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MRS Advances

Full-Scale Assembly 30 cm Drop Test

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ABSTRACT

Can Spent Nuclear Fuel withstand the shocks and vibrations experienced during normal conditions of transport? This question was the motivation for the multi-modal transportation test (MMTT) (Summer 2017), 1/3-scale cask 30 cm drop test (December 2018), and full-scale assembly 30 cm drop tests (June 2019). The full-scale ENSA ENUN 32P cask with 3 surrogate 17x17 PWR assemblies was used in the MMTT. The 1/3-scale cask was a mockup of this cask. The 30 cm drop tests provided the accelerations on the 1/3-scale dummy assemblies. These data were used to design full-scale assembly drop tests with the goal to quantify the strain fuel rods experience inside a cask when dropped from a height of 30 cm. The drop tests were first done with the dummy and then with the surrogate assembly. This paper presents the preliminary results of the tests.

INTRODUCTION

The goal of the full-scale dummy assembly drop test was to obtain data on accelerations of the full-scale dummy assembly during a 30 cm horizontal drop (normal conditions of transport). These data can be then used to design the 30 cm drop test of the full-scale surrogate fuel assembly. A surrogate assembly is one that includes top and bottom nozzles, spacer grids, and tubes filled with non-radioactive material. A dummy assembly has the same mass and cross-sectional area as the surrogate assembly but is made of a single piece of steel. The 30 cm drop is the remaining NRC normal conditions of transportation regulatory requirement (10 CFR 71.71) for which there are no data on the actual surrogate fuel. While obtaining data on the actual fuel is not a direct

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requirement, it provides definitive information which aids in quantifying the risk of fuel breakage resulting from a cask drop from a height of 30 cm or less.

The 30 cm drop test was a follow-on to the 2017 Spanish/US/Korean Multi-Modal Transportation Test (MMTT) that obtained strain and acceleration data on surrogate fuel within the ENUN 32P dual purpose rail cask. The goal of the MMTT was to validate the hypothesis that spent nuclear fuel can withstand the shocks and vibrations from routine transport. Data were collected during actual heavy-haul truck transport through Spain, small ship from Spain to Belgium, large ship from Belgium to the USA, and rail transportation from Baltimore to Pueblo (Colorado). The results can be found in [1-6]. A short video documenting the major test events is available on YouTube [7].

Note that the common assumption is that the cask content experiences the same accelerations as the cask itself. The data from the MMTT demonstrated that the inputs from the shock events were amplified from the cask to the surrogate assemblies. This is demonstrated in Figure 1 using cask-to-surrogate assembly transfer functions. The transfer function is the relationship between accelerometers on the cask and on the fuel assemblies. The transfer functions are shown for the maximum shock event during rail and heavy-haul transport and for the single bump test conducted at the Transportation Technology Center, Inc. (TTCI) test facility in Pueblo (Colorado). One representative transfer function between two accelerometers is shown for each case. The peak around 40 Hz is related to the surrogate assembly natural frequency. The transfer function is around 4 at frequencies above 40 Hz and around 1.5 at frequencies below 20 Hz. The amplification from the cask-to-surrogate assemblies observed in MMTT was one of the motivations for conducting the 30 cm drop test.

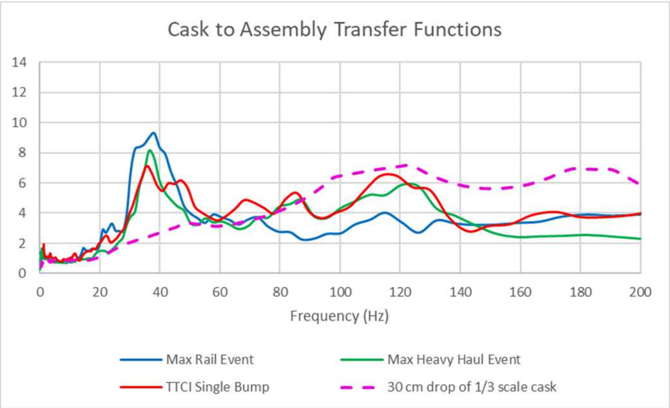

Figure 1. Cask to surrogate assembly transfer functions.

Ideally, the 30 cm drop test would be conducted with the full-scale cask containing surrogate assemblies. However, the cost of a full-scale cask and impact limiters make this test impractical. The decision was made to conduct a 30 cm drop test of the equivalent 1/3 scale cask to obtain acceleration data on the cask and on the 1/3 scale dummy assemblies. The acceleration pulse on the 1/3 scale dummy assemblies can be converted to the expected acceleration pulse of the full-scale dummy assembly. By conducting a series of 30 cm drop tests of the full-scale dummy assembly using different shock absorbing conditions it is possible to find the condition under which the observed acceleration pulse would be similar to the expected acceleration pulse. Achieving this condition means that the effect of the cask and the impact limiters are adequately represented. The same design can be then applied to the 30 cm drop of the full-scale surrogate assembly. The steps of this process are shown in Figure 2.

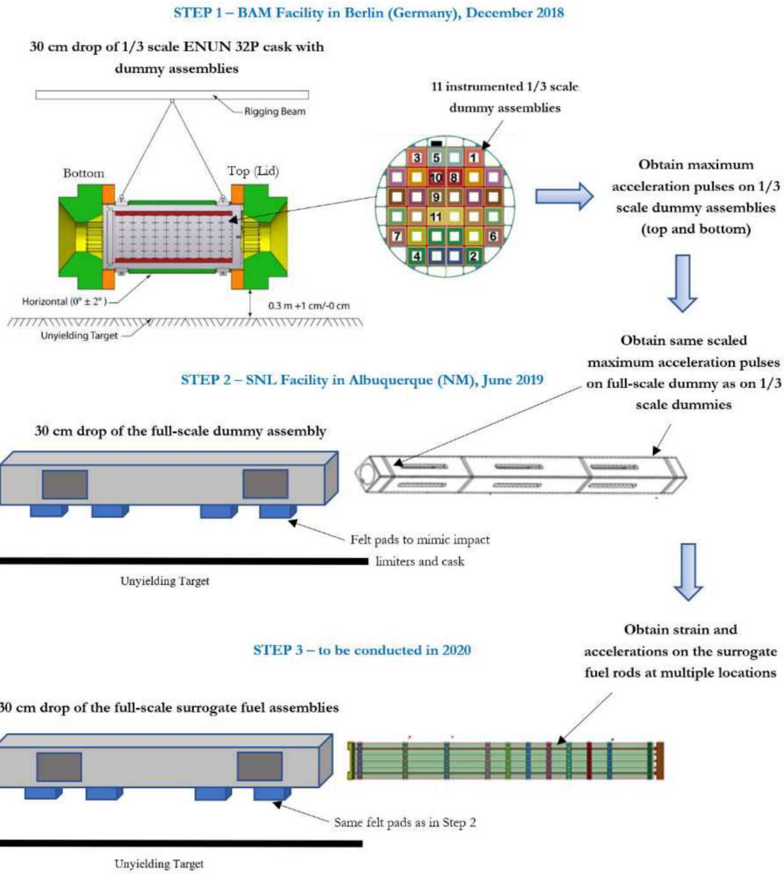

Figure 2. Steps to obtain accelerations and strains on the full-scale surrogate fuel assembly rods.

The 1/3 scale cask test was conducted in December 2018 at the Bundesanstalt for Materialforschung und -prtifung (BAM) indoor facility in Berlin (Germany). The BAM indoor facility, test equipment, and data acquisition system was used to conduct the tests. The 1/3 scale cask, impact limiters and associated hardware were provided by Equipos Nucleares, S. A. (ENSA), a Spanish government-owned company. The 1/3 scale cask contained 32 dummy assemblies. The instrumentation was performed by Sandia National Laboratories (SNL). Eleven dummy assemblies were instrumented with tri-axial and uniaxial accelerometers on the top and bottom nozzle locations. The cask was instrumented with 2 tri-axial accelerometer blocks on the cask top and 2 tri-axial accelerometer blocks on the cask bottom end located 180 degrees apart. All 4 cask accelerometers were located on a plane parallel to the impact vector. The details of this test can be found in [8].

The maximum observed first impact acceleration pulses (filtered to 300 Hz) on the 1/3 scale dummy assemblies are shown in Figure 3 for the top and the bottom locations. The signal is small at the frequencies greater than 300 Hz. The difference between the locations is due to the fact that the horizontal drop is never truly horizontal. In this test the cask hit the target with its lid side first (assembly top). The 30 cm drop of 1/3 scale cask demonstrated that there is amplification from the cask to the dummy assemblies at frequencies greater than 50 Hz (Figure 1).

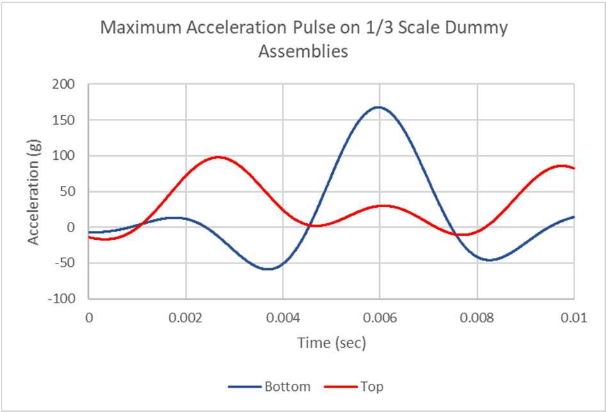

Figure 3. Maximum observed first impact acceleration pulses on the 1/3 scale dummy assemblies.

DROP TEST DETAILS

Conducting 30 cm drop test of the full-scale dummy assembly required manufacturing of a full-scale dummy assembly, purchasing and modification of a basket tube, and manufacturing handling hardware.

The full-scale dummy assembly is the enlarged by 3 times equivalent of the 1/3 scale dummy assembly. ENSA was contracted by SNL to manufacture the full-scale dummy assembly. It was made of a machined carbon steel rod (S335J2 / ST-52). The dummy assembly weight is 700 kg. Figure 4 shows the drawing of the full-scale dummy assembly on the left and the manufactured dummy assembly on the right.

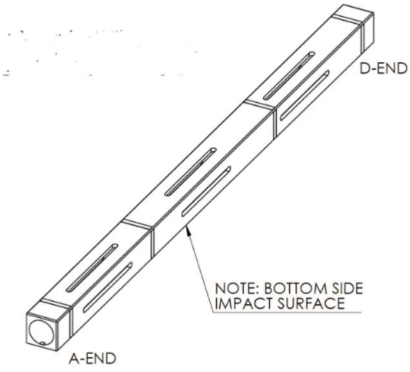

Figure 4. Drawing (left) and actual (right) full-scale dummy assembly.

A full-scale 17x17 PWR basket tube was purchased from ENSA to mimic the boundary conditions the assembly experienced during the 30 cm 1/3 scale cask drop. The basket tubes in the 1/3 scale cask test were the scaled equivalent of this basket tube. The same basket tubes were in the ENUN 32P cask used during the MMTT test. Two windows were cut on one side of the basket tube as shown in Figure 5. These windows will be used to record the behavior of the surrogate assembly rods during the 30 cm drop test by way of high-speed video cameras.

The basket tube was made of MMC, which consists of a matrix of 'pure' aluminum material (very soft) with boron carbide insertions in it (extremely hard). This made it very difficult to machine or grind the basket tube - neither drilling holes or welding was possible. To handle the basket tube, a steel plate was manufactured and attached to the basket tube by steel clamps (Figure 5). Two hoist rings were installed in the steel plate to allow for lifting and handling.

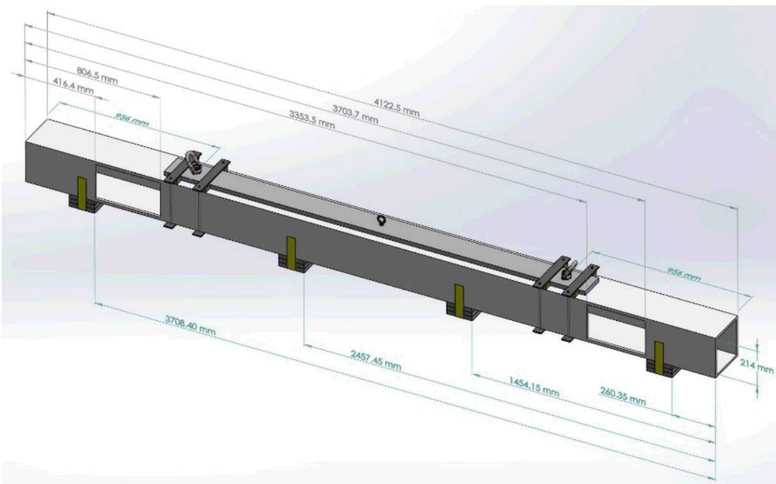

Figure 5. Full-scale 17x17 PWR assembly basket tube.

The full-scale dummy assembly was instrumented with tri-axial accelerometers in the openings on the top and bottom ends and 3 strain gauges as shown in Figure 6.

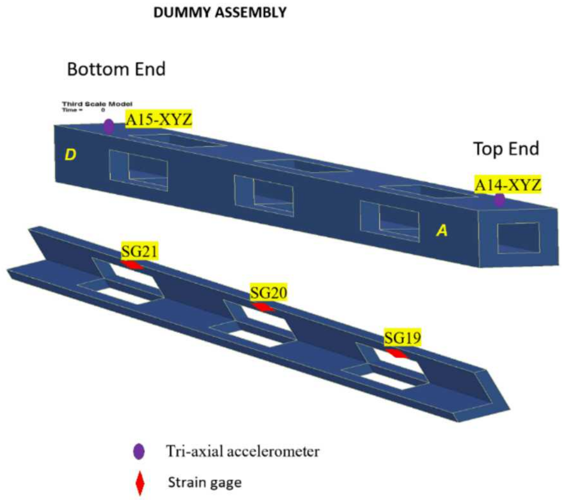

Figure 6. Full-scale dummy assembly instrumentation.

The basket tube was instrumented with two tri-axial accelerometers on the top face as shown in Figure 7. Two uniaxial accelerometers were placed on the target.

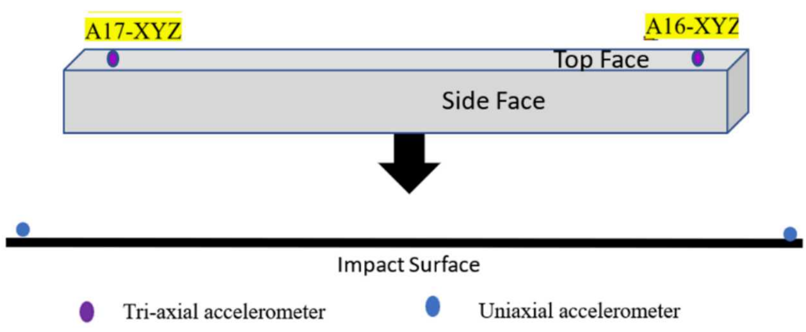

Figure 7. Full-scale basket tube and target surface instrumentation.

The instrumented dummy assembly was inserted in the basket tube (Figure 8, left) and transported to the SNL drop tower facility (Figure 8, right). All tests were conducted at this facility (Figure 9, left) in June 2019. The test setup is shown in Figure 9 on the right.

Figure 8. Dummy assembly (left) and basket tube (right) handling.

Figure 9. SNL drop tower facility (left) and test setup (right).

The felt pads were used as a shock absorbing material. Four pads were attached to the bottom face of the basket tube as shown in Figure 9. Four tests were performed to get the desired acceleration pulse. After each test the pulse amplitude, duration, and shape were examined and the felt dimensions were adjusted. The felt pad dimensions are provided in Table 1. The acceleration time histories on the dummy assembly in four tests are shown in Figure 10. Figure 11 shows the felt pad configuration in Test 4.

Table I. Felt pad dimensions in different drop tests.

Drop Test	**Pad Dimensions (in)**		
	Width	Length	Thickness
Test 1	10	12	1
Test 2	9	12	2
Test 3	10	6	2
Test 4	10	6	3

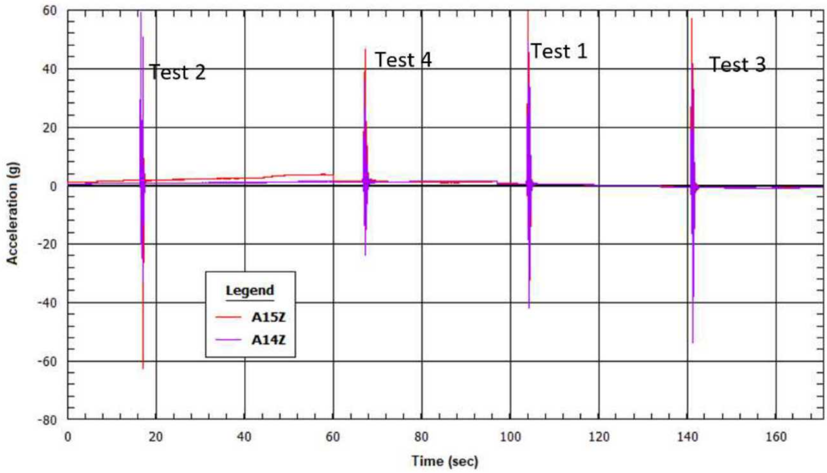

Figure 10. The acceleration time histories on the dummy assembly in four 30 cm drop tests.

Figure 11. Felt pad configuration in Test 4.

The acceleration pulses on the dummy assembly in Test 4 showed good agreement with the expected acceleration pulses (Figure 12). As mentioned earlier, the expected pulses were calculated by scaling the maximum pulses observed on the top and bottom of the 1/3 scale dummy assembly in the 1/3 scale cask drop test (Figure 2). Note that the full-scale assembly drop was virtually horizontal and the accelerations on the both sides of the assembly are very similar. In the 1/3 scale cask drop, the cask lid (top) end hit the target first. This resulted in the different timing of the peak maximum acceleration that can’t be reproduced with a strictly horizontal drop.

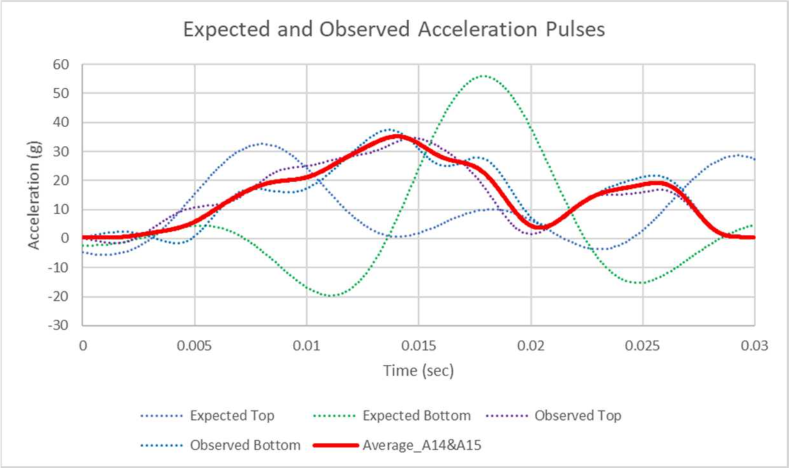

Figure 12. The observed and expected acceleration pulses on the dummy assembly in Test 4.

CONCLUSIONS

The 30 cm drop tests of the full-scale dummy assembly allowed shock absorbing felt pads to be designed to adequately represent the effect of the cask and the impact limiters. This design will be used in the 30 cm drop of the full-scale surrogate assembly (Figure 13). The assembly will be instrumented with multiple accelerometers and strain gauges to obtain acceleration and strain data at different locations on the rods. The behavior of the fuel rods, as seen in two windows in the basket tube will also be recorded during the drop using high-speed video cameras.

These data will help to determine whether or not the fuel rods can maintain their integrity inside a cask when dropped from a height of 30 cm. The test will be conducted in the spring of 2020.

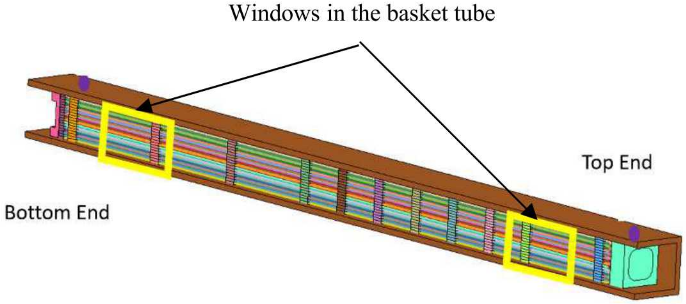

Figure 13. The sketch of the full-scale surrogate assembly in the basket tube.

ACKNOWLEDGMENTS

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