3.0 Thermal

The Croft Safkeg-LS Design No. 3979A package is a Type B(U) package designed for the transport of non-fissile nuclides and limited quantities of fissile nuclides in solid, and gaseous form. Liquid fissile nuclides have been excluded from the application based on the staff's concerns with regard to gas generation and the applicant not currently addressing the issue. The package is composed of a single resealable containment vessel (CV) carried within insulating cork packing in an outer stainless steel keg. Thermal protection of the contents within the CV is provided by the outer cork, top cork, inner cork, and the outer keg skin. All content is contained within inserts which are placed inside the containment vessel. Also the applicant has limited the amount of plutonium shipped to being no more than an A2 quantity, thereby avoiding the packaging and thermal testing requirements of 71.64, Special Requirements for Plutonium Air Shipments.

The thermal evaluation of the package was primarily based on finite element analysis models. The Abaqus version 6.8-1 computer program was used for the thermal analysis of the package. The models created were benchmarked with a self heating test and a furnace test comparable to NCT and HAC, respectively, to confirm the analytical results.

3.1 Description of the Thermal Design

Design Features that are significant with respect to heat transfer in the Safkeg-LS 3979A are the stainless steel keg outer skin, stainless steel keg inner liner, the cork liner, the top and side corks, the stainless steel containment vessel, and the lead shielding in the containment vessel. All material shipped is enclosed into tungsten or stainless steel inserts which serve the purpose of convenience handling and shielding All of these features are axi-symmetric. The keg and the cork provide the containment vessel with protection from impact and fire. Under HAC fire conditions the keg skin is designed to heat up very quickly with the cork providing insulation to the containment vessel, as a result of its low thermal conductivity and ablation properties. The keg body has a fuse plug which melts above 98°C to permit pressure relief of the gas evolution within the keg cavity when the cork heats up during HAC fire. At the request of the staff the applicant performed a sensitivity study of the effect of the air gaps on the NCT and the HAC fire. However, the staff noted that the thermal modeling did not include consideration of the effect of the packaging air gap widths to which the applicant performed a sensitivity study with the air gaps closed and cork conductivity modeled in lieu of air. Also, the staff identified that the thermal modeling didn't include consideration of the inserts nor any temperature effect on the content. As a result of the staffs comment the applicant reanalyzed the package to include the maximum temperature inside the inserts which was determined to be 128°C (NCT) and 198°C (HAC). In addition the licensee committed to not loading any solid material with a melting temperature less than 250°C.

The staff has reviewed the thermal design features and finds that these features are appropriately described pending satisfactory resolution of the applicable RAIs.

3.1.1 Decay Heat

The package as originally submitted was designed for the transport of non-fissile nuclides and limited quantities of fissile nuclides in solid, liquid, and gaseous form. The contents decay heat was limited to a maximum of 10 W for solids and gases and 5 W for liquids. However, in response to a staff question regading gas generation in the liquid content, the applicant withdrew the liquid as being an authorized content until it has ample time to complete the analysis.

The staff verified that the heat output limits specified in the General Information section for each content type were under the decay heat limits specified.

3.1.2 Summary Tables of Temperatures

Table 3-1 summarizes the maximum temperatures reached under NCT and HAC conditions by the containment vessel cavity with different internal heat loads up to the maximum allowed internal heat load, per content decay heat limitations. Tables 3-2 and 3-3 provide comprehensive temperatures and component locations for NCT and HAC, respectively, and show the allowable material temperature limits for each component. Table 3-3 also summarizes the peak temperatures and the time at which they occur in the package resulting from the HAC thermal test and the period of post test heating of the internal parts of the package. The maximum temperatures calculated are all within the acceptable temperature limits for the package components except for the containment vessel O-ring. The peak temperature of the containment vessel O-ring is 183 C which is above its continuous duty operation of 149 C. The applicant proposes a batch test program to qualify each batch by ensuring the containment vessel remains leaktight after being subjected to 200C for 24 hours and is described in Chapter 8 of the SAR. Refer to the Materials SER for further discussion of the acceptability of this containment vessel seal material including radiation effects.

Table 3-4 shows the maximum design pressure of 8 bar absolute under NCT and 11 bar absolute under HAC conditions. However, pressurization effects for liquid contents due to gas generation and limiting combustible gases in the package to less than 5% by volume over one year have not yet been evaluated.

The staff reviewed these tables and the analyses used to determine the results, and found that the analyses were appropriately utilized.

3.1.3 Evaluation by Analysis

A finite element analysis using the Abaqus version 6.8-1 software was used to thermally model the package. The package is represented by an axi-symmetrical two dimensional geometry used to develop and execute thermal models that simulate the steady-state and transient temperatures arising from the evaluated NCT and HAC environments. Section 3.5.2 of the application provides a detailed report of the modeling and evaluations. The heat sources were appropriately modeled as heat fluxes at the containment vessel inner wall. The correct material properties were applied to the different components in the model. The conduction, convection, and radiation heat transfer modes were used adequately to simulate heat transfer throughout the package. The boundary conditions were also properly applied for both NCT and HAC. Furthermore, the thermal model was benchmarked against a prototype package tested under a self heating and furnace test. The tests were representative of NCT and HAC, respectively.

3.2 Material Properties and Component Specifications

The materials that affect the package's heat transfer capabilities are the Stainless Steel Type 304, Lead, and the Cork. The material properties used for the finite element analysis were determined by the staff to be representative of the package materials of construction. The stainless steel components of the package include the containment vessel and the keg. The containment vessel also contains lead shielding. The seals on the containment vessel lid are made from Ethlylene Propylene. The maximum temperatures reached by each component are given in Tables 3-2 and 3-3 for NCT and HAC, respectively. Each component is below its maximum allowable service temperature under NCT and HAC conditions except for the seal material which is discussed above and in the material evaluation SER. The minimum allowable service temperature of each component was also verified by the staff to be less than or equal to minus 40°C.

3.6 Evaluation by Analysis

A finite element analysis using the Abaqus version 6.8-1 software was used to thermally model the package. The package is represented by an axi-symmetrical two dimensional geometry used to develop and execute thermal models that simulate the steady-state and transient temperatures arising from the evaluated NCT and HAC environments. Section 3.5.2 of the application provides a detailed report of the modeling and evaluations. The heat sources were appropriately modeled as heat fluxes at the containment vessel inner wall. The correct material properties were applied to the different components in the model. The conduction, convection, and radiation heat transfer modes were used adequately to simulate heat transfer throughout the package. The boundary conditions were also properly applied for both NCT and HAC. Furthermore, the thermal model was benchmarked against a prototype package tested under a self heating and furnace test. The tests were representative of NCT and HAC, respectively.

3.4 Thermal Evaluation under Normal Conditions of Transport

As previously mentioned, the applicant has used a finite element model to determine the temperatures of the package under NCT. Sections 3.3, 3.3.1, and 3.5.2 (SERCO/TAS/5388/001 Thermal Analysis of the SAFKEG LS Design) of the application provide details of the finite element steady state and transient analyses. Section 3.3.1 of the application evaluates the package under the conditions specified in 10 CFR 71.43(g). The evaluation shows that the maximum temperature of the accessible surface is 43°C which is reached on the keg lid. This meets the regulatory limit of 50°C. Figure 3-4 and 3-5 display the transient temperatures of the significant package components, and Figure 3-6 displays the maximum temperatures throughout the package under NCT. The peak temperatures experienced during NCT conditions with insolation are shown in Table 3-2 along with the allowable maximum temperatures for each component. Each component has a large thermal margin with the smallest being the containment seal with a thermal margin at 34°C. For the NCT cold evaluation all the package components were within their allowable service limits when evaluated at a thermal equilibrium temperature of -40°C.

The staff reviewed the analyses used to determine the results, and found that the analyses were appropriately utilized.

3.4.1 Maximum Normal Operating Pressure

Section 3.3.2 of the application provides an assessment of the maximum normal operating pressure in practice. The only pressure increases within the package are expected to come from the rise of component temperatures during NCT. The pressure is expected to rise ~30% according to Boyle's and Charles' Laws. Therefore, the maximum pressure expected during NCT is less than 2 bar absolute. The gaseous contents initially present in the package are not expected to significantly increase the pressure of the package under any condition. Liquid content are not part of this application and as such have not been evaluated for hydrogen generation. However, the temperatures are such that the liquid contents would not boil, thus there is no pressure increase due to the vapor pressure. The staff has determined that the package does not exceed the maximum design pressure of 8 bar absolute.

3.5 Thermal Evaluation under Hypothetical Accident Conditions

As stated in the application, Section 3.4 presents the predicted system temperatures and pressures for the package under the hypothetical accident condition (HAC) thermal test specified in §71.73(c)(4). The HAC thermal test was also performed using finite element analysis, similar to the model used for the NCT test. Section 3.5.2 provides a detailed report of the model. The HAC transient analysis is continued for a sufficient time after the end of the fire to ensure that all package components have reached their peak temperatures.

The staff also reviewed the analysis used to determine these results, and found that the analyses were appropriately utilized.

3.5.1 Initial Conditions

The initial temperature distribution for the HAC evaluation is taken at the end of a 12 hour period of insolation under NCT with a maximum content decay heat of 10 W at an ambient temperature of 38°C in the package's vertical orientation. All components are at their maximum temperatures as shown in Table 3-2. The staff finds that these conditions are the appropriate initial conditions for the HAC analysis.

3.5.2 Fire Test Conditions

As stated in the application, the thermal evaluation of the package for the HAC thermal test is performed by analysis. The analytical model is similar to the NCT thermal model. The keg surface emissivity is increased to reflect the expected surface conditions during the fire per §71.73(c)(4). During the heating phase all exterior surfaces of the keg were assumed to receive heat by forced convection and radiation from the furnace simulating a fully engulfing fire. The fire temperature was set at 800°C with an emissivity coefficient of 1.0. The transient analysis included 30 minute fire test followed by a 12 hour cooling period. The staff finds that the conditions used are acceptable.

In addition, the applicant performed a confirmatory thermal test using a prototype test specimen that had been subjected to the free drop and puncture testes. The thermal test provided confirmation that the package design meets the performance requirements in 10 CFR Part 71.

3.5.3 Maximum Temperatures and Pressure

The maximum temperatures of the package components for the HAC thermal test are summarized in Table 3-3. The results show that the maximum temperatures of the package components are all considerably lower than the maximum allowable temperatures. The smallest temperature margin for the HAC thermal test occurs in the containment vessel lid seal, which reaches a maximum temperature of 183°C versus a HAC temperature limit of 200°C. As discussed above containment seal material is batch tested to leaktight criteria after 24 hours at 200C. The lead in the containment vessel body is not permitted to melt and there is a 70°C margin between the maximum temperature reached and the melting temperature of the lead.

The applicant has excluded liquid content from this application, including any materials that would change phase from a solid to a liquid, Therefore, no analysis is required pressure increases due to vaporization. The maximum pressures in the containment vessel under NCT and HAC are shown in Table 3-4 and they bound the associated actual expected pressures.

The staff reviewed the results of the temperature and pressure analysis and found that they were acceptable.

3.5.4 Maximum Thermal Stresses

The maximum thermal stresses are discussed in structural chapter are are shown to be within their allowable limits.

3.6 Conclusions

Based on review of the statements and representations in the application, the staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.