Sensitivity Analyses of a Type A Transportation Package

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INTRODUCTION

Type A transportation packages are used to transport significant quantities of radioactive sources for medical and nuclear fuel cycle applications. In this work, a high fidelity two-dimensional (2-D) radial and axial heat transfer model of a Type A transportation package has been developed using the finite-element computer code COMSOL Multiphysics (Ref. 1). Several calculations were completed to support the licensing process and to perform a sensitivity study. The variables evaluated in the sensitivity study are: radiation heat transfer on the surface of the package and the thermal conductivity of the heat source. Specialized COMSOL parametric features were used to accelerate sensitivity analyses, with varying physical and boundary conditions, which resulted in an improvement in run time, compared to other traditional approaches.

METHODOLOGY

These transportation packages are designed and constructed to meet stringent structural, shielding and thermal requirements for licensing. The thermal licensing requirements are addressed in this paper and are given in 10 CFR 71 (Ref. 2) and 49 CFR 173 (Ref. 3). Two Cases need to be analyzed at an ambient air temperature of 38°C (311 K). The first Case is a calculation in the shade, and the acceptance criterion is that the resulting temperature of the package surface is under 50°C (323 K) for nonexclusive use shipment, or 85°C (358 K) for exclusive use shipment. The second Case is a calculation in the sun, with insolation of 775 W/m^2 on the top surface and 388 W/m^2 on the side surfaces. The acceptance criterion for this Case is that the calculated temperature of every component is below its temperature limit and there is no limit for the temperature of the surface.

Figure 1 shows the configuration of the package studied and Fig. 2 shows the 2-D COMSOL model, using an accurate Computer Aided Design (CAD) geometry. This azimuthally symmetric COMSOL model captures the multi-dimensional conductive heat transfer through different components. A radioactive heat source of Q = 19 W is located at the center and is surrounded by different components that provide containment, shielding, insulation, and structural support. As shown in Fig. 2, the materials are curium oxide for the heat source, stainless steel (SS), aluminum (AL), lead, air for the gaps, high-density polyethylene (HDPE), plywood (PW), and carbon steel (CS) for the outside container, which is a 55-gal drum. The bottom surface of the drum is assumed to be adiabatic.

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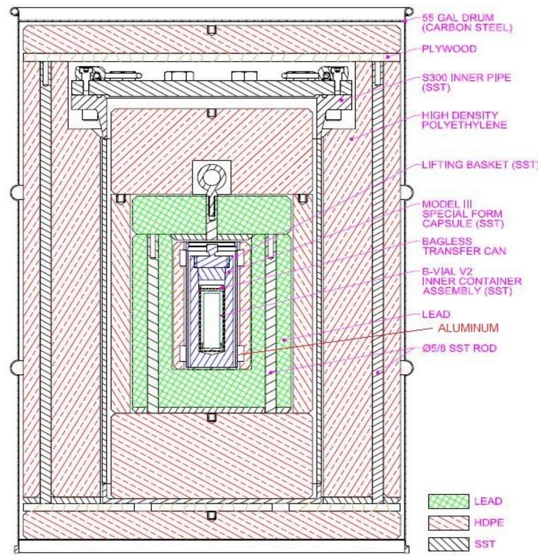

Fig. 1. Type A Transportation Package configuration.

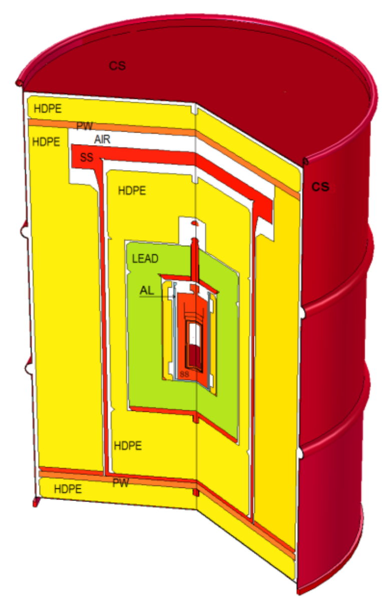

Fig. 2. COMSOL 2-D model of the package showing the different components and materials.

The thermal conductivity used for the heat source was k = 0.2 W/(m K), and values of 0.15 and 0.1 W/(m K) were evaluated since uncertainties are associated with this property.

RESULTS

The results of the different calculations of this sensitivity study are shown in Table I. Heat is removed only by conduction inside the package.

Calculations have been completed with the heat removed from the surface of the package by natural convection only (a conservative approach) or by natural convection plus radiation, with an emissivity of 0.7, combined (a more realistic approach). For Case 1A (calculation in the shade with natural convection only), adding radiation heat transfer (Case 1B) reduced the calculated temperatures by ~3 K. The temperatures of the outside surface were not very high (<48.8°C) compared to the air temperature of 38°C, and radiation heat transfer was not important. However, for Case 2A (insolation with natural convection), the surface temperatures were high (between 112°C and 139°C), and adding radiation heat transfer on the surface changed the results significantly. By adding radiation (Case 2B), the calculated temperatures were reduced by 30 K in the heat source, by 35 K in the HDPE, and by 37 K on the surface of the drum. Figure 3 shows radially calculated temperatures for Case 2B with a maximum calculated temperature of 369°C (642 K) at the center of the heat source and a minimum temperature of 78°C (351 K) at the surface of the drum.

Calculated temperatures of the surface of the drum for Case 1B and Case 2B are shown in Figs. 4 and 5, respectively.

For Case 1B, the maximum temperature of the drum was at the bottom surface, which is assumed adiabatic. For Case 2B, the maximum temperature was at the top surface due to the solar insolation. These calculations have also shown that heat was removed by the top and side surfaces in Case 1. However for Case 2, the top surface received more heat than it removed, and most heat was removed by the side surface.

Additional calculations were completed for the previous Case 2B with two different values of the thermal conductivity of the heat source: k = 0.15 and k = 0.1 W/(m K). The base value used was k = 0.2 W/(m K). Results are shown in Fig. 6 for the three calculations (Cases 2B, 2C and 2D of Table I). The temperature calculated at the center of the heat source increased as the k value decreased. The temperatures of the remaining components of the package did not change. The maximum calculated temperature was 537°C (810 K) for the case with k = 0.1 W/(m K), which is 168 K higher than the value calculated with k = 0.2 W/(m K). All the calculated temperatures were below the limits of each material and within the acceptance criteria of each case analyzed. The maximum allowable temperature of the HPDE is 135 °C — all calculations, except Case 2A (which is a conservative calculation), met this limit.

TABLE I. Calculated Temperatures for the Different Cases Analyzed

CASE	Heat transfer mode on the surface of the drum	Tmax, heat source (°C)	Tmax, HDPE (°C)	Tsurface (°C)	Thermal conductivity of the heat source, k (W/m*K)
1A.-Shade	Natural Convection	339	72.3	40.3–48.8	0.2
1B	Nat. Conv. + Radiation	336	69.1	38.6–45.1	0.2
2A.-Insolation	Natural Convection	399	141	112–139	0.2
2B	Nat. Conv. + Radiation	369	106	76.7–102	0.2
2C	Nat. Conv. + Radiation	424	106	76.7–102	0.15
2D	Nat. Conv. + Radiation	537	106	76.7–102	0.1

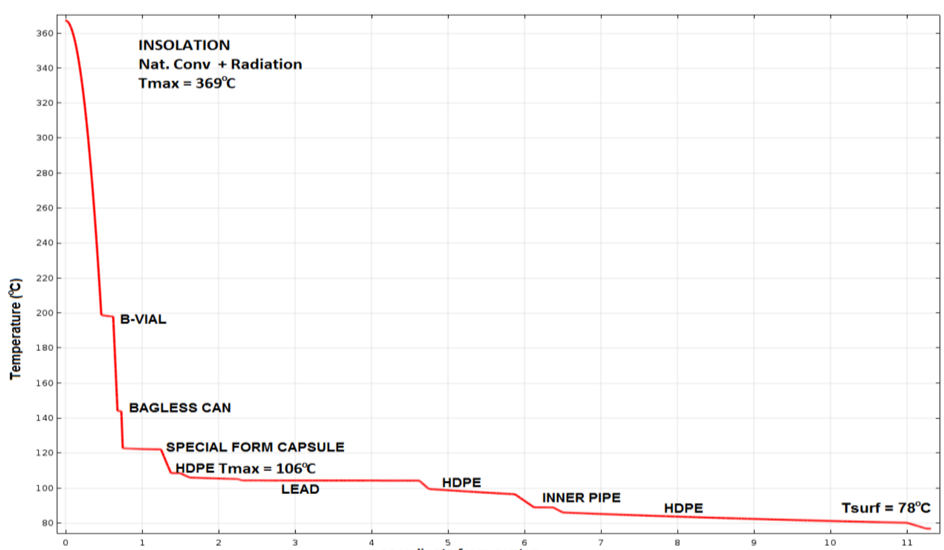

Fig. 3. Radially calculated temperatures (°C) for Case 2B with natural convection and radiation on the surface.

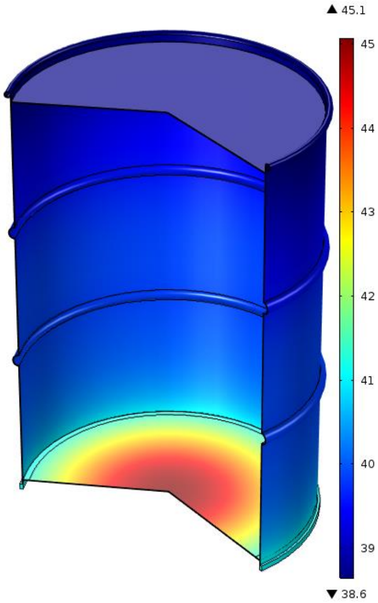

Fig. 4. Calculated surface temperatures (in °C) for Case 1B (maximum 45.1°C at the bottom)

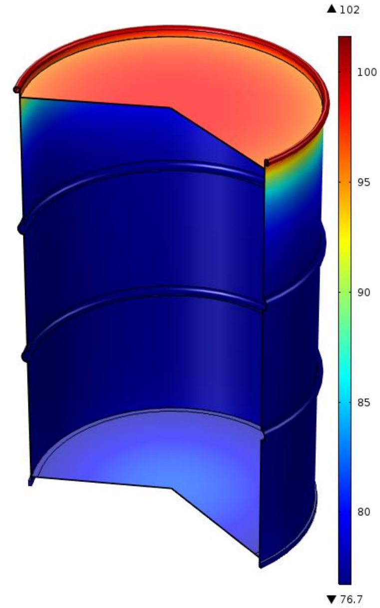

Fig. 5. Calculated surface temperatures (in °C) for Case 2B (maximum 102°C at the top).

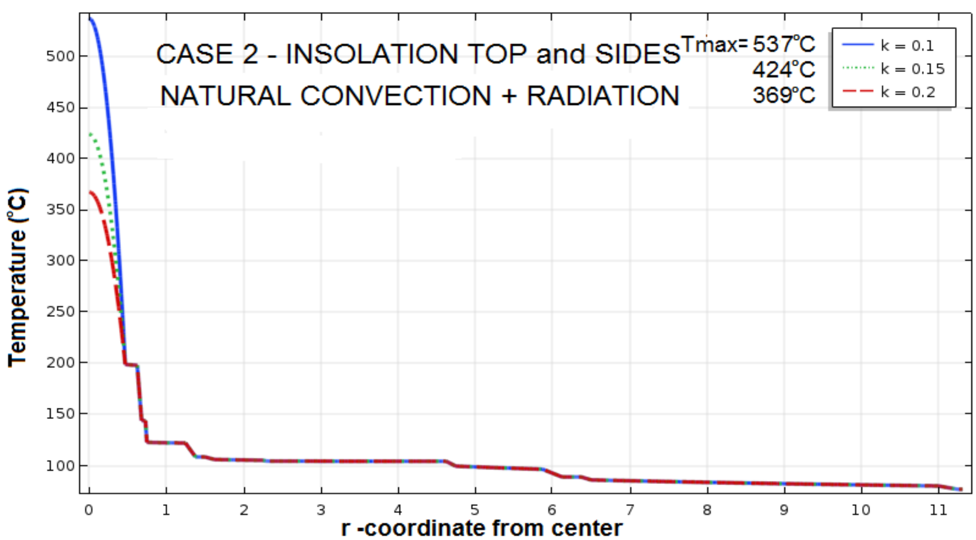

Fig. 6. Radially calculated temperatures (°C) for three different thermal conductivities of the heat source.

CONCLUSIONS

These COMSOL calculations have demonstrated that this Type A package meets the thermal licensing requirements, even for non-exclusive use shipment. All the calculated temperatures are below the maximum allowable temperatures for each material. These Calculations have also shown the importance of considering radiation heat transfer on the surface of the package when the surface temperatures are elevated (Case 2A), as well as other interesting aspects of how the heat is transferred inside the package. Varying the thermal conductivity of the heat source only changes the temperature of the heat source.

REFERENCES

1. COMSOL Multiphysics Computer Code, http://www.comsol.com
2. CODE OF FEDERAL REGULATIONS, Title 10, Part 71, US Nuclear Regulatory Commission.
3. CODE OF FEDERAL REGULATIONS, Title 49, Transportation, Part 173, General Requirements for Shipments and Packaging.