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Thermal-Fluids Analyses of Model 9977 and 9975 Shipping Packages Under Normal and Hazard Analysis Conditions

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ABSTRACT

The Model 9975 and Model 9977 Shipping Packages have been designed as replacements for the Department of Transportation (DOT) Fission Specification 6M package. Each shipping package consists of a 6-inch diameter Containment Vessel (6CV), a drum overpack filled with foam insulation, and a lid that also has several layers of insulation. While originally designed to ship Heat Source and RTG contents, the 9975 and 9977 shipping packages have been reanalyzed to significantly expand their Contents in support of additional Department of Energy (DOE) missions. The design and analysis details of the 9975 and 9977 packages are given in the Safety Analysis Report for Package (SARP).

The Model 9977 Shipping Package is evaluated to determine the decay heat wattage that can be placed inside of two 2-quart SAVY containers held inside the package containment vessel while remaining under the thermal limits set in the 9977 SARP. These analyses determine the temperatures of components of interest during normal conditions of transport (NCT) and hypothetical accident conditions (HAC). Additionally, the Model 9975 Shipping Package is evaluated to determine the maximum O-ring temperatures under HAC using 20-year and 30-year degraded fiberboard insulation material properties.

INTRODUCTION

The Model 9977 package has been designed as a replacement for the Department of Transportation (DOT) Fissile Specification 6M package. The 9977 package consists of a 6-inch diameter Containment Vessel (6CV), a drum overpack filled with foam, and a lid that has several layers of insulation [1]. Previous analyses of the 9977 shipping package have been conducted for wattage variations and storage array conditions [2,3]. The purpose of this study was to determine the maximum allowable content wattage in each of two 2-quart sized SAVY containers inside the 6CV. The analysis will evaluate both Normal Conditions of Transport (NCT) and a Hypothetical Accident Condition (HAC) of a 30-minute fully engulfing fire.

The 9975 shipping package is used to store plutonium bearing materials packaged in a DOE-STD-3013 container. The 9975 shipping package consists of a 35 gallon drum, a primary containment vessel (PCV), a secondary containment vessel (SCV), lead shielding, and fiberboard thermal insulation and has been previously analyzed for sensitivity to material variations [4]. For the K-Area Complex (KAC) at the Savannah River Site, the 9975 package is used as a storage container and has therefore been analyzed for facility accident conditions [5,6]. Recent structural and thermal accident analyses have shown that a 9975 with a 3013 container maintains containment for up to 20 years for both the 3013 container and at least one of the two 9975 containment vessels [7]. This study further evaluates the used of the 9975 package beyond 20 years.

Figure 1 is a schematic of the 9977 (left) and 9975 (right) packages. The 9977 package is shown to contain two SAVY containers. The contents will be placed within the 6CV, which is closed with a cone seal plug having a set of double O-rings and a cone seal nut. The CV is loaded into a cylindrical drum liner and held in place by upper and lower load distributor fixtures (LDF) and surrounded by a Heat Dissipation Sleeve. The packages are closed by bolting the lid in place. The design and analysis details of the 9977 package are given in the Safety Analysis Report for Packaging (SARP) [1].

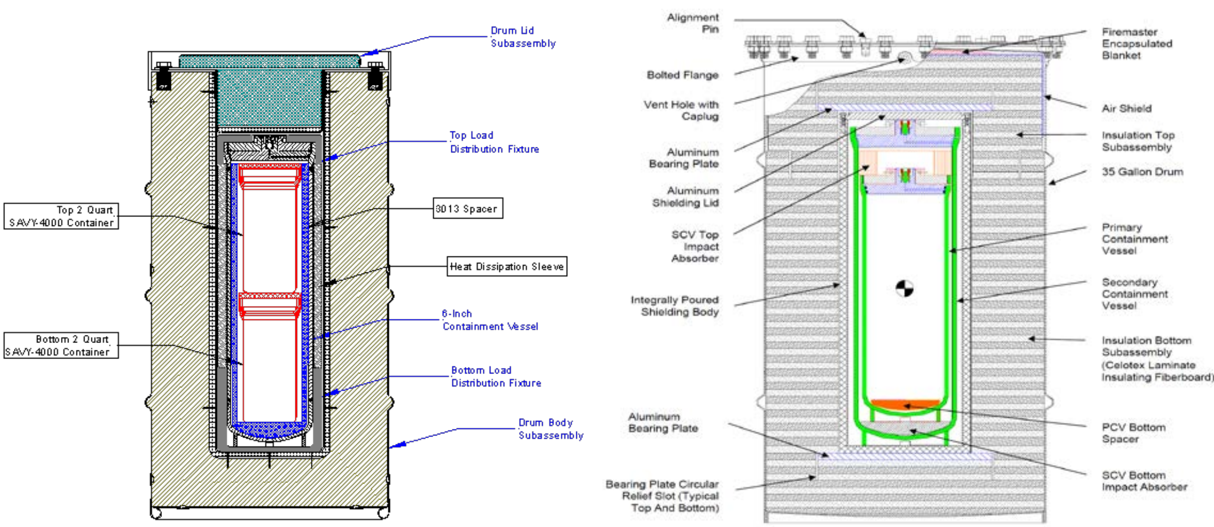


Figure 1. Left) 9977 Package with two SAVY containers, Right) 9975 Package with Primary and Secondary Containment Vessels.

DESCRIPTION OF THE WORK

9977 Model Analyses

The 9977 package with SAVY containers internal to the CV is analyzed for the 10CFR71 [8] normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The internal heat source was varied from 12.5 W to 19 W per SAVY (for a total of 25-38 watts in the CV) to determine the maximum content heat load that can be placed in the 9977 package and still meet thermal requirements for shipping described in the SARP [1].

Evaluations for the suitability of shipping include analyzing the package under solar heat flux and fire conditions. In all cases, predicted component temperatures are compared to thermal limits to ensure that the package CV does not leak. For NCT solar conditions, 10CFR71 prescribes a total heat of 800 cal/cm^2 for flat surfaces facing upwards and 400 cal/cm^2 for curved surfaces over a 12 hour period. For fire analysis, the package starts at the NCT conditions, is exposed to a 30 minute 800°C fire, and allowed to cool down post fire without artificial cooling.

The 9977 package has foam insulation between the inner drum liner and the exterior drum surface. This foam decomposes when exposed to high (fire) temperatures. The decomposition rate and heat of reaction is not well documented. Therefore, based on past engulfing fire tests of the 9977 package, it was determined that the 9977 internal contents reach a maximum of 87°F over their NCT temperatures during a fire/post fire event. For this thermal analysis, the NCT and the post-fire cooldown were modeled. The initial conditions of the post fire transient are 87°F above the NCT temperature predictions for contents located within the drum liner. The foam is assumed to char and have thermal properties of air and a temperature equal to the fire temperature, 800°C.

9975 Model Analyses

The 9975 package has been used for extended storage of nuclear materials. Periodic surveillance of the 9975 packages has show degradation of the fiberboard insulation between the drum liner and the outer drum surface. Simulations have been conducted to determine the effects of the degraded fiberboard on the thermal performance of the package.

Evaluations of the 9975 package include boundary conditions equivalent to the previously mentioned 9977 conditions. Additional modifications in the simulation include the changes to the beginning of life (BOL) fiberboard material thermal properties, as listed in Table 1. The density, thermal conductivity, and heat capacity of the fiberboard material are taken to be 90% and 80% of the BOL values for the 20 year and 30 year degraded scenarios, respectively.

Table 1. Beginning of Life Fiberboard Properties

Material	Density (kg/m^3)	Thermal Conductivity (W/m/K)	Heat Capacity (J/kg/K)
Pre-Fire Softwood Fiberboard (Radial)	16.598	0.05824 @ 77°F 0.05824 @ 122°F 0.05761 @ 185°F	0.3057 @ 77°F 0.3511 @ 122°F
Pre-Fire Softwood Fiberboard (Axial)	16.598	0.03253@ 77°F 0.03357 @ 122°F 0.03386 @ 185°F	0.3057 @ 77°F 0.3511 @ 122°F
During-Fire Fiberboard	15.40 @ 80°F 15.40 @ 475°F 8.5 @ 810°F 3.5 @ 1500°F	0.035 @ 80°F 0.450 @ 170°F 0.550 @ 200°F 0.090 @ 210°F 0.070 @ 500°F	0.25 @ 80°F 0.50 @ 475°F 0.50 @ 810°F 0.50 @ 1500°F

Note: The material properties for the post fire cooldown mode are equivalent to the pre-fire values. This causes the package to retain heat longer yielding conservative temperature results.

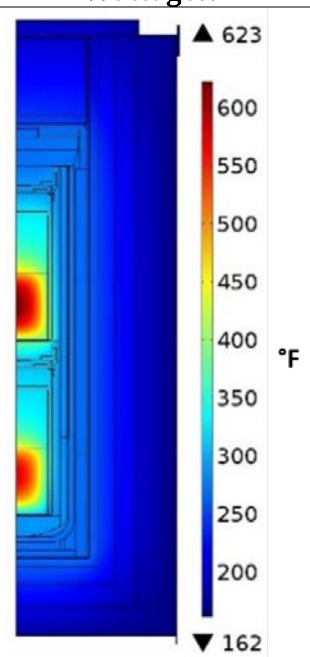
Additional inputs for both models consist of package geometry and all material thermal properties. These inputs are used in creating finite element thermal models that are used to analyze the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC).

RESULTS

9977 Model Analyses

Table 2 lists the maximum content and other package component temperatures for the 9977 shipping package for the NCT/pre-fire models. A 2-D thermal profile of the 9977 package containing dual SAVY, each containing a 15 W heat source, is provided within Table 2 for reference. Also, note that the maximum component temperatures that exceed their respective temperature limits are shown in red. The 9977 package thermal analyses show that each SAVY container can have a maximum of 15 watts (30 watts for the total 9977 package) and still remain below the thermal limits for the CV as set in the SARP.

Table 2. Maximum 9977 Components Temperatures (F) during NCT for Various Content Wattages.



Component	Dual 12.5 watts	Dual 15 watts	Dual 17 watts	Dual 19 watts	Limit (F)
CV	271	290	**306**	**321**	300
CV O-rings	259	277	290	304	400
Foam Insulation	247	263	276	288	300
Drum	188	189	189	190	N/A
Top Contents	552	621	676	729	N/A
Bottom Contents	506	571	622	673	N/A
SAVY O-rings	293	315	333	351	392

The results of the Post-Fire Cooldown simulations are given in Table 3 for the limiting case with 15 W sources. Note that all source cases were run, but only the 15 W source cases are reported here for brevity. The maximum temperature that each component reaches is shown in blue. For all cases analyzed, the CV and CV O-rings remain below their respective HAC thermal limits of 600^{o}F each. With respect to the amount of foam insulation remaining, as the amount of foam at the beginning of the post-fire cooldown phase decreases, the maximum temperature reached for the CV and CV O-rings all decreases as well as the time to reach the maximum component temperature. This is attributed to the density and heat capacity differences between the char (air properties) and the foam insulation which causes heat to be trapped inside the package for a longer period of time (during the post-fire cooldown).

Table 3. Maximum 9977 Component Temperatures during Post Fire Cooldown with Dual 15 watt SAVYs

	2.3-Inch Un-decomposed Foam			1.0-Inch Un-decomposed Foam			All Char		
Time (hr)	CV (°F)	CV O-rings (°F)	Contents (°F)	CV (°F)	CV O-rings (°F)	Contents (°F)	CV (°F)	CV O-rings (°F)	Contents (°F)
0.0	377	377	708	377	377	708	377	377	708
0.5	410	393	754	410	393	754	411	394	754
1.0	416	405	787	417	406	787	416	404	787
1.5	422	413	**798**	422	412	**798**	419	408	**798**
2.0	427	417	794	425	415	794	420	**409**	794
2.5	430	420	785	427	**416**	785	**421**	409	785
3.0	433	**422**	775	**428**	416	775	421	408	775
3.5	434	422	767	428	416	767	420	407	766
4.0	**435**	422	761	428	415	760	420	406	758
4.5	435	422	755	427	413	755	419	405	752
5.0	434	421	752	426	412	750	418	404	747
5.5	434	420	749	425	411	747	417	403	743
6.0	433	419	747	423	409	744	416	402	740
7.0	431	417	745	422	408	741	415	401	737
8.0	430	416	744	421	406	739	414	400	734
9.0	429	414	742	419	405	737	413	398	732
10.0	427	413	741	418	403	736	412	397	730

9975 Model Analyses

The maximum temperatures of the 9975 shipping package components with a 19 W source within the lower 3013 container are shown in Table 4 for the HAC evaluations. With 20-year and 30-year degraded fiberboard thermal properties, the maximum component temperatures remain below their respective SARP temperature limits. Note that the PCV and SCV O-ring maximum temperatures, which are typically the critical component temperatures, are 314°F and 310°F, respectively, and remain well below the 400°F temperature limit. The package components with 30-year degraded fiberboard result in lower internal component (Contents, SCV, PCV, and O-rings) maximum temperatures and higher external component (Lead Shield, Fiberboard, and Drum Surface) maximum temperatures. This can be attributed to increased heat transfer through the fiberboard that had been more degraded (older).

Table 4. Maximum 9975 Component Temperatures during Post Fire Cooldown with Degraded Fiberboard Properties.

Component	20yr Degraded Fiberboard HAC Temperature (F)	30yr Degraded Fiberboard HAC Temperature (F)	Temperature Limit (F)
Drum Surface	1471	1471	NA
Fiberboard	1471	1471	NA
PCV	342	337	NA
PCV O-rings	321	314	400
SCV	333	331	NA
SCV O-rings	317	310	400
Lead Shield	371	425	600
Contents	568	562	NA

CONCLUSIONS

Based on the thermal analysis of a 9977 shipping package containing dual 2-quart SAVY containers, a maximum of 15 watts of decay heat per SAVY container (30 watts per full 9977 shipping package) ensures that all maximum component temperatures remain below their respective temperature limits. Based on the temperature limits set in the SARP [1] for the 9977 package, the limiting conditions/component is the 300°F temperature limit of the CV under NCT conditions. For the highest heat decay rate case of 38 watts total (19 watts per SAVY), the NCT temperature of the CV reaches a temperature of 321°F, exceeding the SARP's limit of 300°F. The 300°F temperature limit for the CV was chosen to maximize the allowed design pressure under NCT, but the calculated CV temperature of 321°F is well below the stainless steel CV's melting point. Even after the HAC analyses, the CV maximum temperatures remain well below the melting point for stainless steel.

Based on the thermal analysis of the 9975 shipping package using 20-year and 30-year degraded thermal properties for the fiberboard insulation, it is calculated that the maximum PCV and SCV O-Ring temperatures remain below the SARP's 400°F component temperature limit. The 30-year degraded fiberboard results in lower maximum component temperatures for the internal components and higher maximum component temperatures for the external components. This trend is attributed to the increased heat transfer through the degraded fiberboard, which allows higher internal component temperatures during the HAC fire (increased heat transfer from the fire to the package) and lower internal component temperatures during the post-fire cooldown (increased heat transfer from the package to the ambient). Note that the maximum component temperatures are reached during the cooldown phase for all components and all degradation levels.

Taking the degraded insulation results trends from the 9975 shipping package analysis and applying them to the 9977 shipping package analysis results, an argument can be made for increasing the allowable content loading wattage within aged 9977 shipping packages. The trends show that the maximum total heat source wattage may be *increased* under extended storage scenarios because the degraded insulation properties would allow *more* heat transfer to the environment, which would *reduce* the maximum temperature under NCT. By this same reasoning, the package contents would also have higher component temperatures during a HAC fire event, but should still have lower absolute maximum component temperatures during the post-fire cooldown phase and, thus, stay below the SARP's component temperature limits.

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