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THERMAL UPGRADING OF 9977 RADIOACTIVE MATERIAL (RAM) TYPE B PACKAGE

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ABSTRACT

The 9977 package is a radioactive material package that was originally certified to ship Heat Sources and RTG contents up to 19 watts and it is now being reviewed to significantly expand its contents in support of additional DOE missions. Thermal upgrading will be accomplished by employing stacked 3013 containers, a 3013 aluminum spacer and an external aluminum sleeve for enhanced heat transfer. The 7th Addendum to the original 9977 package Safety Basis Report describing these modifications is under review for the DOE certification. The analyses described in this paper show that this well-designed and conservatively analyzed package can be upgraded to carry contents with decay heat up to 38 watts with some simple design modifications.

INTRODUCTION

The Model 9977 package has been designed as a replacement for the Department of Transportation (DOT) Fissile Specification 6M package. The 9977 package is a very versatile Type B package which is certified to transport and store a wide spectrum of radioactive materials.[1] The package was analyzed quite conservatively to increase its usefulness and store different payload configurations. Its versatility is evident from several daughter packages such as the 9978 and H1700, and several addendums where the payloads have been modified to suit the Shipper's needs without additional testing.

9977 Package

The 9977 package consists of a single 6-inch diameter Containment Vessel (6CV), a drum overpack filled with rigid polyurethane foam, and a closure lid that has several layers of insulation. The 6CV is identical to the well tested secondary containment vessel (SCV) used in the 9975 packagings. The 9977 package has been designed to conform to the new regulations requiring only one containment vessel for the Type B quantities. The package was designed to ship heat sources up to 19 watts. Figure 1 shows the basic 9977 without any specific payload.

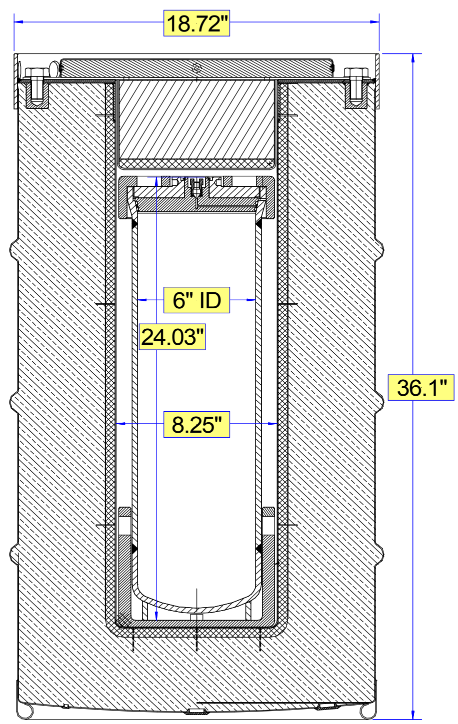

Figure 1 – Original 9977 Packaging

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Modified 9977 Package

The original 9977 design is being modified to significantly expand its Contents in support of additional DOE missions. Figure 2 is a schematic of the modified 9977 package with the two DOE-STD-3013 containers. The 3013 containers within a 3013 Spacer 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 6CV is loaded into a cylindrical drum liner and is held in place by upper and lower load distributor fixtures (LDF) and surrounded by an aluminum sleeve. These thermal and structural payload improvements have enabled the Design Authority to upgrade the thermal rating of the 9977 package from 19 watts to 38 watts. This new addendum to the 9977 SARP is currently under regulatory review.

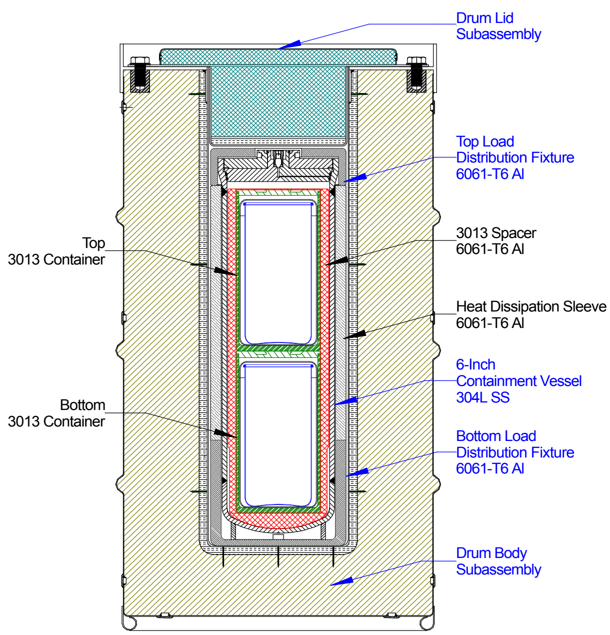

Figure 2 – Modified 9977 Packaging

Comparison between Two Designs

Table 1 shows a comparison between the two designs as regards to the component design and payload configuration.

Table 1: Comparison of Significant Items

Item	Original 9977	Modified 9977
Overpack	No change	No change
Containment Vessel	6CV	6CV
Load Distributors	No change	No change
Payload Configuration	Not specified	3013 containers
Contents	Not specified	PuO_2/UO_2
Heat Dissipation Sleeve	No	Yes
3013 Spacer	No	Yes
Thermal Loading	19 watts	38 watts

Package Functional Requirements

Critical components of the 9977 package are 6CV, the seals and the foam. The containment vessel seals are O-rings that must be maintained below certain temperature for the seals to remain leaktight. The foam must maintain its impact and insulation properties to protect the package for accident conditions, primarily during the fire. Table 2 gives the temperature limits for these components for their structural and thermal integrity.

Table 2: Temperature Limits

Component	Temperature Limits (ºF)
O-Rings	400
6CV	400
Foam	300
Drum	122

The drum temperature is the maximum allowed in 10 CFR Part 71.43g (still air at 100˚F and in the shade) for a non-exclusive use shipment.

MATHEMATICAL MODEL AND COMPUTATIONS

The package components are cylindrical in geometry and the boundary conditions are uniform all around. Therefore, an axisymmetric model will represent the package very well. The computational thermal models solve the following steady state heat transfer Equation (1) in cylindrical coordinates for an axisymmetric geometry.

$$k_1 \frac{\partial^2 T}{\partial r^2} + \frac{k_1}{r}\frac{\partial T}{\partial r} + k_2 \frac{\partial^2 T}{\partial z^2} + q''' = 0 \qquad (1)$$

Where q''' is the volumetric heat generation by the fissile material per unit time, k_1 and k_2 are the temperature dependant thermal conductivities of the materials in the r and z directions, and T is the temperature. k_1 and k_2 are different for some orthotropic materials but they are same for the isotropic materials. The partial differential equations was numerically solved using Patran/Thermal software.[3]

THERMAL MODELS

The models for the Normal Conditions of Transport (NCT) were developed using the MSC/Patran-Thermal® general purpose heat transfer software. Boundary conditions used in the models either satisfied or were more limiting than those specified for NCT in 10CFR 71.71.[1] The 9977 model for all NCT analyses includes interior metal surfaces, namely the drum liner, liner around the inner lid and the metal interface between the lid and the lower part of the drum. Figure 2 shows a material representation of an axisymmetric model of the 9977 package with two 3013 containers. Due to the geometrical symmetry around the axis of the package, only half of the model is shown.

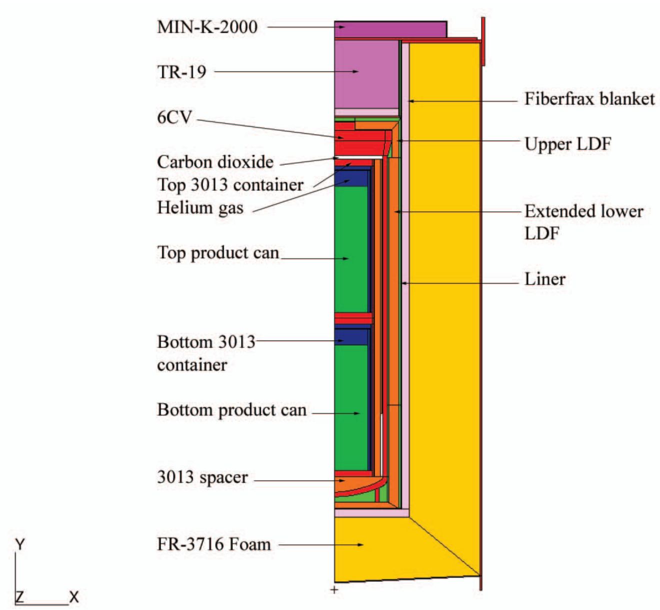

Figure 3: 9977 Components for the NCT model

The drum surface absorptivity for the solar radiation is based on *as received* stainless steel surface with a *medium* finish. The absorptivity and emissivity values are obtained by integrating the solar intensity and thermal radiations over the applicable wavelength spectrum.[4] A total absorptivity value of 0.498 (≈ 0.50) and a total emissivity value of 0.21 are used in the NCT analysis. A sensitivity analysis was performed to evaluate the variation in drum surface finish from polished to very dull surface. 10CFR 71.71 prescribes a total insolation energy of 800 cal/cm^2 over a period of 12 hours on a horizontal surface and 400 cal/cm^2 over a period of 12 hours on the vertical surface. The package is normally transported in upright orientation. Therefore, the corresponding time averaged heat fluxes are 245.77 Btu/ft^2-hr on the top of the package and 122.88 Btu/ft^2-hr on the side of the package. The applied solar fluxes using absorptivity of 0.50 are 122.88 Btu/ft^2-hr on the top of the package and 61.44 Btu/ft^2-hr on the side of the package.

Note: Thermal analysis for the original 9977 design used solar heat fluxes of 245.77 Btu/ft^2-hr on the top and 122.88 Btu/ft^2-hr on the side of the package. Solar thermal loading is a dominant loading in the NCT thermal analyses.

Description of the NCT Models

Two NCT models are analyzed: (1) NCT with insolation and; (2) NCT under shade. The model with insolation accounts for the solar thermal loading and is termed NCT/Solar. The model for NCT in shade is without solar heating and is termed NCT/Shade. NCT/Shade is important in that it forms the initial condition for the fire analysis in a hypothetical accident condition (HAC)[1]. NCT/Shade is also required to ensure that the temperature limit on any accessible drum surface does not exceed 122˚F (see Table 2). Important NCT thermal model parameters are listed below:

NCT/Solar Thermal Model

1. The drum is in an upright position.
2. The ambient temperature is 100^{o}F.
3. The bottom surface is adiabatic.
4. There is radiative heat transfer from the side and the top of the drum to the ambient. Radiation heat transfer is considered in all internal cavities. Gray body assumption is used in all calculations.
5. There is natural convection heat transfer from the side and the top of the drum to the ambient. No convection is modeled in the internal cavities. This is conservative as it results in higher local temperatures.
6. Insolation is applied as solar heat flux. The applied solar fluxes are 122.88 Btu/ft^2-hr on the top of the package and 61.44 Btu/ft^2-hr on the side of the package. These heat fluxes are applied continuously rather than as a step function with a period of 12 hours.
7. Material properties for compressed Fiberfrax® were applied to the blanket surrounding the drum liner.
8. The payload contains heat sources outputting a maximum of 38 watts uniformly distributed in two 3013 containers. The heat rate is limited to a maximum of 19 watts in each container.
9. No contact resistance is modeled between the contacting surfaces. This assumption is reasonable due to small temperatures gradients and slow heating. This assumption has been substantiated through several prototype testing of packages.
10. The NCT thermal model is a steady-state model.

NCT/Shade Thermal Models

NCT/Shade conditions are same as NCT/Solar except that no solar heating is applied.

RESULTS

Table 3 gives the component temperatures during NCT for the package. The results show that the maximum component temperatures are below the design limits indicated in Table 2.

[1] HAC results are not presented in this paper.

Table 3: Component Temperatures during NCT

Component	NCT/Solar (°F)	NCT/Shade (°F)
CV	310	257
O-rings	299	243
Foam	291	236
Drum	189	110
Top Contents	559	513
Bottom Contents	555	505
CV Cavity (Average)	369	319

Table 4 shows a comparison of the key component temperatures of the modified package, described here, during NCT/Solar with the original 9977 package that was certified for 19 watts. The modified package with is analyzed for 38 watts.

Table 4: Temperature Comparison for NCT/Solar

Component	Modified 9977 with 38 Watts (°F)	Original 9977 with 19 Watts (°F)
CV	310	312
O-rings	299	302
Foam	291	295
Drum	189	250

It is interesting to note that the component temperatures during NCT/Solar were higher in the original 9977 design (19 watts) than the modified 9977 design (38 watts). This is partly due to the solar flux (solar absorptivity = 1.0[2]) applied in the original 9977 and partly due to the heat dissipation aluminum sleeves and spacers that were placed in the modified design.

Figure 5 shows the temperature profiles for the package, Figure 6 for the containment vessel and Figure 7 for the foam under NCT/Solar conditions. Figure 8 shows the temperature profiles for the package under NCT/Shade conditions.

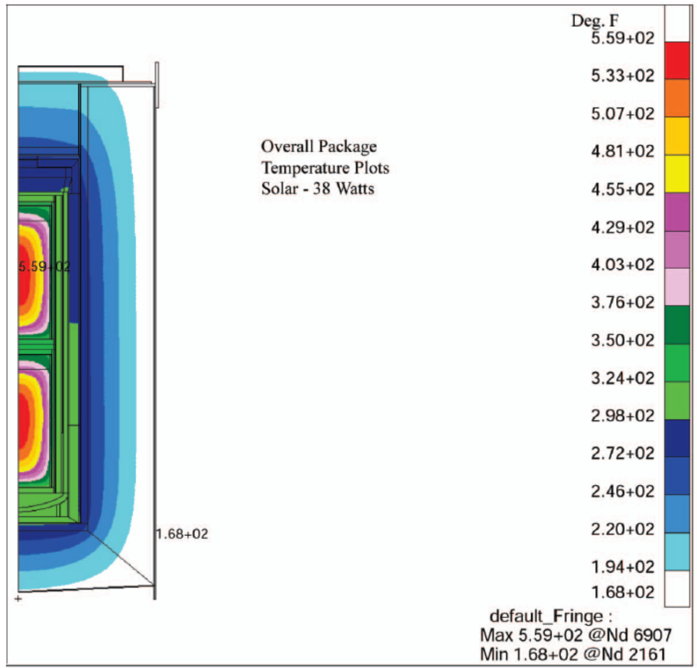

Figure 5 – Temperature profiles for the package under NCT/Solar

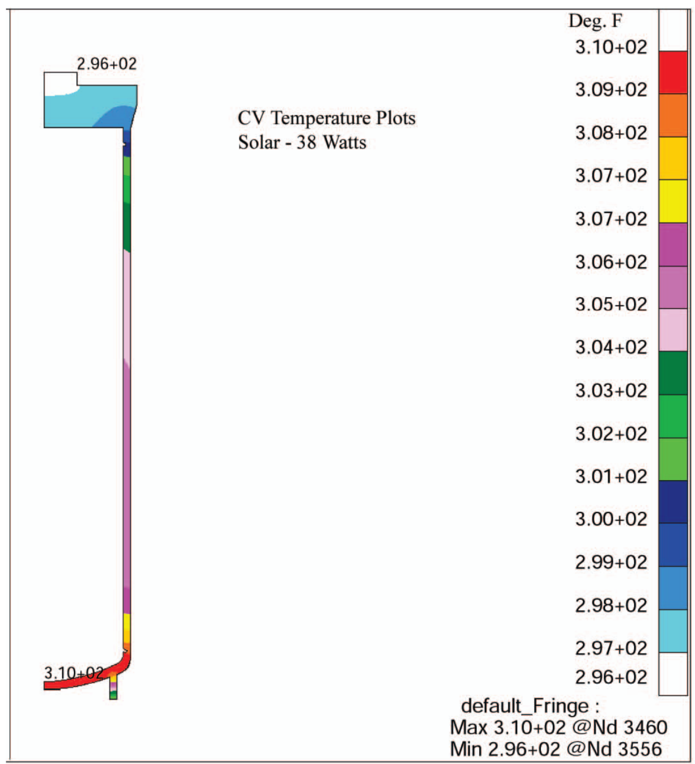

Figure 6 – Temperature Curves for the Containment Vessels and O-Rings under NCT/Solar

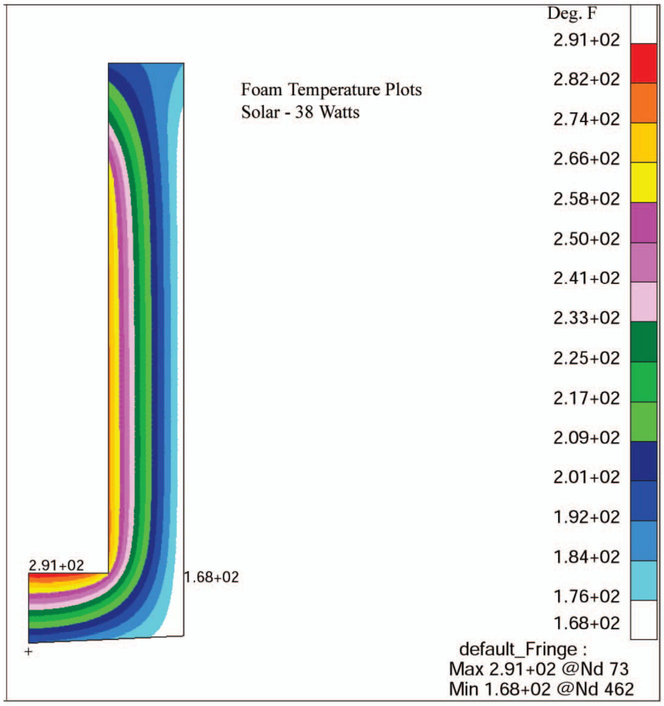

Figure 7: Temperature profile for the foam under NCT/Solar

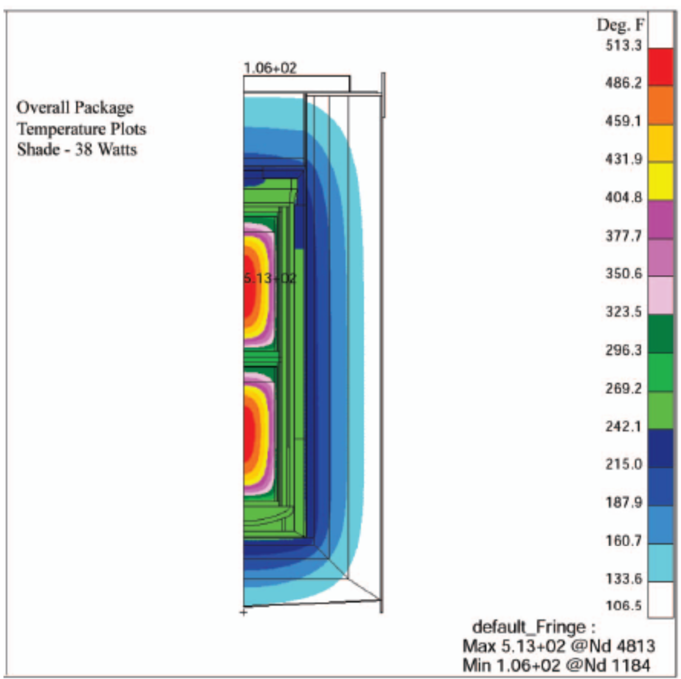

Figure 8 – Temperature profiles for the package under NCT/Shade

Sensitivity Analyses

A mesh sensitivity analysis was performed to assess the impact of finer finite element mesh on the package temperatures. The number of elements was increased from about 7600 to 15400. The maximum content temperature with the higher mesh density was found to be 558°F as compared to 559°F with lower mesh density. Therefore, the results reported in this report are based on models with about 7600 elements. A second sensitivity analysis was performed to evaluate the impact of variation in drum surface finish on the package temperatures during NCT. Table 5 lists the drum surface finishes evaluated in Reference [4]. The drum surface finish evaluated in the analyses in this report is the *as received (medium)* finish. The two cases evaluated in the sensitivity analysis are the *polished* and the *as received (very dull surface)* finishes. It should be noted that the drum surface is not machined, sand blasted or lapped during fabrication and therefore these finishes were not evaluated.

Table 5: Drum Surface Finishes[4]

Case	Description	Solar Absorp tance	Emittance (400ºK)
1	303 stainless ground rough	0.485	0.168
2	303 stainless lapped	0.347	0.108
3	303 stainless machined fine	0.545	0.162
4	303 stainless lapped	0.385	0.107
5	303 stainless sandblasted lightly	0.612	0.343
6	Stainless as received (close to polished)	0.391	0.124
7	Stainless as received (medium)	0.498	0.210
8	Stainless as received (very dull surface)	0.570	0.296

The component temperatures for the surface finishes in Cases 6 and 8 are summarized in Table 6. Surface finish in Case 7 has been assumed in the analyses for final results.

Table 6: Maximum Component Temperatures

Case	Description	CV Wall (°F)	O-rings (°F)	Foam (°F)
6	Stainless as received (close to polished)	305	293	285
7	Stainless as received (medium)	310	299	291
8	Stainless as received (very dull surface)	308	296	288

While an absorptivity value of 0.5 may be considered un-conservative for real world applications, the sensitivity analysis shows that the design is good for real world application where the surface finish may vary from the polished surface to a dull surface. In addition, the solar flux is applied all around the surface which is impossible in real world. The solar thermal loading in real world application will be well below the applied loading.

Table 6 shows that the component temperatures for Case 8 are lower than Case 7 even though the solar absorptivity for Case 8 is higher. The component temperatures are affected both by absorptivity and emissivity of the surface. Higher absorptivity increases the component temperatures while the higher emissivity decreases the component temperatures. In this case, the increase in emissivity for the Case 8 is 41% while the absorptivity increases only by 14%.

Additional Analyses

Additional analyses covering hypothetical accident conditions (fire) have been completed and have been found to meet all the requirements of the regulations in 10 CFR Part 71. Analyses have also been finalized to meet the long-term storage requirements of the storage facilities in the K-Area Complex at Savannah River Site. Publications are planned to present those analyses in the future.

DISCUSSION

Thermal analyses were performed to evaluate the design modifications to the original 9977 package to meet new payload requirements. The modifications are simple to implement without the need to modify the overpack or perform any additional NCT or the HAC fire testing. The analyses demonstrate the robustness of the 9977 package and how well designed and conservatively analyzed radioactive material packages could be made versatile.

CONCLUSIONS

1. The analyses show that the component temperatures are below their design limits with a loading of 38 watts.
2. The sensitivity analyses show the robustness of the package with practical drum surface finishes.
3. The package modifications are simple and can be easily implemented without additional testing.

DISCLAIMER

REFERENCES

1. *Packaging and Transportation of Radioactive Material*. Code of Federal Regulations, Title 10, Part 71, (10 CFR Part 71), Washington, DC (2002).
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