SRNS-STI-2010-00151

Proceedings of PVP2010
2010 ASME Pressure Vessel and Piping Division Conference
July 18-22, 2010, Bellevue, WA, USA
PVP2010-25337

DEVELOPMENT OF BURN TEST SPECIFICATIONS FOR FIRE PROTECTION MATERIALS IN RAM PACKAGES

Narendra K. Gupta
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 5300, nick.gupta@srnl.doe.gov

Paul S. Blanton
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 3738, paul.blanton@srnl.doe.gov

Allen C. Smith
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 2943, allen.smith@srnl.doe.gov

ABSTRACT

The regulations in 10 CFR 71 require that the radioactive material (RAM) packages must be able to withstand specific fire conditions given in 10 CFR 71.73 during Hypothetical Accident Conditions (HAC). This requirement is normally satisfied by extensive testing of full scale test specimens under required test conditions. Since fire test planning and execution is expensive and only provides a single snapshot into a package performance, every effort is made to minimize testing and supplement tests with results from computational thermal models. However, the accuracy of such thermal models depends heavily on the thermal properties of the fire insulating materials that are rarely available at the regulatory fire temperatures. To the best of authors' knowledge no test standards exist that could be used to test the insulating materials and derive their thermal properties for the RAM package design. This paper presents a review of the existing industry fire testing standards and proposes testing methods that could serve as a standardized specification for testing fire insulating materials for use in RAM packages.

BACKGROUND

Both numerical and closed form analyses of RAM packagings require thermal property information for the materials employed. In addition to the usual thermal property information (thermal conductivity and specific heat), the response of the materials to fire exposure is essential to predict the material performance under the regulatory Hypothetical Accident Condition Fire Test. Average thermal properties and models adjusted to account for decomposition have successfully been employed in analyses of various packagings. More refined solutions, applicable for extended exposure analyses require more detailed information on the material's behavior. The analyst needs information on the variation of properties with temperature and how the properties change as the material undergoes thermal decomposition. The decomposition process (as applicable) and intermediate forms of material must also be characterized.

TYPICAL CONTENTS OF TEST STANDARDS

Materials testing standards follow a consistent format that lists the essential topics which must be addressed by the standard. For the evaluation of thermal performance of materials standard proposed here, the applicable topics are:

Scope

Describes the purpose and applicability of the standard

Terminology

Lists definitions of terms and symbols. Key equations may also be included.

Summary Test Method

Describes the method of testing.
(The section describes how a property or characteristic is tested and response evaluated.)
Outlines the testing concept.

Significance and Use

Identifies the application of the results obtained from the test performed under the standard.

Apparatus

The apparatuses employed for the tests are described in sufficient detail that results of testing will be consistent and are reproducible by independent investigators.

Hazards

Hazards associated with testing of thermal insulating materials, such as hot surfaces, combustible and poisonous gaseous products, persistent stored heat and need for fire protection system should be noted here.

Sampling

How many specimens must be tested
How are specimens obtained (fabricated as specimens or cut from sample package?)

Specimen Preparation

What is the configuration of specimens when tested?
Size (length, width, and thickness), sample holder, insulation wrapping , etc. and any conditioning required.

Calibration and Standardization

Standard M&TE QA for temperature measurement apparatus and other test apparatus.

Procedure

Outlines the essential steps of the test procedure.

Interpretation of Results

Defines application of the results obtained from the tests. (in this case, Results are input for analytical models.)

Other guidance on meaning of data

Report

Formal test report prepared

Precision and Bias

Applicable to instrumentation employed

Of these, terminology, calibration, required report, and precision and bias are typical of all testing standards, and do not need to be addressed in this proposal.

ESSENTIAL ELEMENTS

The essential topics specific to thermal testing of materials for RAM packaging, are:

Scope
Significance & Interpretation of Results
Method
Apparatus
Specimens/sampling
Procedure
Hazards

Scope

Testing method proposed here measures and describes thermal response of materials, products and assemblies (such as laminated insulation), used for thermal protection of radioactive materials packagings, in response to HAC fire test heat input, under controlled laboratory conditions.

Note: Tests for thermal conductivity[3] and specific heat[4], are performed using standard methods and are not part of this standard. Similarly, analysis of any gaseous decomposition products would be by standard methods and not addressed here.[5]

Significance and interpretation of results

The data obtained from these tests of overpack materials for radioactive materials packages are essential to developing accurate analytical models of the thermal performance of the packages. The data will be used for predicting the response of the packages during fire events such as the regulatory HAC thermal test and evaluation of the response to challenges beyond the regulatory tests. The data will be used to develop models of the behavior of the material for use in these analyses.

Method

The test proposed here subjects the subject material to the radiation heat transfer at HAC fire temperature for 30 minutes with no extinguishing of specimen following the exposure. As such, it parallels requirement for the regulatory HAC fire event.

(Special case for air transport and storage applications would extend time to 60 minutes and 90 minutes.). Data consists of characterization of material loss or decomposition for 1-D specimen in terms of recession of decomposition front from original dimension, measurement of temperature distribution in specimen during test, and weight loss as a result of decomposition.

The thermal insulating material in radioactive materials packagings is typically contained within a shell that retains the material and protects if from wear and weathering. The shell restricts air flow to the insulation material, which affects decomposition of the insulating materials. In order to

investigate the response of the material to the fire event, the test method may be required to expose specimens directly to the heat source and specimens enclosed within a shell.

The objective is 1-Dimensional heat transfer in the test specimen. For this reason, the sides of the specimen will be insulated and the specimen support structure will be insulated. The specimen size should be as large as can be practically burned in a test facility. The specimens sizes suggested here have been used by vendors and testing labs. The exposed specimen will be 30 cm by 30 cm for the exposed face, and 15 cm thick. The canned specimens will be canned within a 603 by 700 (#10) food pack can (OD 6.03" x 7.0" long), vented at the exposed end and insulated on the cylindrical sides.

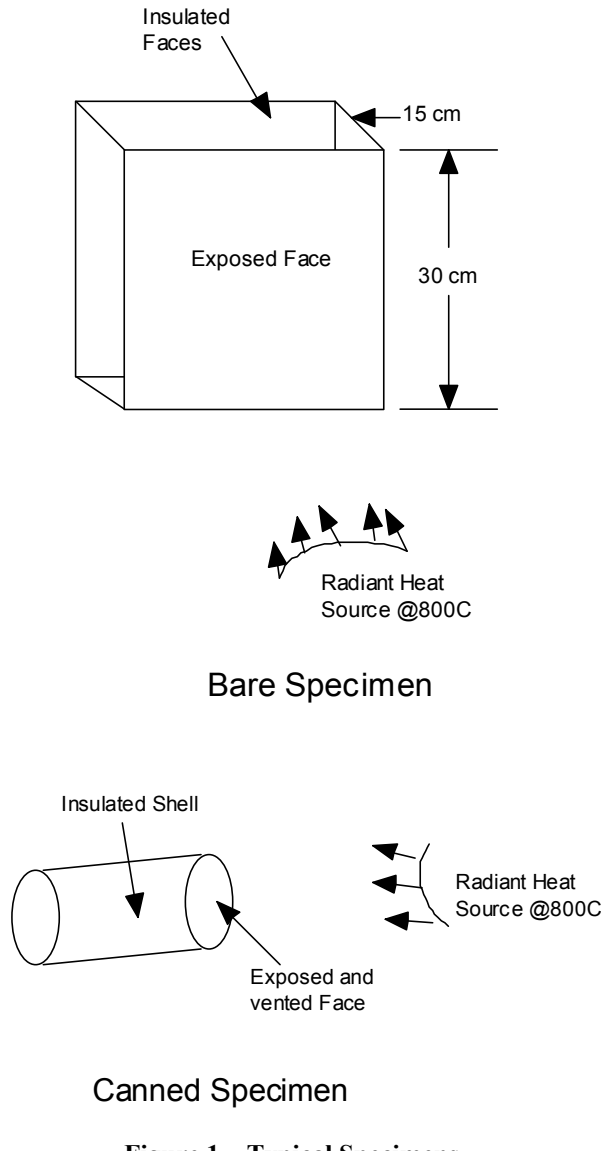

Figure 1 – Typical Specimens

Data / Evaluation – Interpretation of Results

The test results will consist of gross and sectional weight loss, depth of degradation and temperature time history for thermocouples imbedded in the material being tested. For purposes of evaluation, the specimen will be divided into regions 2 cm thick, with the thermocouples installed at the mid point of each region, along the centerline of the specimen. In this arrangement, the thermocouple closest to the exposed face will be 1 cm from the face. Characterization of material will include determination of any regions of discoloration or apparent degradation.

The results will provide direct information for determining required thickness of insulation for a packaging and will provide guidance for developing and benchmarking constitutive models of materials properties for use in analytical (numerical) models of thermal tests of packagings.

Apparatus

Standard Heat Input. Thermal properties testing for packaging materials requires a standard heat source. To be consistent with the requirements of the regulatory and guidance documents [1, 2], the heat source must be a radiation heat source, maintained at 800ºC. An electric or gas-fired furnace, controlled to the regulatory temperature would meet these requirements and be easy to control. The furnace must be vented because most materials will out gas when heated and while undergoing thermal decomposition. Accordingly, its heating capacity must be sufficiently large that it can maintain wall temperature under the vented condition. The furnace is required to maintain, or quickly recover temperature when the test article is introduced into the enclosure. A furnace with swing-away door is envisioned. The door will swing clear of the test article, which is then moved into position and becomes one wall of the furnace enclosure. Furnace size may be a factor depending upon the specimen size. The minimum furnace size would be a cube with side dimensions the same as the specimen side length (i.e., 20 cm.).

Specimen Holder. A consistent (standard) way of holding the specimen is required. Separate configurations are needed for the two specimen configurations.

The specimen holder encloses and Supports specimen over its entire length for the duration of the test. The specimen holder must enclose the specimen, so that as the specimen undergoes thermal decomposition (i.e., as the exposed face recedes) the specimen holder prevents any opening between the un-degraded part of the specimen and the specimen holder. The end of the specimen opposite heat source is exposed to ambient air at 20±2ºC. The specimen holder must allow for insulation on the sides of the specimen.

A bulkhead will be provided to hold the cylindrical, enclosed specimen in the specimen holder. The bulkhead will consist of a square metal plate, conforming to the specimen holder, with a 157 mm diameter hole for the enclosed specimen. The enclosed specimen will be held with the top extending 25 mm beyond the bulkhead into the furnace enclosure The outside of the bulkhead will be insulated with a minimum of 2 cm of fiberglass or ceramic fiber insulation to minimize heat loss. The portion of the specimen can extending beyond the bulkhead insulation will be left un-insulated (i.e., exposed to ambient air at 20±2ºC). Provision will be made to clamp the canned specimen to the bulkhead in the position specified.

The furnace vents will be incorporated into the specimen holder, at the bottom and at the top.

Specimens/Sampling

Specimens may be made from stock, or otherwise fabricated for tests or may be cut from sample packages. The source must be noted as part of the data record for the test. Two types of specimens shall be tested for each material, exposed and enclosed. A minimum of ten specimens of each type must be tested.

Specimen Configuration

In order to address the conditions under which materials are employed in radioactive materials packagings, two configurations of specimen must be tested, exposed, and enclosed.

The "exposed" specimen will be 30 cm square and a minimum of 15 cm long. The square face will be exposed to the radiant heat source, with the opposite end exposed to ambient air. The sides shall be insulated with a 6 mm thickness or more of tightly wrapped fiberglass or ceramic fiber cloth or mat for the sides to remain adiabatic. The specimen will be located in the specimen holder so that it is initially in the same plane as that occupied by the face of the door ±3 mm. The specimen shall be sufficiently long that at the end of the test a minimum of 2.5 cm of undegraded material remains.

The enclosed specimen will be cylindrical, 153 mm in diameter and 175 mm long, and wrapped with 1.5 mm thick fiberglass or ceramic fiber cloth. The ends of the specimen will not be covered. The wrapped specimen will be sealed within a 603 by 700 food can, having two, 13 mm holes on the side, immediately adjacent to the rolled seam at one end (the heated end) located 180º apart. The canned specimen will be located in the specimen holder so that the vent holes are aligned with the vents.

For testing of crushed or broken samples, adhesive paper may be applied to the unheated face, to stabilize the specimen.

Procedure

The test will be conducted by exposing the specimen to the heat source for the duration of the test, then removing the specimen from the heat source and allowing it to cool without any mechanical assistance. The basic steps in the procedure are:

- Preheat furnace with alternate door in place
  (The furnace must be thoroughly preheated. For a small, 30 cm square furnace, a 4 hr preheat period should be employed.)
- To start test, open the furnace door, and place the specimen in position.
  (In this position, the face of the specimen forms one wall of the furnace enclosure.)
- The duration of the Test is 30 minutes after the furnace temperature is stabilized after the introduction of the sample.
  (The test duration will be longer for air transport and storage cases)
- At the end of the test period, remove the specimen from the furnace and turn the heated surface so that it does not receive heat input from the furnace.
  (The furnace door should be replaced to minimize heat transfer from the furnace to the specimen or specimen environment. A thermal radiation shield between the furnace and the specimen may be required.)
- The specimen is allowed to cool to ambient temperature without assisting cooldown or extinguishing any flames.
- After cooldown, the weight and dimensions of the specimen will be recorded.

Some foam materials may intumesce during the testing. The intumesced decomposition product may escape by way of the furnace vents. The flow of such material should not be obstructed.

Hazards

The solid and gaseous decomposition products are likely to be flammable and may burn as they exit from the furnace vents. For this reason, the test must be conducted in a facility which can tolerate these open flames. Potential safety hazards during fire experiments should be carefully studied to be evaluate fire hazards for a specific facility.[6]

The furnace surfaces will be hot and the surfaces of the specimen, especially during the cooldown phase, will be extremely hot. These components must be behind an isolation barricade and clearly marked as HOT.

RECOMMENDATION

A packaging materials thermal testing standard is needed and it is recommended that it be developed. The outline

provided here is believed to address the essential elements of such a standard.

It is recognized that there are limits to interpretation of results from testing to any standard. Accordingly, notification of limitations should be included in the standard, such as:
"the standard should not be used as the sole basis to describe or appraise the thermal performance of materials incorporated into packagings under actual exposure conditions. Also, the Standard does not purport to address all safety concerns, if any, associated with its use. It is the responsibility of the user of the standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use."

Finally, because some testing may require use of samples taken from actual packages, a small specimen case using 4 in sq samples and 4 in cans may be needed. Results from such small sample testing will need to be benchmarked against the full size sample performance.

CONTRACT NUMBER

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

DISCLAIMER

REFERENCES

1. Title 10, United States Code of Federal Regulations, Part 71, Packaging and Transportation of Radioactive Material (10 CFR 71), 2005.

2. IAEA Regulations for Safe Transport of Radioactive Materials, TS-R-1, International Atomic Energy Agency, 2005.

3. ASTM C518-04 Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

4. ASTM Standard C 351-82, Standard Test Method for Mean Specific Heat of Thermal Insulation, 1982.

5. ASTM Standard E800, Guide for Measurement of Gases Present or Generated during Fires.

6. Example of fire test standards

- ASTM E176-09a Standard Terminology for Fire Standards
- ASTM D3675 Test Method for Surface Flammability of Flexible Cellular Materials using Radiant Heat Energy Source
- ASTM E136 Test Method for Behavior of Materials in Vertical Tube Furnace at 750°C
- E603 – Guide for Room Fire Experiments
- ISO13943 – Fire Safety-Vocabulary