## CONTENTS



# 3 THERMAL EVALUATION

This section identifies the key thermal design features for the Safkeg-HS 3977A package. The maximum temperatures at both NCT and HAC conditions have been calculated for these features by a Finite Element Analysis (FEA) and a thermal model of the package. The FEA and the thermal model of the package were validated against testing of a prototype Safkeg-HS 3977A package under steady state internal heating and by the results of the 800°C fire test carried out on a similar design the SAFKEG-LS 3979A. The test procedure and results of the tests and the FEA are presented and discussed within this section.

The maximum operational temperatures determined for the maximum contents heating have been listed and shown to be lower than the maximum design temperatures of the package.

## 3.1 Description of Thermal Design

The Safkeg-HS 3977A is designed to transport a range of nuclides, with a maximum allowable heat output of 30 W for solids and gases and 5 W for liquids. The following sections detail the design features affecting the thermal performance of the package.

### 3.1.1 Design Features

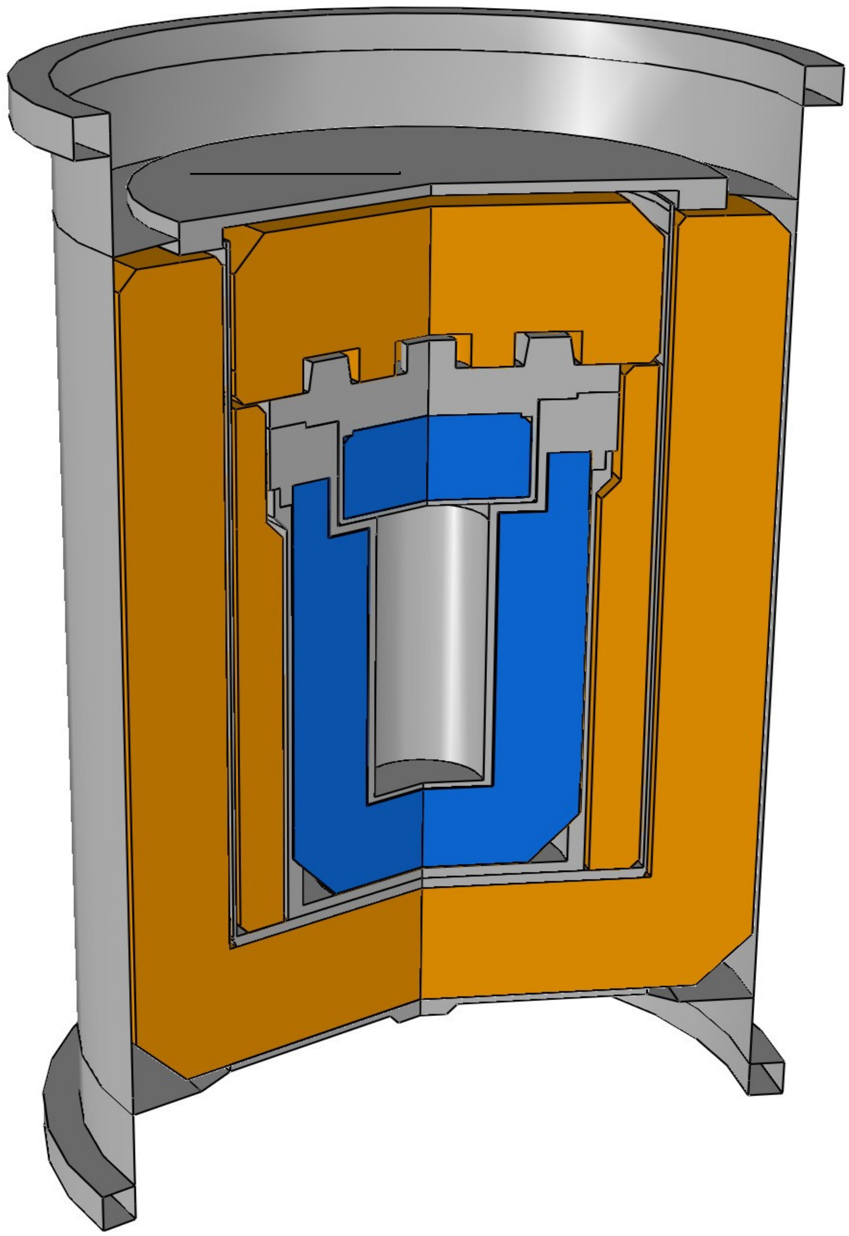
The only design features that are significant with respect to heat transfer in the Safkeg-HS 3977A are:

- The stainless steel keg outer skin
- The stainless steel keg inner liner
- The cork liner
- Top cork and side cork
- The stainless steel containment vessel
- The depleted uranium shielding in the containment vessel

These features are all axi-symmetric and are illustrated in Figure 3-1.

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. Since heating of the cork during the HAC fire causes gas evolution within the keg cavity, a fuse plug is provided in the bottom of the keg. On heating above 98$^{o}$C the fuse plug melts allowing pressure relief of the keg cavity.

The package does not have any mechanical cooling.



Materials
Grey – Stainless steel
Brown – Cork
Blue – Depleted Uranium

**Figure 3-1 Thermal Design Properties**

### 3.1.2 Content's Decay Heat [71.33 (b)(7)]

The contents decay heat is limited to a maximum of 30 W for solids and gases and 5 W for liquids.

### 3.1.3 Summary Tables of Temperatures

The maximum temperatures reached under NCT and HAC conditions have been determined using an FEA thermal model detailed in the report AMEC/6335/001 appended in Section 3.5.2. Table 3-1 summarizes the results of this report and presents the maximum temperatures reached in the containment vessel cavity with internal heat loads from 0 to 30 Watts under NCT and HAC thermal conditions.

**Table 3-1 Maximum Containment Vessel Calculated Temperatures under NCT and HAC**
(Ambient 38°C, with and without insolation)

| | Maximum Temperature under heat load (°C) | | |
|---|---|---|---|
| Heat load (W) | 0 | 5 | 30 |
| NCT – no insolation | 38.0 | 58.9 | 148.4 |
| NCT – with insolation | 58.8 | 78.1 | 163.2 |
| HAC – with insolation | 115.4 | 132.0 | 208.0 |

The maximum temperatures within the containment vessel are generated at 30W; therefore the temperatures reached at critical locations with this heat load were calculated in the SERCO report under NCT and are summarized here in Table 3-2. The maximum temperatures calculated are all within the acceptable temperature limits for the package components.

The temperature of the Shielding Inserts under NCT and HAC conditions with contents emitting 0 W, 5 W and 30 W has been determined in Calculation Sheet CS 2012-01 [appended in Section 3.5.2] as 12°C above that of the CV body: this is based on the worst case assumption that all the heat from the contents, which is emitted as radiation, is absorbed within the Shielding Insert. The maximum resulting temperatures of the Shielding Inserts calculated are presented in Table 3-2 and Table 3-3: these temperatures are within the acceptable temperature limits for the all the components of the inserts.

**Table 3-2 Summary of Package Temperatures under NCT**
(Ambient 38°C, with and without insolation)

| *Location* | Maximum Temperature (°C) | | | | | | Temperature Limit (°C) |
|---|---|---|---|---|---|---|---|
| | No insolation | | | With Insolation | | | |
| Internal Heat Load W | 0 | 5 | 30 | 0 | 5 | 30 | |

**Table 3-2 Summary of Package Temperatures under NCT**
(Ambient 38$^{o}$C, with and without insolation)

| Location | Maximum Temperature ($^{o}$C) | | | | | | Temperature Limit ($^{o}$C) |
|---|---|---|---|---|---|---|---|
| | No insolation | | | With Insolation | | | |
| Shielding Insert | 38 | 60.9 | 158.4 | 58.8 | 80.1 | 173.2 | 427 (1) |
| Shielding Insert seal | 38 | 60.9 | 158.4 | 58.8 | 80.1 | 173.2 | 150 (4) |
| Containment vessel cavity | 38 | 58.9 | 148.4 | 58.8 | 78.1 | 163.2 | 427 (1) |
| Containment vessel lid seal | 38 | 56.2 | 135.0 | 59.5 | 76.4 | 151.1 | 150 (4) |
| Cork (2) | 38 | 56.2 | 135.0 | 59.5 | 76.4 | 151.1 | 140/160 (3) |
| Keg lid | 38 | 39.7 | 46.5 | 97.5 | 98.4 | 102.4 | 427 (1) |
| Keg bottom | 38 | 41.5 | 56.8 | 69.9 | 72.0 | 84.5 | 427 (1) |
| Mid height on keg surface | 38 | 39.8 | 46.8 | 65.4 | 66.4 | 71.2 | 427 (1) |

1. The allowable temperature limit for steel when relied upon for structural support is 427$^{o}$C as specified in ASME Section II Part D [3.1].
2. Maximum cork temperature is same as the CV which it carries.
3. [3.7]
4. EP O-ring temperature limit for continuous operation

The minimum package temperature is limited by the ambient conditions, therefore the minimum temperature of the package is assumed to be -40$^{o}$C.

Table 3-3 summarizes the data obtained from the AMEC report (section 3.5.2) for the peak temperatures in the package resulting from the HAC thermal test and the period of post test heating of the internal parts of the package. As can be seen, all the CV components remain within acceptable temperature limits.

**Table 3-3 Summary of Package Temperatures for HAC Thermal Test**
(Ambient 38°C, with insolation)

| Internal Heat Load W | 0W | | 5W | | 30W | | |
|---|---|---|---|---|---|---|---|
| **Location** | Max T (ºC) | Time After Fire Start (mins) | Max T (ºC) | Time After Fire Start (mins) | Max T (ºC) | Time After Fire Start (mins) | |
| Shielding Insert | 115.4 | 210 | 134.0 | 210 | 218.0 | 180 | 427 |
| Shielding Insert seal | 115.4 | 210 | 134.0 | 210 | 218.0 | 180 | 200 |
| Containment vessel cavity | 115.4 | 210 | 132.0 | 210 | 208.0 | 180 | 1427 |
| Containment vessel lid seal | 115.3 | 254 | 130.1 | 244 | 196.3 | 210 | 200 |
| Cork | 787.4 | 30 | 787.6 | 30 | 788.2 | 30 | N/A |
| Depleted Uranium Shielding | 115.3 | 210 | 130.3 | 210 | 198.2 | 180 | 1120 |
| Keg lid | 784.3 | 30 | 784.4 | 30 | 785.0 | 30 | 1427 |
| Keg bottom | 788.6 | 30 | 788.7 | 30 | 789.3 | 30 | 1427 |
| Mid height on keg surface | 786.6 | 30 | 786.6 | 30 | 786.1 | 30 | 1427 |

### 3.1.4 Summary Tables of Maximum Pressures

Table 3-4 shows the maximum design pressure under NCT and HAC.

**Table 3-4 Summary Table of Maximum Pressures in the Containment Vessel**

| Case | Maximum Pressure kPa (bar) abs |
|---|---|
| MNOP | 7 bar (700 kPa) gauge<br>8 bar (800 kPa) abs |
| HAC | 10 bar (1,000 kPa) gauge<br>11 bar (1,100 kPa) abs |

## 3.2 Material Properties and Component Specifications

### 3.2.1 Material Properties

The materials affecting heat transfer within and from the package are cork, depleted uranium and stainless steel type 304L. The thermal properties for each material are summarized in Table 3-5.

**Table 3-5: Thermal Properties of Packaging Materials**

| Material | Property | Temperature (℃) | Value | Reference |
|---|---|---|---|---|
| 304 Stainless Steel | Conductivity | 21 | 14.9 W/m/K | [3.1] |
| | | 38 | 15.0 W/m/K | |
| | | 93 | 16.1 W/m/K | |
| | | 149 | 16.9 W/m/K | |
| | | 205 | 18.0 W/m/K | |
| | | 260 | 18.9 W/m/K | |
| | | 316 | 19.5 W/m/K | |
| | | 371 | 20.4 W/m/K | |
| | | 427 | 21.1 W/m/K | |
| | | 482 | 22.0 W/m/K | |
| | | 538 | 22.8 W/m/K | |
| | | 593 | 23.5 W/m/K | |
| | | 649 | 24.2 W/m/K | |
| | | 705 | 25.1 W/m/K | |
| | | 760 | 25.8 W/m/K | |
| | | 816 | 26.5 W/m/K | |
| | Density | - | 7900 kg/m$^3$ | [3.2] |
| | Specific Heat | 21 | 483 J/kg/K | [3.1] |
| | | 38 | 486 J/kg/K | |
| | | 93 | 506 J/kg/K | |
| | | 149 | 520 J/kg/K | |
| | | 205 | 535 J/kg/K | |
| | | 260 | 544 J/kg/K | |
| | | 316 | 551 J/kg/K | |
| | | 371 | 559 J/kg/K | |
| | | 427 | 562 J/kg/K | |

**Table 3-5: Thermal Properties of Packaging Materials**

| Material | Property | Temperature (℃) | Value | Reference |
|---|---|---|---|---|
| | | 482 | 570 J/kg/K | |
| | | 538 | 577 J/kg/K | |
| | | 593 | 583 J/kg/K | |
| | | 649 | 585 J/kg/K | |
| | | 705 | 591 J/kg/K | |
| | | 760 | 596 J/kg/K | |
| | | 816 | 601 J/kg/K | |
| Depleted Uranium | Conductivity | 0 | 23.1 W/m/K | [3.3] |
| | | 400 | 32.5 W/m/K | [3.3] |
| | Density | - | 18,650 kg/m$^3$ | [3.4] |
| | Specific Heat | 0 | 117.5 J/kg/K | [3.3] |
| | | 300 | 142.0 J/kg/K | |
| Cork | Conductivity | - | See Figure 3-3 | [3.7] |
| | Density | - | 290 kg/m3 | [3.7] |
| | Specific Heat | - | 1650 J/kg/K | [3.7]e |

During a fire the cork experiences temperatures up to ~800°C. No measurements of cork properties at high temperatures are available. However, the HAC thermal test has been performed on the Safkeg-LS 3979A package as detailed in report CTR 2009/21, this package uses the same cork specification as the HS design. The test has then been simulated using the LS model in order to validate the model and, to demonstrate the acceptability of the thermal properties assumed for the cork. It was found that, in order to obtain agreement with the measured temperatures, the thermal conductivity of the cork needed to be increased by 50%. It should be noted that these thermal properties, validated against the furnace test, are 'effective' properties that include any effects of charring and shrinkage of the cork.

The NCT thermal test performed on the Safkeg-HS 3977A package has also been simulated using the model. As with the LS design it was found that, to produce the best agreement with the measured temperatures, the thermal conductivity of the cork needed to be reduced by 15%. Because cork is a natural material, this degree of variation in conductivity may well be possible. To ensure that all the calculations performed with the model are pessimistic, the lower, fitted conductivity has been assumed for the calculations of temperature during normal transport and the higher, measured thermal conductivity assumed for the calculations of temperature during the fire accident. Values used for the thermal conductivity of the cork are shown in Figure 3-2.

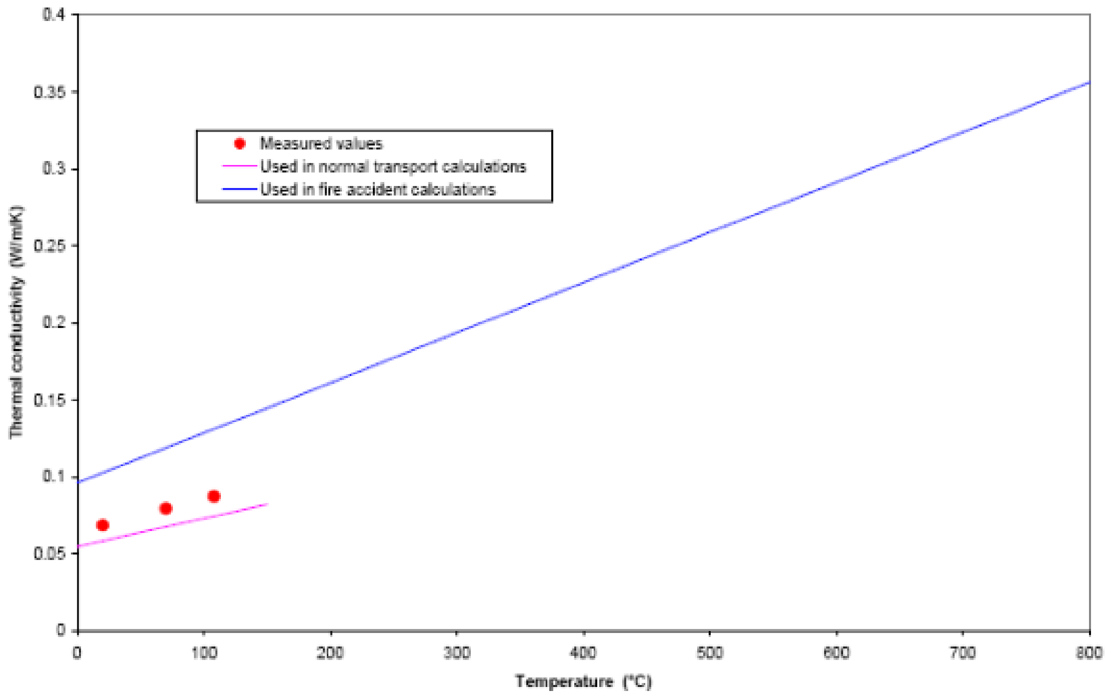



**Figure 3-2 Thermal Conductivity of Cork**

The package surface and internal emissivity values used in the thermal evaluation are given in Table 3-6. The emissivity of stainless steel can vary significantly depending upon the surface finish and level of oxidation. The values presented in Table 3-6 are shown to produce good agreement with the measured temperatures in the steady state heating test carried out in report CTR 2010/02 and are discussed in depth in Sections 3.3 and 3.4.2.

**Table 3-6: Emissivities used in the Thermal Model**

| Material | Condition | Value | Reference |
|---|---|---|---|
| 304 Stainless Steel | Internal surfaces | 0.2 | [3.8] |
| | External surface – Heating test and NCT | 0.25 | [3.8] |
| | External surface – fire test | 0.8 | [3.9] |
| Cork | All conditions | 0.95 | [3.10] |
| Depleted Uranium | Internal surfaces (un-oxidised) | 0.31 | |

### 3.2.2 Component Specifications

The components that are important to thermal performance are the outer keg, the cork packing material, the containment vessel and the containment seal. The outer keg and the containment vessel are manufactured from stainless steel 304L with the containment seal manufactured from Ethylene Propylene rubber.

The allowable service temperatures for all the components cover the maximum and minimum temperatures anticipated during NCT and HAC conditions of transport. The minimum allowable service temperature for all components is less than or equal to -40°C. The maximum service temperature for each component is determined from the temperatures calculated from the thermal model.

The upper temperature reached by the stainless steel in the keg is 102°C for continuous operations and 788°C for short term operations. The upper temperature reached by the stainless steel in the containment vessel is < 163°C for continuous operations and 210°C for short term operations under HAC conditions.

The allowable temperature limit for steel when relied upon for structural support is 427°C as specified in ASME Section II Part D [3.1]. During the HAC test the temperature of the keg skin exceeds this temperature for a short period of time. During a fire the steel is providing shielding to the cork from the direct exposure of the flames, its main function is not providing structural support therefore the maximum allowable temperature it can reach is 1427°C, which is the melting point of steel.

The depleted uranium shielding reaches a maximum temperature of 198°C during HAC conditions. The depleted uranium does not provide any structural function therefore it is limited by its melting point of 1130°C.

The cork is unaffected by temperatures up to 140°C and hardens slightly by 160 °C which is higher than the maximum temperature for the cork packing under NCT where cork temperatures may reach 151 °C for a thin layer of the cork adjacent to the CV. Under HAC conditions the cork reaches a maximum temperature of 788°C. Cork ablates under high temperatures and leaves a low density carbonaceous layer which provides insulation equivalent to still $CO_2$.

The upper temperature reached by the containment seal is 151°C for continuous operation (NCT conditions), and 196°C for short term operation (HAC conditions). These temperatures are within the allowable range of the O-ring material properties. The O-rings are specified as Ethylene Propylene rubber to ASTM D2000 M3 BA 810 A14 B13 F17 Z1, where Z1 stands for hardness of 75±5 IRHD (or Shore A) (see drawings in Section 1.3.2). EP has a recommended temperature range of -57°C (-70°F) to 150°C (302°F) for continuous static and dynamic use with a maximum temperature of up to 204°C (400°F) for 2 hours duration as specified in the Parker O-Ring Handbook [3.11]. The ASTM D2000 standard F17 ensures that the O-ring material is suitable for use at -40°C. The critical characteristic tests specified section 8.3.2 provides assurance that the material supplied for use in packages, provides the required degree of sealing at 150$^{o}$C for 1000 hours and at 200$^{o}$C for 24 hours.

Under HAC conditions it is anticipated from the LS Furnace test, that the O-ring remains above 150$^{o}$C for 8 ¼ hours reaching a maximum temperature of 196$^{o}$C. Therefore the O-rings operate outside of the temperature ranges specified. In order to validate the O rings for use, each batch of O-rings will be tested to ensure they meet the critical requirement of remaining leak tight after 24 hours at 200$^{o}$C - the test is specified in the drawings in section 1.3.3.

## 3.3 Thermal Evaluation under Normal Conditions of Transport

The Safkeg-HS 3977A package has been evaluated for compliance with 10 CFR 71 by thermally modeling the package. The thermal model has been validated by comparison against both an experimental self heating test carried out on the 3977A package (simulating normal conditions of transport) and a furnace test (simulating the fire accident), carried out on a similar package 3979A.

NCT Thermal Test

A 30 W cartridge heater located inside an aluminum block was placed in the cavity of the containment vessel. The package was orientated in the vertical position on a wooden board covered with aluminum foil. The temperature of the package was monitored using thermocouples located in seven positions on and in the package three thermocouples on the containment vessel surface, one on the top cork, one on the keg liner and two on the keg surface. Temperatures were logged every minute until the package temperature reached equilibrium. The surface temperature of the package was then mapped using thermocouples attached to the surface of the package and a hand held digital thermometer. The package was repositioned in the horizontal orientation and the temperatures logged until the package reached thermal equilibrium. The surface temperature of the keg was mapped using thermocouples attached to the surface of the package and a hand held digital thermometer.

Thermal Model

The analytical model is described in detail the Report AMEC/6335/001 (Section 3.5.2).

### 3.3.1 Heat and Cold

The finite element model has been used to determine the temperature of the container under normal conditions of transport in the absence of solar insolation as described in the report AMEC/6335/001 (Section 3.5.2).

The maximum temperatures reached, under NCT with no insolation and ambient of 38$^{o}$C, at the containment seal and on the keg surface are given in Table 3-2. As shown the maximum temperature of the accessible surface is 42$^{o}$C which is reached on the keg lid, the base of the keg reaches 45$^{o}$C however this surface is not accessible and therefore not considered. This demonstrates that the package is capable of fulfilling the requirements of 71.73 (g) as the accessible surface temperature is less than 50°C with maximum contents heat load of 30W.

The package temperatures have also been modeled under normal conditions of transport and subject to solar insolation as described in the report AMEC/6335/001 (Section 3.5.2).

Figure 3-3 shows the transient temperature at various locations on the outer surface of the keg with a 30W heat load. The highest temperatures occur on the top of the container because the insolation flux is greater on the top than on the side. The maximum predicted temperature, which occurs on the top, is 102°C. Figure 3-4 shows the transient temperature at the inner containment vessel lid seal. It can be seen that the maximum temperature has effectively been reached after 1½ days. The maximum seal temperature is predicted to be 146°C. Figure 3-5 shows 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 listed. Each component has a thermal margin with the smallest being the containment seal with a thermal margin at 4°C.

For the NCT cold evaluation the package is assumed to be in an ambient of -40°C, with zero insolation and zero heat decay. No analysis has been carried out because it has pessimistically been assumed that the package and all the components will eventually reach thermal equilibrium at -40°C. This temperature is within the allowable service limits for all the components.

The temperatures reached are within the bounding conditions for the package which are as follows:

| NCT Operating Condition | CV |
|---|---|
| Assumed Max. Temperature | °C |
| Max. Pressure | 7 bar (700kPa) gauge<br>8.0 bar (800kPa ) abs |
| Min. Temperature | -40°C |
| Min. Pressure | -1 bar (-100kPa) gauge<br>0 kPa (0 bar) abs |

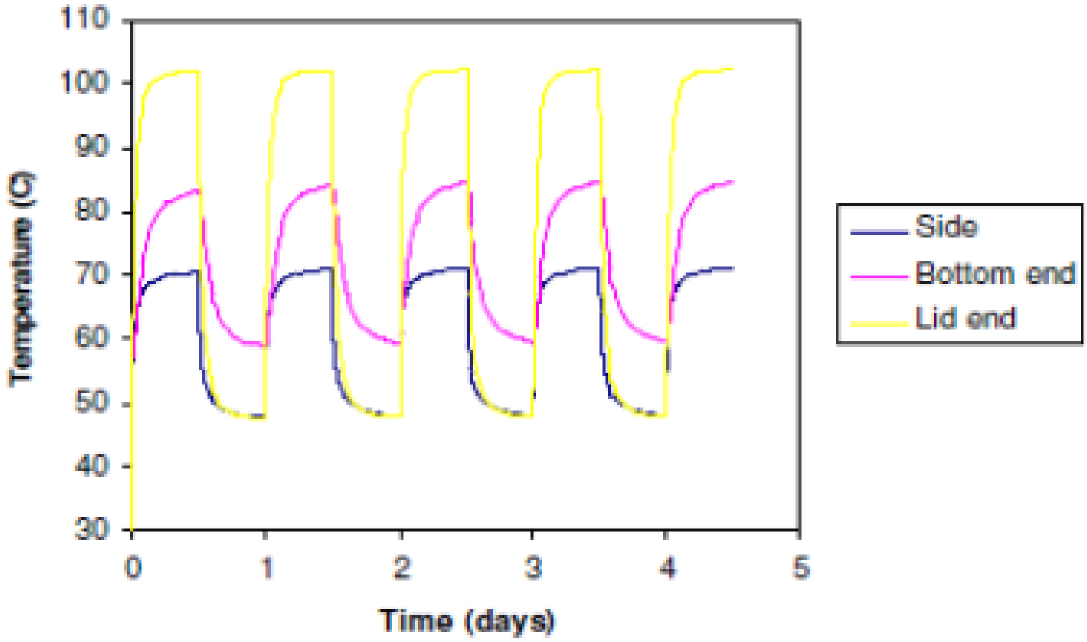



**Figure 3-3 Predicted temperature on the Outside of the Keg During Normal Transport with Insolation**

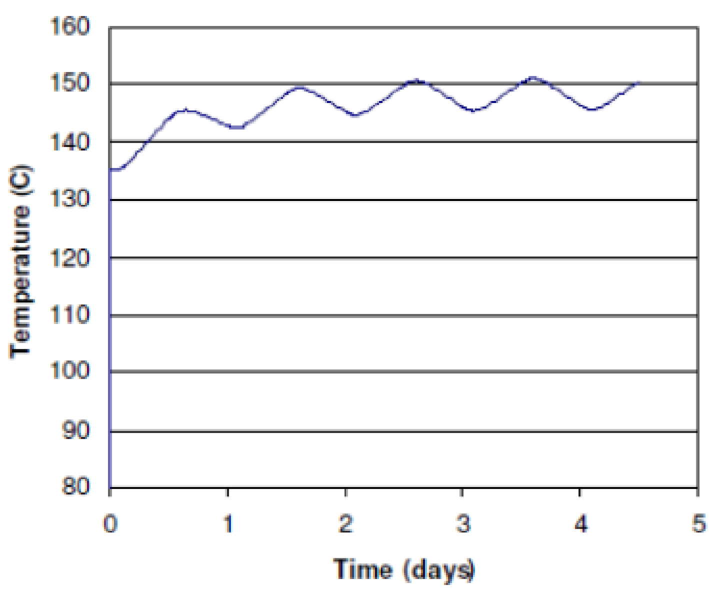



**Figure 3-4 Predicted Temperature at the Containment vessel lid Seal During Normal Conditions of Transport with Insolation**

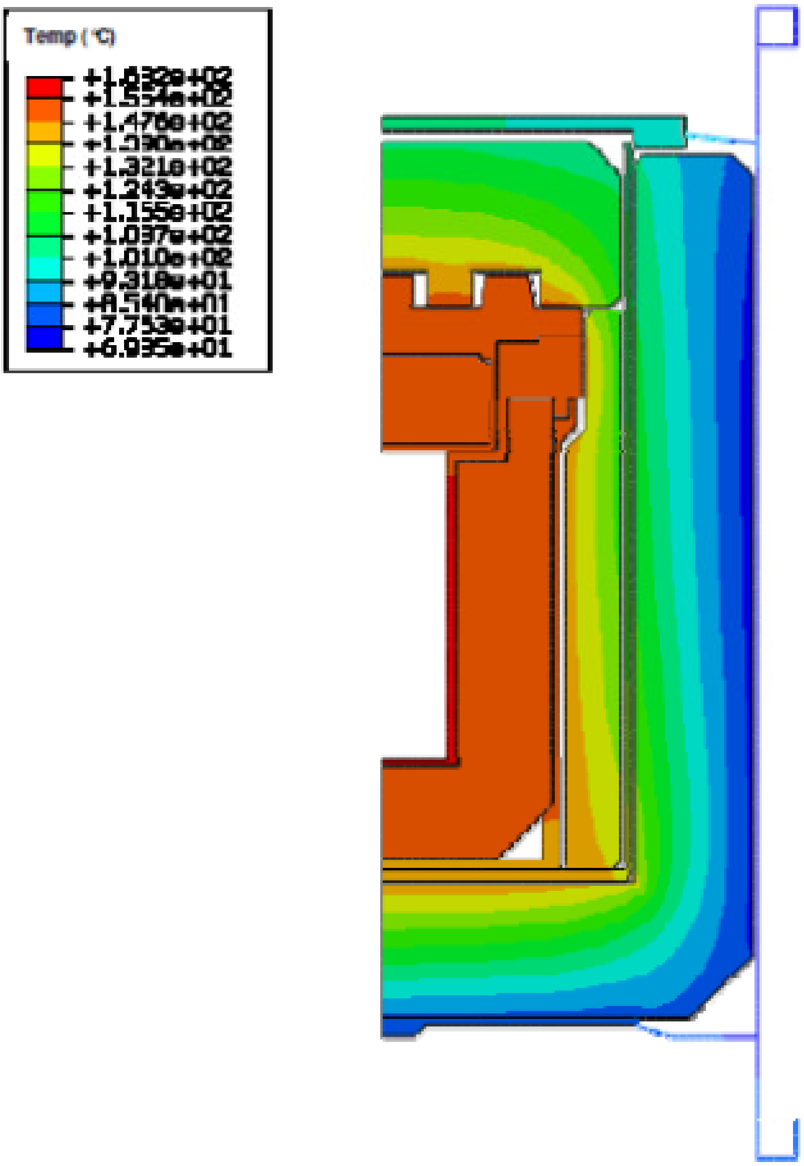



**Figure 3-5 Predicted Temperature Profile under Normal Conditions of Transport With Solar Insolation and 30W heat load**

### 3.3.2 Maximum Normal Operating Pressure [71.33 (b)(5)]

The MNOP is 7 bar (700 kPa) gauge.

For solid contents emitting 30W, under NCT the maximum temperature of the CV is 163°C and the maximum temperature of the Shielding Insert and air within the CV is 173°C. Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the Shielding Insert, calculated according to Boyle's and Charles' Laws, would be 1.63 bar (163 kPa) gauge (see Calculation Sheet CS 2012/02),which is well within the design envelope.

For liquid contents emitting 5W, under NCT maximum temperature of the CV is 78°C and the maximum temperature of the Shielding Insert and air within the CV is 80°C. (Section 3.1.3, Table 3-1). There is no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C) as the temperature is < 100°C.

The bounding temperatures and pressures for the package are as follows.

| NCT Operating Condition | CV |
|---|---|
| Assumed Max. Temperature | 160°C |
| Max. Pressure | 800kPa (8.0 bar) abs |
| Min. Temperature | -40°C |
| Min. Pressure | 0 kPa (0 bar) abs |

The contents to be shipped include research samples in liquid form for which the details are not currently known and therefore an analysis of gas generation by radiolysis is not possible. Therefore, for liquid contents as specified for Contents Type CT-4 and CT-5, the shipper is required to limit the contents such that "Liquid contents must be such that $H_2$ concentration < 5% and pressure <7bar g for shipment up to 1 year".

The heat load for liquid contents is limited to 5W for which the calculated maximum temperature of the CV under NCT is 78°C (Section 3.1.3, Table 3-1). There is therefore no pressure increase due to the vapour pressure of the liquid contents (the liquid contents are aqueous with a boiling point of 100°C).

## 3.4 Thermal Evaluation under Hypothetical Accident Conditions

### 3.4.1 Initial Conditions

The initial conditions used for the thermal model of the fire test are taken at the end of a 12 hour period of insolation under Normal Conditions of Transport with a content decay heat of 30 W. All components are at their maximum temperatures as shown in Table 3-2.

A series of NCT and HAC drop and penetration tests was carried out on a prototype package (see Section 2.12.2). These tests caused denting of the top and bottom skirts of the package with minimal damage to the keg body.

These ‘skirts’ are not significant to the thermal performance and it is judged that the damaged ‘skirt’ would provide greater protection in a fire than an undamaged ‘skirt’ (since, when bent over, it will provide shielding of the top and bottom of the keg from the fire). The finite element model used to model the fire accident was therefore unchanged from that used to model Normal Conditions of Transport.

### 3.4.2 Fire Test Conditions [71.73 (c)(4)]

The thermal assessment of the package under fire conditions has been carried out using a finite element model and validated against a fire test carried out on a prototype Safkeg-LS 3979A package. The model and analysis used is described in detail in section 5 of the Report SERCO/TAS/5388/002 (Section 3.5.2).

### 3.4.3 Maximum Temperatures and Pressure

The maximum temperatures experienced by the components of the Safkeg-HS 3977A package calculated under a HAC fire test, with an ambient temperature of 38°C and insolation, are given in Table 3-3. The temperature each component reaches during the HAC thermal test is within it maximum allowable service temperature.

At the end of the heating phase the external surface of the keg is close to the temperature of the fire (800°C). Figure 3-6 shows the predicted temperature on the exterior surface of the keg. The outer skin of the keg heats up and cools down rapidly because it is insulated from the inner containment vessel by the cork. The temperature of the keg lid changes more slowly than that of the side or base because the lid is thicker than the outer shell and therefore has a greater thermal capacity.

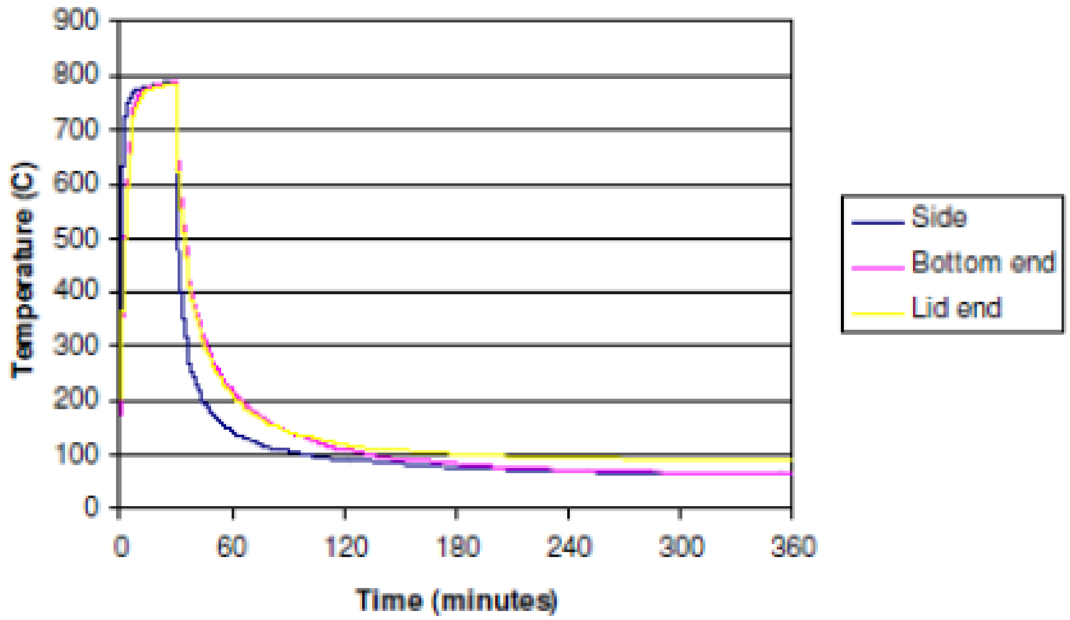



Figure 20 – Predicted Temperature on the Outside of the Keg during the Fire Accident – Internal Heat Load of 30W

**Figure 3-6 Predicted Temperature of the Outside of the Keg during the Fire Test and 30W heat load**

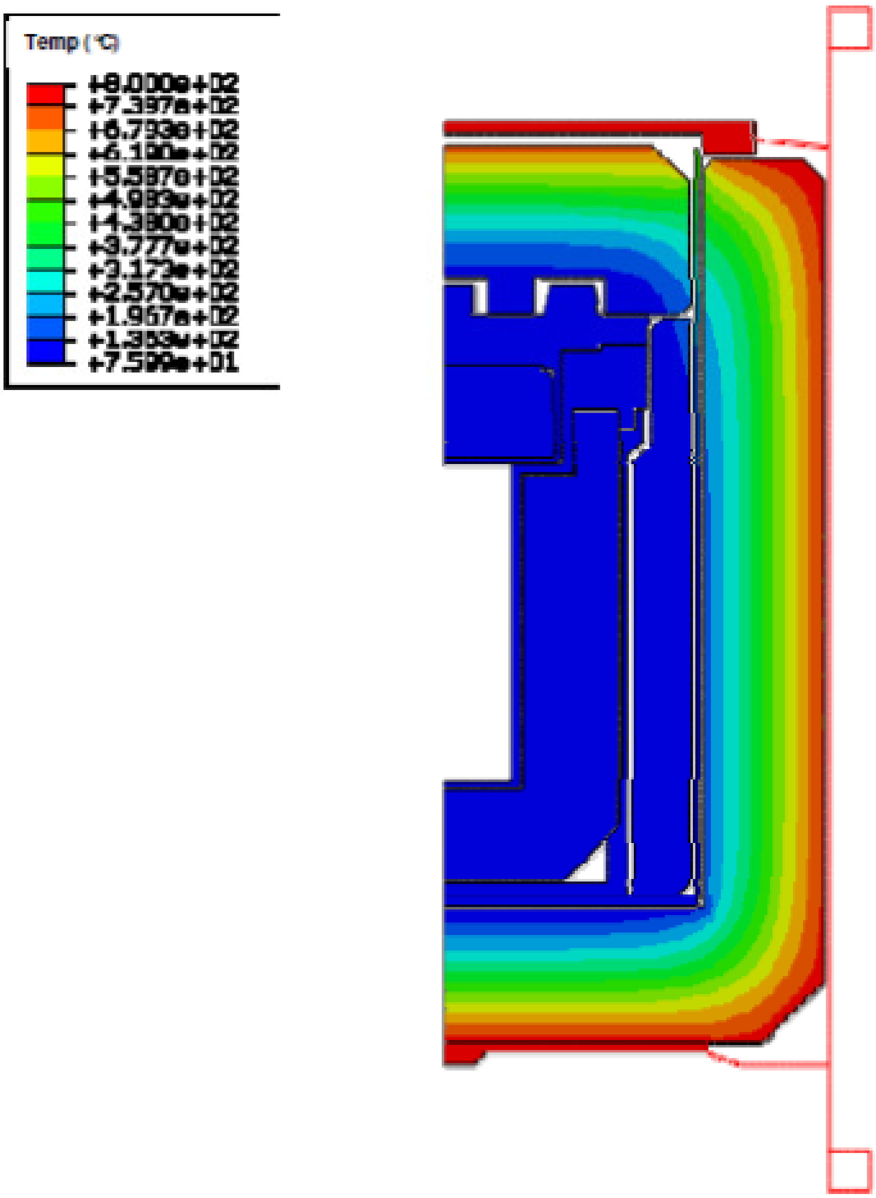



**Figure 3-7  Predicted Temperature Profile at the end of the Heating Phase of the Fire Accident and a 30 W heat load**

Figure 3-8 shows the predicted temperature of the inner containment vessel seal during and after the thermal test. The lid seal reaches a maximum temperature of 192°C after 3 ½ hours. A similar maximum temperature is experienced by the depleted uranium shielding this temperature is well below its melting point of 1130°C.

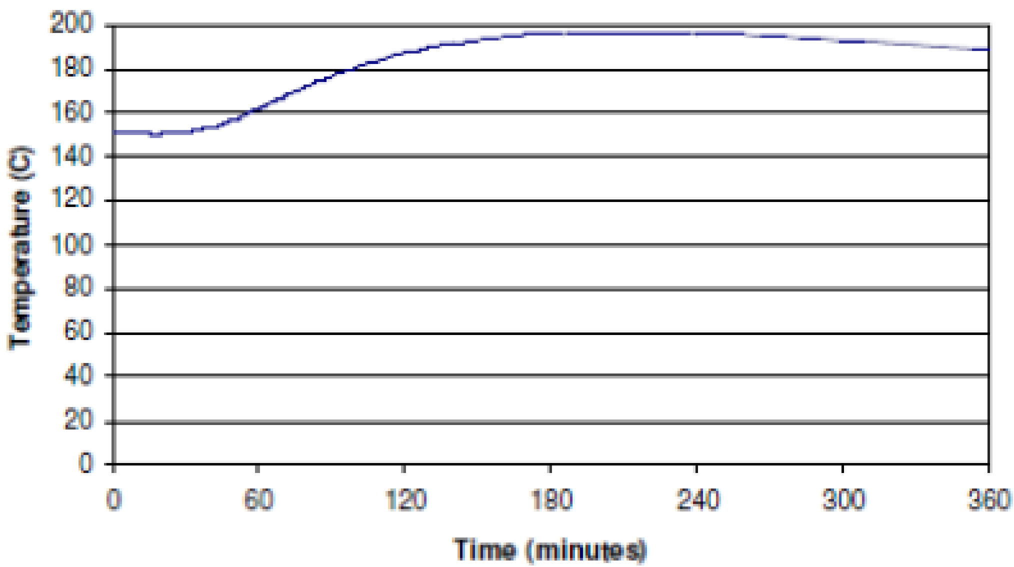



Figure 21 – Predicted Temperature of the Containment Vessel Lid Seal during the Fire Accident – Internal Heat Load of 30W

**Figure 3-8 Predicted Temperature of the Containment Vessel Lid Seal during the Fire Test with a 30 W source**

The Design Pressure of the CV is 10 bar (1,000 kPa) gauge.

For solid contents emitting 30W, under HAC the maximum temperature of the CV is 208°C and the maximum temperature of the Shielding Insert and air within the CV is 218°C. Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the Shielding Insert, calculated according to Boyle's and Charles' Laws, would be 1.8 bar (180 kPa) gauge (see Calculation Sheet CS 2012/02 in section 2.12.2), which is well within the design envelope.

For liquid contents emitting 5W, under HAC the maximum temperature of the CV is 132°C and the maximum temperature of the insert is 134 °C (Section 3.1.3, Table 3-1). Assuming the content were loaded at 20°C and a pressure of 1 bar abs, the pressure at the maximum temperature of the CV, calculated according to Boyle's and Charles' Laws, would be 1.38 bar (138 kPa) gauge. However, the vapour pressure of the liquid contents (the liquid contents are aqueous) would be 3.0 bar gauge (from steam tables). Therefore the maximum pressure within the CV would be 3.0 bar gauge which is well within the design envelope.

The temperatures reached are within the bounding conditions for the package which are as follows:

| HAC Operating Condition | CV |
|---|---|
| Assumed Max. Temperature | 200°C |
| Max. Pressure | 10 bar (1,000 kPa) gauge<br>11 bar (1,100 kPa) abs |
| Min. Temperature | -40°C |
| Min. Pressure | -1 bar (-100 kPa) gauge<br>0 bar (0 kPa) abs |

### 3.4.4 Maximum Thermal Stress

As discussed in section 2.7.4.3 the NCT heat calculations bound the HAC test results. The resulting stresses from the NCT heat results are discussed in section 2.6.1.3 and 2.6.1.4. All the stresses calculated are within the allowable limits for the containment vessel.

### 3.4.5 Accident Conditions for Fissile Material Packages for Air Transport [71.55(f)]

Not applicable – air shipment of fissile material is not specified.

## 3.5 Appendix

### 3.5.1 References

[3.1] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, 2001 Edition

[3.2] Design Manual for Structural Stainless Steel (Second edition), The Steel Construction Institute, Building series, Vol 3

[3.3] Edwards A.L, 'For Computer Heat-Conduction Calculations a Compilation of Thermal Properties Data', UCRL-50589, 1969

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[3.13] Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material', 2005 Edition, IAEA Safety Guide No. TS-G-1.1 (Rev. 1), 2008.

### 3.5.2 Supporting Documents

| Document Reference | Title |
|---|---|
| AMEC/6335/001 | Thermal Analysis of the SAFKEG HS Design |
| CS 2012/01 | SAFKEG-HS 3977A – Maximum temperature of CV inserts |