT^4, is multiplied by the flame emissivity, ε, in order to account for the fact that soot clouds in flames behave as if they were weak black body emitters. A second definition of flame emissivity, often used for package analysis, assumes that the flame emissivity, ε, is the surface emissivity of a large, high-temperature, gray-body surface that both emits and reflects energy and completely surrounds the package under analysis. The second definition leads to slightly higher (conservative) heat fluxes to the package surface, and also leads to a zero heat flux as the package surface reaches the fire temperature. For the first definition, the heat flux falls to zero while the package surface is somewhat below the fire temperature. For package qualification, use of the second definition is often more convenient, especially with computer codes that model surface-to-surface thermal radiation, and is usually permitted by regulatory authorities.

6.4 Convective heat transfer from moving air at 800°C shall also be included in the analysis of the hypothetical accident condition. Convection correlations shall be chosen to conform to the configuration (vertical or horizontal, flat or curved surface) that is used for package transport. Typical flow velocities for combustion gases measured in large fires range are in the 1 to 10 m/s range with mean velocities near the middle of that range (see Schneider and Kent, 1989, Gregory, et al, 1987, and Koski, et al, 1996). No external non-natural cooling of the package after heat input is permitted after the fire event,, and combustion shall proceed until it stops naturally. During the fire, effects of solar radiation are often neglected for analysis and test purposes.

6.5 For purposes of analysis, the hypothetical accident thermal conditions are specified by the surface heat flux values. Peak regulatory heat fluxes for low surface temperatures typically range from 55 to 65 kW/m^2. Convective heat transfer from air is estimated from convective heat transfer correlations, and contributes of 15 to 20 % of the total heat flux. The value of 15 to 20 % value is consistent with experimental estimates. Recent versions of the regulations specify moving, hot air for convection calculations, and an appropriate forced convection correlation shall be used in place of the older practice that assumed still air convection. A further discussion of heat flux values is provided in 7.2.

6.6 While 10CFR71 or SSR-6 values represent typical package average heat fluxes in pool fires, large variations in heat flux depending on both time and location have been observed in actual pool fires. Local heat fluxes as high as 150 kW/m^2 under low wind conditions are routinely observed for low package surface temperatures. For high winds, heat fluxes as high as 400 kW/m^2 are observed locally. Local flux values are a function of several parameters, including height above the pool. Thus the size, shape, and construction of the package affects local heat flux conditions. Designers shall keep the possible differences between the hypothetical accident and actual test conditions in mind during the design and testing process. These differences explain some unpleasant surprises such as localized high seal or cargo temperatures that have occurred during the testing process.

6.7 For proper testing, good simulations of both the regulatory hydrocarbon fire heat flux transient and resulting material temperatures shall be achieved. Unless both the heat flux and material surface temperature transients are simultaneously reproduced, then the thermal stresses resulting from material temperature gradients and the final container temperature are reported to be erroneously high or low. Some test methods are better suited to meeting these required transient conditions for a particular package than others. The relative benefits and limitations of the various methods in simulating the pool fire environment are discussed in the following sections.

7. Procedure

7.1 *Qualification by Analysis*

7.1.1 *Benefits, Limitations:*

7.1.1.1 The objective of thermal qualification of radioactive material transportation packages by analysis is to ensure that containment of the contents, shielding of radiation from the contents, and the sub-criticality of the contents is maintained per the regulations. The analysis determines the thermal behavior in response to the thermal conditions specified in the regulations for normal conditions of transport and for hypothetical accident conditions by calculating the maximum temperatures and temperature gradients for the various components of the package being qualified. Refer to Appendix X3 for specific requirements of the regulations.

7.1.1.2 Temperatures that are typically determined by analysis are package surface temperatures and the temperature distribution throughout the package during normal conditions of transport and during thermal accident conditions. In addition, maximum pressure inside the package is determined for both normal and accident conditions.

7.1.1.3 While an analysis cannot fully take place of an actual test, performing the thermal analysis on a radioactive material transportation package allows the applicant to estimate, with relatively high accuracy, the anticipated thermal behavior of the package during both normal and accident conditions without actually exposing a package to the extreme conditions of the thermal qualification tests described in Section 6. Qualification by analysis is also a necessity in those cases where only a design is being qualified and an actual specimen for a radioactive materials package does not exist.

7.1.1.4 While today's thermal codes provide a useful tool to perform the thermal qualification by analysis producing reliable results, the limitation of any method lies in the experience of the user, the completeness of the model and accuracy of the input data. Since in these analyses the heat transfer is the main phenomenon being modeled and since it is mostly nonlinear, the thermal code used shall be verified against available data or benchmarked against other codes that have been verified. In addition, limitations of analyses for determining the thermal behavior of a package include as-built package geometry, real material properties including phase changes and destruction of insulation, and real fire characteristics, including actual convection. Code software used shall be managed in a manner consistent with the appropriate QA methodology outlined in NQA-1 or ISO 9000 as appropriate.

7.1.2 *Model Preparation*—This section describes the various aspects a thermal model shall include and the methodology of preparing a representative model.

7.1.2.1 A common approach to analyzing a package is to model the package as a drum or in a cylindrical configuration. This approach considers the package as an axisymmetric circular cylinder (outer shell) with a constant internal heat source. Another common approach is to model the packages as a finite length right circular cylinder with an impact limiter (which also acts as a thermal insulator to the package). The outer shell will surround a cylindrical structure that contains the content heat source.

7.1.2.2 Thermal protection of a typical radioactive materials package includes the impact limiters placed at the ends of the package and the thermal shield surrounding the cylindrical section of the package. The impact limiters consist of a low-density material, such as polyurethane foam, wood, or other organic material enclosed in a steel shell, hollow steel structures or aluminum honeycomb design structure. The low-density configuration impact limiter usually has a low effective thermal conductivity.

7.1.2.3 The low thermal conductivity impact limiter reduces the heat transfer from the ends of the cask during normal conditions of transport, and into the ends of the cask during hypothetical accident conditions. Analysis often shows that for polyurethane foam impact limiters, the foam burns during a hypothetical accident and off-gases creating pressure within the impact limiter structure. This, along with the thermal expansion of the materials is to be considered in order to provide for the worst case conduction/insulating properties. Credit for the insulating properties of the impact limiters shall be taken only when structural analyses can demonstrate that the limiter remains in place under hypothetical accident conditions.

7.1.2.4 The thermal shield of radioactive waste and spent fuel packages typically is a stainless steel shell surrounding the cylindrical structural shell of the package. A gap is created between the thermal shield and the structural shell of the package. Because of the low conductivity of air contained in the gap, the heat resistance of the gap greatly reduces the heat transfer rate during both normal conditions of transport and hypothetical accident conditions. Heat transfer across the gap between the thermal shield and structural shell is modeled with conduction and radiation. Natural convection in the gap is usually neglected. Drum type packages usually have an integral thermal shield.

7.1.2.5 The package contents and their heat generation shall be considered in the model preparation. The impact limiter and the thermal shield insulation properties will result in slightly elevated temperatures during normal conditions of transport due to the resistance to heat flow from the package. Thus the package interior has higher temperatures than the surrounding ambient temperature.

7.1.2.6 When creating the model and selecting the nodes, it is important to represent all materials of construction and components essential to containment in the model. Fig. 1 shows a typical nodal network/finite difference model with node selection for temperature information on a package with an impact limiter. Additional nodes will need to be created and utilized for an accurate Finite Element Analysis or Finite Difference Analysis model.

7.1.2.7 The mesh selected in the model for temperature profile analysis in the thermal portion of the hypothetical accident analysis shall be varied depending on the temperature gradients. The finest mesh is located near the outer surface of the package where the steepest temperature gradients occur. The mesh size is increased as temperature gradients decrease, which usually occurs as the distance from the surface increases. A test for proper mesh size is to refine the mesh further and demonstrate that no significant change in calculated temperatures results from the refinement.

7.1.2.8 *Thermo-physical Properties of Typical Materials:*

(1) The thermal properties of the materials of construction need to be defined and documented as they are critical to achieving meaningful results from the analysis. Properties of the various components involved are often obtained from reference materials but all sources are to be verified for reliability by determining that the properties were measured in accordance with accepted standards (that is, ASTM) and under an accepted quality assurance program (that is, NQA-1 or ISO 9000).

(2) The material properties used need to cover the temperature range of the conditions being analyzed. If materials have properties that change with temperature, they shall be modeled with the appropriate variable properties. Note that uncertainties in the temperature dependence of material property data increase with the variation of temperature from "room temperature." Additional testing is necessary for any material that does not have well defined material properties.

(3) Parts that are small or thin, or both, and do not have a measurable affect on the overall heat transfer rates are often omitted from the model. Typical examples for this are thin parts that have high thermal conductivity and are not separated by air gaps from other components of the package being analyzed. Thin parts separated by gaps, however, act as thermal radiation shields that greatly affect the overall heat transfer rate and shall be considered.

(4) When a material phase change or decomposition is expected to occur, the analysis shall consider replacing the material properties with conservative values. For example, polyurethane begins to decompose at 200 °C (400 °F), and the