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# Design of a New Type B Multi-Purpose Transportation Package

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## ABSTRACT

This paper describes the design of a new radioactive materials transportation package and the analyses performed on the design for engineering and licensing purposes. This new package, called the Multi-Purpose Transportation Package (MPTP) is designed to transport tritiated heavy water in a secondary container or solid radioactive material in a shielded flask. The MPTP design meets all the requirements specified in the Canadian and International Atomic Energy Agency (IAEA) Regulations, including the performance requirements under routine (incident free), normal and accident conditions of transport. An application for certification ("license") of the MPTP as a Type B(U) package has been submitted to the Canadian Nuclear Safety Commission (CNSC). When a Certificate for Transport Design is issued by the CNSC, Ontario Power Generation (OPG) will be in a position to procure an initial set of these packages.

## 1.0 INTRODUCTION

The Nuclear Waste Management Division (NWMD) of Ontario Power Generation (OPG) has the responsibility to safely and economically manage all radioactive waste generated by OPG and Bruce Power reactors. The management of this material includes the transportation, processing, storage and eventual disposal of all low and intermediate level waste and used fuel.

The Radioactive Waste Transportation Design (RWTD) Section of the NWMD is responsible for the design, engineering and licensing of OPG's radioactive material transportation package fleet. This fleet consists of a variety of Type B, Type A, Industrial and Excepted packages. Two important Type B(U) packages within the fleet are the Tritiated Heavy Water Transportation Package (THWTP) and Radioactive Filter Transportation Package (RFTP). The RFTP design is based on the design of the THWTP.

The six THWTPs are used to transport tritiated heavy water from OPG and Bruce Power nuclear generating stations to the Darlington Tritium Removal Facility (DTRF) for de-tritiation. The three RFTPs are used to transport solid radioactive materials in shielded flasks to the Western Waste Management Facility (WWMF) for storage. The THWTPs and RFTPs have been in-service for 15 to 20 years. Given the age of these packages and the on-going need for the transportation of their payloads, the NWMD has decided to design, analyze and licence a "multi-purpose" transportation package authorized to ship the payloads of the THWTP and RFTP.

The MPTP has been shown to meet all the requirements specified in the Canadian Nuclear Safety Commission's, "Packaging and Transport of Nuclear Substances Regulations (PTNSR)" [R-1], including the performance requirements for routine (incident free), normal and accident conditions of transport. The PTNSR are based on and refer to the performance requirements specified in the 1996 Edition (Revised) IAEA Regulations [R- 2].

The engineering approach taken to show compliance with the Regulation requirements was through analytical prediction of the package performance rather than physical testing. Since the MPTP design is very similar to the RFTP design [R-3], the successful scale model impact testing performed for the RFTP design provided confidence that the MPTP design will also withstand the impact tests.

The package's performance under normal and accident conditions (including impacts and fire) was performed by the Computational Mechanics Development Group of Atomic Energy of Canada Limited's (AECL's), using the H3DMAP finite element computer code [R-4]. H3DMAP is a non-linear, general-purpose three-dimensional continuum mechanics code that has been used for over 20 years by Ontario Hydro, Ontario Power Generation, Kinetrics and AECL.

## 2.0 RADIOACTIVE CONTENTS

The MPTP has been designed to transport two major categories of radioactive material:

(1) Category 1 – Tritiated Heavy Water

Each MPTP can carry a maximum of 5,400 kg (11,900 lb) of tritiated heavy water with a design tritium concentration not exceeding 3.7 x $10^{12}$ Bq/kg (100 Ci/kg) inside a secondary container. Tritium is a low energy ß-emitter and no shielding, other than the package structure, is required. The total activity of this content is 20,000 TBq (540 kCi).

(2) Category 2 – Solid Radioactive Material

There are three sub-categories of solid radioactive material that the MPTP could transport. Each one will be contained within a shielded flask that is surrounded and protected by dunnage inside the MPTP. The maximum payload weight, consisting of radioactive contents, shielded flask, and dunnage, will be 7,530 kg (16,600 lbs).

(i) Category 2a – Radioactive Filters and Ion Exchange Columns

This payload will contain radionuclides as fixed ions in an ion exchange resin column or particles within a filter. The decay heat will be negligible and the total activity of this content is 15 TBq (409 Ci).

(ii) Category 2b – Solid Intermediate Level Waste

This payload consists primarily of activated solid metals (such as zirconium-niobium alloy, nickel alloy or stainless steel). Small amounts of swarf (cutting residue) and crud may be present. The maximum decay heat of the payload will not exceed 50 watts and the total activity of this content is 300 TBq (8.1 kCi).

(iii) Category 2c – Primary Side Cleaning Waste

This radioactive material produced during steam generator primary side cleaning will consist of solid, magnetite fines, containing activated corrosion products. The predominant radionuclides in the Primary Side Cleaning (PSC) waste are iron-55, cobalt-60, niobium-95 and tritium. The total activity of this content is 20 TBq (540 Ci).

## 3.0 DESCRIPTION OF THE TRANSPORTATION PACKAGE

There are two MPTP configurations, Configuration 1 and 2, to suit the two major categories of radioactive contents described in Section 2.0. The package assemblies for the two major configurations are shown in Figures 3-1 and 3-2. Both configurations of the MPTP, as assembled for transport, consist of the payload (including radioactive materials, secondary container/shielded flask and when required, dunnage), the containment vessel and the outer packaging body and cover. It is not intended to inter-change the package assemblies once they are configured for their respective payload.

### 3.1 The Containment Vessel

The containment vessel encloses the payload and provides a barrier against the release of radioactive material for all MPTP configurations. The vessel consists of a body and a large top-mounted primary lid connected by twelve, Nitronic-60 socket head cap screws. The vessel has the form of an upright cylinder and is made from Type 304L or 316L stainless steel. The interior cavity has dimensions of 1,835 mm (72¼") in diameter and a height of 2,097 mm (82 9/16").

The body and primary lid are joined with a flanged and bolted closure at the outer periphery of the vessel. The joint is sealed with two O-rings held in machined dovetail-type grooves (see Figure 3.3). On the top surface of the primary lid flange there are two small ports ("Containment Test Port" & "Inter-seal Port" as shown in Figure 3-3) each closed with a plug and an O-ring. The inner O-ring at the lid/body joint and the Containment Port plug O-ring constitute the containment seals. The outer O-ring at the lid/body joint and the Inter-seal Port are provided for convenience in carrying out leak testing. The O-rings are made of solid silicone or fluorocarbon rubber.

The containment vessel is a separate, removable unit of the packaging, but only the primary lid is removed during normal loading and unloading operations.

### 3.2 Containment Access Plate

When the MPTP is configured for tritiated heavy water shipments (Configuration 1), a specific containment vessel primary lid is used that incorporates a central opening and inner flange. The opening provides a direct path to the fittings on the secondary container that holds the tritiated heavy water.

For transport, the central opening is closed with a small lid designated the "containment access plate". The containment access plate is secured to the primary lid central flange with six Nitronic-60 cap screws. The joint between the access plate and primary lid is sealed with two O-rings held in machined dovetail-type grooves. On the top surface of the access plate there is a small port (designated the "Inter-seal Port") with a quick-disconnect nipple that provides a penetration to the O-ring inter-space. The inner O-ring at the lid/access plate joint is the containment seal. The outer O-ring at the joint and the Inter-seal Port is provided for convenience in carrying out leak testing. The O-rings are made of solid silicone or fluorocarbon rubber.

## 3.3 The Outer Packaging

The outer packaging consists of a body and top-mounted cover. It is designed to provide thermal and mechanical protection for the containment vessel and payload. The assembled outer packaging has the form of an upright cylinder and is constructed from Type 304L or 316L stainless steel plates, 5 mm ($^{3}/_{16}$") and 19 mm (¾") thick, which form the inner and outer shells, respectively. The spaces between the shells are filled with rigid, high-density (288 $kg/m^3$ or 18 $lb/ft^3$) polyurethane foam. The assembled outer packaging has external dimensions of 2,438 mm (96") diameter and a height of 2,743 mm (108").

The outer packaging cover is fastened to the body with twenty-four special, socket head cap screws that extend through sleeves in the cover and engage in a set of cylindrical ("swivel") nuts retained in a flange in the outer packaging body. The nuts can be removed and replaced in the event of damage or wear. The nuts and cap screws are both made of Nitronic-60 stainless steel. The outer wall of the cover extends over the outer packaging body to resist relative sideway movements between the cover and body.

## 3.4 Outer Packaging Access Cover

When the MPTP is configured for tritiated heavy water shipments, (Configuration 1), a specific outer packaging cover is used that incorporates a central opening and inner flange. The opening extends to the bottom of the cover and provides direct access to the containment access plate (see Section 3.2). For transport, the opening in the primary outer packaging cover is closed with a large stepped plug designated the "outer packaging access cover". The interior of the plug is filled with high-density polyurethane foam like the other components of the outer packaging. The access cover is fastened to the primary cover with six Nitronic-60 cap screws. There is a flat gasket at the joint between the access and primary covers to prevent the ingress of water from rain or snow.

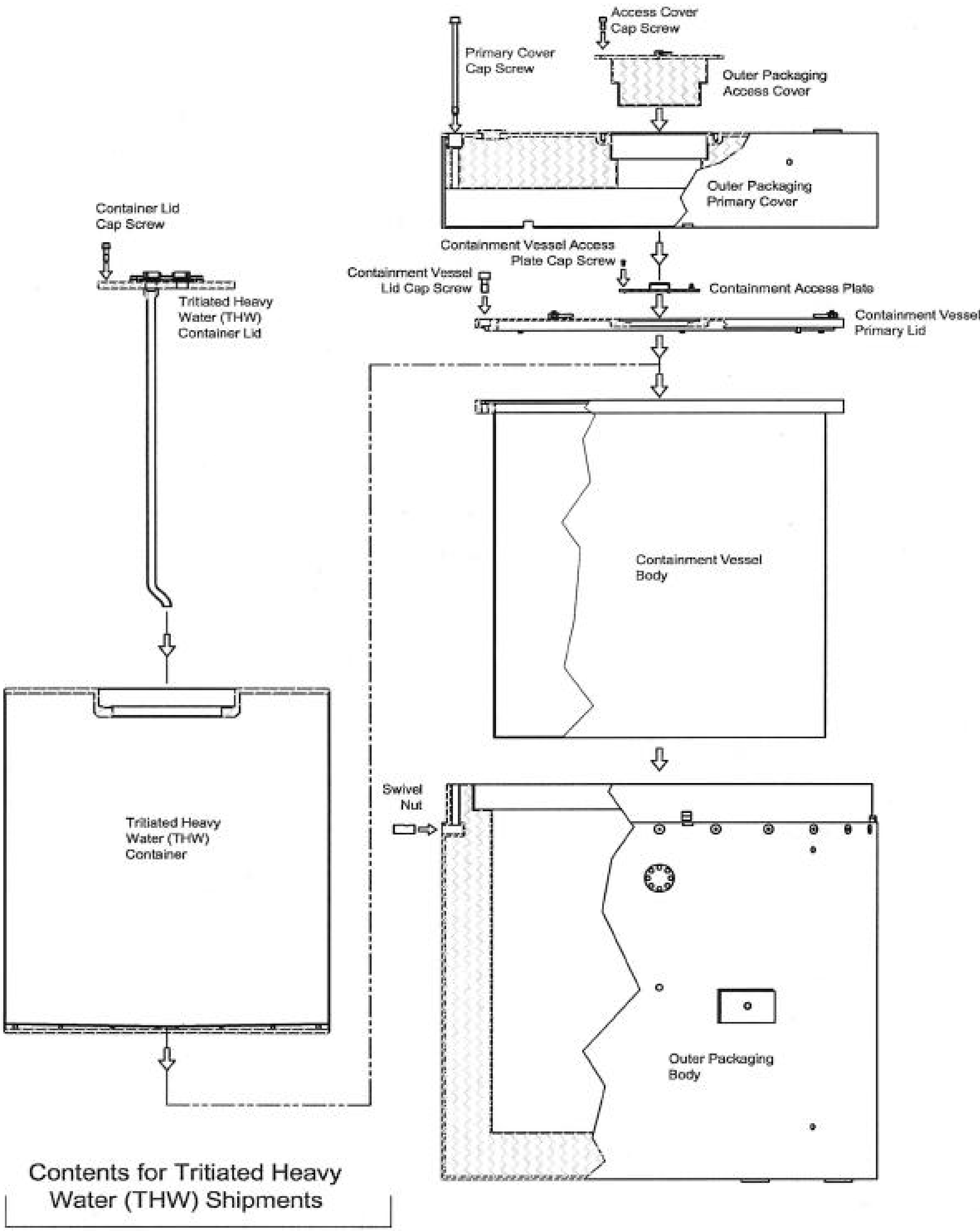


**Figure 3-1. Multi-Purpose Transportation Package – Exploded Arrangement for Tritiated Heavy Water Payload (Configuration 1)**

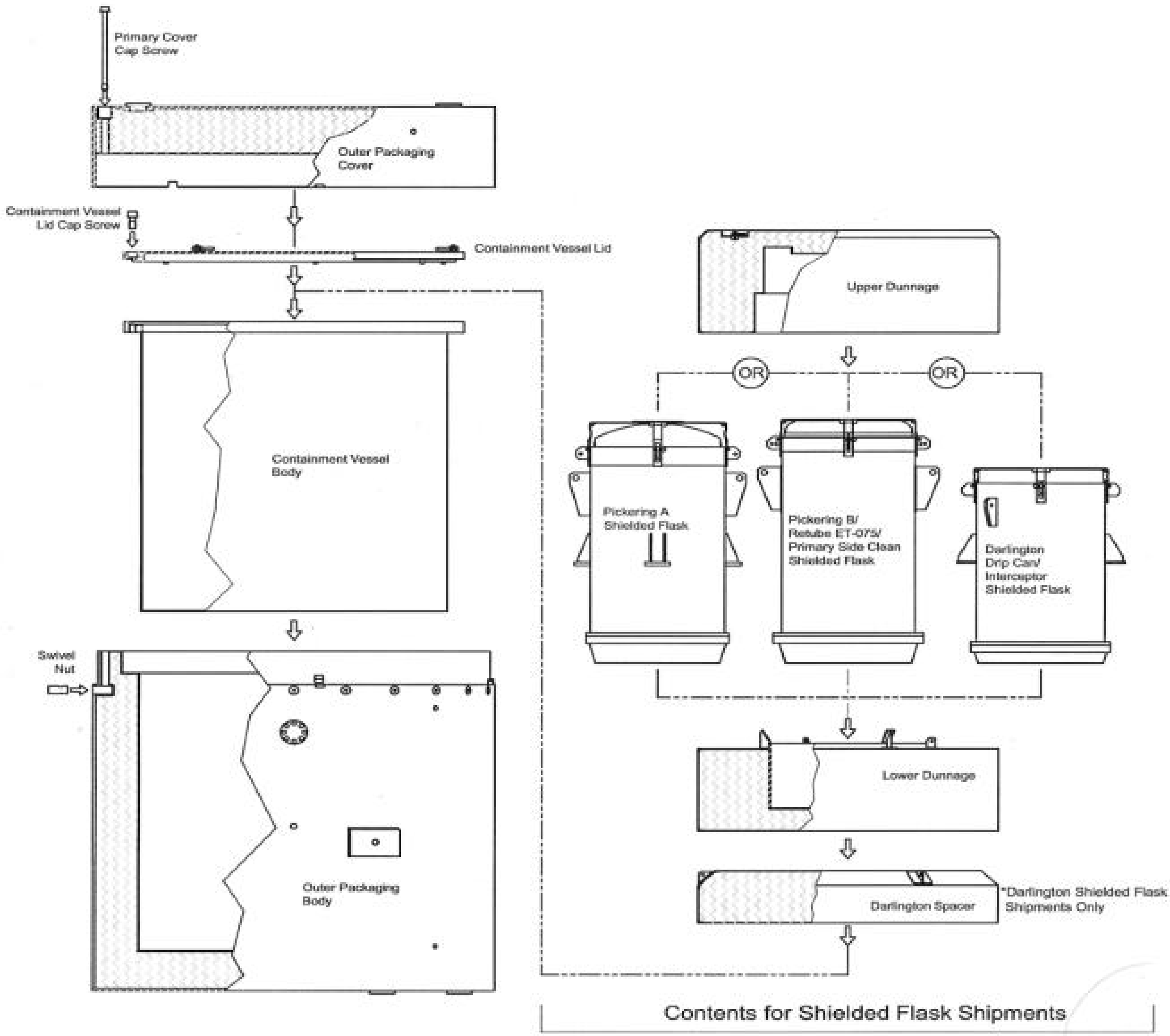


**Figure 3-2. Multi-Purpose Transportation Package - Exploded Arrangement for Solid Radioactive Material/Shielded Flask (Configuration 2)**

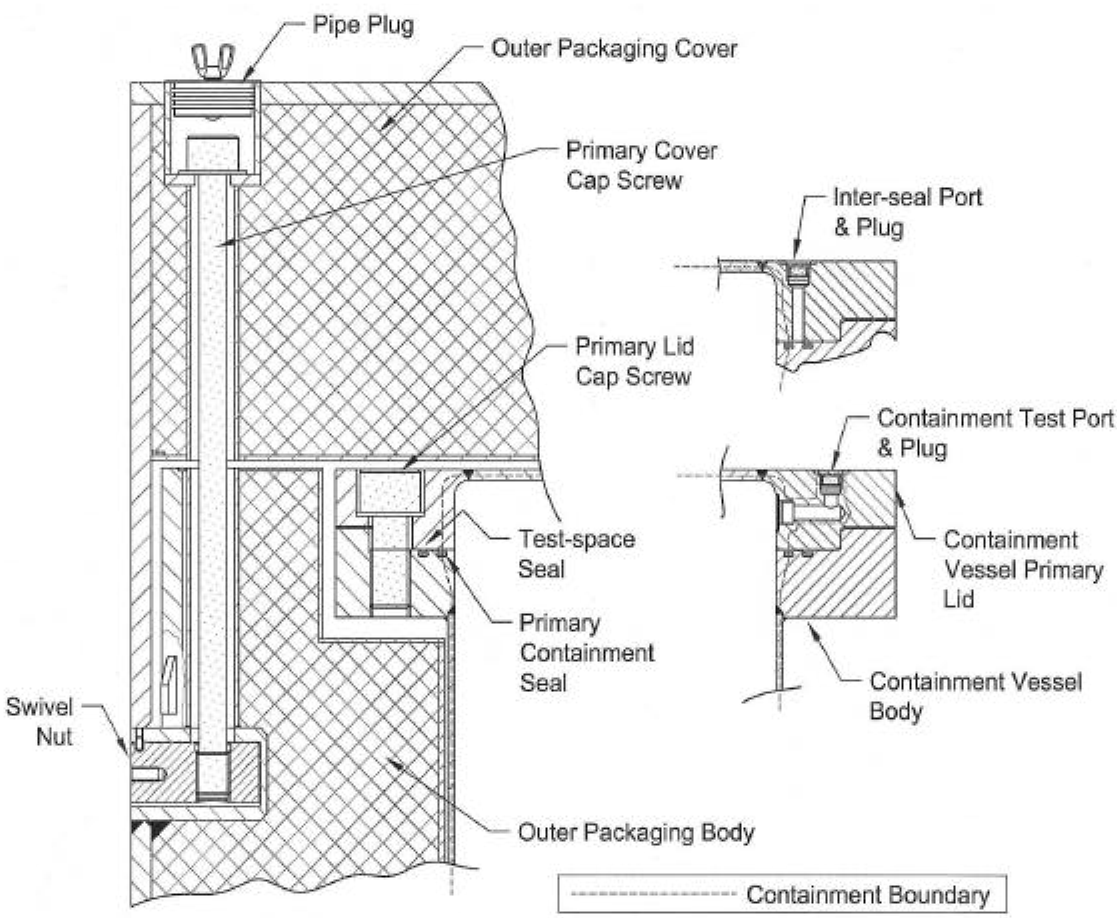


**Figure 3-3: Multi-Purpose Transportation Package (Configurations 1 and 2) Seal Details**

## 4.0 STRUCTURAL ANALYSES

The structural analyses performed on the MPTP demonstrate the strength of the design under the hypothetical accident conditions specified in the Regulations [R-2]. The response of the MPTP package to 9.0 m drops onto an unyielding surface and a 1.0 m drop onto a steel pin were analyzed using the H3DMAP Version 7 computer program [R-4].

Five different drop cases were analyzed based on engineering judgement of the configurations/orientations that would cause the most damage to the package's safety features and that would lead to the maximum damage in the subsequent thermal test (see Section 5.0). The five cases are identified in Table 4-1. The overall conclusion of the analyses was that the MPTP in either Configuration 1 or 2 would withstand the 9 m drop test condition. Descriptions of Cases 2, 3, and 4 only are provided in Sections 4.1 to 4.3. These cases cover the range of drop orientations for the package.

**Table 4-1: 9 metre Drop Analysis Cases**

| Case | Drop Orientation and Configuration (Payload) |
|---|---|
| 1 | Top Edge – Configuration 1 (Tritiated Heavy Water) |
| 2 | Top Flat End – Configuration 1 (Tritiated Heavy Water) |
| 3 | Flat Side – Configuration 1 (Tritiated Heavy Water) |
| 4 | Top Edge – Configuration 2 (Solid Radioactive Material/Shielded Flask) |
| 5 | Top Flat End – Configuration 2 (Solid Radioactive Material/Shielded Flask) |

### 4.1 Case 2: Top Flat End Drop of Configuration 1 (Tritiated Heavy Water Payload)

This case evaluated the effects of a 9 m (30 ft) drop with the package inverted and package long axis perpendicular to the impact surface. The analysis showed that the deformation of the outer packaging cover (bulging of the foam and stainless steel shell side-walls) was relatively small due to the large impact surface.

The containment vessel and tritiated heavy water container showed no indications of failure and therefore it is predicted that the tritiated heavy water would be retained within the container and there would be no effect on the integrity of the containment vessel.

### 4.2 Case 3: Side Drop of Configuration 1 (Tritiated Heavy Water Payload)

This case evaluated the effects of a 9 m (30 ft) drop with the package long axis parallel to the impact surface. The analysis showed that there were high-localized strains in the outer packaging cover outer shell and top plate. The strains were due to bending and therefore it is possible that localized (and therefore acceptable) tearing of the exterior stainless steel plates could occur. The long cap screw adjacent to point of impact was bent substantially but the strains would not cause failure.

The containment vessel and tritiated heavy water container showed no indications of failure and therefore it is predicted that the tritiated heavy water would be retained within the container and there is no effect on the integrity of the containment vessel.

### 4.3 Case 4: Top Edge Drop of Configuration 2 (Solid Radioactive Material/ Shielded Flask Payload)

This case evaluated the effects of a 9 m (30 ft) drop with the initial point of impact at the edge of the outer packaging cover. The initial orientation of the package placed its centre of gravity vertically in line with the point of impact. The analysis showed that there was flattening of the outer packaging cover stainless steel shell and foam in the vicinity of the initial point of impact (see Figure 4-1). There was localized (and therefore acceptable) tearing in the sleeves for the outer packaging cover cap screw and also significant deformation of the cap screws in the vicinity of the initial point of impact. There were high-localized stresses in the upper dunnage inner shell, but they were compressive and tearing was not predicted.

The containment vessel and shielded flask showed no indications of failure. Therefore, it is predicted that the radioactive material would be retained within the flask and there would be no effect on the integrity of the containment vessel or the shielding effectiveness of the package.

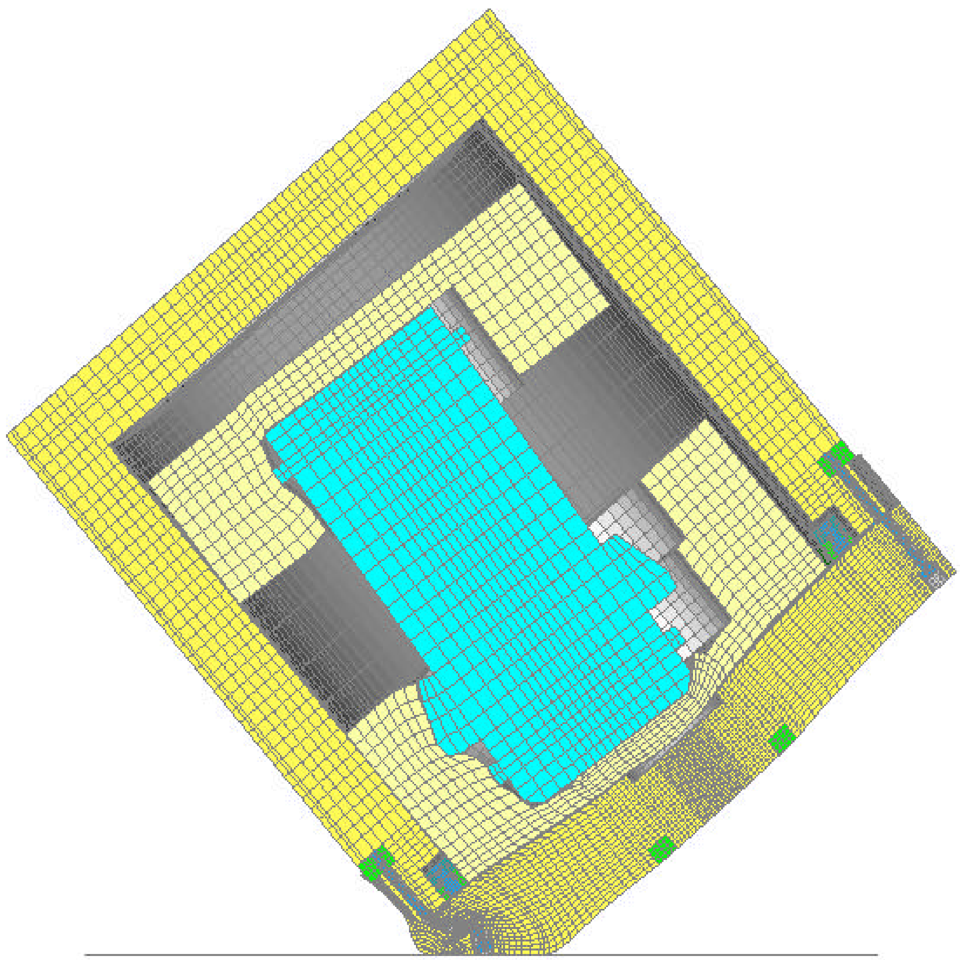

**Figure 4-1: Overall Deformation at End of Simulation - Case 4[1]**

## 4.4 Drop of 1 metre onto a Steel Bar

This case evaluated the effects of a drop of the MPTP onto a mild steel bar mounted perpendicularly on an unyielding surface. The lowest point of the package was 1 metre above the end of the bar prior to the drop.

[1] Courtesy of G. Morandin, AECL.

The MPTP in the heaviest configuration (Configuration 2 with the solid radioactive material and shielded flask payload) was analyzed and the initial point of impact was selected as the centre of the outer packaging bottom plate. Deformation occurred in the bottom plate of the outer packaging body in the vicinity of the initial point of impact. Ductile tearing of the bottom plate was not predicted.

## 5.0 THERMAL ANALYSES

Thermal analyses were performed using the H3DMAP Version 7 computer program [R-4]. The analyses demonstrated that the MPTP design complies with the temperature related requirements specified in the Regulations [R-2]. Table 5-1 summarizes the maximum temperatures from the various analyses performed. The thermal analysis for Configuration 1 under accident conditions is only described in Section 5.1.

**Table 5-1: Thermal Analyses Results**

| **MPTP Configuration 1 (Tritiated Heavy Water Container Payload)** | | | | |
|---|---|---|---|---|
| | Containment Seal Maximum Temperature [°C] | Containment Air Maximum Temperature [°C] | Tritiated Water Maximum Temperature [°C] | Outer Surface Maximum Temperature [°C] |
| **Normal Conditions** | 56 | 55 | 49 | 102 |
| **Accident Conditions** | 74 | 74 | 59 | 782 |
| **MPTP Configuration 2 (Solid Radioactive Material/Shielded Flask Payload)** | | | | |
| | Containment Seal Maximum Temp. [°C] | Containment Air Maximum Temp. [°C] | Shielded Flask Maximum Temp. [°C] | Outer Surface Maximum Temp. [°C] |
| **Normal Conditions** | 59 | 67 | 53 | 102 |
| **Accident Conditions** | 86 | 94 | 54 | 782 |

### 5.1 Package Temperatures under Accident Conditions

The thermal test representing a fire accident condition is described in the Regulations [R-2, paragraph 728] as an engulfing fire of 30-minute duration with a constant temperature of 800°C. At the start of the test the package is in thermal equilibrium under conditions of an ambient temperature of 38°C, solar insolation and maximum internal heat generation by the radioactive contents.

### 5.1.1 Evaluation

Configuration 1 of the MPTP (tritiated heavy water container payload) was analyzed using a model that included the effects of the most damaging drop orientation (Case 1: The top edge drop). The damage was represented in the analysis model by a chamfer of the outer packaging primary cover measuring 356 mm (14") across the top and 178 mm (7") along the side. The damage was conservatively modeled as symmetrical (i.e., around the entire outer packaging primary cover periphery) instead of only on the impact side. The analysis evaluated the temperatures during the 30-minute fire, followed by an approximately 23½ hour cool-down period.

The thermal analysis predicted that a small portion of the polyurethane foam adjacent to the outer packaging outer shell would become hot enough to char. The foam immediately behind the charred region remained intact with its insulation properties unaffected. Charring of the foam stops when the heat source is removed.

The containment air and tritiated heavy water temperatures listed in Table 5-1 are actually local maximums. The average fluid (air or water) temperatures are lower. The accident conditions temperatures of 75°C for the containment air, 59°C for the air and water in the tritiated heavy water container were conservatively used to determine the maximum accident condition pressures. The maximum containment seal temperature of 74°C is well within the seal material's operating temperature range.

The package outer surface reaches a maximum temperature of 782°C. While extended service at this temperature would be problematic for the stainless steel material of the outer packaging outer shells, the exposure involved in the thermal test will not significantly degrade the stainless steel.

## 6.0 CONCLUSIONS

The MPTP is designed to transport tritiated heavy water (up to 100 Ci/kg) and solid radioactive materials in shielded flasks. It is a third generation Type B(U) package based on the successful designs of the Radioactive Filter Transportation Package and Tritiated Heavy Water Transportation Package.

The package design complies with all the requirements specified in the CNSC and IAEA Regulations. The impact and thermal analyses performed demonstrate that the MPTP will provide the necessary protection and containment of the radioactive contents under routine (incident free), normal and accident conditions of transport.

## 7.0 REFERENCES


(1) Canadian Nuclear Safety Commission, Nuclear Safety and Control Act, “Packaging and Transport of Nuclear Substances Regulations”, SOR/2000-208, 31 May 2000, plus amendment SOR/2003-405, 3 December 2003.

(2) International Atomic Energy Agency (IAEA) Safety Standards Series, “Regulations for the Safe Transport of Radioactive Material”, 1996 Edition (Revised), No. TS-R-1 (ST-1, Revised), Vienna, 2000.

(3) Canadian Nuclear Safety Commission, Certificate for Transport Package Design, Radioactive Filter Transportation Package (RFTP), CDN/2058/B(U)-96, (Rev. 5).

(4) Sauve, R.G., Morandin, G., “Computer Program Documentation: User’s Manual, Programmer’s Manual H3DMAP Version 7: A Three Dimensional Finite Element Computer Code for Linear and Nonlinear Continuum Mechanics”, Atomic Energy of Canada Limited Report No. CW-114515-225-001, June 2003.