Thermal Analysis of the SWTC-285 and –150 Transport Containers

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ABSTRACT

Nirex is developing transport container designs capable of transporting the UK's intermediate level waste packages from their sites of arising to future waste management facilities. The transport package described in this paper is the Standard Waste Transport Container. Two types of SWTC have been investigated to date, with wall thicknesses of 285mm and 150mm. These are referred to as the SWTC-285 and SWTC-150 respectively.

This paper describes the assessment of the thermal performance of the SWTC-285 and SWTC-150. The temperature of the containers both during normal transport and the regulatory thermal test are assessed using a Finite Element model. The distortion of the container due to thermal stresses during the thermal test is also calculated and the resulting gap at the lid seals determined.

INTRODUCTION

UK Nirex Limited (Nirex) is responsible for investigating options for the safe, environmentally sound, and efficient, disposal of the United Kingdom's intermediate and certain low level wastes. Part of that responsibility involves the provision of advice to the UK waste producers on the suitability of their waste packaging proposals against the foreseen requirements for future storage, transport, handling and potential disposal. In order to be confident that the advice is fully reflective of transport issues, Nirex is developing the range of transport containers necessary to transport radioactive waste from sites of arising to future waste management facilities.

Nirex had previously developed a design of transport package, the RSTC, for transporting the full range of Nirex standard ILW waste containers to Sellafield, where the repository was originally planned to be located. However, the repository may now be located elsewhere in the UK and the waste containers currently at Sellafield will need to be transported to this new location. Some BNFL waste containers differ from the Nirex design, however, and will not fit inside the RSTC.

A new range of packaging designs, entitled the Sellafield Waste Transport Containers, are therefore being developed. Two types of SWTC have currently been designed with wall thicknesses of 285mm and 150mm. These are referred to as the SWTC-285 and SWTC-150 respectively.

Analyses have been carried out to assess the impact and thermal performance of the SWTC-285 and SWTC-150 containers against the IAEA Regulations[1]. This paper describes the assessment of the thermal performance and covers the temperature of the containers under normal transport conditions and the temperatures and resulting thermal distortions experienced during the regulatory thermal test.

DESCRIPTION OF THE SWTC-285 AND -150 CONTAINERS

The SWTC-285 and –150 containers are both designed to transport approximately 3m^3 of waste packed into drums or boxes. The SWTC-285 has a thicker wall to provide greater shielding so that it can transport waste with higher activity.

The general design of the SWTC-285 and –150 containers are very similar. Both are cuboid in shape, approximately 2.2m high and 2.5m square, and both have bolted lids. The general design of the SWTC-150 is shown in Figure 1. Both containers are intended to be constructed from forged stainless steel.

To provide impact protection, both the SWTC-285 and –150 have projections called up-stands on the top of the body and lid. These will deform in a lid-down drop test, thereby reducing the effect of the impact on the container body, lid bolts and contents. Vertical ribs are similarly provided around each of the corners of the container to provide protection against side impacts. Both containers are provided with a crushable honeycomb material on the inside of the container, below the lid, to minimise the effect of the contents impacting upon the lid during a lid-down drop test.

Both the SWTC-285 and –150 containers are clad with thermal insulation on the outside. On the SWTC-285, a 25mm thick layer of cork is provided over the lid and most of the sides. On the SWTC-150, all of the sides (excluding the vertical ribs) are covered by a 25mm thick layer of cork. A 10mm thick layer of microtherm is also provided below the base of the container. Both the cork and microtherm are clad in stainless steel.

GENERAL METHODOLOGY OF THE THERMAL ANALYSIS

The objective of the thermal assessments was to demonstrate that the proposed designs of the SWTC-285 and -150 containers would meet all the requirements, with respect to thermal performance, specified in the IAEA Regulation [1] for a type B container. The thermal performance of the containers was assessed with 3-dimensional Finite Element models using the FEAT [2] code.

The heat generated by the waste inside the containers was represented in the calculations, but the waste packages themselves were not explicitly modelled. This was a pessimistic assumption since the waste packages would be expected to absorb some of the heat entering the SWTC-285 and -150 containers during the thermal test. Making this simplification ensured that the assessed performance of the containers did not depend upon the type or volume of waste being transported.

The FEAT code is capable of performing both stress and thermal calculations. The distortion of the SWTC-285 and -150 containers due to thermal stresses was calculated at frequent intervals during the thermal test and the resulting gap at the lid seal determined. The temperature distribution through the containers, at the time when FEAT predicted the seal gap to be greatest, was passed to the ABAQUS [3] code for a more detailed structural assessment to be performed. These calculations of thermal distortions are described in this paper. Structural calculations of the impact performance of the SWSTC-285 and -150 containers were also performed, using the DYNA3D code [4]. These calculations, which assessed the performance of the containers during the regulatory drop tests and punch tests, are not reported in the current paper.

A vent valve is located in the lid of both the SWTC-285 and –150 containers. These vent valves are complex structures made up of several components with narrow air gaps between them. It was not considered practical to include a detailed model of the vent valves in the 3-dimensional models of each container. A separate, detailed, axi-symmetric model was therefore used to determine the thermal performance of the vent valves during the thermal test.

DESCRIPTION OF THE FE MODELS

The Finite Element models representing the SWTC-285 and –150 containers were generally similar. The mesh of the SWTC-150 model is shown in Figure 2. The model is 3-dimensional but, because of the symmetry of the container, only a 1/8 segment of the whole container is represented. The model shown contains 47,000 elements and 210,000 nodes and explicitly represents:

- The stainless steel body
- The stainless steel lid
- The up-stands on the top of the body and lid
- The lid pintle
- The ribs on the outside of the body
- The lid bolts
- The cork on top of the lid
- The cork on the outside of the body
- The microtherm on the bottom of the body
- The stainless steel cladding around the cork and microtherm

The body and lid were not represented as being physically connected, apart from through the bolts, as distortion of the lid and body during the thermal test was expected to result in a small gap being created between the seal faces. Heat transfer across this narrow gap was modelled via boundary conditions.

The model shown in Figure 2 represents the SWTC-150 container in an undamaged state. However, the IAEA Regulations [1] require the thermal test to be performed on a container which has already been subjected to the Regulatory impact tests. These include a 9m drop test onto a rigid flat surface and a 1m drop onto a 150mm diameter punch.

The response of the SWTC-285 and –150 containers to the Regulatory impact tests had been assessed using the DYNA3D code [4]. From the 9m drop test the most severe damage, with respect to thermal performance, was predicted to be the deformation of the up-stands on the body. From the punch test the most severe damage, with respect to thermal performance, was predicted to be the removal of an area of the cork insulation adjacent to the lid bolts.

Modified Finite Element models of both the SWTC-285 and –150 containers were generated representing the containers damaged by the drop and punch test. A total of three models were therefore produced for each container. These models represented:

- The undamaged container
- The containers damaged by the drop test
- The container damaged by the punch test

For each of these models, calculations were performed to determine the temperature distribution through the containers both under normal transport condition and during the IAEA Regulatory thermal test.

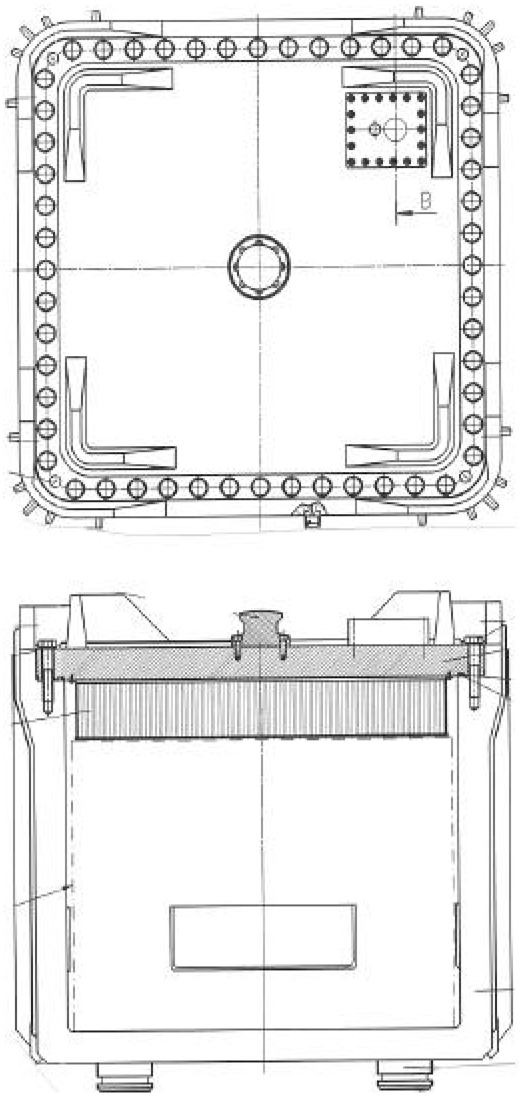

Figure 1 – General Arrangement of the SWTC-150 Container

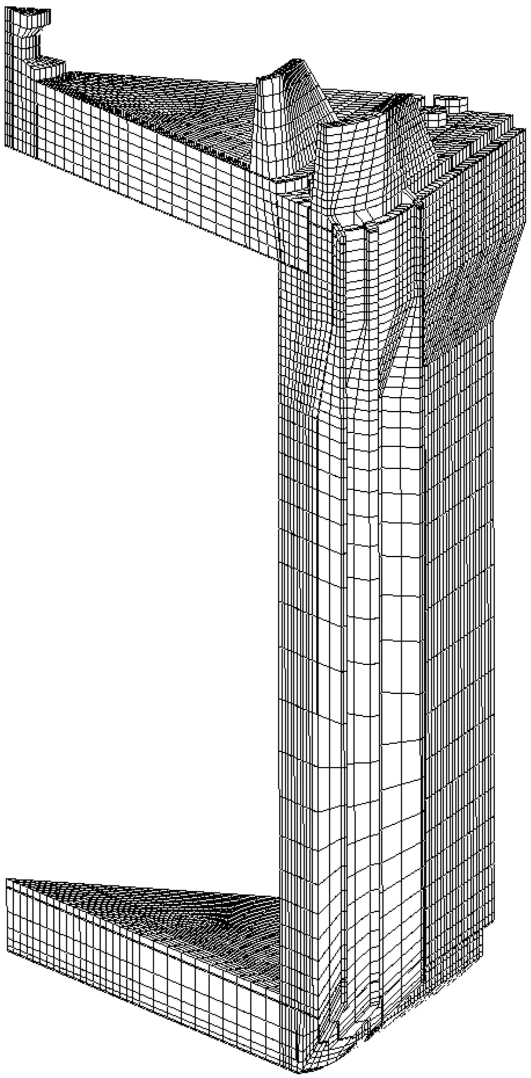

Figure 2 – Finite Element Mesh of the SWTC-150 Container

BOUNDARY CONDITIONS

The boundary conditions used in the calculation of temperatures during normal transport were based upon the requirements for a type B(U) container [1]. An ambient temperature of 38°C was therefore modelled and solar radiation included. Because the thermal capacities of the SWTC-285 and –150 are very large, the insolation fluxes specified in the IAEA Regulations to be applied for 12 hours each day were halved to give steady average fluxes. The insolation flux was modelled by modifying the black body temperature to which the surfaces exchange heat by radiation. This temperature is 84.8°C on the top and 51.7°C on the side, obtained from the radiative heat exchange equation:

$$Q = \sigma\left(T_e^{4} - T_{amb}^{4}\right)$$

where	Q	is the insolation heat flux (400W/m^2 and 100W/m^2 respectively)
	σ	is Stefan's constant,
	T_e	is the effective black body temperature (in absolute units),
and	T_{amb}	is the ambient temperature (311.2K).

Radiation was modelled to a black body surface around each container. A ray-tracing calculation, including the effects of reflection, was used to determine the radiation heat flux to or from each individual element.

Natural convection was modelled using heat transfer coefficients derived from standard published correlations.

The waste inside the SWTC-285 and –150 was assumed to be generating 200W of heat. This heat load was represented as a constant heat flux applied uniformly over the inside of the body and lid.

The boundary conditions used in the calculation of temperatures during the heating phase of the thermal test represented the container being enveloped in a pool fire at a temperature of 800°C, as specified in the IAEA Regulations [1]. The Regulations specify that the fire should be assumed to have an emissivity of 0.9. Reflection of radiation from the fire is unphysical. Radiation was therefore modelled as being from a black surface at a temperature of 772.3°C, obtained from the equation:

$$t_{eff}^{4} = 0.9 \times t_{fire}^{4} + 0.1 \times t_{amb}^{4}$$

where t_{eff}, t_{fire} and t_{amb} are the absolute temperatures of the effective black body source, the fire and the ambient respectively.

The top and sides of the SWC-285 and -150 have a complex shape. Radiation was therefore modelled to a black body surface surrounding each container. This is illustrated in Figure 3. A ray-tracing calculation, including the effects of reflection, was used to determine the radiation heat flux to or from each individual element. To represent the opacity of real flames, any surface more than 0.2m away from the up-stands, lid pintle or ribs was assumed to see only flames at an effective temperature of 772.3°C.

For convection heat transfer from the fire, a convection coefficient of $15W/m^2/K$ was used. This is pessimistic compared to the value of 'about $10W/m^2/K$' recommended by the IAEA Advisory Material [5].

During the cooling phase of the thermal test, the same boundary conditions were applied as during normal transport. The full values of solar insolation specified by the IAEA Regulations were applied in this case, however, representing the fire test occurring during the daytime.

TEMPERATURES DURING NORMAL TRANSPORT

A similar temperature distribution during normal transport was predicted for both the SWTC-285 and – 150 containers. The internal heat load of 200W was found to have a negligible effect upon the container temperatures, the resulting temperature distribution being dominated by ambient conditions and solar insolation. The temperature of the containers was predicted to be about 40°C on the bottom and to increase with height to about 60°C on the top. This reflects the heat flux from solar insolation increasing from zero on the bottom surface to $400W/m^2$ average on the top.

TEMPERATURES DURING THE THERMAL TEST

Figure 4 shows the predicted temperature of the undamaged SWTC-150 at the end of the 30 minute heating phase of the thermal test. Temperatures approaching 800°C are predicted on the cladding around the cork and microtherm insulation, but the temperatures of the body and lid of the container have not changed significantly from those predicted during normal transport. A modest rise in temperature is predicted around the lid bolts, an area which is not insulated. A more significant temperature rise, to over 600°C, is predicted at the ends of the up-stands, ribs and lid pintle.

During the cooling phase of the thermal test, the heat stored in the hot ribs and up-stands is gradually conducted into the container body and lid. The thermal capacity of the containers, especially the SWTC-285, is very large however and so the resulting rise in temperature is only modest. The highest temperatures were found to occur for the model which included damage from the punch test, due to the assumed removal of some of the cork insulation. For both the SWTC-285 and – 150, the peak temperature of the lid seal is predicted to be less than 180°C, well within its temperature limitations. This peak temperature occurs at around 1 hour after the start of the thermal test.

On the inside of the container, the lid is predicted to be the hottest surface on the SWTC-150, reaching an average temperature of 112°C 2½ hours after the start of the thermal test. On the SWTC-285 the base is the hottest surface because it is not covered by any insulation. It is predicted to reach an average temperature of 131°C. From these surface temperatures, and the predicted response of the waste packages, the pressure inside the containers was determined. For the SWTC-285, the maximum pressure during normal operation of 7 bar was predicted to increase to a maximum of 14 bar during the thermal test. For the SWTC-150, the pressure was only predicted to increase from 7 bar to 9 bar during the thermal test.

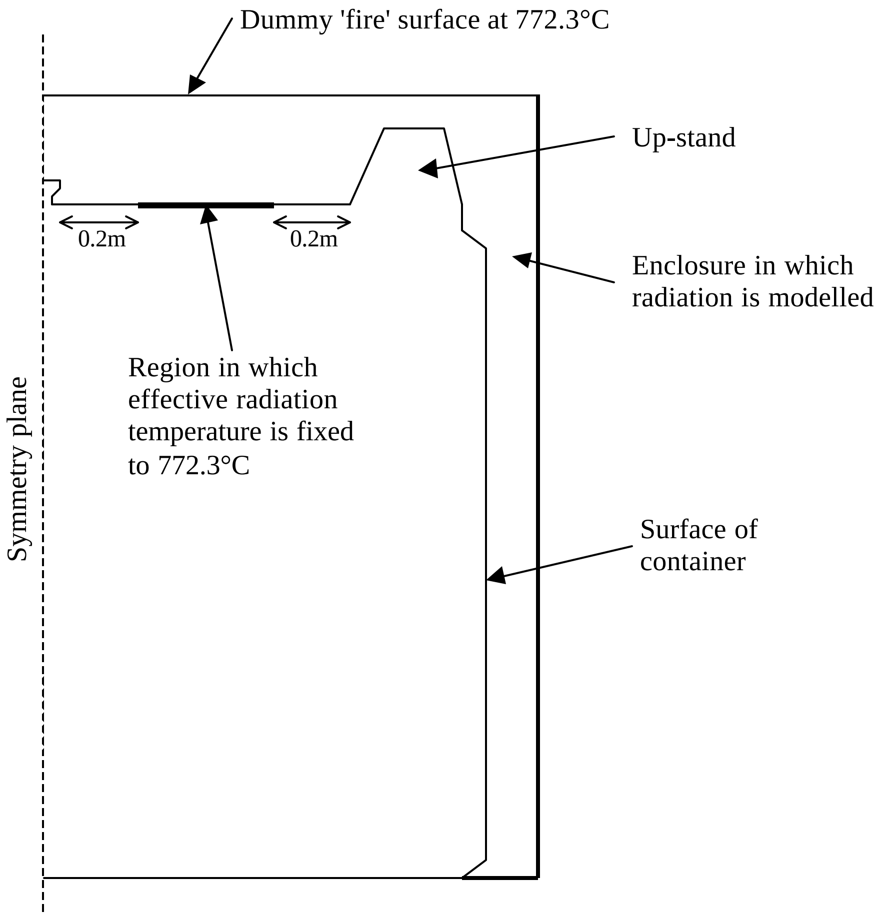

Figure 3 – The Modelling of Radiation from the Fire to the Surface of the Containers

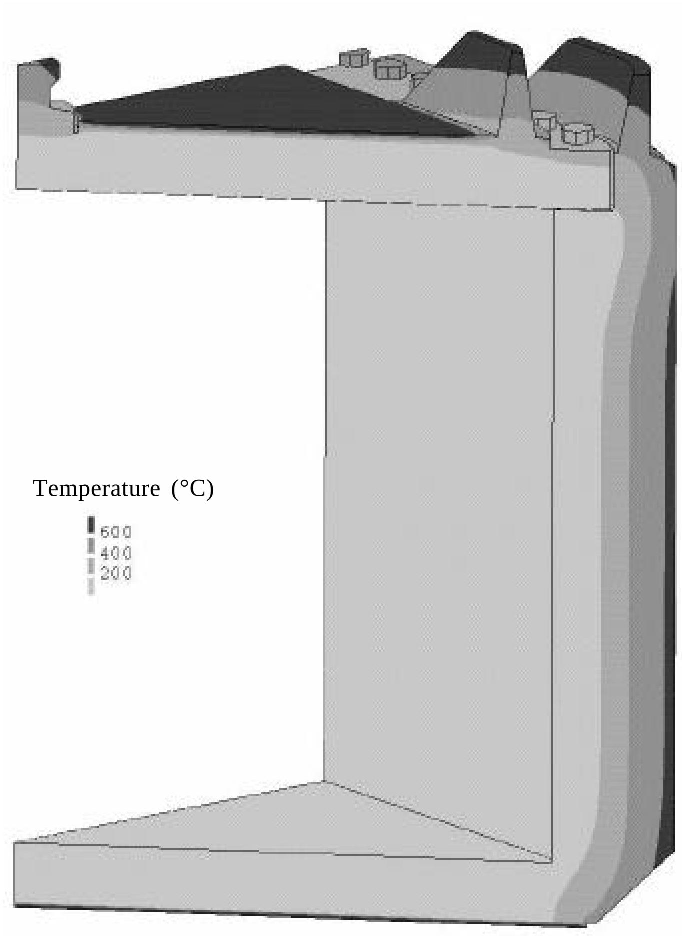

Figure 4 – Temperature of the SWTC-150 Container at 30 Minutes during the Thermal Test

SEAL GAP DURING THE THERMAL TEST

The FEAT calculations of thermal distortion during the thermal test showed that, for both the SWTC-285 and –150, the heat from the fire produced a bowing of the lid and body. The resulting gap around the lid seals was predicted to be greatest at the end of the heating phase of the thermal test, when the temperature gradients were a maximum.

To perform a more detailed analysis of the thermal distortion, the temperature distribution in each container and its lid at the end of the heating phase was passed to the ABAQUS [3] code. The insulation and its cladding were removed from the model for this analysis as they are structurally unimportant. The lid bolts were also removed and replaced by beam elements, attached to the body and lid using kinematic constraints. A pair of contact surfaces was defined on the underside of the lid and the sealing face of the body. It was assumed that there was no pre-load remaining in the bolts following the impact tests, which occur prior to the thermal test.

For the SWTC-285, the maximum gap around the inner lid seal due to thermal distortion was predicted to be 0.5mm and this maximum was predicted to occur at the corners of the lid. For the SWTC-150, the corresponding maximum gap around the inner lid seal was predicted to be 0.8mm, this maximum occurring 0.6m from the corner of the lid. Even when these gaps were added to the permanent distortion predicted to be caused by the impact tests, the resulting gaps were still sufficiently small that containment would not be lost from either container.

CONCLUSIONS

The thermal performance of two new designs of container for transporting waste packages has been assessed. The thermal performance of both the SWTC-285 and SWTC-150 has been shown to meet the requirements of the IAEA Regulations. All the seals are predicted to remain well within their temperature limits during the thermal test. The gap between the body and lid, around the lid seals, caused by thermal distortion during the thermal test, was also shown to remain sufficiently small for containment not to be lost.

REFERENCES

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3. ‘ABAQUS/Standard v5.8 User’s Manual’, Hibbitt, Karlsson and Sorensen Inc, 1998.

4. ‘LS-DYNA User’s Manual (version 940)’. Livermore Software Technology Corporation, 1997.

5. ‘Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition), Third Edition’, IAEA safety Series No 37, IAEA Vienna, 1987.