ONTARIO HYDRO TRITIATED HEAVY WATER TRANSPORTATION PACKAGE

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Abstract

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Ontario Hydro currently operates 15 heavy water moderated reactors generating 10 GW of electrical power. As the moderator thermalizes neutrons, a small fraction of these neutrons is absorbed by the heavy water thus forming tritiated heavy water. To minimize occupational dose due to the accumulated tritium in the moderator heavy water, heavy water will be routinely removed from the reactor moderators and transported to the Darlington Tritium Facility where tritium is removed from the heavy water and the processed heavy water will be returned to the reactors for use. For the efficient and safe transport of the tritiated heavy water from the nuclear generating stations to the Tritium Removal Facility, Ontario Hydro has designed and licensed a new Type B(U) package for bulk shipment use. The tritiated heavy water transportation package consists of a stainless steel container and an overpack. The package is licensed as a Type B(U) package and is capable of carrying up to 5000 kg of tritiated heavy water with a maximum tritium content of 20 PBq. To support the licensing application, engineering evaluation and computer analyses supported by benchmark tests were used to demonstrate that the package will comply with all the tested and accident conditions as required by the AECB (Atomic Energy Control Board (of Canada)) Transport Packaging of Radioactive Materials Regulations. The computer programs used to simulate the dynamics of the mechanical test and to determine the effects of the dynamic stresses and strains to the package include DYNA-3D and HONDO. For the thermal test simulation, a microcomputer spreadsheet program was initially used to estimate the gross heat transfer rate during normal and fire test conditions and when the package is exposed to −40°C for an extended period. For the detailed thermal analysis to simulate the effect of the fire test, an in-house finite element program HEATR was used. This paper gives a description of the package and its design features. It carries on to discuss compliance with the regulations, the materials, property testing and the computer program benchmarking. Finally there is a discussion about manufacturing of the package and then its operation.

1. INTRODUCTION

Ontario Hydro (OH) currently operates 15 heavy water moderated reactors generating 10 GW of electrical power. As the moderator thermalizes neutrons, a small fraction of these neutrons is absorbed by the heavy water thus forming tritiated heavy water. To minimize occupational dose due to the accumulated tritium in the moderator heavy water, heavy water will be routinely removed from the reactor moderators and transported to the Darlington Tritium Facility where tritium is removed from the heavy water and the processed heavy water will be returned to the reactors for use. For the efficient and safe transport of the tritiated heavy water from the nuclear generating stations to the Tritium Removal Facility, OH has designed a new Type B(U) transport package for the bulk shipment of the tritiated heavy water. Following is a description of the package design.

2. PACKAGE DESCRIPTION

The tritiated heavy water transportation package consists of two main components: the tritiated heavy water container and overpack, as shown in Fig. 1.

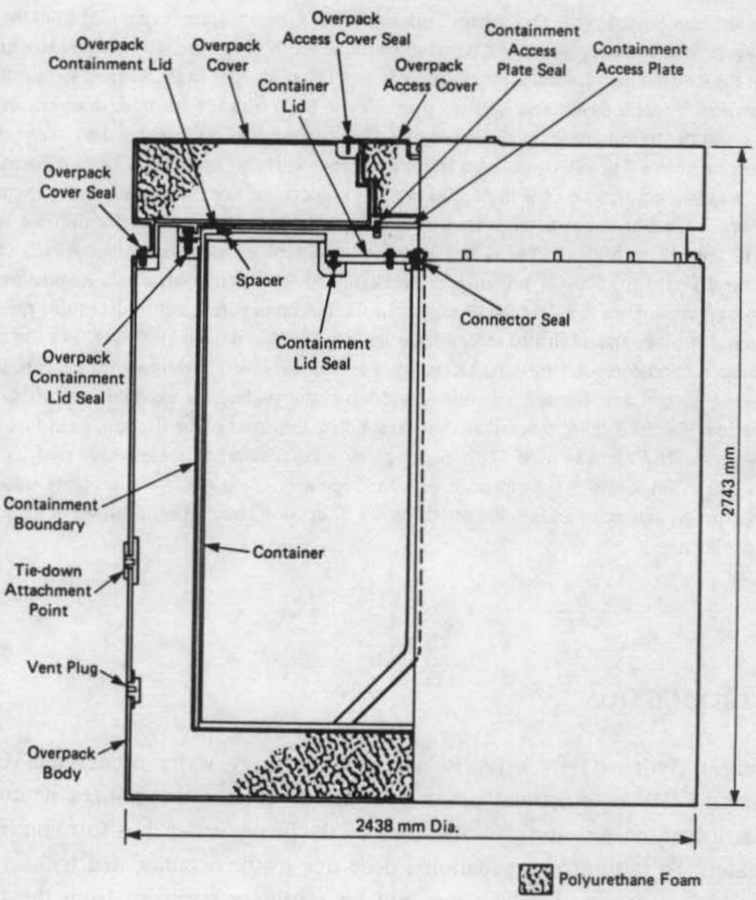

FIG. 1. Tritiated heavy water transport package; general arrangement.

The container is a stainless steel cylinder with flat ends. It provides the first barrier against release of tritiated heavy water. To facilitate loading and unloading of tritiated heavy water from the container, specially developed quick disconnects are incorporated in the top head for filling and emptying. A liquid level detector is used to ensure that the container will not be overfilled.

The container is approximately 1.83 m diameter and 2.08 m high. It is a welded stainless steel cylindrical vessel, with 6.4 mm thick wall, and 25.4 mm thick flat ends.

The overpack forms the outer packaging and houses the container during shipment. The overpack is a stainless steel and polyurethane foam structure in the form of a vertical cylinder. It is designed to provide thermal and impact protection for the container during normal, tested and accident conditions. The inner casing, with its lid (overpack containment lid), provides the main containment for the radioactive material.

During normal operation, the packages remain fully secured to the transport trailer. Only the centrally located overpack access cover and containment access plate are detached for access to the container. Connections are then made with the filling system in the loading and unloading stations.

The overpack is a stainless steel welded design with inner and outer casings. The annulus is filled with high density polyurethane foam. Silicon rubber gaskets are used for sealing the bolted surfaces and prevent any leakage of radioactive materials from the package under any condition.

3. DESIGN CONSIDERATIONS

When the need for the bulk shipment of tritiated heavy water arose due to the decision to locate the Tritium Removal Facility at the Darlington Generating Station, consideration was given for the use of different packaging methods and shipment modes. Bulk transportation by road using Type B(U) packages was found to provide the safest and most flexible system. However, a standard package suitable for this application was not available, and Ontario Hydro decided to develop its own tritiated heavy water transport package.

Different concepts were evaluated using the following criteria:

(a) The package must be licensable as a Type B(U) package.
(b) The package must be easily transportable, i.e. no special permit required for travelling on the highway.
(c) There is no special shielding requirement, as tritium is a beta emitter.
(d) The loading and unloading of tritiated heavy water must be easily accomplished and occupational doses for the operation must be minimized.

After evaluation of different design variations, the present concept was chosen for further development. Detailed design and engineering analyses were to be followed with fabrication of a first production package.

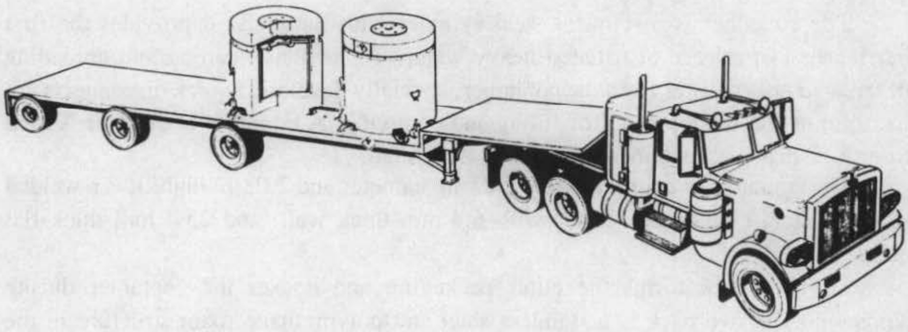

FIG. 2. Complete tritiated heavy water transport system.

The present configuration was chosen to maximize the capacity to weight ratio suitable for a regular road tractor/trailer system. Each package weighs approximately 16 800 kg when loaded to capacity with 4900 L of tritiated heavy water. Two such packages can be carried on a trailer with no special permits. The complete tritiated heavy water transport system is shown in Fig. 2. A sandwiched stainless steel and polyurethane foam construction was chosen for its ability to absorb impact energy and its superior thermal insulation rating. To prevent high accident strains experienced by the external casing being transmitted to the inner containment casing, the containment is nested in polyurethane foam and the inner casing is thus isolated from the exterior casing.

4. STRUCTURAL ANALYSIS

To support the Type B package licensing application, effects of static loading due to normal and tested conditions were evaluated using standard engineering calculations. A microcomputer was used extensively to provide documented calculations. It also provided an easy way to evaluate design alternatives. Engineering calculations were also used to provide a first evaluation of the effectiveness of the package to resist the accident mechanical drop tests and to predict the worst drop test orientation.

For the detailed analysis of the effect of the mechanical tests (the 1 m punch drop; the 9 m corner and flat top drop) two finite element computer analysis programs were used. HONDO, the two dimensional finite element analysis program was used for the axisymmetric analysis of the flat end drop and the punch drop on the centre of the flat ends. The three dimensional program DYNA-3D was used for the corner drop onto an unyielding target.

As information on the mechanical properties of the polyurethane foam used is unavailable in the literature, laboratory tests were performed on the foam materials to provide the computer program with the required material model.

A quarter scale punch drop simulating a portion of the package was performed to benchmark the computer programs. Both the HONDO and DYNA-3D programs provided a close correlation with the laboratory test results, providing confidence in the capability of both computer programs to predict accurately the effects of the drop tests.

The drop test analyses showed that the polyurethane foam absorbs sufficient impact energy to prevent damage to the containment casing and cover. It is noted that the outer casing of the package will deform substantially during a 9 m corner drop onto an unyielding target (see Fig. 3). However, the forces transmitted to the inner casing (containment) are minimal and no significant distortion of the sealing flange occurs, ensuring that containment will remain intact after the drop tests.

5. THERMAL ANALYSIS

The fire test and other thermal test conditions were evaluated using thermal calculations and a finite element computer program HEATR. Laboratory tests were

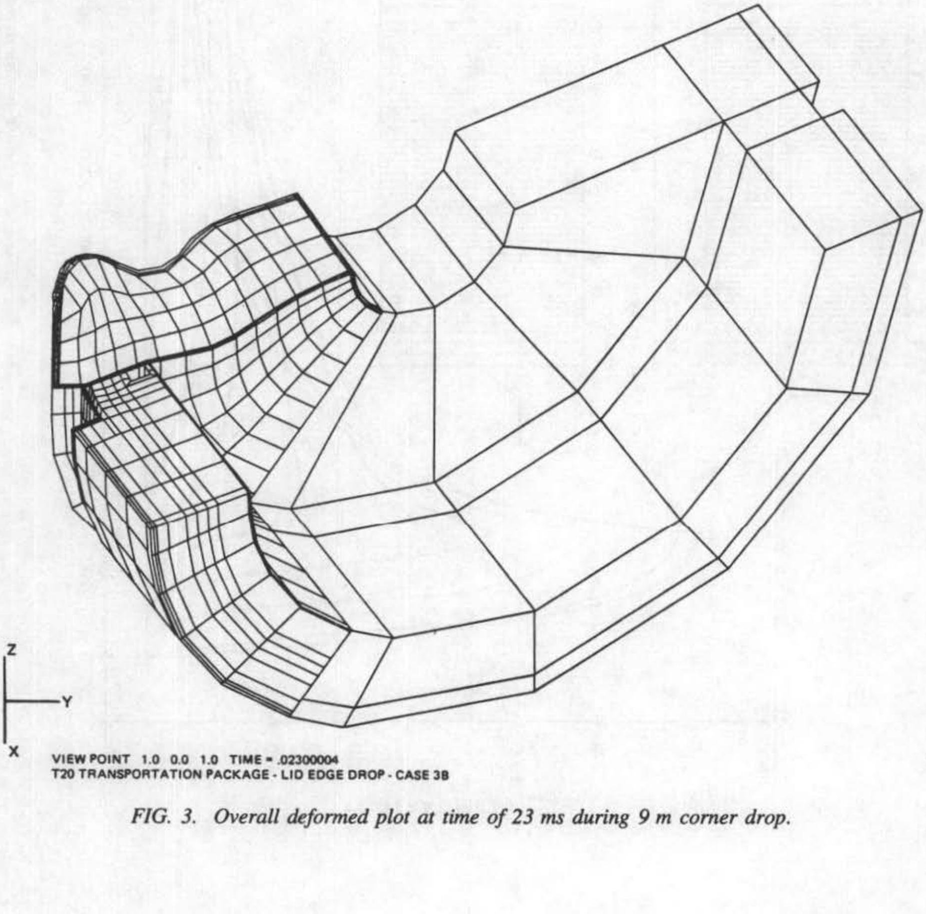

FIG. 3. Overall deformed plot at time of 23 ms during 9 m corner drop.

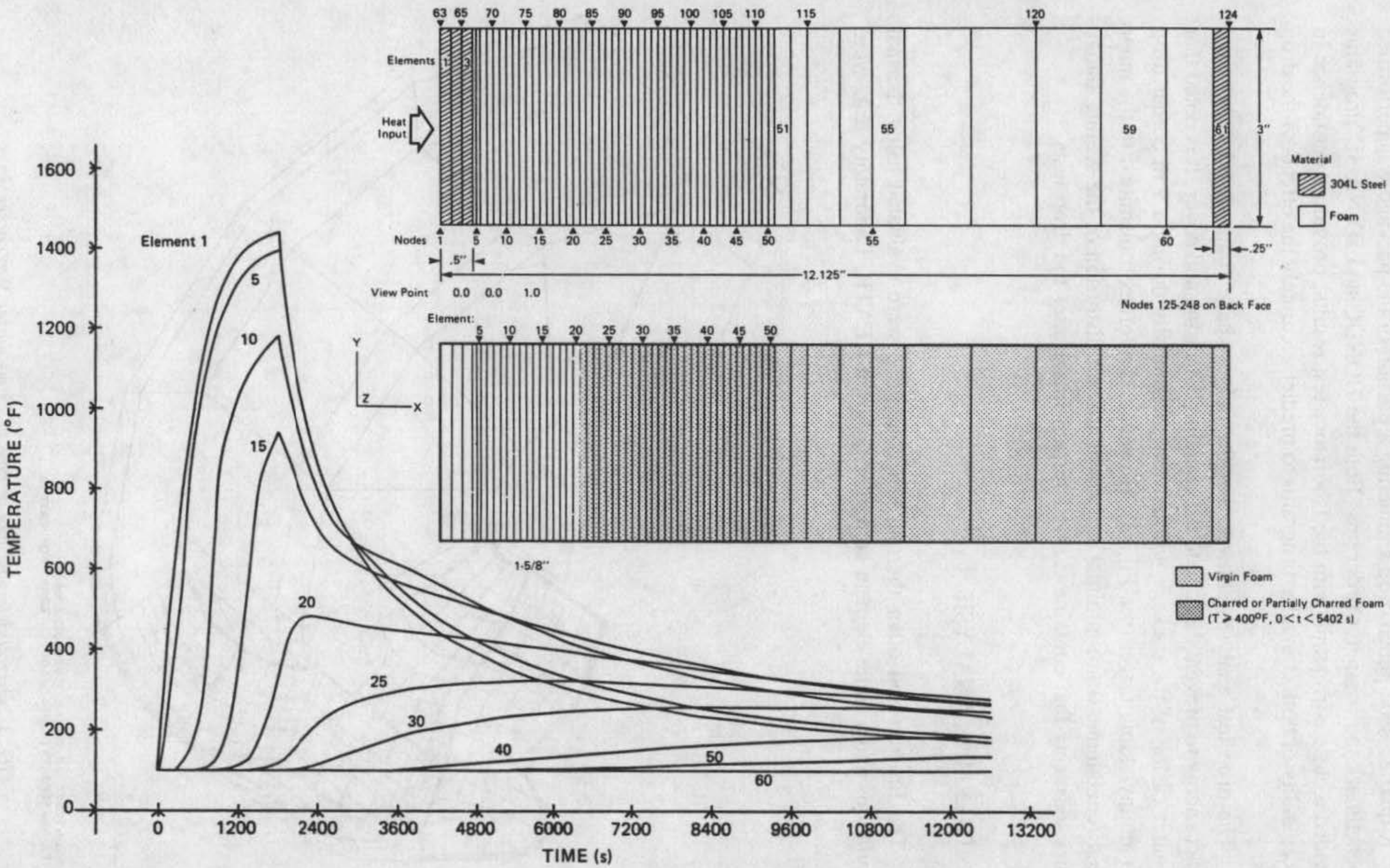

FIG. 4. Typical temperature profile during 30 minute fire test.

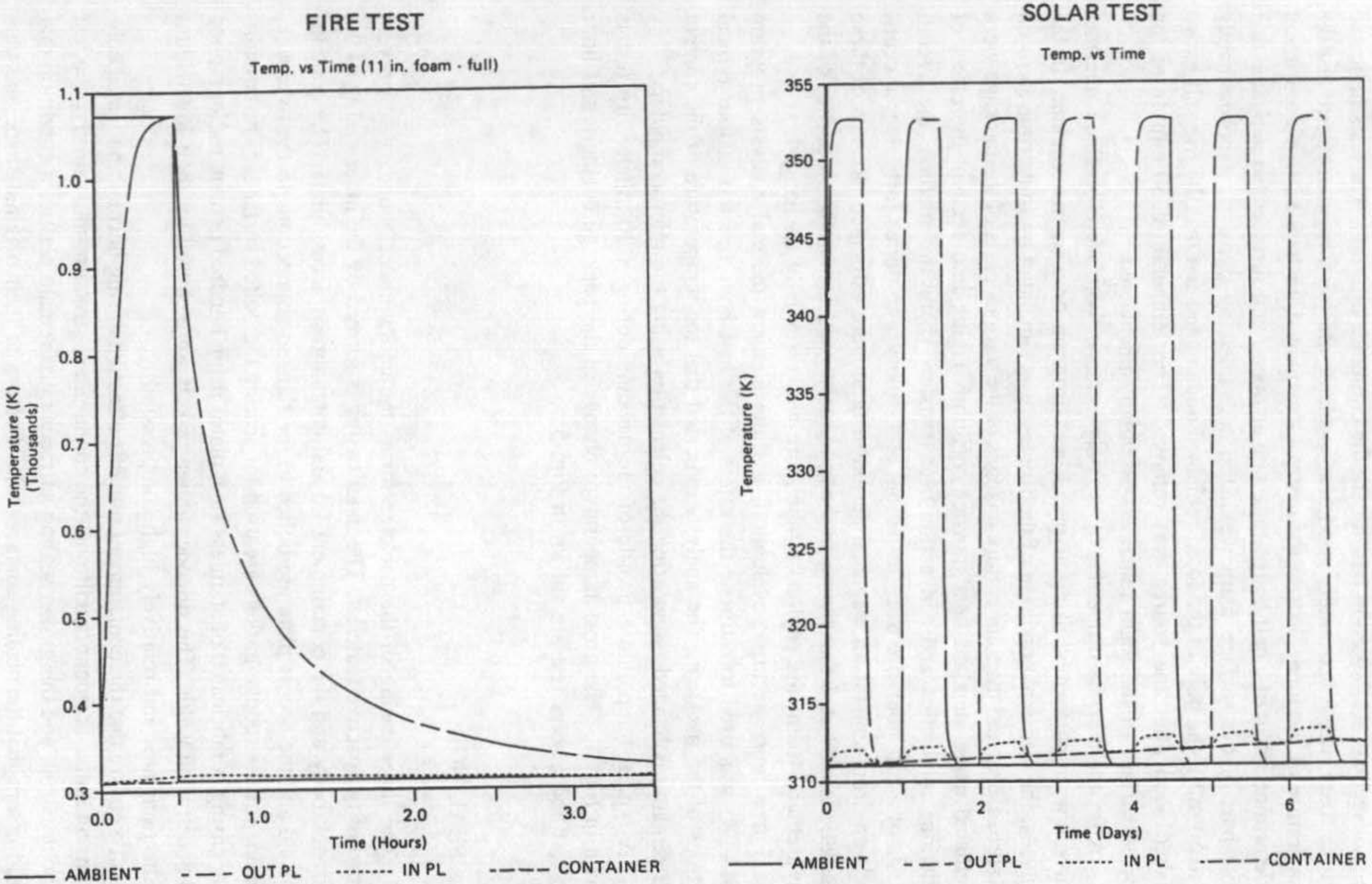

FIG. 5. Gross temperature change of package during half hour fire test and solar test.

performed to provide the thermal properties of the foam, and a full size section of the package was also tested to benchmark the computer program. The tests indicated that the foam was an extremely good heat insulator: during a regulatory fire test the temperature of the inner wall of the overpack remained unchanged. An experiment to determine effect of a half hour fire test on an open foam surface also indicated that while part of the surface foam would be consumed by pyrolysis (approximately 25 to 50 mm), the bulk of the foam remained undamaged and that the fire self extinguished soon after the source was removed. The temperature 50 mm from the charred surface of the foam remained essentially unchanged.

After the thermal properties of the polyurethane foam were obtained, thermal analyses were performed using a spreadsheet program on a microcomputer. In the analyses, the transient condition of the fire test was simulated by finite time steps on the spreadsheet and the temperature changes of the various parts of the package were calculated using standard heat transfer equations taking into account the effect of radiation, conduction and convection heat transfer. Using this method, the overall effects of a half hour fire test, insolation, and exposure to minus forty degree centigrade environment for an extended period of time were estimated. Results of these calculations indicated that owing to the extremely good insulating properties of the polyurethane foam, the payload temperature was essentially unchanged.

For a more accurate evaluation, a finite element thermal analysis program (HEATR) was used to estimate the effect of the half hour fire test at four typical sections of the package. The analysis indicated that the temperature of the content will remain unchanged, supporting the calculation using the microcomputers.

A typical temperature profile of the package during a 30 minute fire test is shown in Fig. 4. The gross temperature change of the package during a half hour fire test and a solar test are shown in Fig. 5.

6. SEALING

The inner casing of the package forms the containment boundary to prevent spread of radioactive material. The inner casing is formed by the inner casing of the overpack body and the containment lid and containment access plate. The containment lid and the access plate are bolted to the flanged connections to the overpack. Silicone rubber sponge gaskets are used for sealing the bolted surfaces. The containment casing is fabricated of stainless steel plates using hundred percent radiographed full penetration welds. The silicone rubber gaskets were chosen for their low tritium permeation rates and relatively high compressibility.

To ensure that the containment remains effective during normal and tested conditions and after accident conditions, the containment structure must survive the test without tearing and the gasket sealing surfaces must remain elastic; a condition that would assure that the sealing surfaces would return to their original shape and thus provide sealing as designed.

During normal and tested conditions, the containment was found not to be excessively stressed. The containment basically was only exposed to low pressure conditions. Temperature changes were small and did not have any significant effect on effectiveness of the containment system.

From the finite element computer analyses for the accident drop tests, the stresses experienced at the seal/flange area of the containment cover were well within the elastic range of the stainless steel material used. Therefore the seal/flange area would return to its original condition after impact and the gasket would remain effective in maintaining containment sealing.

7. SHIELDING

Since the tritiated heavy water to be transported would be relatively pure and the gamma radiation level expected to be very low, no special shielding was provided in the package design. The external dose rate would be measured during preparation for shipment and would be limited to 2 mSv/h (200 mrem/h) on the surface, and 100 μSv/h (10 mrem/h) at 1 m.

8. MANUFACTURING

A total of four packages and two trailers will be procured for the transportation of tritiated heavy water between Pickering Generation Station and the Darlington Tritium Removal Facility. To ensure that the packages can be constructed per specification, the first package had been fabricated in advance. There were several areas of concern, including:

— the fabrication of the stainless steel double shells;
— the proper installation of polyurethane foam in the annulus space to assure the lack of significant voids which would affect the safety characteristics of the package.

To ensure the adequacy of the foaming procedure before actual fabrication of the packages, a 1.2×1.2 m^2 wall section of the package was fabricated and the foam installed. Different installation procedures were tried. Voids were introduced and different non-destructive examination procedures were used to examine the section. Full radiographic examination was found the most reliable technique for quality assurance purposes.

9. OPERATING AND MAINTENANCE

During normal operation, the packages remain fully secured to the trailer bed during loading and unloading of tritiated heavy water. To facilitate the filling and emptying operations, small centrally located openings are provided in the overpack cover and the containment lid to allow easy access to the container. The large overpack cover and the main containment lid remain bolted and the seals undisturbed during these operations. To facilitate connection of the container with the instation filling system, specially designed low profile quick disconnect couplings were attached to the top head of the container where they can be easily accessed. To prevent any tritiated heavy water running down the side of the container into the interspace between the overpack containment and the container after disconnection of the couplings, a well was incorporated in the top head of the container to catch any drippings and provide easy means of cleanup prior to shipment.

10. CONCLUSION

Ontario Hydro has designed a new Type B transportation package suitable for the shipment of tritiated heavy water. The design and implementation took approximately two and a half years. It is expected that further packages based on similar concepts will be designed for other applications.