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Horizontal 30 cm Drop Test of 1/3 Scale ENSA ENUN 32P Dual Purpose Cask

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ABSTRACT

SNL in collaboration with PNNL, BAM (Germany), and ENSA (Spain) conducted two 30 cm drop tests of a 1/3 scale cask. The tests took place in December 2018 at the BAM facility in Berlin. The 1/3 scale cask and impact limiters were provided by ENSA. This cask is a mockup of the ENSA ENUN 32P cask, which included a full load of 32 1/3 scale dummy fuel assemblies. The major goals were: (1) complete normal conditions of transport (NCT) mechanical testing environment; (2) to better understand the potential implications of handling incidents; and (3) to learn if the transfer function from the cask through the basket to the fuel is the same for more severe impacts as for shocks in the over-the-rail tests.

The tests were a follow-on to the 2017 Spanish/US/Korean Multi-Modal International Transportation Test that obtained strain and acceleration data on surrogate fuel within the ENSA ENUN 32P cask, the basket, the cask, the cradle and the conveyance during heavy-haul truck, ship, and rail transport. The purpose of these tests was to validate the hypothesis that spent nuclear fuel can withstand the shocks and vibrations from normal conditions of transport without failure. The 30 cm drop is the remaining NRC regulatory requirement under normal conditions of transportation (10 CFR 71.71) for which no data on the surrogate fuel are available. While obtaining data on the fuel assemblies is not a direct requirement, it provides definitive information regarding the risk of fuel breakage from a cask drop from a height of 30 cm or less.

Two horizontal drop configurations were implemented. In the first configuration, the cask was in its regular transport and handling position. In the second configuration, the cask was rotated 45 degrees counter clockwise about its longitudinal axis. The purpose of the second configuration was to quantify the potential variation of fuel assembly impact response due to a change in basket orientation.

The accelerations on the dummy assemblies, basket, and cask body were measured during the test. SNL installed 34 accelerometers on 11 dummy assemblies, 12 accelerometers on the cask, and 3 accelerometers on the basket.

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INTRODUCTION

Sandia National Laboratories (SNL) in collaboration with Pacific Northwest National Laboratory (PNNL), Bundesanstalt für Materialforschung und -prüfung (BAM) (Germany), and Equipos Nucleares, S.A., S.M.E. (ENSA) (Spain) conducted two 30 cm drop tests of a 1/3 scale cask. The tests took place in December 2018 at the BAM facility in Berlin. The 1/3 scale cask and impact limiters were provided by ENSA. This cask is a mockup of the ENSA ENUN 32P cask, which included a full load of 32 1/3 scale dummy fuel assemblies. The major objectives were: (1) complete normal conditions of transport (NCT) mechanical testing environment; (2) to better understand the potential implications of handling incidents; and (3) to learn if the transfer function from the cask through the basket to the fuel is the same for more severe impacts as for shocks in the over-the-rail tests.

The tests were a follow-on to the 2017 Spanish/US/Korean International Multi-Modal Transportation Test (MMTT) that obtained strain and acceleration data on surrogate fuel within the ENSA ENUN 32P cask, the basket, the cask, the cradle and the conveyance during heavy-haul truck, ship, and rail transport [1]. The goal of the MMTT was to validate the hypothesis that spent nuclear fuel can withstand the shocks and vibrations of normal conditions of transport without failure. A short video documenting the major test events is available on YouTube [2]. The 30 cm drop is the remaining NRC regulatory requirement under normal conditions of transportation (10 CFR 71.71) for which no data on the surrogate fuel are available. While obtaining data on the fuel assemblies is not a direct requirement, it provides definitive information regarding the risk of fuel breakage from a cask drop from a height of 30 cm or less.

The goal of the 30 cm drop test was to measure accelerations on the cask and on the dummy assemblies. The 1/3-scale ENSA ENUN-32P cask is the scaled model of the same cask used in the multi-modal transportation test. SNL conducted a series of tests with the 1/3 scale ENSA ENUN-32P cask in 2010 to test the impact limiter performance [3]. The instrumentation in these tests was on the outside of the cask. The data collected in 2010 for the 30 cm drop test provided useful information on what accelerations to expect on the cask. The maximum average acceleration was around 30-35 g. This translates into a maximum average acceleration around 10-12 g on the full-scale cask.

The maximum accelerations on the full-scale ENSA cask in the MMTT were observed during the series of rail tests at the Federal Railroad Administration (FRA) Transportation Technology Center, Inc. (TTCI) located in Pueblo, CO [4]. Figure 1 shows maximum acceleration on the cask in X, Y, and Z directions for each TTCI test. The highest acceleration on the cask was 1.3 g in the vertical direction in the coupling test at 8 mph. This is nearly an order of magnitude lower than the expected accelerations on the cask during the 30 cm drop test. As it was demonstrated by MMTT, the accelerations on the surrogate assembly are amplified compared to the accelerations on the cask. The maximum acceleration on the surrogate assembly was 18 g in the 8 mph coupling test at TTCI. The experimental data for the cask to assembly transfer function are needed for more severe impacts, such as a 30 cm drop.

Note that strains were not measured in the 1/3-scale drop test because the strain does not scale well [5] and because the 1/3 scale dummy assembly are structurally very different from the actual (surrogate) fuel assembly used in the multimodal transportation tests. Strains will be measured in the full-scale assembly drop tests at SNL in the summer of 2019.

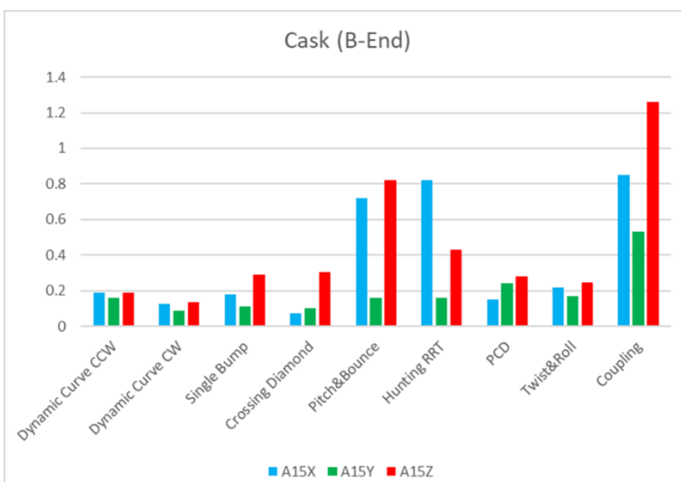

Figure 1. Maximum accelerations on the cask observed in TTCI tests.

TEST HARDWARE

Figure 2 shows the solid model of the 1/3 scale ENSA ENUN-32 cask with the impact limiters. The cask was provided by ENSA. Due to the high cost of new impact limiters, it was decided to use the impact limiters from the 2010 test series. ENSA identified two suitable used impact limiters. Figure 3 shows the damaged bottom impact limiter. This impact limiter was converted to an upper one (on the lid side). Another bottom impact limiter with similar damage was used on the bottom. The position of the damaged impact limiter during the test is shown in Figure 3.

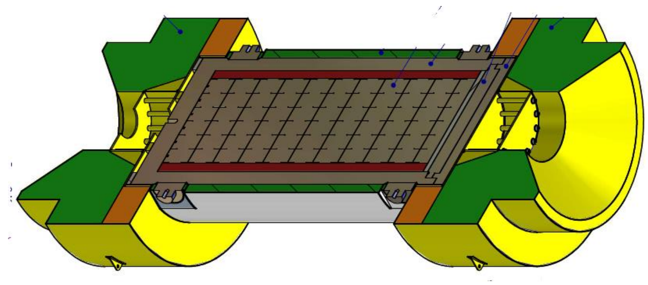

Figure 2. Solid model of the 1/3 Scale ENSA ENUN-32 cask with impact limiters.

Figure 3. Damaged bottom impact limiter (left) and its position during the drop test (right).

The original lids (external and internal) of the 1/3 scale ENSA cask were not used in the test. Instead, a special lid was manufactured. This lid has the same weight as two original lids and has two 5 cm holes for the instrumentation cables. Figure 4 shows the solid model of the special lid.

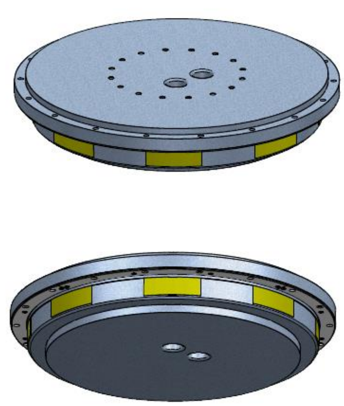

Figure 4. Solid model of the special lid manufactured for to be used in 30 cm Drop Test.

32 1/3 scale dummy assemblies were provided by ENSA along with the cask. The solid model of the dummy assembly and its photo while being pulled from the cask are shown in Figure 5.

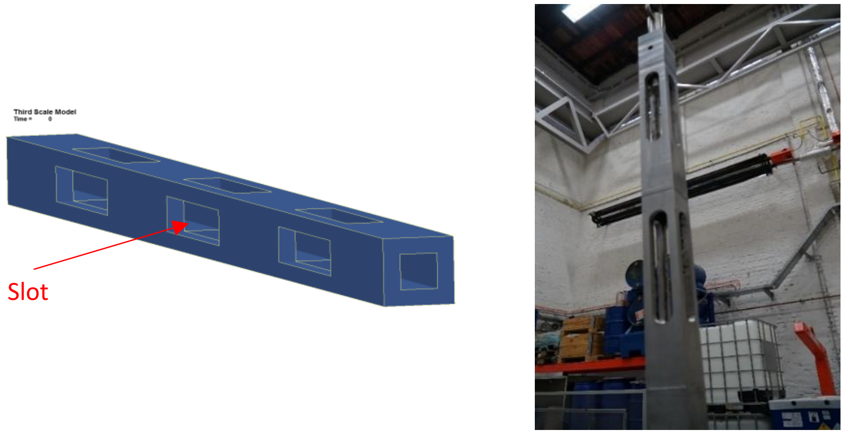

Figure 5. Solid model of the dummy assembly (left) and photo of the dummy assembly (right).

TEST CONFIGURATION

Two horizontal drop test configurations were used. These configurations are shown in Figure 6. In the first configuration, the cask is in its normal position. In the second configuration, the cask is rotated 45 degrees counter clockwise when looking at the lid end about its longitudinal axis. The purpose of the 45 degrees rotation test was to quantify the potential variation of fuel assembly impact response due to a change in basket orientation. The fuel assemblies within the cask are expected to witness higher acceleration pulses than the cask body. Loads transmitted to the fuel assemblies are transmitted through the basket structure. Rotating the basket orientation in the second test changes the contact area between the basket and the simulated dummy assemblies, and it changes the load path through the basket structure. This secondary test provides data to compare against the primary horizontal drop test to determine if there is a significant difference in fuel assembly loading due to basket orientation.

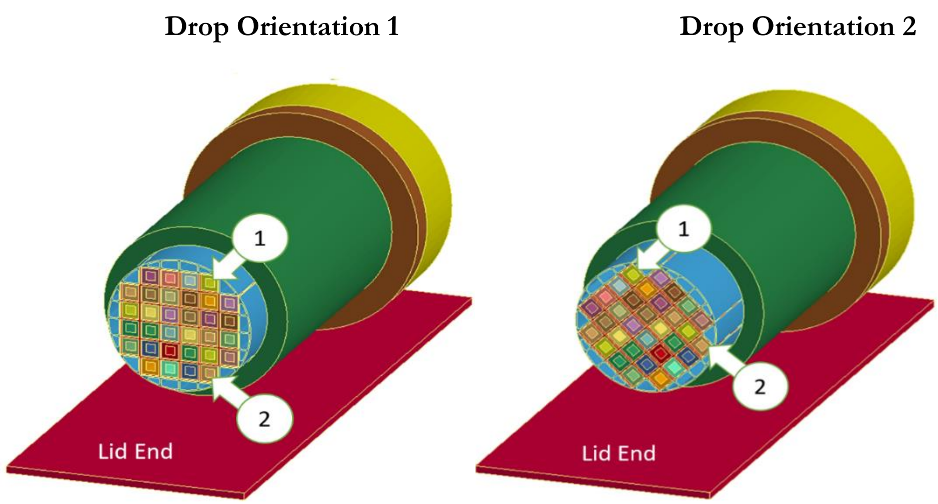

Figure 6. 30 cm drop test configuration.

INSTRUMENTATION

The unit was instrumented by the SNL team at the BAM facility. The cask, with impact limiters, modified lid, dummy assemblies, and handling tools, were transported from the ENSA facility to BAM in November 2018.

The cask was instrumented with 2 tri-axial accelerometer blocks on the cask top and 2 tri-axial accelerometer blocks on the cask bottom (Figure 7). Endevco model 7270A accelerometers were used. The cask instrumentation was the same as in the 2010 series of tests [3].

Eleven dummy assemblies were instrumented on the A (lid) side with tri-axial accelerometers in locations 1-4 and uniaxial (vertical) accelerometers in locations 5-11. Seven dummy assemblies were instrumented on the D (bottom) side with tri-axial accelerometers in locations 1-4 and uniaxial (vertical) accelerometers in locations 5-7. One tri-axial accelerometer was placed on the basket. Figure 8 (left) shows the locations 1 through 11 and the location on the basket. Figure 8 (right) is a photo of the instrumented dummy assemblies.

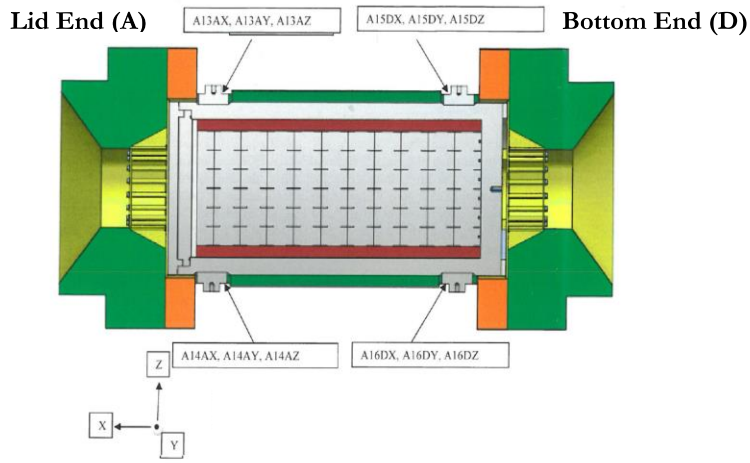

Figure 7. Cask instrumentation in 30 cm drop test.

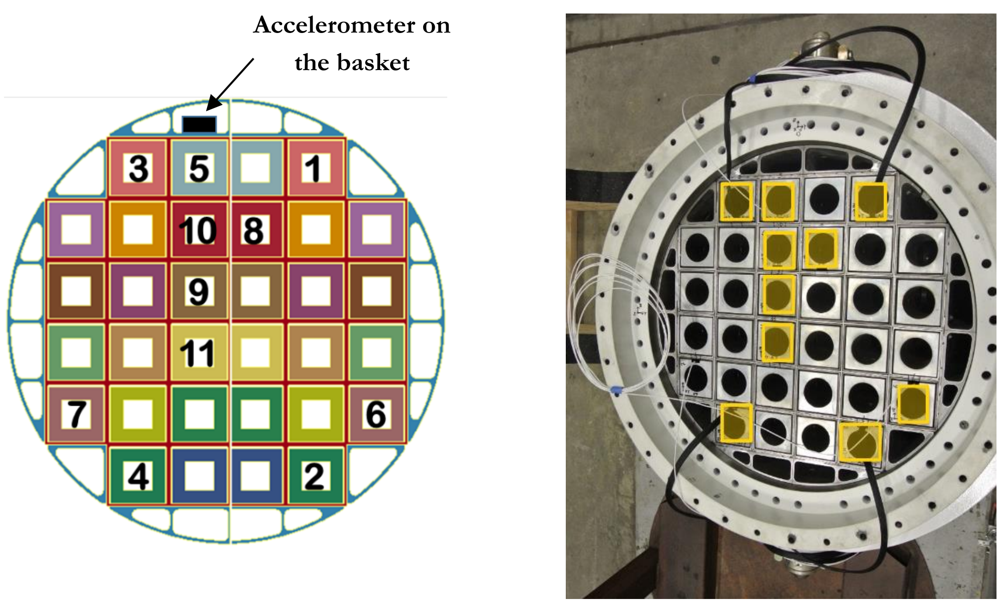

Figure 8. Dummy assembly instrumentation in 30 cm drop test.

The locations of instrumentation on the dummy assemblies were selected based on pre-test modeling completed by PNNL [6]. Modeling predicted that the simulated assembly response is dominated by rigid body motion (not much deflection) despite the slots (slots are shown in Figure 5). The modeling results demonstrated that the gross motion of each zone is very similar, with some variation. Slightly different accelerometer signals are expected in each zone, but the difference in response is likely high-frequency, short duration. The recommended accelerometer locations are roughly at the center of mass of upper (A) and bottom (D) zones to minimize potential noise from the edges. Figure 9 shows the instrumentation installation in progress for the dummy assemblies from locations 4, 5, 7, and 9.

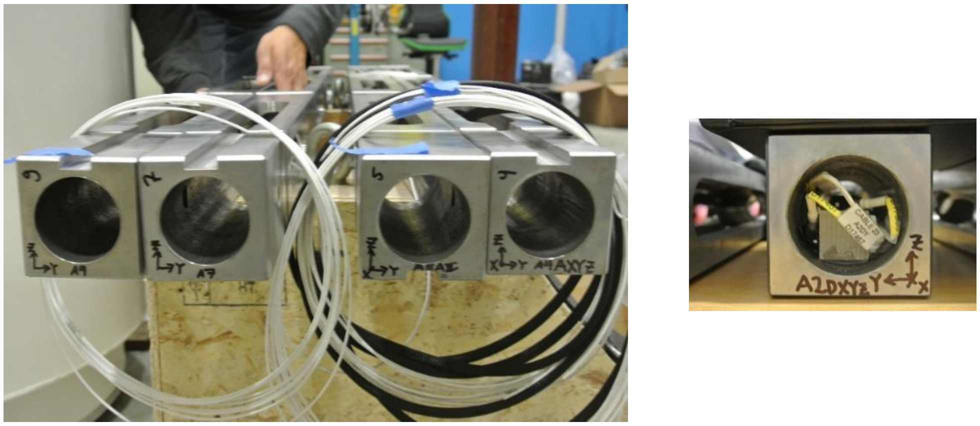

Figure 9. Dummy assemblies from locations 4, 5, 7, and 9 (left) and tri-axial accelerometer block (right).

DATA ACQUISITION AND TEST SETUP

The tests were conducted at the BAM indoor facility. The BAM indoor facility is located in a closed building on the grounds of the BAM branch in Berlin. The target was a reinforced concrete block with a mass of 280,000 kg and with dimensions of 6 m x 6 m x 3 m. The impact pad was a steel plate of 18,700 kg (4 m x 2 m x 0.3 m) embedded and fixed onto the concrete block.

A BAM data acquisition (DAQ) system was used. The BAM DAQ is designed to record decelerations and strains during the extremely short period of the impact event. The sampling rate was 200 kSamples/s. The data acquisition was performed by BAM staff. The test setup minutes before the first drop on December 11, 2018 is shown in Figure 10. The second drop was on December 12, 2018.

Figure 10. 30 cm drop test set up before the first drop (December 11, 2018).

PRELIMINARY DATA ANALYSIS RESULTS

Time history of vertical accelerations on the cask filtered to 300 Hz (there is practically no signal above 300 Hz) in the first drop is shown in Figure 11. The cask front end hit the target surface 2 milliseconds before the back end. The cask bounced 7 times.

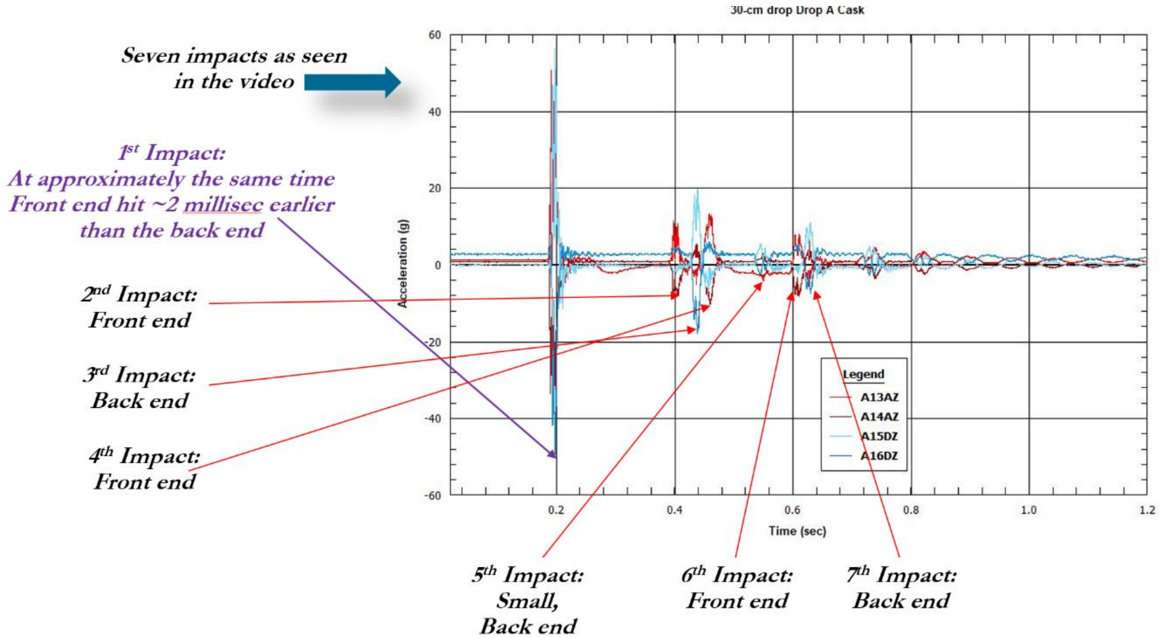

Figure 11. Time history of vertical accelerations on the cask filtered to 300 Hz.

The accelerations on the cask during the first impact in the first drop were compared to the 2010 data filtered to 300 Hz. Figure 112 shows the accelerations on the cask in the 2010 test and Figure 113 shows the accelerations on the cask in the 2018 test.

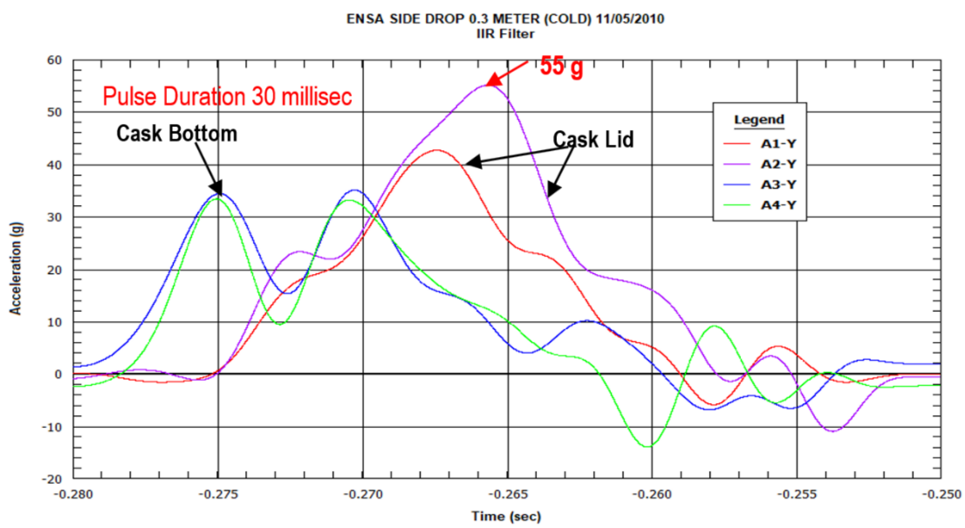

Figure 12. 2010 Test: First Impact Time History Filtered to 300 Hz.

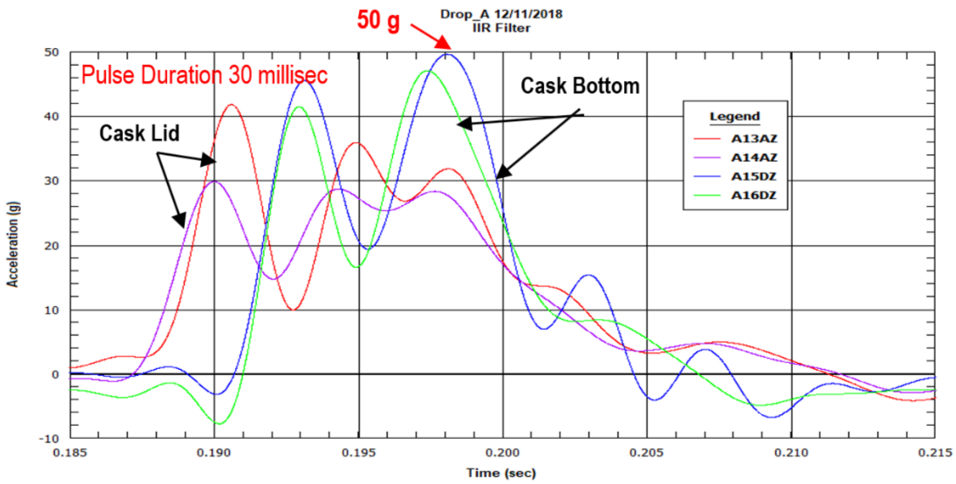

Figure 13. 2018 Test: First Impact Time History Filtered to 300 Hz.

The accelerations observed in 2010 are very similar to the ones observed in 2018 with the maximum acceleration of 55 g in 2010 and 50 g in 2018. The duration of the first impact pulse was the same (30 millisec). Some differences exist because the horizontal drop is never truly horizontal. In 2010, the cask first hit the target with its bottom side and in 2018 it hit the target with its lid side. Also, the impact limiters used in the 2018 tests were not new and may have had slightly different stiffness.

The maximum and minimum accelerations on the dummy assemblies at the bottom of the cask (side D) were observed in locations 5 and 6, respectively. The acceleration time histories at these locations are shown in Figure 14. The maximum and minimum accelerations on the dummy assemblies at the front of the cask (side A) were observed in locations 10 and 2, respectively. The acceleration time histories at these locations are shown in Figure 15. The accelerations on the dummy assemblies are higher than on the cask. The degree of amplification varies with the dummy assembly location.

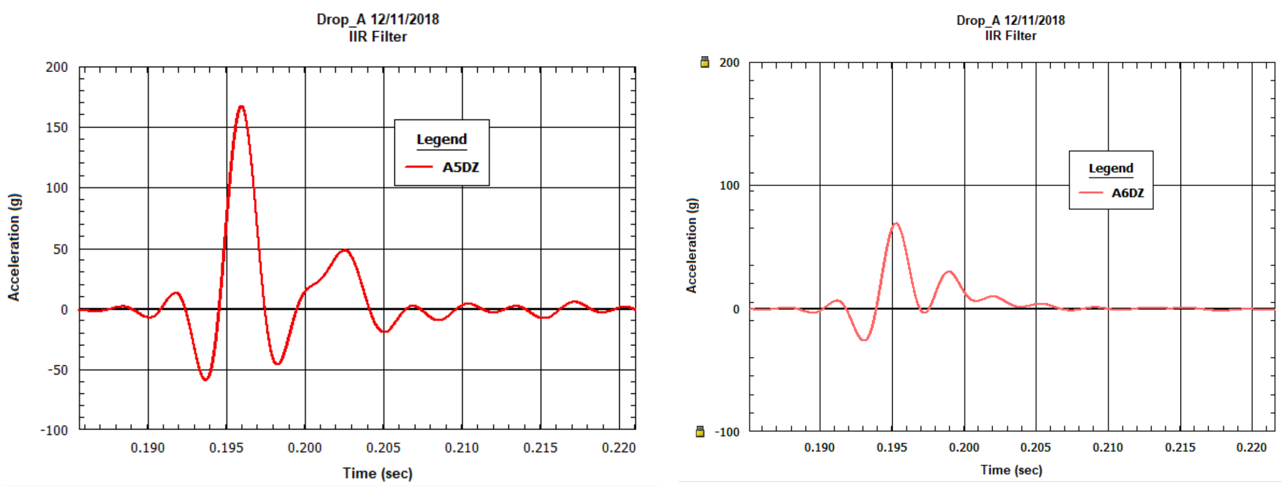

Figure 14. The back side of the dummy assembly acceleration time histories at locations 5 (left) and 6 (right).

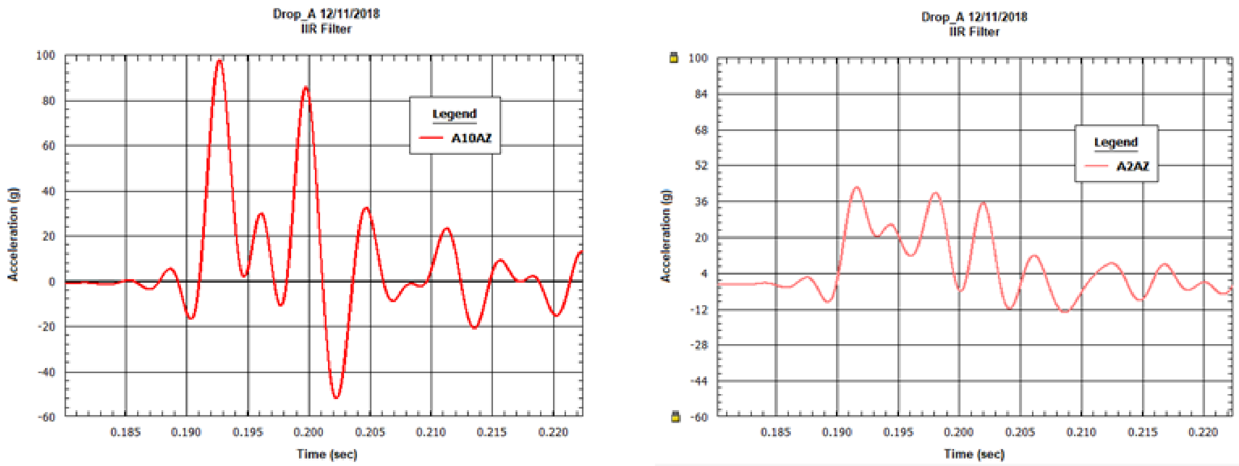

Figure 15. The front side of the dummy assembly acceleration time histories at locations 10 (left) and 2 (right).

The cask to the dummy assembly transfer function for the 30 cm drop (configuration 1) is shown in Figure 16 in red. The dummy assembly average between location 10 on the front side and location 5 on the back side (maximum acceleration locations) and the cask average on the front end and the bottom were used to calculate the transfer function. Shown in blue in Figure 16 is the full-scale cask to full-scale surrogate assembly transfer function calculated for the single bump test at TTCI completed as a part of MMTT. The single bump test was the one with highest accelerations compared to other TTCI tests, except coupling. In the high band frequencies, the differences between the full-scale surrogate assembly and 1/3 scale dummy assemblies are due to the surrogate assemblies chattering inside the basket tube. The differences within the 0-200 frequency band are related to the surrogate assembly natural frequency (~45 Hz). The full-scale assembly drop tests at SNL will provide the experimental data for this frequency band of primary interest.

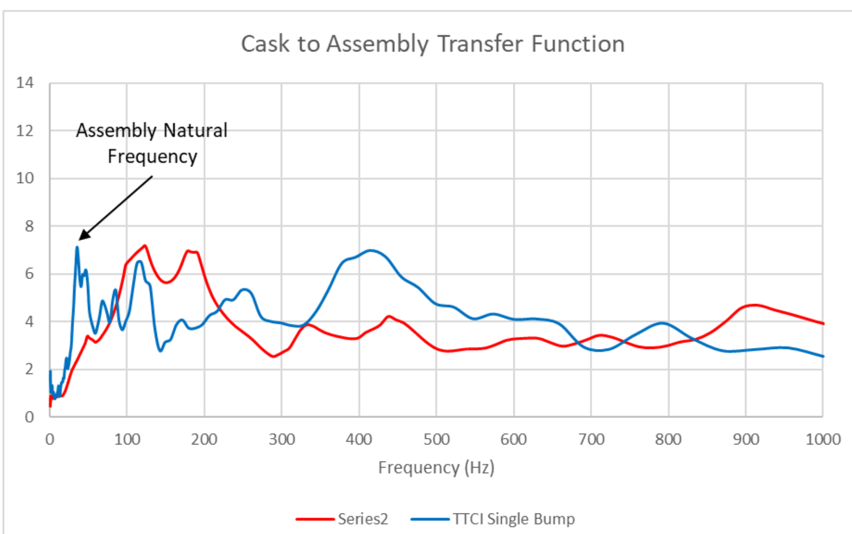

Figure 16. Cask to Assembly transfer function in 30 cm drop test and in MMTT rail test.

SUMMARY

The 30 cm drop test of the 1/3 scale ENSA ENUN 32P cask is an example of successful international collaboration. The cask, impact limiters, dummy assembly, modified lid, and handling tools were provided by ENSA. PNNL provided pre-test modeling predictions that were used in selecting accelerometer locations.

The tests were performed at the BAM indoor facility in Berlin. BAM staff made all the preparations for the tests and conducted the data acquisition. SNL staff instrumented the cask, the dummy assembly, and the basket. The data were successfully acquired for 34 accelerometers on 11 dummy assemblies, 12 accelerometers on the cask, and 3 accelerometers on the basket.

The major goal of the 1/3 scale cask drop tests was measuring the accelerations on the dummy assemblies. Based on these data, a series of drop tests with a full-scale assembly will be conducted at SNL in the summer of 2019 to obtain the strain data on the full-scale surrogate assembly. The major input from the 1/3 scale cask drop tests to the full-scale assembly drop tests are the accelerations on the dummy assembly and the transfer function from the cask to the dummy assembly. These inputs are only applicable to the full-scale dummy assembly because the dummy assembly is structurally very different from the surrogate fuel assembly. The full-scale dummy assembly will be dropped onto a programming material to provide the same shock pulse (converted to full-scale in the acceleration and time domain) the 1/3 scale dummy assemblies experienced in the 1/3-scale cask drop test. The programming material from the dummy assembly drop tests will be then used in the full-scale surrogate assembly drop tests to quantify the strain fuel rods experience inside a cask when dropped from a height of 30 cm.

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