

Normal Condition on Transport Thermal Analysis and Testing of a Type B Drum Package (U)

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NORMAL CONDITIONS OF TRANSPORT THERMAL ANALYSIS AND TESTING OF A TYPE B DRUM PACKAGE

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ABSTRACT

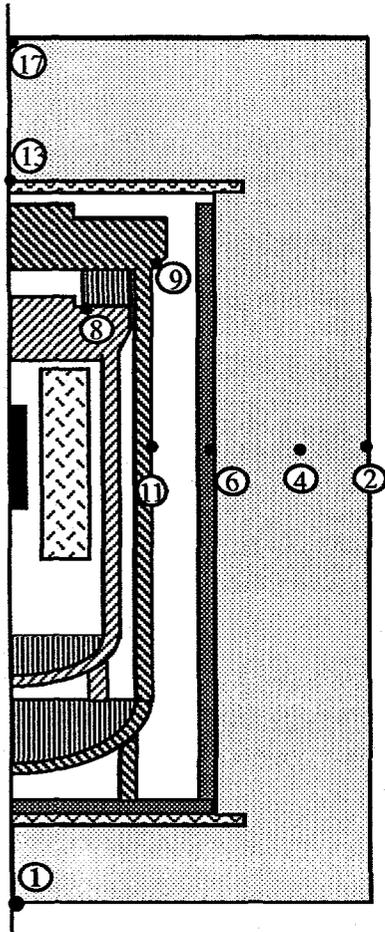
Increasing the content limits of radioactive material packagings can save money and increase transportation safety by decreasing the total number of shipments required to transport large quantities of material. The contents of drum packages can be limited by unacceptable containment vessel pressures and temperatures due to the thermal properties of the insulation. The purpose of this work is to understand and predict the effects of insulation properties on containment system performance.

The type B shipping container used in the study is a double containment stainless steel drum package with fiberboard insulation. The package is primarily used to transport uranium and plutonium metals and oxides. A normal condition of transport (NCT) thermal test was performed to benchmark an NCT analysis of the package. A 21 W heater was placed in an instrumented package to simulate the maximum source decay heat. The package reached thermal equilibrium 120 hours after the heater was turned on. Testing took place indoors to minimize ambient temperature fluctuations. The thermal analysis of the package used fiberboard properties reported in the literature and resulted in temperature significantly

greater than those measured during the test. Details of the NCT test will be described and transient temperatures at key thermocouple locations within the package will be presented. Analytical results using nominal fiberboard properties will be presented. Explanations of the results and the attempt to benchmark the analysis will be presented. The discovery that fiberboard has an anisotropic thermal conductivity and its effect on thermal performance will also be discussed.

I. INTRODUCTION

The 9975 shipping package is representative of Type B packagings developed at Savannah River Site (SRS). Major package components include the primary containment vessel (PCV), secondary containment vessel (SCV), lead shield, cane fiberboard insulation, and drum. Two bearing plates support the containment vessels. Energy absorbers are positioned within the PCV and SCV. The PCV, SCV, and 35-gallon drum are stainless steel. The bearing plates and energy absorbers are aluminum. The fiberboard is made from sugar cane fibers bonded together with organic glue. The package has an overall height of 34 inches and diameter of 18 inches. The packaging components are shown in Figure 1.



Thermocouple Locations	
No.	Location
1	Drum bottom
2	Drum side
4	Fiberboard mid-wall
6	Lead side
8	PCV lid
9	SCV seal
11	SCV side
13	Upper bearing plate
17	Drum lid

Materials	
	Heater
	Fiberboard
	Bearing plate
	Lead shield
	SCV
	PCV
	Energy absorber
	Mock mass
	Air gap

Figure 1: Axisymmetric 9975 Test Package Model

The radioactive package contents may take the form of a powder or solid. The source is enclosed within multiple cans and bags and occupies all or part of the available vessel volume. Similar Type B packages have previously been certified for shipping uranium and plutonium sources which generate up to 30 watts.

Certified packages must meet numerous thermal requirements as specified in 10 CFR 71 for Normal Conditions of Transport (NCT). Initial conditions include an ambient temperature of 100°F and heat loss by radiation and natural convection. The maximum temperatures attained by the containment vessel seals and fiberboard, and the maximum containment vessel pressures must be shown to remain within allowable limits.

Demonstrating that the 9975 package complies with 10 CFR 71 for NCT can be efficiently accomplished by computer modeling. A model of the 9975 package has been developed and an NCT thermal test performed to benchmark the computer model. Comparison of the test data and model predictions provided the opportunity to investigate characteristics of fiberboard, such as the directional dependence of thermal conductivity.

II. PREVIOUS WORK

Lewallen [1] in 1972 discusses the thermal limits of fiberboard for use in shipping radioactive materials. Lewallen concludes that the maximum fiberboard temperature must not exceed 250° F during NCT. Above 250° F fiberboard experiences structural degradation. Lewallen plotted the maximum normal insulation temperature as a function of content wattage for a range of insulation thicknesses. The plot apparently uses the fiberboard thermal conductivity of 0.031 Btu/hr-ft-°F provided by the manufacturer.

A thermal test with fiberboard insulation was completed by Cadelli in 1982[2]. Four blocks of insulation were heated

from 200° F to 350° F and measurements made to determine the change in weight and thickness. Qualitative analysis of fiberboard condition was recorded at every 25° F increment in temperature. Cadelli concluded that the fiberboard can withstand uniform temperatures up to 300° F without degradation. Cadelli also references the thermal conductivity provided by the manufacturer of 0.031 Btu/hr-ft-°F.

In 1988 Sanchez et. al [3] measured the thermal conductivity, specific heat, and density of fiberboard. Data were obtained for temperatures between of 77° F and 532° F. The report notes that measurements were complicated by shrinking of the sample thickness as the temperature increased and charring occurred. Fiberboard degradation is found to commence at around 250° F. Sanchez reports temperature dependent thermal properties of fiberboard as shown in Table 1.

Temperature (°F)	Thermal Conductivity (Btu-hr-ft-°F)	Density (lb _m /ft ³)	Specific Heat (Btu/lb _m)
77	0.031	16.86	0.306
187	0.034	17.36	0.360
295	0.036	17.86	0.417
439	0.038	18.54	0.489
532	0.029	19.54	0.493

Table 1 : Fiberboard Thermal Properties

III. THERMAL TESTING

The 9975 package was tested in the radiant heat facility at Sandia National Laboratory. The package tested included the PCV, SCV, bottom and side lead shield, upper and lower bearing plates, and energy absorbers.

The unit tested was similar to the package shown in Figure 1 with minor differences. The tested package includes an air shield on the upper fiberboard to prevent air from igniting the fiberboard following the fire test, which is performed after the NCT test. Also, the

unit tested had a small air space between the top of the fiberboard and drum lid. Neither of these differences are expected to have a significant effect on the temperature comparisons between the test and the model.

The 9975 package included a steel (mock content) mass and an electric heater to simulate a nominal 21 W heat source (Figure 1). The mock content and heater were secured with set screws and did not contact the PCV. Eighteen thermocouples were distributed throughout the package, of which six were located 180° apart from other thermocouples at the same height and radius. Containment boundaries were breached where necessary, as no post-test pressure testing was planned. The NCT thermal test was not preceded by any other hypothetical accident condition test.

The 9975 package was located in a building maintained at a constant ambient temperature (average 75.5° F). A shroud provided surroundings with black-body radiant properties. The package was oriented in an upright position and raised off of the ground to expose the bottom drum surface to air flow.

Heater power was maintained at approximately 22W, slightly in excess of the design 21W. Heater power was terminated at 120 hours, when package temperatures had nearly reached steady state as based on observation and preliminary analysis. The test performed as intended and provided temperatures at the 18 thermocouple locations.

IV. THERMAL ANALYSIS

An axisymmetric finite element model was developed for the 9975 shipping package configured for the thermal test. The model included the primary package components, heater, and mock mass (Figure 1). Also shown in Figure 1 are the nine thermocouple locations at which model temperatures were compared with

the test package temperatures. Since the air shield was not included in the model the three thermocouples for the air shield are not shown in the figure. Also, six thermocouples located 180° apart from one another are shown at the same location.

Heat generated inside the PCV is conducted through all package materials and is transported by both conduction and radiation across the internal air gaps to the environment. The heater was modeled as having a total volumetric heat source equal to the heater wattage. Heat loss to the environment occurs by natural convection and radiation from all drum surfaces. Both the heater power and the ambient temperature were set to match the test data every 12 hours and were interpolated at times in-between. Table 2 shows the surface emissivities[4] and Table 3 shows the convection correlations used in the heat transfer analysis[4], where T_s is the drum surface temperature and T_∞ is the ambient temperature.

Component	Emissivity
Heater	0.05
Mock Mass	0.6
PCV, SCV	0.6
Bearing plates	0.2
Energy absorbers	0.2
Lead shield	0.28
Drum wall	0.21

Table 2: Component Emissivities

Drum Surface	Coefficient
Top	$0.22(T_s - T_\infty)^{1/3}$
Side	$0.19(T_s - T_\infty)^{1/3}$
Bottom	$0.11(T_s - T_\infty)^{1/4}$

Table 3 : Natural Convection Coefficients

Temperatures were computed by P3/Thermal™[5], a commercially available heat transfer software package. View factors among elements surfaces were computed by P3/Viewfactor™, a

module of P/Thermal™. Both 120-hour transient and steady-state temperatures were computed for the 9975 package model.

Thermal properties required for the model were thermal conductivity, specific heat, and density. Thermal properties for all package components, except the fiberboard, are well known and available within the P/Thermal™ material library.

Previous investigations of the fiberboard thermal properties make no mention of possible anisotropy. The manufacture's value of 0.031 Btu/hr-ft-°F applies to heat transmission perpendicular to the plane of the fiberboard, as this direction determines the fiberboard's R-value. Type B packagings typically use stacked one-half inch thick fiberboard disks glued together. In a upright drum package, then, the axial direction is perpendicular to the plane of the fiberboard (out-of-plane), and the radial direction is parallel to the plane of the fiberboard (in plane).

It was thought that fiberboard, like wood, would have a higher conductivity parallel (in-plane) to fiber orientation than perpendicular (out-of-plane) to fiber orientation. Therefore, any analysis to determine the heat transfer through the side of the drum using the out-of-plane conductivity value may not provide accurate temperature predictions.

SRS contracted with an independent laboratory to determine the conductivity for an in-plane sample of fiberboard. A 1' x 1' x 2" thick specimen was fabricated from 25 one-half inch thick sheathing grade cane fiberboard pieces. The pieces were glued and clamped. An in-plane conductivity of 0.0723 Btu/hr-ft-°F was measured for the sample. This is more than twice the out-of-plane value commonly used in performing NCT thermal analysis. Recently, a new series of tests were conducted with similar results.

Two separate analyses were completed for the 9975 package model. The only parameter varied between the analyses was the fiberboard thermal conductivity. The first analyses uses an isotropic fiberboard thermal conductivity as shown in Table 1. The second analyses considers an anisotropic fiberboard thermal conductivity where the values of the out-of-plane conductivity are found in Table 1 and 0.0723 Btu/hr-ft-°F is the in-plane conductivity.

V. DISCUSSION OF RESULTS

Temperatures from the 9975 test package and computer model are compared in Table 3 at the nine thermocouple locations at 120 hours. Table 3 shows the thermocouple channel number, location, and the temperature results. Temperatures are given for the test and for the computer model using both an isotropic and anisotropic fiberboard thermal conductivity. The temperature differences between the model temperatures and test temperatures are shown in parentheses (test temperatures subtracted from model temperatures). Figure 2 plots the temperature as a function of time at the SCV seal for the test package, isotropic model, and anisotropic model. The SCV seal is selected as a representative point within the package.

No.	Location	Temperatures (°F)		
		Test	Isotropic Model	Anisotropic Model
1	Drum bottom	85	94 (9)	87 (2)
2	Drum side	88	88 (0)	88 (0)
4	Fiberboard mid-wall	107	123 (16)	106 (-1)
6	Lead side	134	174 (40)	133 (-1)
8	PCV lid	168	201 (33)	163 (-5)
9	SCV seal	149	197 (48)	159 (10)
11	SCV side	149	192 (43)	153 (4)
13	Upper bearing plate	122	140 (18)	112 (-10)
17	Drum lid	86	87 (1)	84 (-2)

Table 3 : Test vs. Model Temperatures

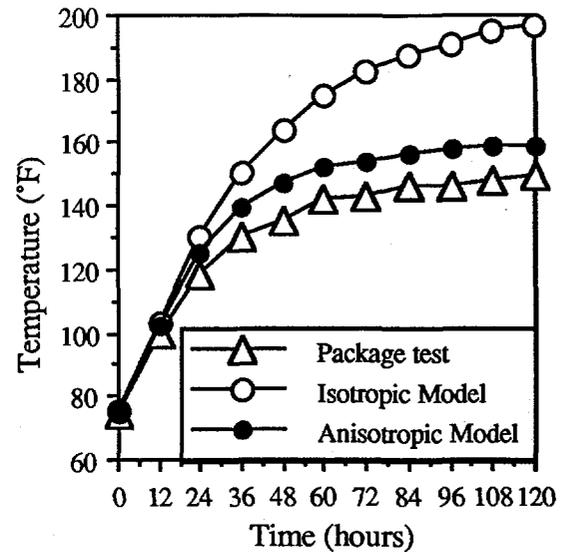


Figure 2: Temperature vs. Time for Package Test, Isotropic Model, and Anisotropic Model

The test results compare well with the isotropic model results at the outside of the drum; particularly at the drum side and drum lid where the temperatures match exactly. Matching the drum boundary temperature indicates that the environment (natural convection, radiation, and ambient temperature) and internal heat generation are correctly modeled. Temperature differences between the test and isotropic model increase with decreasing distance to the package centerline. The model consistently over predicts the measured test temperatures by a significant amount. The differences are particularly notable for the in-plane temperature gradient across the fiberboard from the drum side to the lead shield. The test and model differences increase from zero at the drum wall to 16° F at thermocouple no. 4 (fiberboard mid-wall) and 40° F at thermocouple no. 6 (lead side). Temperature differences at or near the containment vessels range from 18° F at the bearing plate to 48° F at the SCV seal. Over predicting the containment vessel temperatures by this amount would severely limits contents and vessel performance.

The anisotropic model results agreed more closely with test results. Test results compare well with anisotropic model results at the outside of the drum. Furthermore, the temperature differences between the test and anisotropic model are significantly less than the differences between the test and isotropic model. At thermocouples no. 4 (fiberboard mid-wall) and 6 (lead side) the model under predicts the test temperature by 1° F. Model temperature predictions at or near the containment vessels range from under prediction of 10° F at the upper bearing plate to over prediction of 10° F at the SCV seal. This discrepancy can be attributed to an air gap in the model.

Several discrepancies between the test package and models contribute to the difference between temperatures measured and temperatures predicted. First, the shortened fiberboard cavity caused the lead sleeve to contact the upper bearing plate, providing a conduction path. It is likely that an air gap existed between the SCV and upper bearing plate, but the gap width is not known. Additionally, the energy absorbers do not necessarily make ideal contact for conduction as they are modeled. These factors all contribute to the temperature differences seen at the seal areas of the containment vessels.

At the completion of the 120 hour transient, steady-state temperatures were compared with the final transient temperatures. The largest difference between temperatures at the thermocouple locations was 4° F and occurred at the SCV seal and PCV lid. The four degree temperature difference indicates that the steady-state temperature distribution had essentially been obtained after 120 hours of heating.

VI. CONCLUSIONS

Computer model temperature predictions have been benchmarked against a 9975 package NCT test. The internal test temperatures are significantly greater

than those predicted by the computer model using the isotropic fiberboard conductivity, but compare reasonably well with the computer model using the anisotropic fiberboard conductivity. These results support the use of the anisotropic material model for fiberboard, where the in-plane conductivity is twice the out-of-plane conductivity.

Thermal analyses of packages which use the values from Table 1 as an isotropic conductivity for the cane fiberboard will predict higher package temperatures than are actually encountered. Although safety is not impacted from analyses that predict conservatively high temperatures, package contents may be unnecessarily limited to avoid exceeding package temperature limits. Further investigations into the performance of cane fiberboard for both NCT and HAC is currently being performed at SRS.

VII. ACKNOWLEDGMENTS

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