# Development of a Concrete Container for Irradiated Fuel Storage and Transport

J.D. Tulk and R.N. Sumar

*Ontario Hydro, Toronto, Canada*

## INTRODUCTION

Ontario Hydro generates more than 67 million MWe-h/year from its 16 nuclear reactors. These reactors are all of the CANDU type and make use of a natural uranium fuel cycle.

Ontario Hydro is committed to storage of used fuel for the next several decades. Additional storage capacity will be required at several station sites. Water filled bays have been very successful, and are well suited to storage of relatively hot newly discharged fuel. However, after a period of initial storage, fuel cools to the point where passively cooled dry storage in sealed concrete containers is feasible. This alternative offers low cost and flexibility, and can be made even more attractive if the same container can be used for transportation without any requirement for re-handling fuel.

## THE CIC CONCEPT

The Concrete Integrated Container (CIC) is being developed by Ontario Hydro as a transportable storage container for CANDU fuel that has cooled for at least 6 years. The design requirement calls for containers that are simple and inexpensive to build and require minimum upkeep after they have been loaded and sealed. They must be well adapted to existing plant facilities and operating procedures and provide excellent radiological protection. Finally, the containers, fitted with impact absorbing overpack structures, are to be licensable as type B(U) transportation packages.

### Design Features

Figure 1 is a schematic view of the CIC. The container is roughly rectangular in shape, with dimensions 2.1 m by 2.4 m by 3.6 metre high. The body and lid are both made of high density (3.5 $Mg/m^3$) reinforced concrete. The internal cavity is designed to hold 384 CANDU fuel bundles, or about 9.2 Mg of used fuel, stacked in four standard modules (baskets). Fuel will be loaded into the container under water in the storage bay. Because of this, it is very important to have a surface finish that can be dried and decontaminated once loading is complete. For this reason, the concrete will be clad inside and out with a steel skin. Surfaces will be painted with epoxy paint to inhibit rust and facilitate cleaning. There will be a drain port near the bottom of the container and a vent in the lid so that water trapped in the container during the loading operation can be removed by draining and vacuum drying.

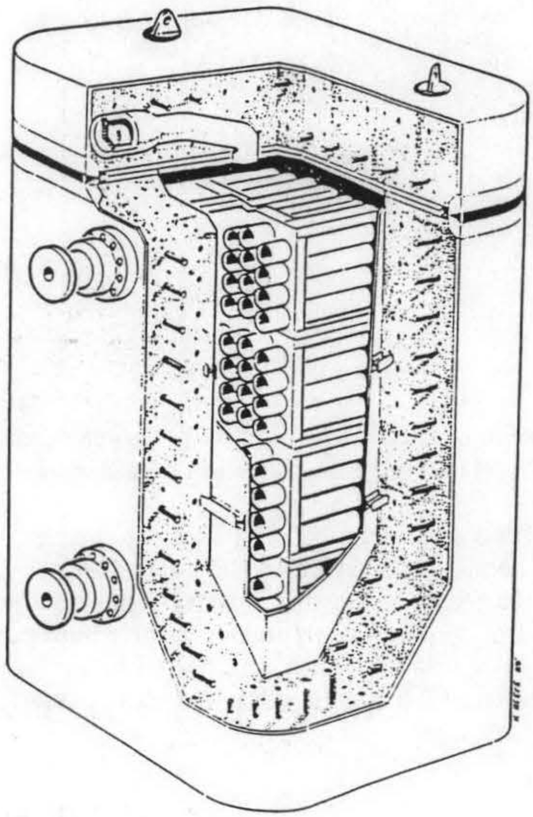

FIGURE 1. The Concrete Integrated Container (CIC)

The container is designed for an internal pressure of 100 kPa(g). The pressure boundary is supplied by the steel liner in the internal cavity and by the lid joint. The current reference design calls for a welded joint between the lid and container body which would serve as both the structural connection and the lid seal. All welds an the containment boundary will be full penetration welds and will be completely radiographed. The outer skin of both the lid and body will be thicker near the weld to provide a strong connection.

**Transportation**

Lifting trunnions and impact limiters will be added to the container for transportation (see Figure 2). The impact limiters will be composite structures with a high-density polyurethane foam core and stainless steel skin. The function of the limiters is to reduce accelerations and to spread out concentrated forces from a corner or edge impact.

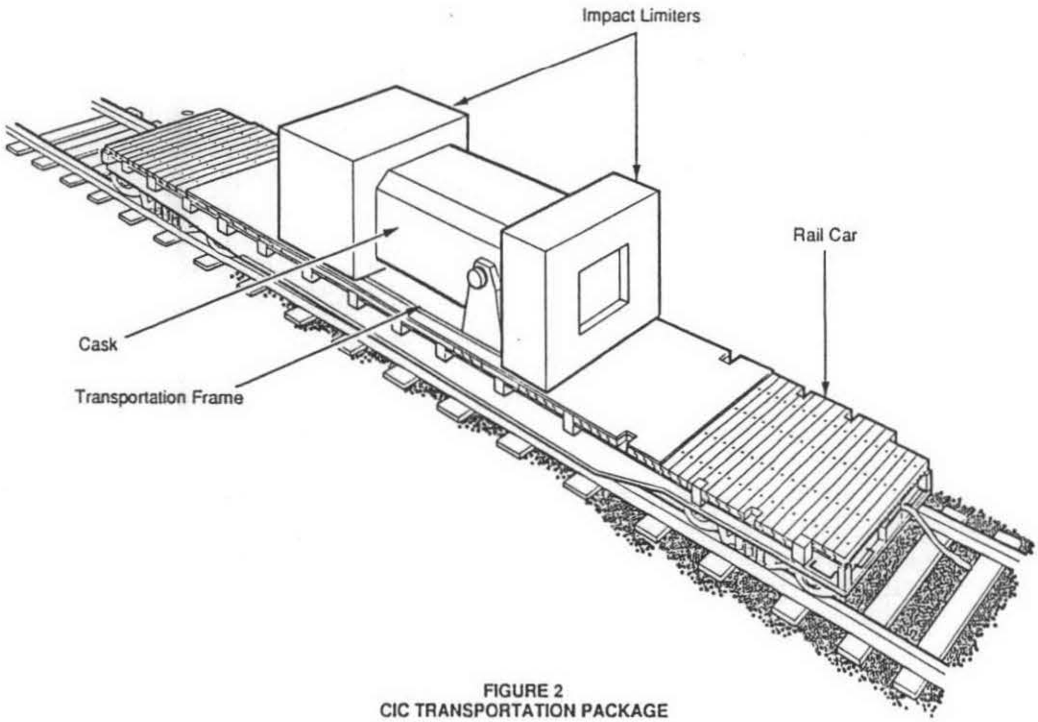


FIGURE 2
CIC TRANSPORTATION PACKAGE

## STORAGE DEMONSTRATION PROGRAM

The storage demonstration was intended to show that the CIC concept is workable and to provide experience in a realistic operational setting.

Two prototype containers have been built. These were built to an earlier design and are cylindrical in shape, 2.6 m in diameter and 3.6 m high. The lid was bolted in place and sealed with elastomeric O-rings. One prototype container is complete and has been loaded under operational conditions in an active storage bay. This container is being monitored in an open storage area for a test period of two years.

The exercise of building, loading and storing the prototype container has yielded a number of valuable lessons. First, it was established that wet loading is feasible. A full load (four fuel modules) was loaded into the container under water in about 45 minutes. With improved interior visibility, this time could be reduced. The container was successfully sealed, drained and dried. Epoxy painted steel surface picked up little surface contamination. Radiological safety exceeded expectations with exterior fields approximately half the design target.

The large-diameter elastomeric O-ring seals in the lid presented problems that could be awkward in a production environment. This feature has been eliminated in the current reference design, which is described above.

## SCALE MODEL IMPACT TESTING

The experience base for concrete as a transportation package material is limited, so the CIC development program has made extensive use of test results to back up design calculations. Because of the considerable size and mass of the package, these tests have been based on reduced scale models.

**Scaling Principles**

Scaling theory - and experience - show that scale model tests can mimic the behaviour of full-scale structures very closely (Yoshimura and Huerta, 1981). However, there are aspects of structural behaviour where the absolute size of the specimen influences results. Examples of scale dependent phenomena include brittle fracture (where crack propagation depends on absolute flaw size), and strain-rate effects. The reliability of scale model effects depends on the how much these scale dependent effects influence the final outcome of the experiment (Donelan and Dowling, 1985).

The CIC transportation package is a relatively complex structure in which the performance depends on interactions between a number of components and materials. Because of this, we have carried out a number of experiments aimed at assessing the effects of scale on steel/concrete composite structures undergoing dynamic loading (Tulk, 1989).

The first stage of testing involved four ring shaped specimens, varying in size from 153 mm diameter to 600 mm diameter. These were dropped edge down onto a thick steel plate from a height of 4.5 metres. The ring configuration was chosen because it provided an opportunity to examine scaling effects for five types of damage: crushing at the point of impact; cracking due to tensile bending stresses; crushing due to compressive bending stresses; shear cracking across a section; and spalling (cracking and separation) of unreinforced "cover" concrete.

The test results showed permanent ovalling deformations scaled well and that patterns of bending, crushing and shearing damage were very consistent across the range of models. However, loss of unreinforced cover concrete was noticeably more severe on the larger specimens. Thus, while overall structural response scaled well, fracture of unreinforced concrete changed with the absolute size of the model. This is not significant for the CIC where shielding concrete is completely contained in a steel shell.

**Container Model Drop Tests**

The next stage of testing involved a series of drop test experiments with small scale models that resembled the CIC. These experiments were based on the IAEA mandated nine-metre drop test and had two objectives: to assess the effects of scale on the behaviour of the whole package and to provide information on the impact resistance of the steel-skinned concrete container concept. The test specimens were nominally 1/4 and 1/8 scale models of the cylindrical CIC design used in the storage demonstration. While not identical to the CIC in detail, they were closely scaled replicas of each other.

Both sizes of model were subjected to a series of nine-metre drop tests including: top corner drops with impact limiter in place; side drops with impact limiters; and top corner drops with no impact limiter. For each test, the models were instrumented with accelerometers and strain gauges.

The first finding from the tests was that impact test results are very consistent over moderate scaling ratios (2:1 in the tests reported here). Figure 3 compares accelerations from 1/4 and 1/8 scale drop tests, with and without impact limiters. In each case, the model was positioned so that impact occurred on an top corner, with the centre of gravity directly above the point of impact. The similarity between 1/4 and 1/8 scale results is evident. As predicted by scaling theory, accelerations are close to twice as high for the smaller models, while impact duration is halved. For the test with impact limiters in place, there was virtually no detectable damage to the concrete components. However, the crush and buckle patterns of the impact limiters are virtually identical for both scales. When the container models were dropped on an upper edge without impact limiters, accelerations where much higher and there was local crushing at the point of impact. The extent of the crushed zone and the nature of the damage scaled well.

We conclude that scale tests can predict the behaviour of larger models reliably, provided some basic conditions are met:

- Scale modeling will be most reliable when the scaling ratios are moderate (We have found very satisfactory results for scaling ratios of 2:1).
- Wherever feasible, model dimensions should be scaled exactly from the prototype. Where scaled sizes or gauges are not available commercially, the next smaller size should be used to ensure that modeling errs on the conservative side.
- Concrete aggregate should be scaled by screening out coarse grades so that bond and interlock characteristics are well modeled (Andre and Sato, 1986). For our testing, a special concrete mix with fine-grade aggregate was developed to match the 28 day strength characteristics of the concrete specified for the full scale CIC.

The testing described here provided very convincing evidence that the combination of a steel shell with a reinforced concrete core forms a very robust structure. They also demonstrated that properly designed impact limiters are very effective in spreading impact load and reducing peak accelerations. Direct impact without impact limiters can cause significant damage, but because concrete absorbs energy well in crushing, damage is highly localized.

**FUTURE PLANS**

Development of the CIC is continuing. The second full-scale prototype will be loaded with used fuel six year old and set up for long-term monitoring to check performance of the the system with respect to temperatures, radiation fields and fission gas concentrations.

Closely detailed quarter-scale and half-scale models of the new container design are being built for a series of drop tests. The same models will be used for fire tests, during which the container models will be immersed in an 800°C fire for up to one half hour. These experiments are part of a program of design and analysis at licensing the CIC as a transportable long-term storage system for used CANDU fuel.

**REFERENCES**

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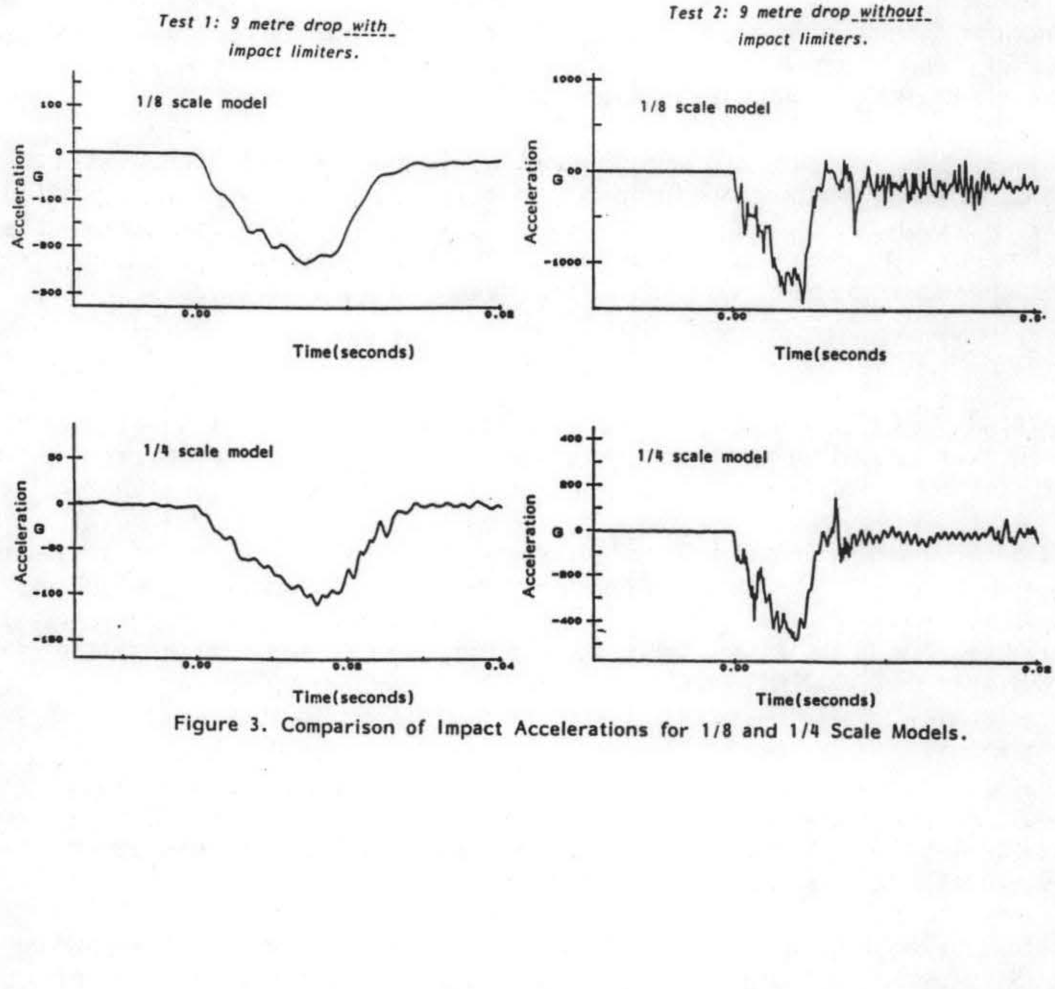


Figure 3. Comparison of Impact Accelerations for 1/8 and 1/4 Scale Models.