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MULTI-PURPOSE TRANSPORTATION PACKAGE – DESIGN AND LICENSING BY ANALYSIS

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ABSTRACT

Ontario Power Generation (OPG) has designed a new Type B(U) Multi-Purpose Transportation Package (MPTP) that will be capable of transporting radioactive payloads currently handled by two separate packages. The two payloads consist of either a liquid payload (tritiated heavy water) in a special container or a solid payload (contaminated purification media) in a shielded flask.

The MPTP is a third generation design that incorporates lessons learned from its predecessors and more than twenty-years of licensing and operating experience with the OPG Type B package fleet. Prior to the MPTP project OPG had designed and licensed its transportation packages using a combination of scale-model testing and computer analysis. The consistency of the results obtained through these two techniques provided OPG with the confidence to design and license the MPTP by analysis only.

Atomic Energy of Canada Ltd (AECL) provided detailed structural and thermal simulations of the MPTP, in both payload configurations, to support OPG's design and licensing efforts. The simulations addressed impact accident scenarios and the thermal conditions under normal and accident conditions as specified in the Canadian and IAEA regulations. Specifically, the order of postulated accidents is simulated such that the package initially experiences an impact and the damaged package is then subjected to an engulfing fire. Since the package deformation due to accidental impact affects the results of the thermal analysis, the predicted damage is included in the fire accident simulations. The MPTP design and licensing work was successful and OPG received Type B(U) certification of the design in 2006.

This paper presents the detailed computer models, describes the simulations, and highlights specific design improvements resulting from the impact and thermal analyses of the MPTP. Also information is provided on the manufacturing and commissioning of the first two MPTPs.

INTRODUCTION

The MPTP is a new Type B(U) package design with two major configurations: one to transport tritiated heavy water (moderator water used in CANDU nuclear reactors) to OPG's tritium removal facility; the other to transport contaminated purification media and other solid waste to OPG's storage facilities. The intention of the MPTP design is not to have packages that could be switched between payloads – there will be MPTPs dedicated to each payload. Instead OPG wants to maximize the commonality between the configurations to reduce licensing, spare parts, procedural and training overhead. The design of the MPTP is based on two existing older transportation package designs that are currently used to transport these payloads. Several enhancements to the original package designs have been incorporated in the MPTP to accommodate both payloads, facilitate leak-testing and provide other improvements. The basic package design is a payload secondary container, housed in a containment vessel, which is enclosed in a protective outer packaging.

As described in this presentation, the structural integrity of the package design was demonstrated by analysis of the package performance under accidental impact scenarios and the thermal conditions under normal and accident fire conditions as specified in the IAEA regulations [1]. The order of postulated accidents was simulated such that the package initially experienced an impact and the damaged package was then subjected to an engulfing fire. Since the package deformation due to accidental impact can affect the results of the thermal analysis, the predicted damage was included in the fire accident simulations. The series of simulations was used to verify the package design and aided in the design enhancements.

PACKAGE CONFIGURATION

The MPTP consists of an outer packaging, a containment vessel and either a secondary container with a liquid payload (Tritiated Heavy Water Container, THWC, **Figure 1**) or a secondary container with a solid payload (Shielded Flask **Figure 2)**. The outer packaging consists of a body, primary cover and a smaller central access cover, each made of polyurethane foam encased in Type 304L stainless steel. The primary cover is fastened to the body using a series of 24 ASME SA-193 Grade B8S long cap screws. Inside the outer packaging is the containment vessel. The containment vessel body, containment vessel primary lid and smaller central containment access plate are constructed from Type 304L stainless steel plates and forgings. The containment vessel primary lid is fastened to the vessel body through an outer bolting flange using a series of 12 ASME SA-193 Grade B8S cap screws. This seal area forms the primary containment boundary. At the centre of the containment vessel primary lid is a containment access plate that allows for access to fill/drain and vent fittings on the THWC lid. The containment access plate is attached to the containment vessel primary lid through a series of 6 countersunk ASME SA-193 Grade B8S cap screws. This area also forms part of the primary containment boundary. The THWC is also constructed from Type 304L stainless steel plates and forgings. The THWC lid is fastened to the container body through a bolting flange using a series of 12 ASME SA-193 Grade B8S cap screws. The THWC will contain approximately 5,200 kg of heavy water.

The Shielded Flask payload consists of a cylindrical steel and lead container holding radioactive filters or vessels. The Shielded Flask is surrounded at the top and bottom by stainless steel sheet encased polyurethane foam dunnage. The containment vessel is similar to the containment vessel configuration for the THWC payload except for the primary lid which omits the central access plate. The outer packaging can be identical to the configuration for the THWC payload or the central access cover can be omitted. Conservatively, the outer packaging with a central access cover configuration was evaluated in the analyses because of the potential vulnerability created by the central opening.

IMPACT AND THERMAL CONDITION SIMULATIONS

The purpose of this work was to verify the package design through analysis of the package simulations being exposed to the regulatory [1] 9 metre impact scenarios followed by the 30 minute engulfing fire at 800°C. During each impact scenario and fire simulation the package was scrutinized for the degree of component damage and evaluated to determine if the structural integrity and containment boundary was maintained. The four impact scenarios considered were: a centre of gravity over top edge drop; a flat end drop on the lid; a flat side drop; and a 1 metre drop of the package onto a steel pin. **Figures 3** to **6** show the overall deformation in each impact simulation of the MPTP (Shielded Flask payload configuration).

The finite element simulations were carried out using the AECL structural and thermal analysis code H3DMAP [2 to 7].

It was determined from initial impact simulations that design changes were necessary to ensure the structural and containment integrity of the package. These changes are described in the following sections.

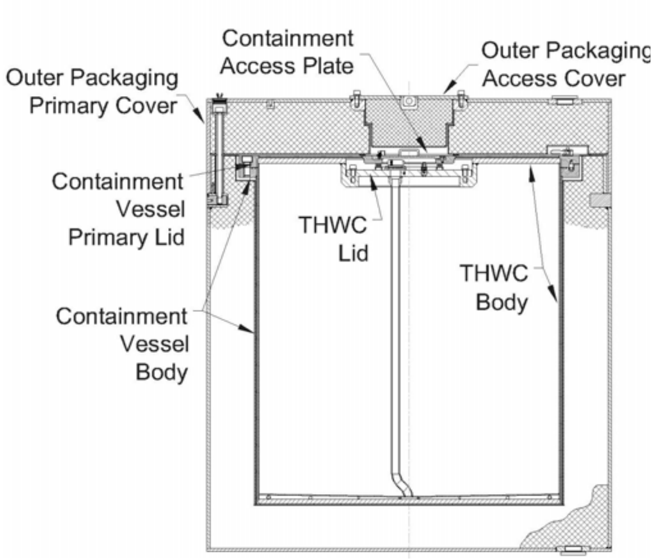


Figure 1. Multi-Purpose Transportation Package - THWC Payload

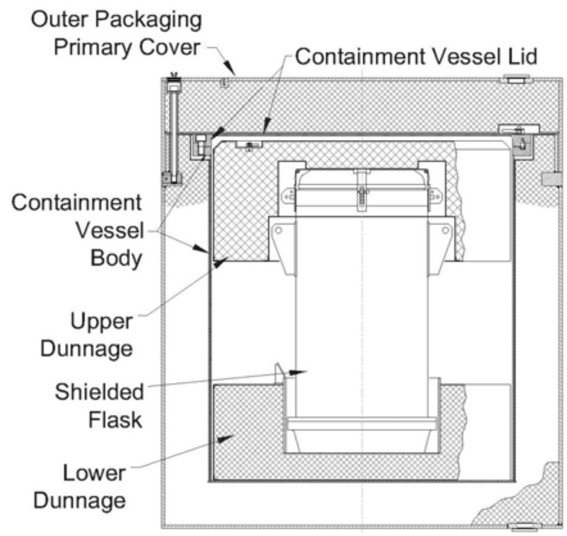


Figure 2. Multi-Purpose Transportation Package – Shielded Flask Payload

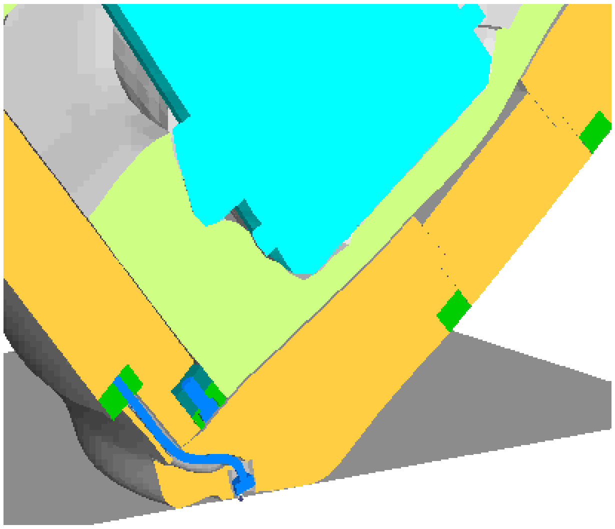


Figure 3. 9 Metre Centre of Gravity Over Top Edge Drop

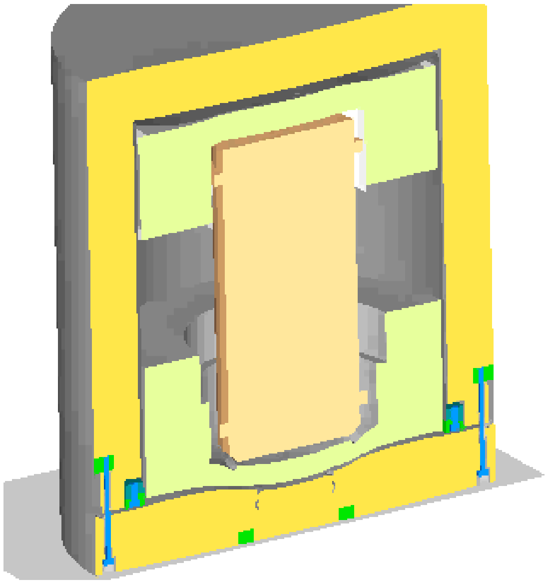


Figure 4. 9 Metre Top Down Flat End Drop

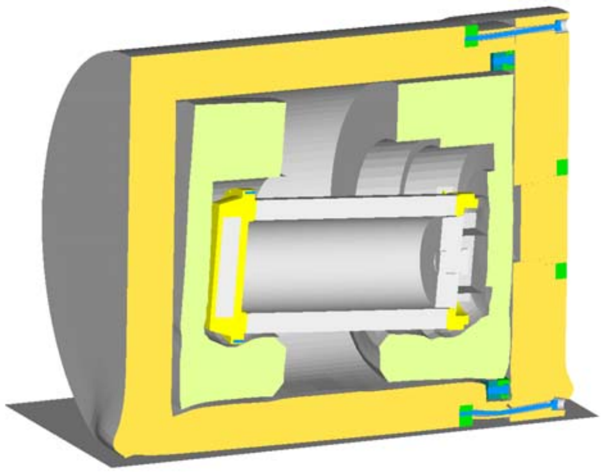


Figure 5. 9 Metre Flat Side Drop

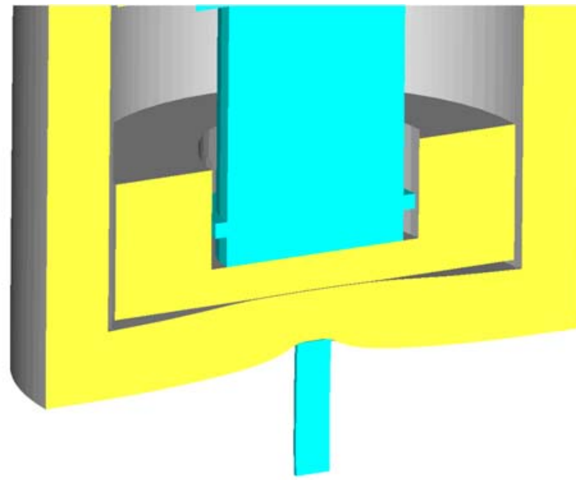


Figure 6. 1 Metre Pin Drop

Containment Vessel Primary Lid Outer Bolting Flange

The containment vessel primary lid outer bolting flange is located at the outer periphery of the containment vessel and is a sealed containment closure in both payload configurations. The original design of the containment vessel lid to body attachment is shown in **Figure 7**. There is a stepped joint between the body and lid at the mid-point of the bolting flange. In this design there is a step down (on the body flange) from the inner sealing surface to the outer edge of the flange. During the initial flat side drop simulation it was found that a separation between the containment vessel and lid occurred at the joint (on the impacted side of the package) due to the high shear loads. **Figure 8** shows the predicted deformation at the joint. The shear loads (from the movement of the lid relative to the body) were resisted by the screws rather than the stepped interface resulting in bending of these fasteners and a subsequent separation of the joint. OPG's older package designs use flat gaskets at the containment closures and these gaskets remain compressed, providing an acceptable seal, with this degree of joint separation. The MPTP uses double o-ring seals at the containment closures to facilitate leak-testing. The o-rings cannot maintain a seal if the joint separates.

A design change was made to mitigate the shear deformation. The direction of the stepped interface was reversed such that the flange steps up (on the body flange) from the inner sealing surface to the outer edge of the flange (**Figure 9)**. This creates a shear boundary on the larger containment vessel body flange that resists the motion of the primary lid during impact and takes the shear load instead of the screws. The result of the design change is presented in **Figure 10**. The relative shear displacement between the two vessel components is eliminated and the shear loads on the screws on the impacted side of package are reduced considerably.

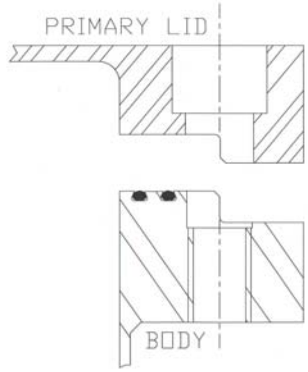


Figure 7. Containment Vessel Closure – Original Design

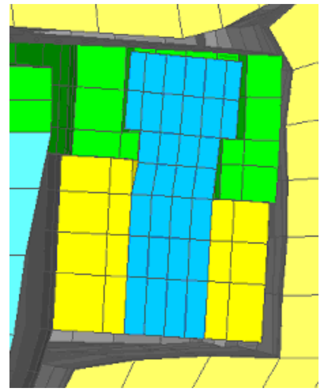


Figure 8. Deformation of Containment Vessel Closure - Original Design

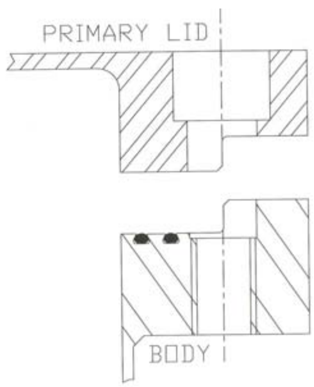


Figure 9. Design Enhancement to Containment Vessel Closure

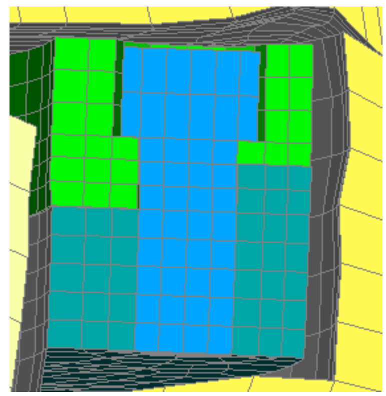


Figure 10. Deformation of Containment Vessel Closure – Enhanced Design

Primary Containment Lid for Shielded Flask Payload

The design of the containment vessel primary lid originally included a central access plate for both payload configurations. This access plate is required for the THWC payload to provide an entry to fittings on the THWC lid used for loading and unloading the heavy water. The access plate did not have a function in the Shielded Flask payload configuration where loading and unloading of the package will be conducted via the primary lid closure. The original design of the primary lid with access plate is presented in **Figure 11,** which also shows with the upper foam dunnage intended to protect the Shielded Flask and containment vessel. In the centre of gravity over top edge drop simulation it was found that the energy transfer from the 6,400 kg Shielded Flask payload through the upper dunnage to the access plate produced a large load on the access plate with plastic deformation of the plate and a breach of the containment boundary due to a gap being created at the plate/primary lid joint. The deformation of the access plate and breach of containment is apparent in **Figure 12**.

The first attempt at a design enhancement was to eliminate the raised centre ring in the foam dunnage that would otherwise impact the access plate, and to add a stiffener plate across the bottom of the bolting flange (**Figure 13**). This eliminates the load transfer to the containment access plate itself but resulted in the load being transferred to the adjacent inner bolting flange of the containment vessel primary lid. This load produced bending of the inner bolting flange and high stresses in the area of the weld between the flange and the adjacent thinner section of the containment vessel primary lid (**Figure 14**). Further attempts at minor changes to the inner flange design could not mitigate the effect of the central concentrated impact load from the Shielded Flask. Since a central means of entry to containment is not required when loading or unloading the Shielded Flask payload, a different containment vessel primary lid design that omitted the inner flange and access plate was developed. This reduction in commonality between the two package configurations was deemed to be acceptable. The re-analysis of the drop simulation with the new containment lid primary design showed much lower strain levels in the lid and no breach of the containment boundary.

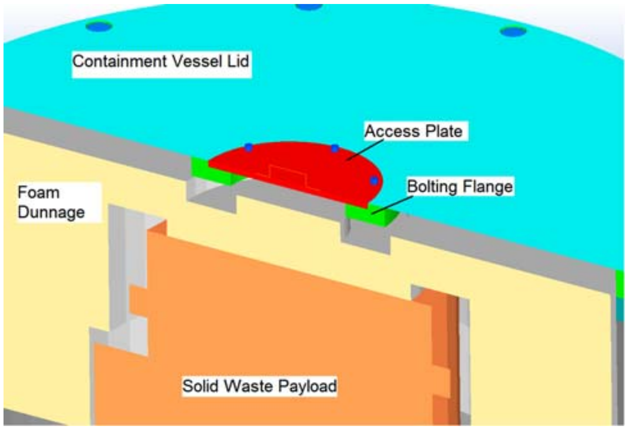


Figure 11. Containment Vessel Model with the Solid Waste Payload – Original Design

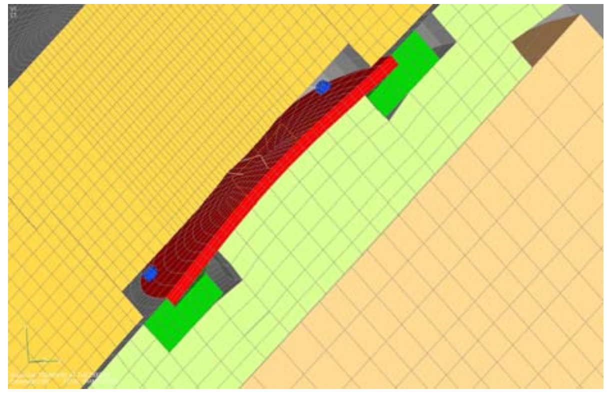


Figure 12. Damage to Containment Vessel Access Plate During Centre of Gravity Over Top Edge Drop

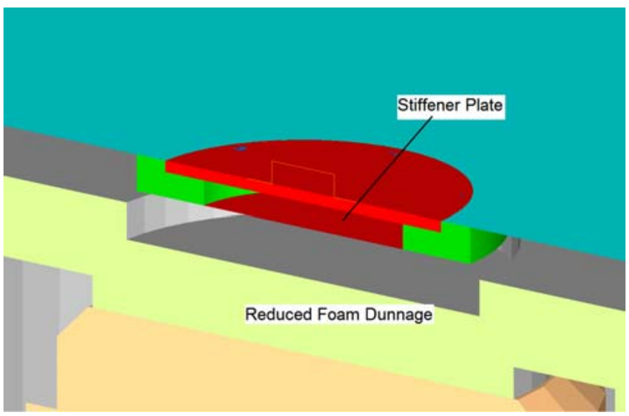


Figure 13. Enhanced Access Plate Design

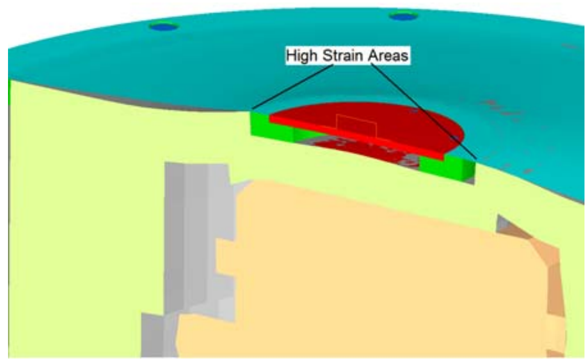


Figure 14. Damage to Containment Vessel Lid at Access Plate Bolting Ring

FIRE ACCIDENT SIMULATION

In the thermal analysis the effect of 12 days of ambient solar heat cycling was simulated to ensure that the package was at steady-state conditions. From these initial conditions a 30-minute fire accident at 800°C was simulated followed by 23½ hours of cooling down. The thermal models of the MPTP in the Shielded Flask payload configuration (with and without impact damage to the outer packaging primary cover) are presented in **Figure 15**. The dark blue elements represent steel plates and bolting flanges, the yellow elements represent polyurethane foam, and the light blue elements represent the Shielded Flask. The white areas represent the air gap elements. The full package is represented using a 5° section with adiabatic boundary conditions on either face (**Figure 17**). This is a reasonable modelling simplification because the heat generation from the fire is uniform around the package. In the fire accident simulation with the impact-damaged MPTP, it was assumed that the impact accident occurred after the initial steady-state conditions from ambient solar heating were achieved (i.e., the starting temperatures were identical to that of an undamaged model just prior to the fire accident). The damage due to impact was conservatively applied using the envelope of deformation from the centre of gravity over top edge drop, which caused the most deformation of the outer packaging. An additional conservatism was that the damage was applied over the entire edge of the axisymmetric model (for the package this would mean 360° of the outer packaging primary cover periphery had been crushed rather than just a sector).

The steady state temperatures of the package due to the ambient solar heating cycle are presented in **Figure 16a**. The temperature of the containment vessel interior air and the Shielded Flask payload are 152°F (67°C) and 128°F (53°C), respectively. **Table 1** lists the component steady state temperatures.

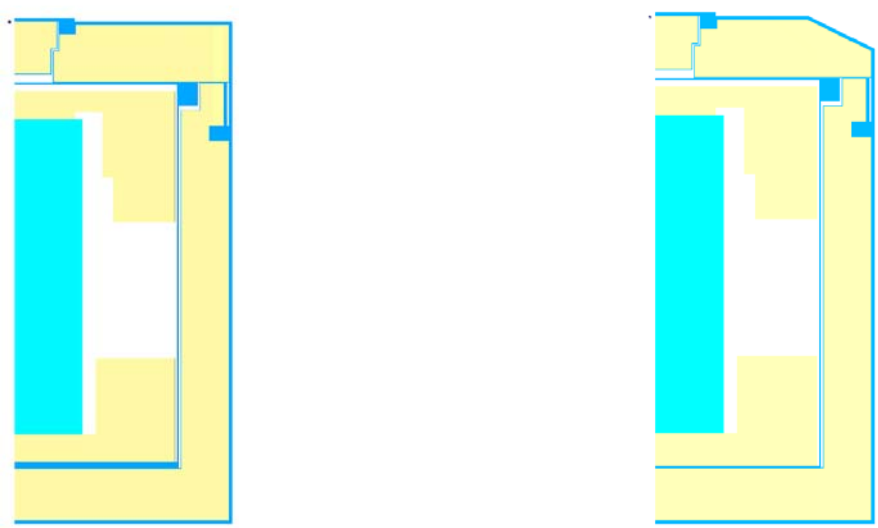
The results of the fire accident simulation indicate that, after the 30-minute fire, a maximum temperature (on the package exterior) of 1440°F (782°C) occurs, which is very close to that of the fire itself (1470°F or 800°C) as shown in **Figure 16b**. The maximum temperature of the air inside the containment vessel is 201°F (94°C). This is a local maximum temperature and does not apply to the entire air mass inside the containment vessel. The maximum temperature of the Shielded Flask payload is 130°F (54°C). This is well below the melting point of the lead shielding in the Flask.

The contour of MPTP temperatures at the end of 23½ hours of cooling down following the fire accident is shown in **Figure 16c**. The maximum temperature in the containment vessel primary lid seal (location 2) occurs approximately 5-1/2 hours after the fire and reaches 186°F (86°C), which is well below the allowable seal material temperature. **Figure 17** illustrates the temperature history of the containment vessel primary lid seal from the beginning of ambient solar heating cycle to the end of the post-fire cooldown.

All of the predicted temperatures are acceptable and will not cause a loss of the package's structural, containment or shielding (in the case of the Shielded Flask payload configuration) integrity.

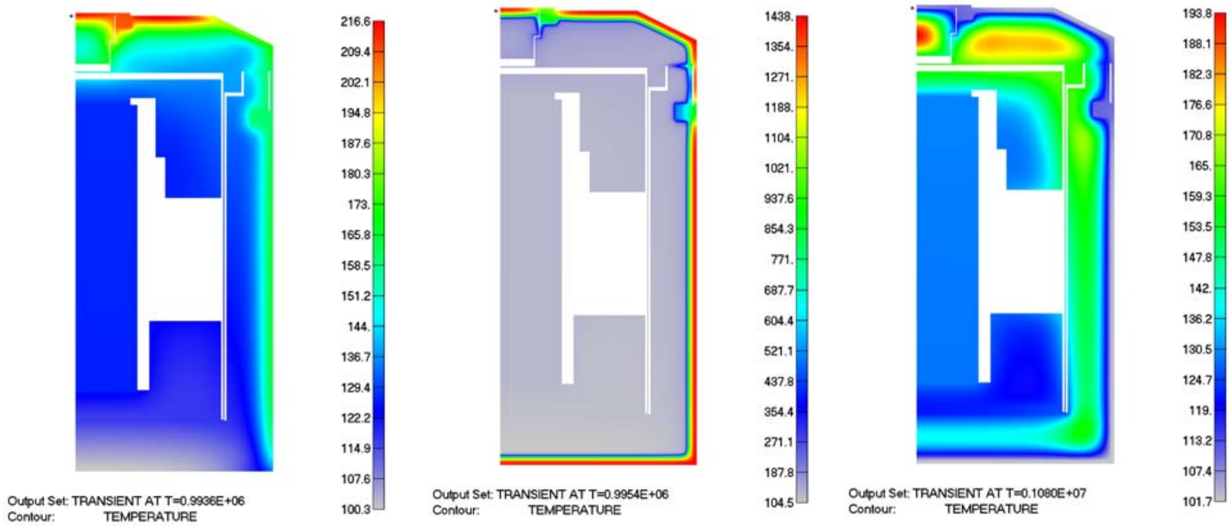
Table 1. Steady-State and Maximum Component Temperatures

Component	Steady State (°F)	Max. Fire Accident (°F)
Containment vessel primary lid seal	139 (59°C)	186 (86°C)
Outer packaging surface	216 (102°C)	1440 (782°C)
Containment vessel air	152 (67°C)	201 (94°C)
Shielded Flask	128 (53°C)	130 (54°C)



(a) Undamaged Model (b) Damaged Model

Figure 15. Side view of FE Model of Shielded Flask Payload for Thermal Analysis



(a) At the end of Ambient Cycle (b) At the end of fire accident (c) 23 ½ h of cool down

Figure 16. Final Simulation Temperatures

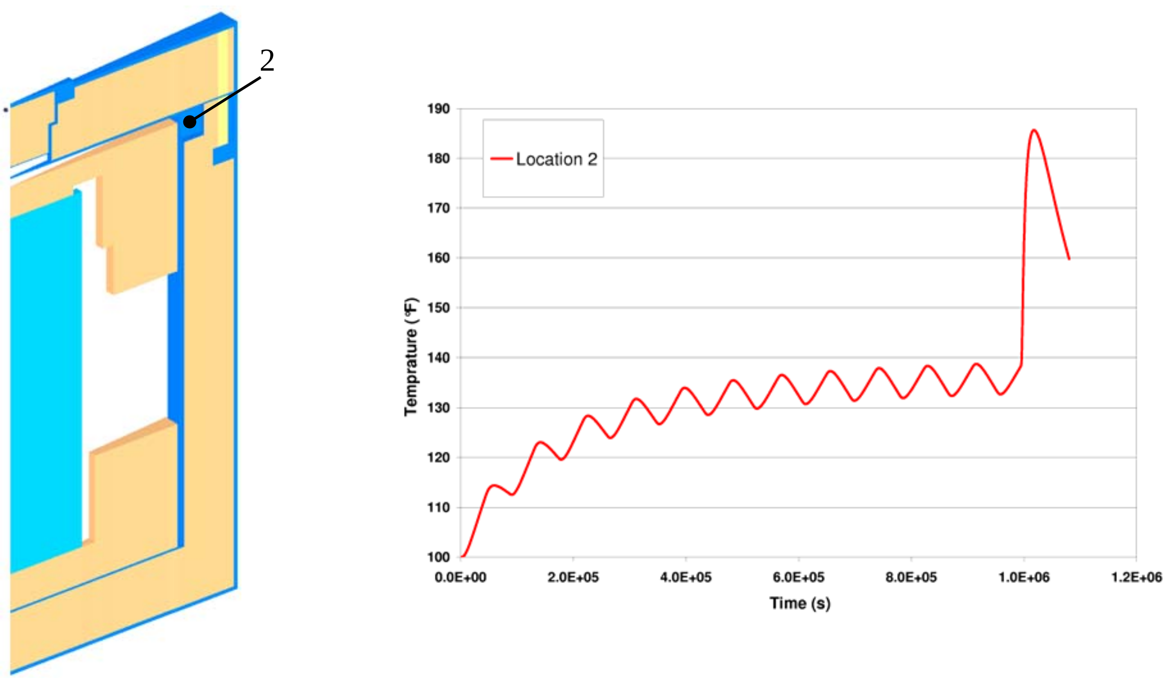


Figure 17. Temperature History at Containment Vessel Primary Lid Seal

MANUFACTURING AND COMMISSIONING

Manufacturing of the first two MPTPs, in the THWC configuration, was completed in the summer of 2007. Commissioning of the packages at OPG's facilities have begun. It is planned that packages will go into service by the end of the first quarter of 2008. Photographs of the two MPTPs (two packages on a single transport trailer) are shown in Figure 18.

Figure 18. Multi-Purpose Transportation Packages

CONCLUSIONS

The impact and thermal analyses performed by AECL supported the development of the MPTP design and the application to the Canadian competent authority for design certification. The application was successful and OPG received Type B(U) certification of the MPTP design (in both payload configurations) in 2006. Design by analysis rather than physical testing permitted two package configurations, several design enhancements, and detailed component interactions to be evaluated with a reasonable cost and schedule.

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