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THE 9975 SHIPPING PACKAGE LTE PREDICTION EFFORTS

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ABSTRACT

The 9975 shipping package, a robust drum-style Type B Fissile Package, is used for transport and storage of Plutonium metals and oxides. At Savannah River Site (SRS), plutonium metals and oxides are stored in a triple-nested 3013 container assembly housed inside the 9975 double-containment vessel (CV). The shipping package structural components include the outer drum shell, fiberboard, primary and secondary CV, lead shielding, plates, and impact limiters made of aluminum-honey combs.

The 9975 shipping package storage life was developed based on the Container Qualification Program (CQP) which used a systematic approach to provide needed information for the safety analysis process by evaluating container functions, requirements and qualification bases. The functions include containment, criticality prevention, and impact and fire resistances. The qualification for the storage period was also provided by the monitoring requirements of the Storage and Surveillance Program (SSP). The 9975 shipping package SSP performs surveillance and accelerated aging tests to ensure any degradation due to aging is detected in advance of such degradation occurring in service. Although the Program has demonstrated that the 9975 package has a robust design that can perform under a variety of conditions, the package was not specifically designed for long term nuclear material storage. Since the existing 9975 Model service storage life of 15 years is due to expire in mid-2017, life time extension (LTE) analysis is needed to extend the storage life for the second time. Therefore, the 9975 shipping package LTE requires a relatively new comprehensive approach which combines existing material data to be used in the package thermal and structural analyses in order to determine the use of the shipping package for long term safe storage of nuclear materials.

The 9975 Model storage life extension evaluation can be divided in two general steps. The initial step is to collect material property data based on three elements: beginning-of-life conditions, as-founded surveillance data, and experimental aging studies. The material data are then modified as applicable to be used in the 9975 Model thermal and structural analyses models. This submittal primarily focuses on the ongoing LTE prediction efforts of the 9975 shipping packages using the new approach and also documents the progress made to date. In addition, the comprehensive approach can be applicable to other similar shipping package designs.

INTRODUCTION

SRS stores packages containing plutonium materials in the K Area Complex (KAC) facility. The Plutonium materials are packaged per DOE-3013 Standard and stored within 9975 shipping packages in KAC. Receipt of actual shipments for storage began in 2002.

The KAC facility Documented Safety Analysis (DSA) credits the 9975 package to perform several safety functions, including criticality prevention, impact resistance, containment, and fire resistance to ensure the plutonium materials remain in a safe configuration during normal and accident conditions. In KAC, the 9975 package is credited to perform its safety function for a period of at least 15 years (shipment and storage). The DSA recognizes the degradation potential for the materials of package construction over time in the KAC storage environment and requires an assessment of materials performance to validate the analysis, and predict the package storage life and the potential need for repackaging.

As illustrated in Figure 1, The 9975 Model is composed of a 35 gallon stainless steel drum with a bolted flange closure. The insulation is Celotex® fiberboard made from sugarcane bagasse or softwood in accordance with American Society for Testing and Materials Specification C208 [11]. The fiberboard surrounds a nominal ½" thick lead shielding cylinder. Inside the shielding are two-nested primary and secondary stainless steel containment vessels (PCV and SCV) with double O-ring seals designed in accordance with Section III, Subsection NB of the American Society of Mechanical Engineers (ASME) Code. The O-ring compounds are specified in several radioactive material package designs and are not exclusive to the 9975 Model.

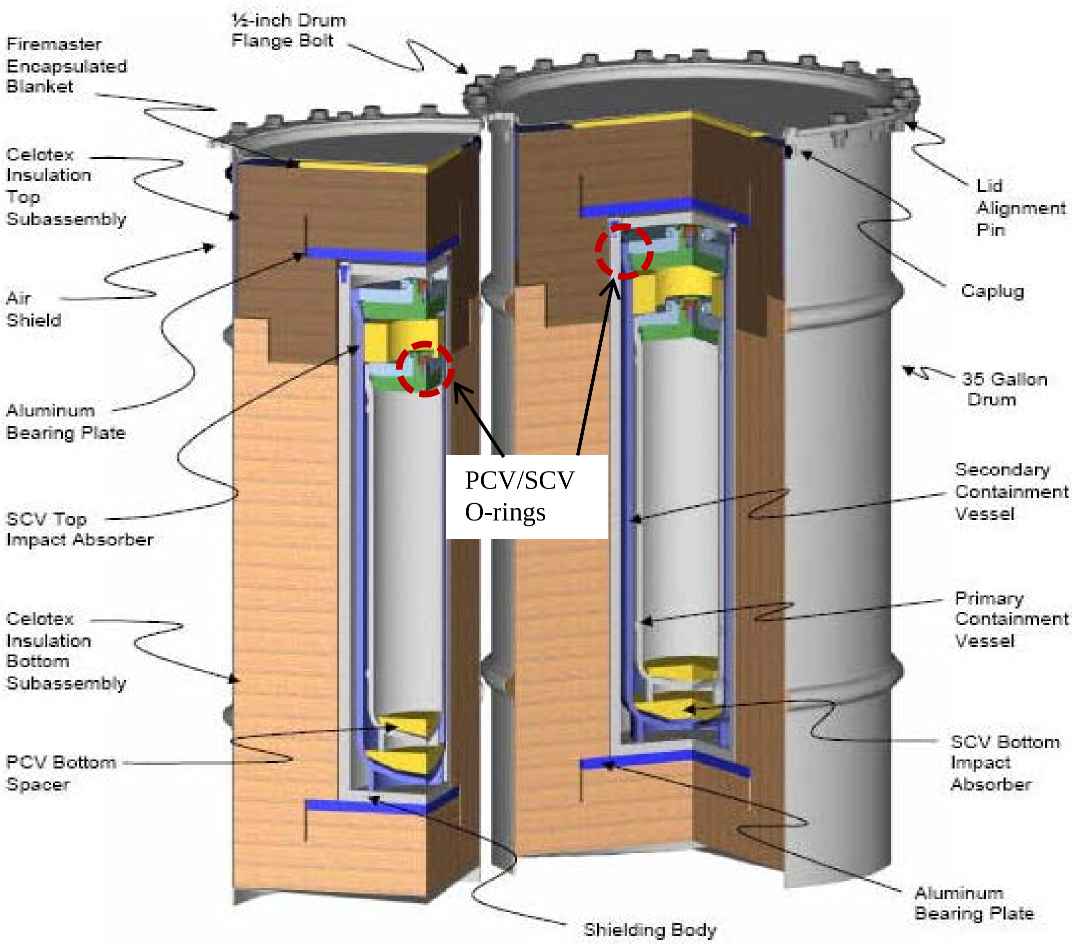

Figure 1: 9975 Shipping Package 3-Dimensional Section View

The 9975 Model is a robust design for shipping, but the package was not specifically designed for long term material storage. A program was initiated in 1998 to approve the use of the 9975 shipping package for interim storage in the KAC facility. Based on available literature and limited test data in combination with a surveillance program, the Model 9975 shipping packages were approved for storage in KAC for 10 years. Subsequently, the need for longer storage periods dictated that a surveillance program be developed to predict Model 9975 lifetime in KAC. Based on continuous surveillance and testing, the service storage life of the 9975 Model was extended from the initial 10 years to 15 years. The oldest packages will meet this new deadline in mid-2017. Therefore, the comprehensive LTE analysis approach is currently ongoing to potentially extend the storage life for the second time.

LTE PREDICTION DISCUSSION

As the flow chart in Figure 2 illustrates, the LTE analyses of the 9975 shipping package involve combination of three elements related to the birth and service history of the package materials. These elements are beginning-of- life (BOL) conditions, experimental aging studies, and field surveillance of the shipping package. The elements ultimately provide different sets of material property inputs. Detailed discussion of each element is provided in the sections below.

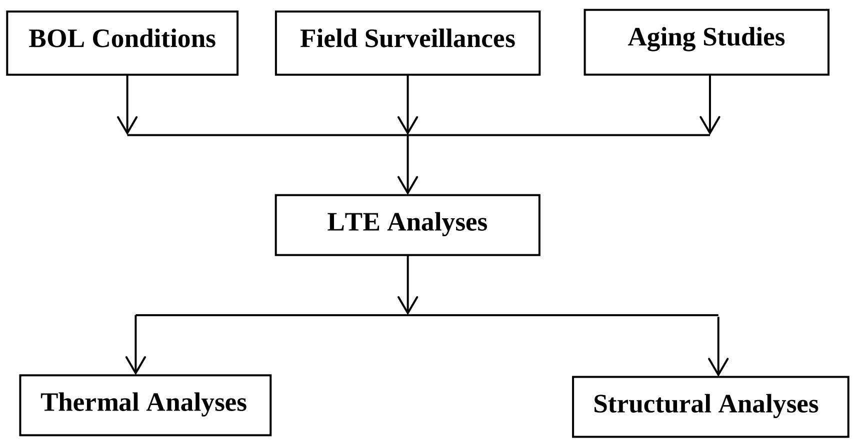

Figure 2: 9975 Shipping Package LTE Analyses Flow Chart

Beginning-Of-Life (BOL) Conditions

The 9975 shipping package BOL conditions are one of the main inputs to the LTE analyses. BOL is baseline condition that explains the shipping package birth history. BOL conditions include information related to component building materials, weld type and condition, requirements, inspections, as-built dimensions and geometries, and environment during packaging, transportation, and initial storage. BOL conditions provide the original reference to the shipping package transportation and storage life. In theory, aging of the shipping package starts from this reference condition. In fact, BOL properties are baseline in the aging studies of the package components, such as the fiberboard [1, 2, and 3] and O-rings [4].

The BOL conditions for the LTE prediction are obtained from the 9975 Safety Analysis Report for Packaging (SARP) [5]. The 9975 SARP requirements are in accordance with Part 71, Title 10 Code of Federal Regulations (10CFR71) for Packaging and Transportation of Radioactive Materials. The SARP identifies components credited for thermal and structural reasons. Thermally, the PCV/SCV O-rings, Celotex® fiberboard, and lead shielding are more limiting. Structurally, the PCV/SCV double containment closure heads are more limiting. Also, the SARP provides the limit to the axial air-gap (< 1inch) between the upper fiberboard outer surface and the drum flange.

Summary of the key BOL input parameters for the 9975 shipping package is in Table 1. For the LTE prediction, two sets of BOL inputs parameters are examined: BOL material parameters of components without and with aging issues. BOL input parameters are kept unchanged in the LTE analyses for components with no aging concern. However, components with aging concern, such as the fiberboard and lead shielding, are modeled based on field surveillance data and/or experimental aging studies, whichever is conservatively bounding.

Table 1: Summary of BOL parameters for the 9975 Shipping Package

<table>
<tr><th rowspan="2">Shipping Package Components</th><th colspan="2">BOL Conditions</th></tr>
<tr><th>Applicable Inspection</th><th>As-designed</th></tr>
<tr><td>PCV/SCV</td><td rowspan="3">Per ASME (Section III, Subsection NB)</td><td rowspan="8">SARP Mechanical, Physical, and Thermal Properties</td></tr>
<tr><td>PCV/SCV O-rings</td></tr>
<tr><td>PCV/SCV upper and lower welds</td></tr>
<tr><td>Drum</td><td rowspan="5">NA</td></tr>
<tr><td>Fiberboard*</td></tr>
<tr><td>Lead Shielding*</td></tr>
<tr><td>Aluminum Plates</td></tr>
<tr><td>Aluminum-honey comb</td></tr>
</table>

*Components with aging data and/or concern

Field Surveillances

Field surveillances provide several inputs relevant to the 9975 shipping package LTE analyses. As indicated in [6 and 7], field surveillances include NDE technique such as visual inspections, leak check, and measurements. These inputs include degradation of the shipping package components due to normal and accident events which could occur during transportation and storage. Degradation of the components can be due to moisture or other chemical reaction. Surveillance data show evidence of drum corrosion, lead shield corrosion, mold and elevated moisture level in the fiberboard [6 and 7]. In addition, surveillance data show axial air-gaps exceeding the SARP [5] requirement, which can result from fiberboard compaction under service loads, especially when elevated levels of moisture are present [12]. Table 2 summarizes the as-founded degradations in the shipping package components. The locations of these anomalies in the shipping package are illustrated in Figure 3. The conservative modeling approach to include the field surveillance degradation data in the LTE analyses is discussed in the LTE Analyses Section. Field surveillance data is also used in experimental aging studies.

Table 2: Summary of the 9975 Shipping Package Degradation

Shipping Package Components	As-found Degradation
Drum	Corrosion**
PCV/SCV O-rings	Few failed Leak Checks*
Fiberboard	Mold
	Axial air-gap > 1”
	Radial air-gap*
	Elevated Moisture Levels
Lead Shielding	Outer Surface Lead Corrosion

*Only few packages failed O-ring leak checks and radial air-gaps [4]

** Some of the corrosions are local and others spread around the bottom drum partial weld

Experimental Aging Studies

Savannah River National Laboratory (SRNL) has conducted a series of experimental tests using as-found and prototypic shipping package material components. The experiments revealed several key parameters to be used in the LTE predictions for the package's continuous safe performance. Extensive experimental tests are being conducted to determine the impact of the fiberboard and Viton O-rings on the long term service life of the shipping packages [1, 2, 3, 5, 6, and 7]. The fiberboard and Viton O-rings are examined at bounding storage conditions and monitored for their material properties and functional performance overtime. Aging environments include elevated temperatures and humidity. Initial packaging conditions and storage environment also contribute to aging concerns with other components such as the drum shell, closure bolts / nuts, and lead shielding. Lead corrosion growth rate is examined in [8 and 9].

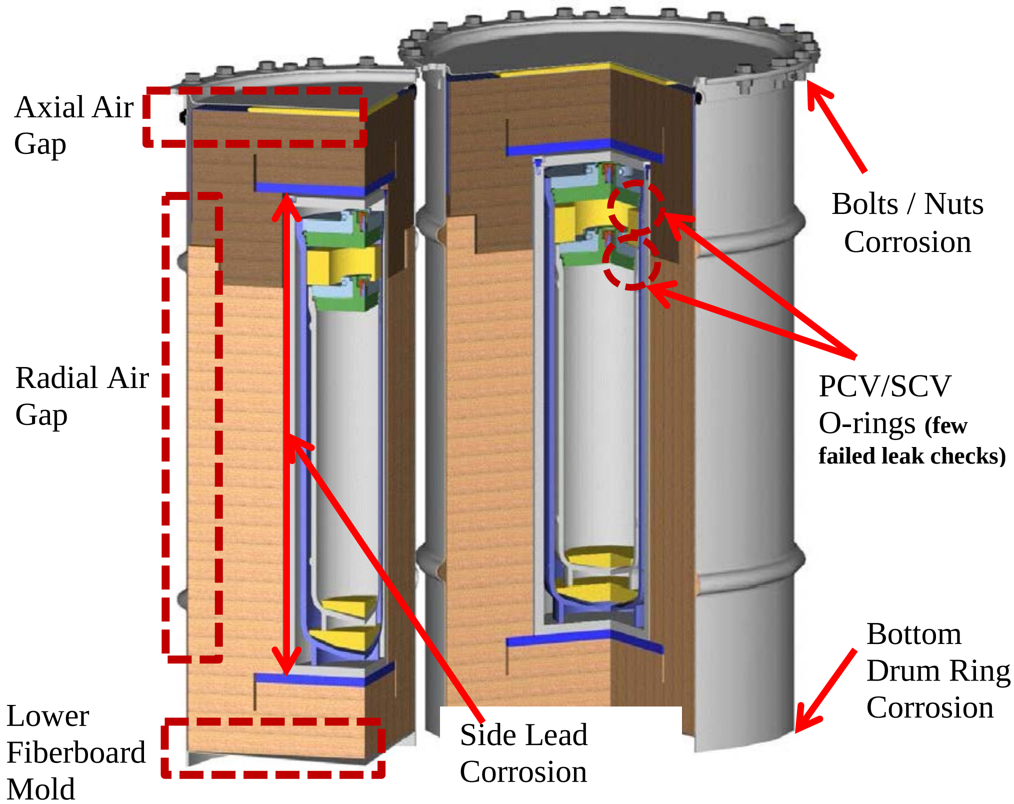

Figure 3: 9975 Shipping Package Field Surveillance Degradations

Although the Viton O-rings are found to be thermally limited, no significant O-ring aging concern was found to date [4]. However, the aging of the fiberboard is significantly dependent on material orientation, temperature and relative humidity. Experimental test findings include degradation rate of the fiberboard at different temperatures and relative humidity levels [3 and 10]. The as-found and accelerated aging studies provided various degradation rates related to density / weight loss, reduction in thermal conductivity, height, and length of the fiberboard [3]. Reduction in the heat capacity of the fiberboard is found to be minor [3]. Also experimental measurements have shown a potentially bounding lead corrosion growth rate (lead degradation) rate of 0.002 inch per year [8 and 9]. Table 3 summarizes the fiberboard and lead shielding aging application in the LTE analyses. The conservative modeling approach to include the data from the aging studies in the LTE prediction is discussed in the LTE Analyses Section.

Table 3: Summary of the 9975 Shipping Package Aging Application

Shipping Package Components	Aging Application
Fiberboard	Conservatively Degraded mechanical, physical, and thermal properties per aging rate
Lead Shielding with corrosion	Lead corrosion growth rate of 0.002 inch / year

LTE ANALYSES

The 9975 LTE analyses combine information from the SARP (BOL conditions), field surveillance, and experimental aging studies. The input data are then used in conjunction with 9975 finite element analysis (FEA) models in order to determine the long term storage performance of the package. The 9975 thermal and structural FEA models are built in COMSOL and ABAQUS, respectively. The thermal and structural analyses of the shipping packages are ongoing in KAC facility and SRNL, respectively. The general descriptions of the shipping package FEA models are given in the section below.

Table 4 summarizes input conditions for the 9975 LTE analyses. These input parameters are material property data including mechanical, physical, and thermal. Shipping package material components that maintain their BOL conditions are modeled as-is. However, materials with aging concerns are modeled in two different ways. The first is to use the degradation rate from the experimental aging studies to estimate the potential loss of material characteristics due to aging. This method is applicable to the fiberboard and lead shield corrosion. The second is to apply element-deletion (ED) approach in order to model the as-found degradations conservatively since aging data are not readily available for all the anomalies found in the shipping packages. For instance, the mold at the bottom of the fiberboard is modeled by removing the portion of the fiberboard currently affected plus some additional portion which could potentially be affected in the future. The axial air gap and drum corrosion are also modeled conservatively. Although few in-service packages show failure of radial gaps, the LTE analyses include radial air gap degradation for additional conservatism.

Table 4: Summary of the 9975 Shipping Package LTE Input Conditions

Shipping Package Components	LTE Analyses Conditions
Portion of the Drum without corrosion	BOL
Portion of the Drum with corrosion	ED to account for corrosion
PCV/SCV	BOL
Portion of the Fiberboard without mold/gaps	Aging degradation rate
Fiberboard with mold, and axial/radial gaps	ED to account for mold, radial, and axial gaps
Portion of Lead Shielding without corrosion	BOL
Portion of Lead Shielding with corrosion	Aging degradation rate
All remaining components	BOL

9975 FEA Model Brief Description

The base 9975 FEA model for the LTE analysis is similar to the SARP model. All the major components in previous Figure 1 (drum, fiberboard, lead shielding, aluminum plates and spacer, PCV/SCV, aluminum-honey comb impact limiters, and 3013 assembly with plutonium materials) are included in the thermal and structural models. The thermal model is 2D-axisymmetric built and the structural model is 3D half-symmetry. The thermal analysis is performed using COMSOL Heat Transfer Module and includes conduction, convection, and radiation. The thermal analysis includes normal KAC storage and fire accident conditions. The structural analysis is performed using ABAQUS Explicit and includes variety of hypothetical impact and drop accidents. Unlike the SARP baseline models, these models use the LTE input parameters discussed above. However, SARP baseline conditions are considered for validation and contrast with the LTE models to estimate any remaining margin as needed.

Preliminary LTE Thermal Results

As previously mentioned, the 9975 shipping package LTE analyses are an ongoing effort. However, some preliminary thermal results are included in this submittal to provide a preview of the findings using the new comprehensive approach. Figure 4 presents the preliminary thermal results of the PCV O-rings after 1.5 hours of fire and 8.5 hours of post-fire accident scenario. The fire and post-fire accident conditions represent a full cycle of heat-up and cool-down events. The fire temperature and post-fire ambient temperature are 1500 ^{0}F and 137 ^{0}F, respectively. The initial condition for the fire accident is normal steady state bounding to the KAC storage environment of 137 ^{0}F. The plutonium material decay heat is 19 watts. The two curves in the figure show the PCV O-ring thermal comparison between baseline (SARP) and long term storage conditions of the 9975 shipping package. The obvious trend in this preliminary case is that the O-rings have some remaining margin despite the loss of more than 30^{0}F due to the shipping package materials degradation.

CONCLUSION

The 9975 Model is a robust design for shipping, but the package was not specifically designed for long term nuclear material storage. The existing 9975 Model service storage life of 15 years is due to expire in mid-2017. LTE analysis is needed to extend the storage life for the second time. Because of the various aging concerns identified in the continuous surveillance and testing data, the 9975 shipping package LTE requires a relatively new comprehensive approach. This approach combines material property data to be used in the package thermal and structural analyses in order to determine the use of the shipping package for long term safe storage of nuclear materials. The material properties include mechanical, physical and thermal data.

The 9975 storage life extension evaluation can be divided in two general steps. The initial step involves three elements: material components beginning-of-life conditions, as-founded surveillance data, and experimental fiberboard aging studies. These elements are then used to generate applicable material property input data to the 9975 shipping package thermal and structural analyses. Therefore, this submittal not only presents the ongoing LTE prediction efforts of the 9975 shipping packages using the new approach, but also documents the work completed to date. In addition, the new comprehensive approach can be applicable to other similar shipping package designs.

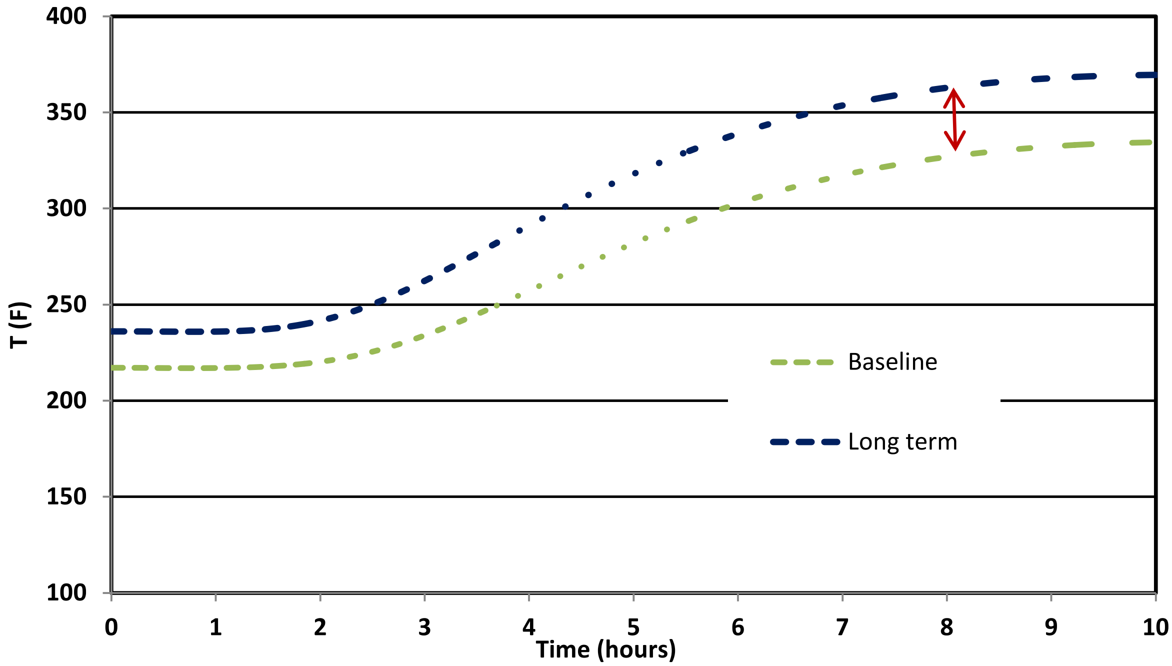

Figure 4: Preliminary Thermal Results of the 9975 shipping package PCV O-ring

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