**Proceedings of the 19th International Symposium on the Packaging and Transportation of Radioactive Materials**
**PATRAM 2019**
**August 4-9, 2019, New Orleans, USA**

**Paper No. 1433**

# Drop Tests of the HI-STAR ATB-1T Cask for Radioactive Materials

**Stefan Anton**

Holtec International
1 Holtec Boulevard
Camden, NJ 08104, USA
Phone: +1 (856) 797 0900 x3659
Cell: +1 (856) 296 9219
s.anton@holtec.com
www.holtecinternational.com

**Venkat Prabhala**

Holtec International
1 Holtec Boulevard
Camden, NJ 08104, USA
Phone: +1 (856) 797 0900 x3605
Cell: +1 (609) 781-7863
v.prabhala@holtec.com
www.holtecinternational.com

## Abstract

Holtec International is developing a transport package for radioactive materials, the HI-STAR ATB-1T. It is designed to transport existing rectangular containers with radioactive materials, hence the HI-STAR ATB-1T is also rectangular. The maximum loaded weight of the HI-STAR ATB 1T package is about 112 metric tons, and due to dimensional restrictions, traditional large impact limiters cannot be used. The package design, therefore, imposes the technical challenge to withstand the regulatory 9 m drop scenarios without the use of large impact limiters.

Holtec has conducted a benchmark test program to support the qualification and licensing of the Package. The test was primarily designed to benchmark the analytical code (LS-DYNA), and not necessarily as the integral test of the entire containment boundary. The regulatory confirmation that the cask withstands the 9-m drop conditions is therefore still performed based on analyses with critical details benchmarked by the tests. Nevertheless, a quarter (1/4) scale model of the transport package was used in the tests. The test program was carried out at a test facility at the Sandia National Laboratory in New Mexico in September 2016. The following three critical drops where performed, all with a single package:

- 9-m flat drop onto the closure lid (expected to maximize acceleration and load on the closure system)
- 9-m CG over bottom corner drop (expected to maximize local deformation)
- 1-m puncture drop in the trunnion area (expected to maximize impact from pin)

Overall, the comparisons between the tests and numerical analyses showed very good agreements, with maximum deformations practically identical between tests and calculations.

It is therefore concluded that the non-linear analytical code is highly capable of predicting the dynamic response including large deformations of the transport package when subject to highly impulsive loads such as those imparted from the package drop tests in compliance with 10CFR71 regulations. It is also demonstrated that the dynamic analysis approach, using a carefully constructed LS-DYNA model, can be used in lieu of physical testing for safety demonstration.

For a video of the tests see https://holtecinternational.com/news/videos/hi-star-atb-1t-drop-test/

## Introduction

Holtec International is currently developing a transport package for radioactive materials for the international and US market, the HI-STAR ATB-1T. It is under licensing review by the USNRC under the governing US regulation (10CFR71). One of the intended applications is the transportation of existing rectangular containers filled with radioactive materials, hence the HI-STAR ATB 1T has also a rectangular form (see Figure 1 below). The maximum weight is about 112 metric tons, i.e. it is similar in weight to typical spent fuel transport systems. Transport casks of this weight typically use large impact limiters to mitigate the impact severity from the drop scenarios required by the regulations, specifically for the 9m free drop scenarios. However, due to weight and space restrictions for the intended application, large impact limiters could not be used for this cask, presenting some distinct design and licensing challenges.

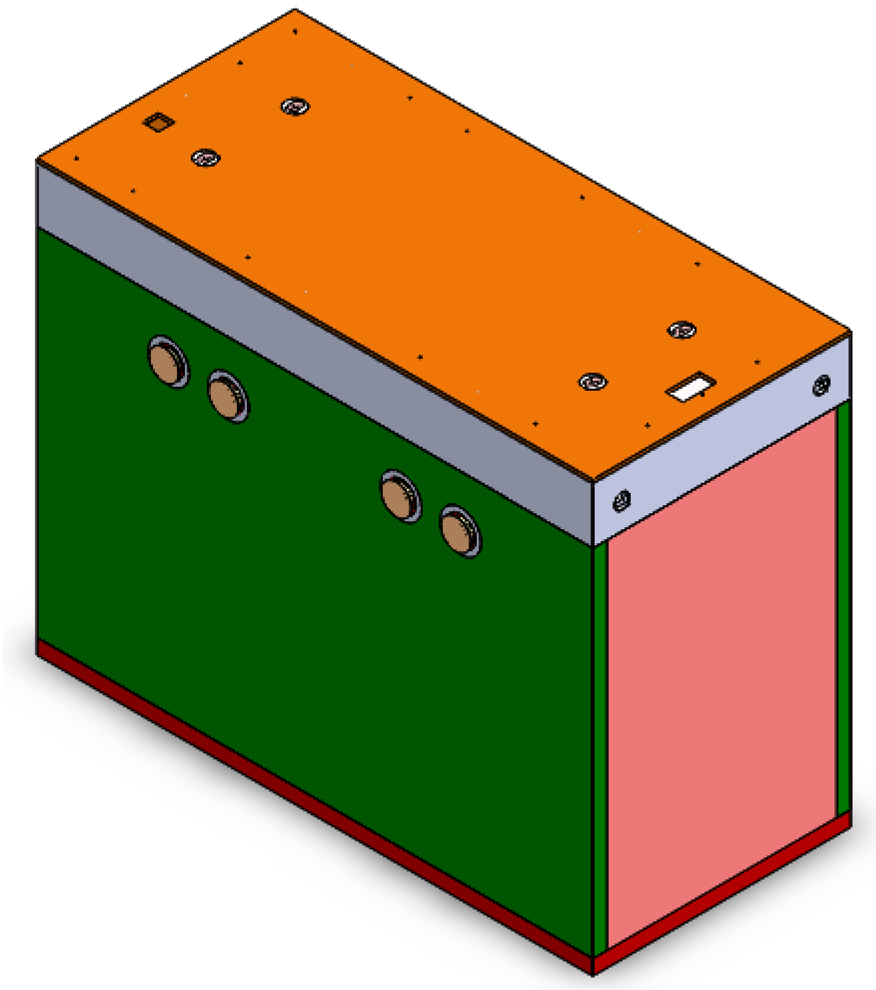


**Figure 1: HI-STAR ATB-1T Package**

Main characteristics of the cask are as follows

- Outer Dimensions 3.7m x 1.7mx 2.9 m
- Loaded weight 113 metric tons
- Maximum content weight 51 metric tons (may include supplemental shielding)
- Maximum Co-60 Activity 3.6 E15 Bq
- Eight trunnions
- Hydraulically locking closure lid (no lid bolts)

To assure containment integrity under the hypothetical transport accidents, without reliance on any large impact limiters, a 2-zone wall system is used, where the inner zone is the containment boundary that undergoes little or no deformation during the drop accidents, and the outer layer is designed to absorb the majority of the energy by deformation of the material. Stainless steel is initially used for both materials, due to its large plastic deformability and hence large energy absorption capability.

## Licensing and Benchmarking Approach

There are several possible approaches to demonstrate the integrity of the containment boundary under the critical hypothetical accident conditions (HAC) pursuant to 10CFR71 regulations. The most extreme approaches would be a) (full scale) physical drop tests of a package demonstrating the integrity, without the need for any supporting calculations; and b) a purely calculational approach, i.e. analyzing the various drop conditions. While the physical tests appear to be the most convincing, they have severe downsides, in that the number of tests is practically limited, and, more importantly, that they are simply go-nogo tests and do not provide any information about the remaining margins to failure. However, pure calculational approaches also pose problems, in terms of the veracity of computer codes, the selection of material models and the material properties. Specifically, for materials which undergo large deformations thereby absorbing the majority of the impact energy, there is a need to have the necessary confidence in the modeling of the material behavior. Hence in reality, a combination of initial tests and subsequent analyses is used nowadays with the main focus on the analyses, due to the high quality of today's computational codes.

When using combinations of tests and analyses, there are also various options for the physical tests. There could be full scale tests or tests using a scaled down version of the package; there could be tests of partial sections of the package to evaluate the behavior of selected design details; or tests for different systems available in the open literature could be used, as long as they can be shown to address essential aspects of the package behavior.

For the HI-STAR ATB-1T, the most critical issue is the behavior of the outer steel zone of the cask that undergoes significant deformation to absorb the majority of the impact energy from drops. A literature search led to tests performed by Idaho National Laboratory (INL) [2], where a MCO stainless steel canister was dropped from 23 ft. height. Analyses were carried by Holtec using an explicit code LS-DYNA [1] following the same initial conditions and materials as the MCO canister. The calculations showed very good qualitative and quantitative agreement, hence supporting the capability of the explicit code LS-DYNA. However, in discussions with the regulator, it became apparent that these existing tests may not be prototypical enough for some of the important features of the HI-STAR ATB-1T. Specifically, INLs tests were performed on rather thin-walled canisters, whereas the outer zones of the HI-STAR ATB-1T are rather thick (about 10 cm). Also, these thick walls have full penetration welds near the edges and corners of the cask, where these welds are exposed to multi-axial large deformations, with nothing similar in the tests using the canisters.

Based on this, a decision was made to perform physical drop tests.

## Physical Drop Test Configurations Selected

The main goal of the drop test configurations was to validate the analysis code and material models for the large deformations and corresponding energy absorption of thick plates connected by full penetration welds. Principally, that could have been achieved by tests on partial models with these configurations. Nevertheless, it was decided to utilize a scaled model of the package in the drop tests. The added benefit of this approach was that also the lid configuration could be tested, a non-standard design using a hydraulic closing system instead of the typically used bolts. The following three drop conditions and orientations were selected:

- Top down drop onto the lid, 30 ft drop. This drop orientation structurally challenges the package closure lid and its connections (Closure Lid Locking System).
- Center-of-Gravity (GC) over corner, 30 ft drop. This drop orientation imparts maximum localized damage/deformation in the package corner and poses maximum threat to welds connecting three distinct containment plates/walls.
- Drop onto the pin, 40 in drop. The impact energy form this drop is much smaller. However, since the area of impact is significantly smaller, it may pose threat to the containment wall at the thinnest section right behind the trunnion.

Since the impact areas on the cask do not overlap for these three drops, a single scaled cask model (quarter scale) was used, with tests performed in the order listed above.

## Tests

The tests were performed in September 2016 at the Sandia National Laboratory (SNL). The aerial view of the test location at SNL is shown in Figure 2 below. Although the primary information to get from the tests were the macroscopic deformations, the cask was also instrumented with numerous accelerometers and strain gages, and two pairs of monochrome high-speed cameras running at 10,000 frames per second (fps) were used to record the tests. The pairs of high-speed cameras were located approximately 90° to each other so as to provide two orthogonal stereo views of the test article upon impact. The outside of the cask was covered with random dot patterns, which allowed evaluations of local strains and deformations using the high-speed cameras.

The individual tests and selected results are discussed and presented below.

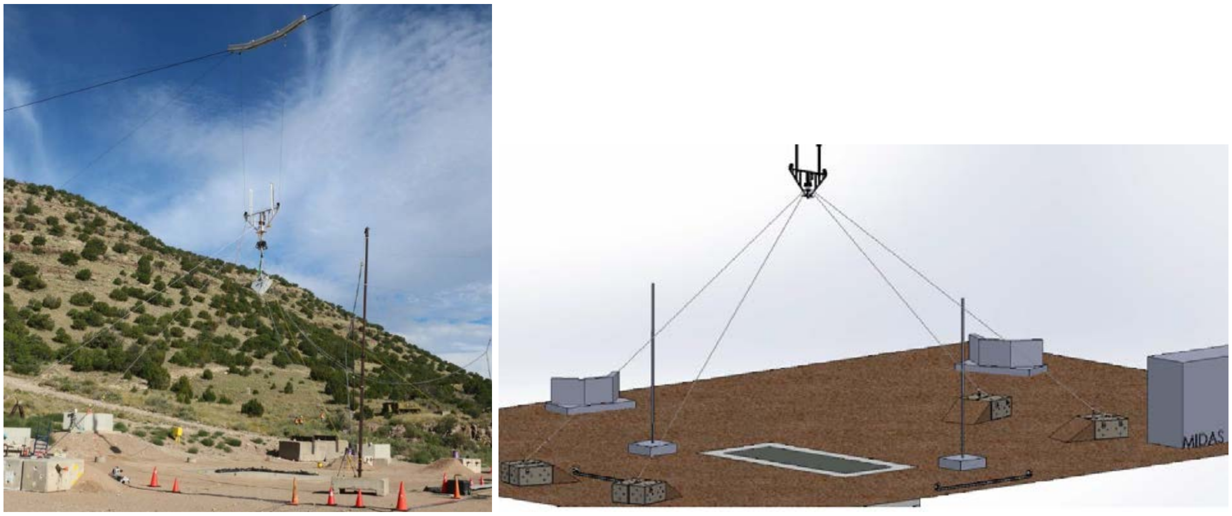



**Figure 2: Aerial Cable Facility and Instrumentation Set-up.**

## Top Down Drop

The top down test did not process exactly as planned. The cask was attached to a release mechanism using several slings, and the slings were not released at the exact same time, imparting a slight angular momentum on the cask. Consequently, the cask was at a slight angle (about 18 degrees) when it hit the ground. This resulted in a secondary impact on the opposite corner of the closure lid flange from the primary impact, and further cask rotations with additional minor impacts. Consequently, the drop was characterized as an oblique top down drop. Nevertheless, assuming the same impact angle in the analysis allowed the intended comparison between test and analysis results. Selected comparisons are shown in Figures 3 and 4, with relevant results shown in Table 1. Figure 3 shows the cask before the primary impact, between the primary and secondary impact, and directly after the secondary impact, both from the test and the analyses. Qualitatively, the cask orientation and physical state matches very well for each of these three situations between test and calculations. Figure 4 shows a similar comparison of the deformation on the top flange of the cask which shows a close agreement between the drop test and the simulation. Table 1 contains a quantitative comparison between the drop test and the simulation results, and again a very good agreement is observed. Other parameters, such as local strains and accelerations were also compared, some of which show some larger differences. However, that is not unexpected based on previous experience with test results. This is related to the fact that these are local or instantaneous values that would naturally have larger uncertainties, specifically for the complex dynamic behavior, as opposed to the integral values such as deformation.

Additionally, the lid closure system experienced minor damage during this drop. This was partially the result of differences between the full-scale design and the test sample for easier scaling, but also prompted some minor design changes in the lid closure system of the package.

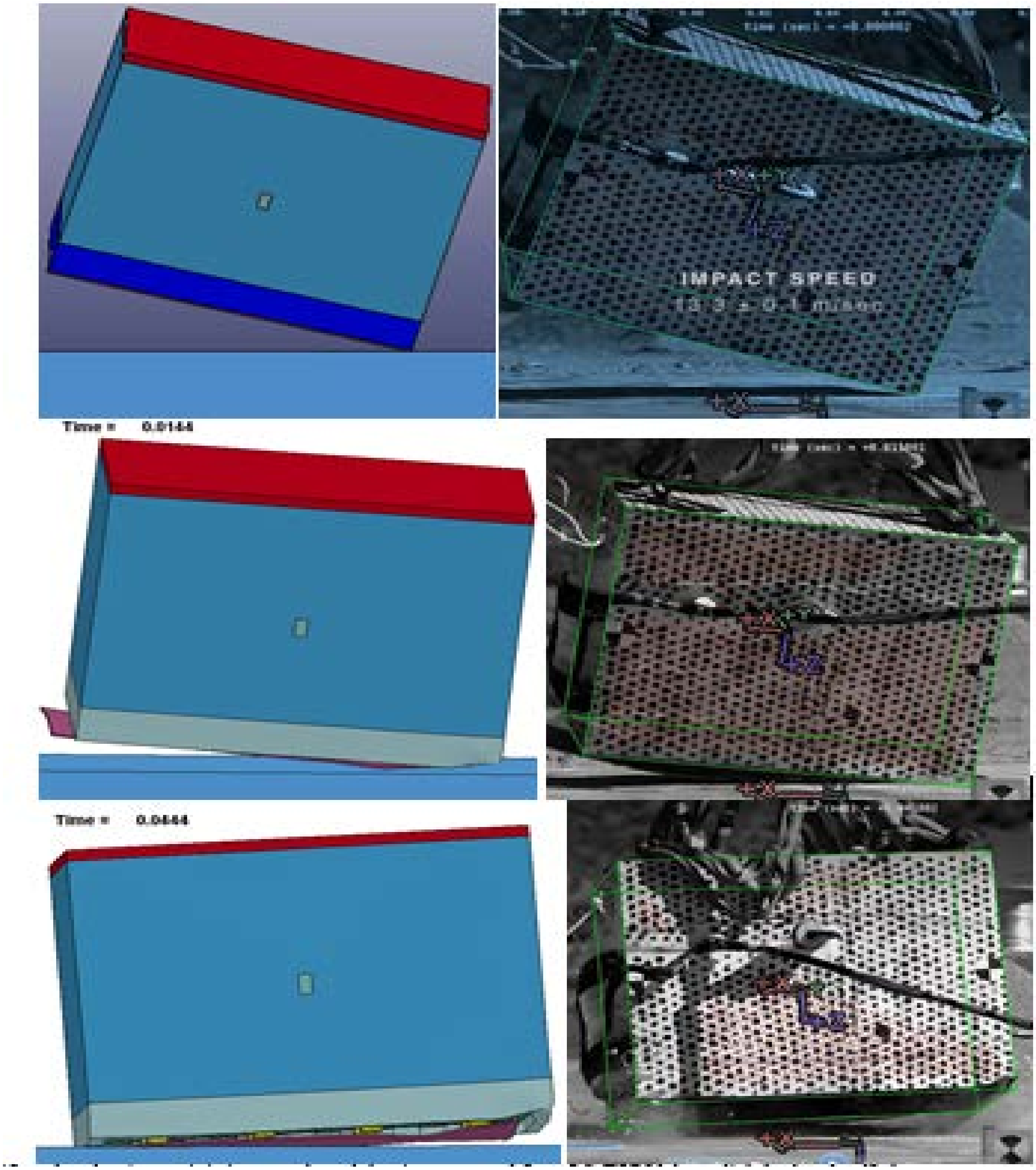
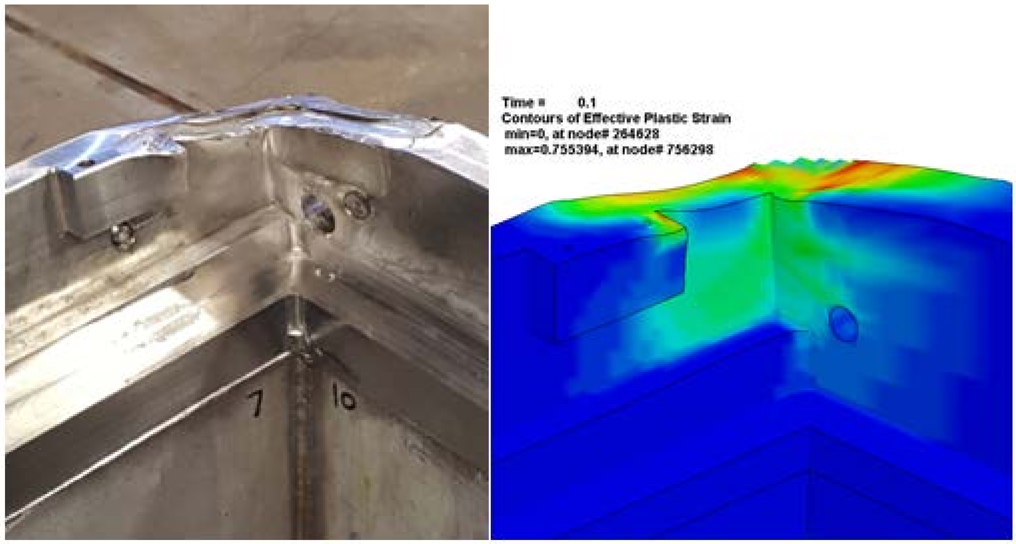
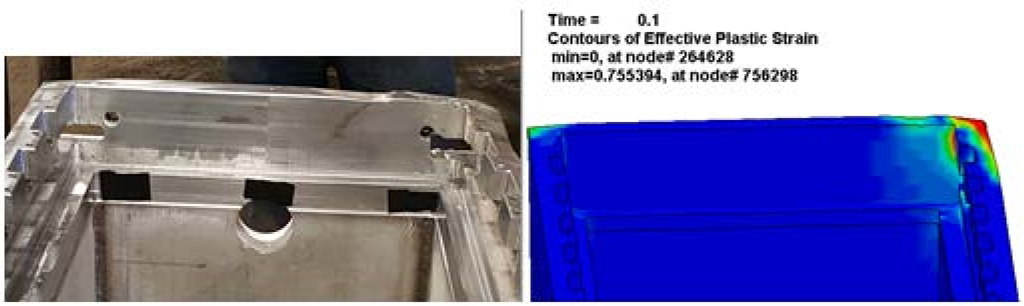



**Figure 3: Oblique Top-Down Drop Test Vs Simulation Comparison**




*Deformaiton from Primary Impact*




*Deformation from Secondary and Tertiary Impact*

**Figure 4: Deformation in Top Flange from Oblique Top-Down Drop**

**Table 1 Summary of Deformations from Oblique Top-Down Drop Event**

| Package Component | Deformation Sustained from Drop Test (in) | Deformation Predicted from Simulation (in) |
|---|---|---|
| Top Flange Deformation (Primary Impact) | **Corner Deformation:**<br>i. **Depth = 1**<br>ii. **Across Shorter Edge = 3.8**<br>iii. **Along Longer Edge = 4.5** | **Corner Deformation:**<br>i. **Depth = 1**<br>ii. **Across shorter Edge = 3.7**<br>iii. **Along Longer Edge = 4.6** |
| Top Flange Deformation (Secondary Impact) | **Corner Deformation:**<br>i. **Across Shorter Edge = ~ 2**<br>ii. **Along Longer Edge = ~ 8** | **Corner Deformation:**<br>i. **Across Shorter Edge= 1.85**<br>ii. **Along Longer Edge = 8** |

## CG Over Corner

The CG-over-corner drop went well, since after some re-adjustment of the release mechanism no momentum was imparted on the cask, hence it impacted the target as expected. Orientations during the drop are compared again in Figure 5, deformations in Figure 6 and measured results in Table 2. As for the oblique top down test, there is a very good agreement between test and analysis. For this drop, both strains and accelerations also matched very well, so the differences found for the oblique top-down drop may have been created by the more complex movement of the cask during and after the impact.

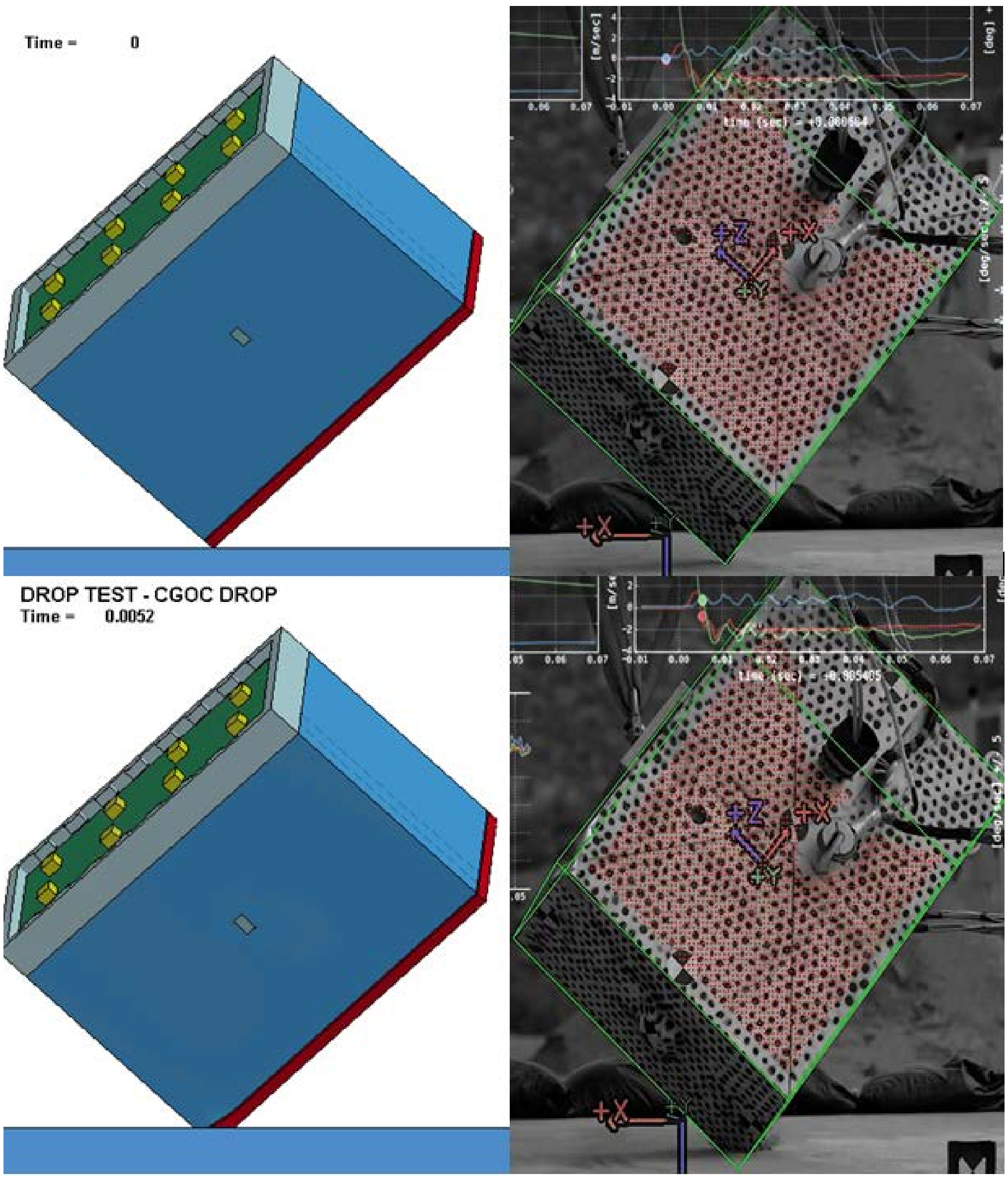



**Figure 5: CGOC Drop Test Vs Simulation Comparison**

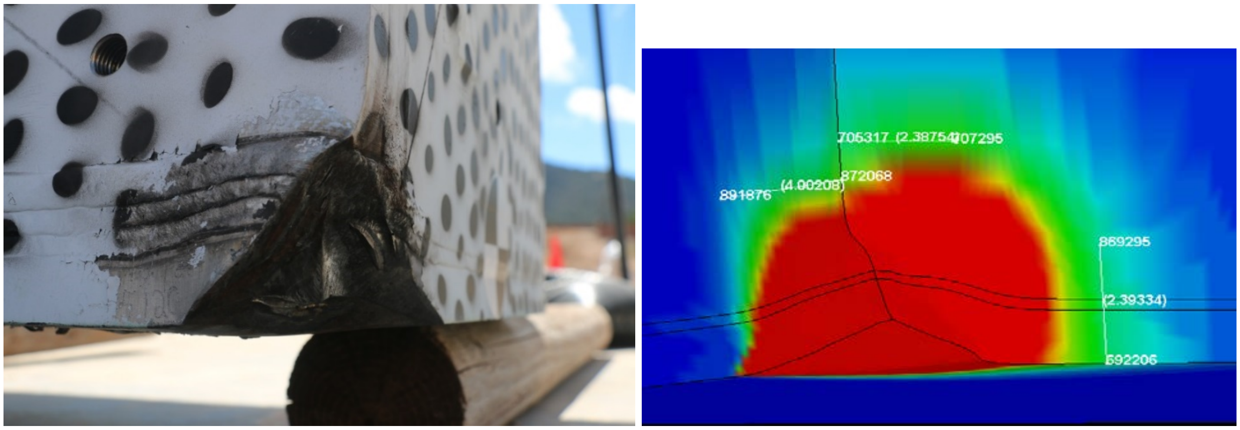



**Figure 6: Outer Shell Deformation from CGOC Drop**

**Table 2 Summary of Deformations in the Key Components from CG-Over-Corner Drop Event**

| Package Component | Deformation Sustained from Drop Test (in.) | Deformation Predicted from Simulation (in.) |
|---|---|---|
| Outer Shell Deformation | Depth Measure = 2.4<br>Deformation Along:<br>Cask Longer Edge = 2.4<br>Cask Shorter Edge = ~ 4.0 | Depth Measure = 2.39<br>Deformation Along:<br>Cask Longer Edge = 2.39<br>Cask Shorter Edge = 4.0 |
| Target Deformation | Indent Length = ~ 4.0<br>Indent Width = 3.0 | Indent Length = ~ 4.22<br>Indent Width = 3.29 |

## Puncture Drop

For the puncture drop the bar was not made part of the target, but was attached to the cask, in order to ensure that the bar would impact the cask in a pre-determined location on the containment wall behind the trunnion where the maximum effect is expected. Figures 7 and 8 show the comparison between the drop test and simulation, and Table 3 compares key results from this drop.

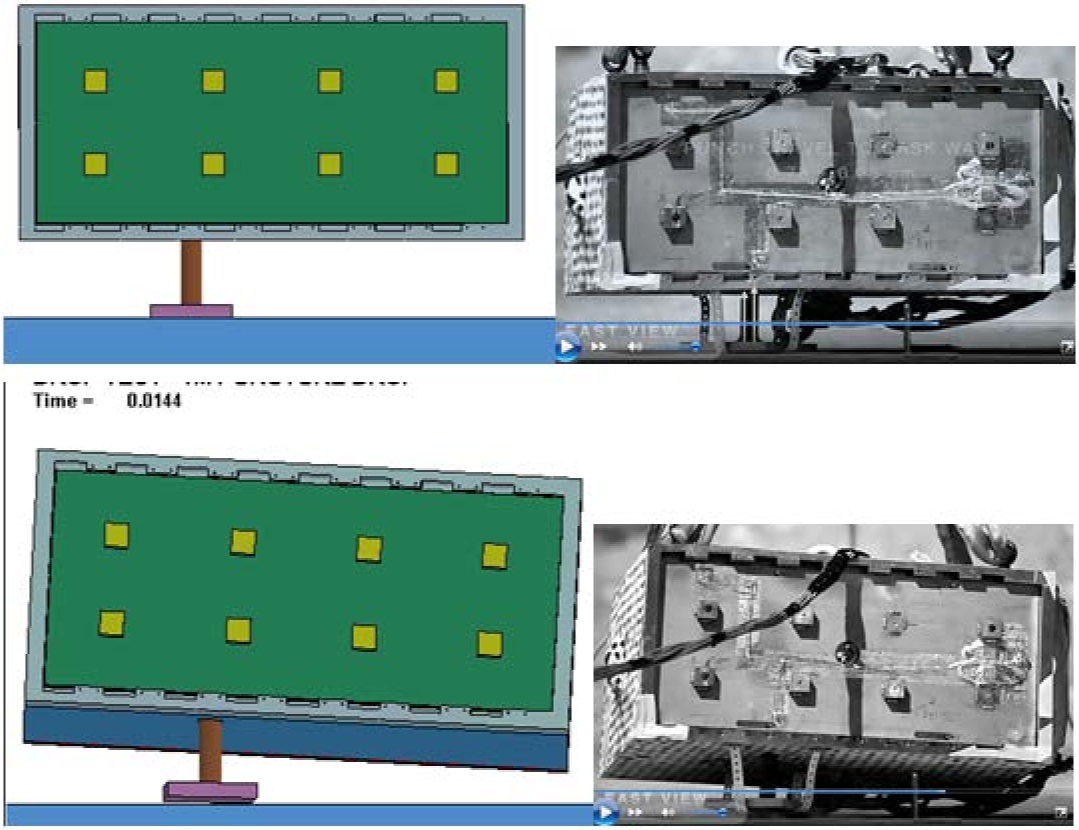



**Figure 7: Puncture Drop Test Vs Simulation Comparison**

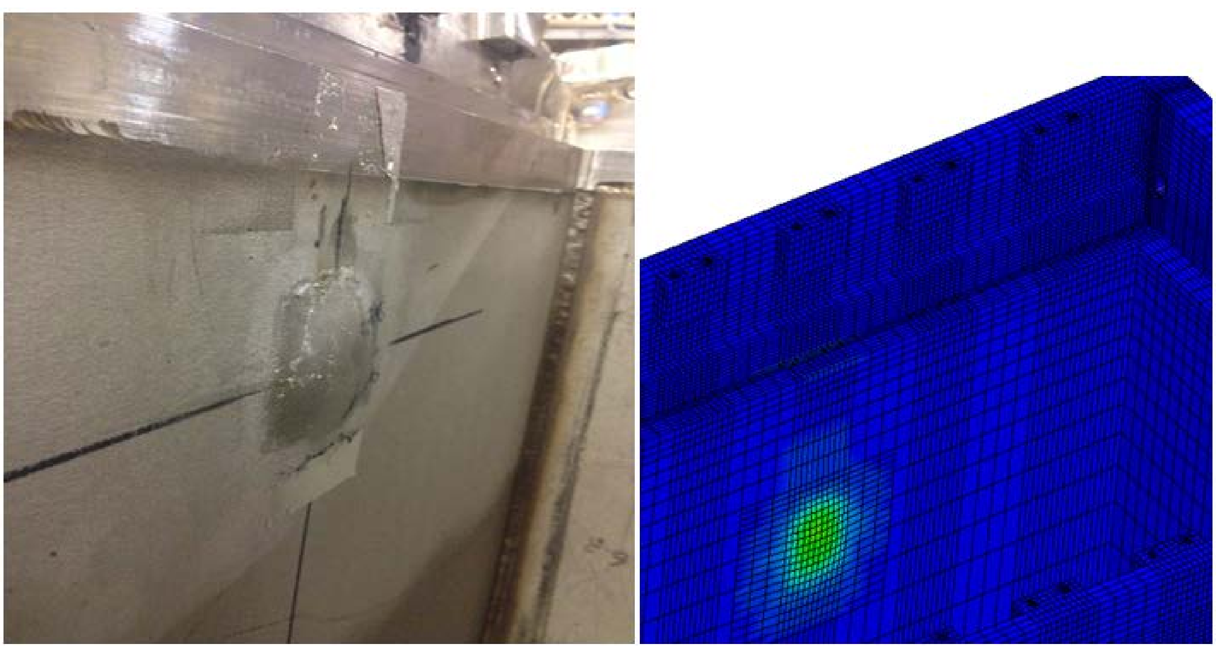


**Figure 8: Deformation of the Package Inner (Containment) Shell from he Puncture Drop**

**Table 3 Summary of Package Deformations from Puncture Drop Event**

| Component | Deformation Sustained from Drop Test (in.) | Deformation Predicted from Simulation (in.) |
|---|---|---|
| Depth of indentation on the Containment Shell: | **0.21875** | **0.2212** |
| Length and Width of Indentation on the Containment Shell: | **3.0** | **3.13** |

## Conclusion

The comparisons between the tests and calculations showed very good agreements. The maximum deformations were practically identical between tests and calculations. Local measurements such as strains and accelerations were also generally in good agreements.

This supports the conclusion that state-of-the-art non-linear analytical codes are highly capable of predicting the dynamic response and large deformations of transport packages with great accuracy, when subject to highly impulsive loads such as those imparted from the package drop tests in compliance with 10CFR71 regulations, even in the absence of large impact limiters. This also supports the conclusion that the dynamic analysis approach, using a carefully constructed LS-DYNA model, can be used in lieu of physical testing for safety demonstration.

## References

[1] LS-DYNA 971, Livermore Software Technology, 2006.

[2] INL-EXT-15-35664, Drop Testing Representative Multi-Canister Overpacks, Idaho National Laboratory, January 2005.