# Update on the transportation work

*Elena Kalinina*

Sandia National Laboratories

**SAND2019-**

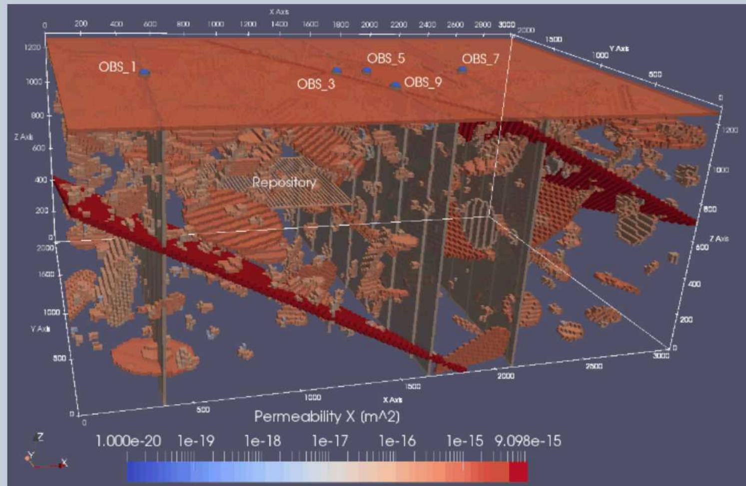
SFWD

# Spent Fuel & Waste Disposition

*Annual Working Group Meeting*
UNLV-SEB – *Las Vegas, Nevada*
*May 21-23, 2019*

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2019-5655PE



# FY18-FY19 Project Publications - SNL

- Kalinina et al. 2018 "Results and correlations from analyses of the ENSA ENUN 32P cask transport tests", Pressure Vessels and Piping Conference, Prague, Czech Republic, 2018.
- Kalinina et al. 2019. International Multi-Modal Spent Nuclear Fuel Transportation Test: The Transportation Test Triathlon, International Conference on the Management of Spent Fuel from Nuclear Power Reactors, Vienna, Austria, 2018.
- Kalinina et al. 2019. Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Specialized Rail Tests, PATRAM, New Orleans, LA, 2019.
- Kalinina et al. 2019. Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Rail Transport, PATRAM, New Orleans, LA, 2019.
- Kalinina et al. 2019. Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Heavy-Haul Transport and Handling, PATRAM, New Orleans, LA, 2019.
- Kalinina et al. 2019. Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Ocean Transport, PATRAM, New Orleans, LA, 2019.
- Kalinina et al. 2019. Horizontal 30 cm Drop Test of 1/3 Scale ENSA ENUN 32P Dual Purpose Cask, PATRAM, New Orleans, LA, 2019.
- Wille et al. 2019. ISO-STANDARD AND IAEA GUIDANCE MATERIAL FOR PACKAGE LOAD ATTACHMENT POINTS – Current Approaches and Developments, PATRAM, New Orleans, LA, 2019.

# FY18-FY19 Project Publications - PNNL

- Klymyshyn et al., 2019. Modeling Shock and Vibration of Used Nuclear Fuel Rods During Normal Conditions of Transportation, IHLRWM Conference, April 2019, Knoxville, TN.
- Kadooka et. Al, 2019. Railcar Dynamics Model of the ENSA/DOE Multimodal Transportation Campaign Rail Conveyance System, IHLRWM Conference, April 2019, Knoxville, TN.
- Spitz et al., 2019. Analyzing the Impact of Buffer Material on Shock and Vibration in Used Nuclear Fuel Transportation, IHLRWM Conference, April 2019, Knoxville, TN.
- Ivanusha et. Al, 2019. The Shock and Vibration Environment for Used Nuclear Fuel Transportation Modeling, IHLRWM Conference, April 2019, Knoxville, TN.
- Klymyshyn et al., 2019. Modeling and Analysis of a One-Third Scale Used Nuclear Fuel Package 30 cm Drop, PATRAM, New Orleans, LA, 2019.
- Klymyshyn et al., 2019. Modeling and Analysis of Used Nuclear Fuel during Normal Conditions of Rail Transportation, PATRAM, New Orleans, LA, 2019.
- Ross et al., 2019. Preliminary Efforts Related to 8-Axle Rail Car Design for Transporting Spent Nuclear Fuel, , PATRAM, New Orleans, LA, 2019.

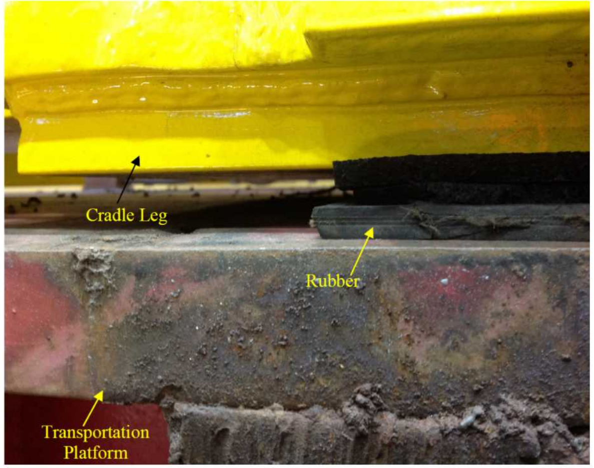
# FY18-FY19 Project Reports – SNL and PNNL


- Kalinina et al. 2018. Data Analysis of ENSA/DOE Rail Cask Tests, SFWD-SFWST-2018-000494, SAND2108-13258 R, Sandia National Laboratories, Albuquerque, NM, 2018.
- Kalinina et al. 2018. Test Plan for the Shaker Table Test, SNL, Albuquerque, NM, August, 2019
- Kalinina et al. 2018. Test Plan for the 30 cm Horizontal Drop of the ENSA 1/3 Scale Cask, SNL, Albuquerque, NM, November, 2019.
- Kalinina et al. 2019. Shaker Table Test, SNL, Albuquerque, NM, March, 2019, SAND2019-3120R.
- Kalinina et al. 2019. Full-Scale Dummy and Surrogate Assembly Drop Test Plan, SNL, Albuquerque, NM, May, 2019.
- Klymyshyn et al., 2018. Modelling and Analysis of the ENSA/DOE Multimodal Transportation Campaign, PNNL-28088. Pacific Northwest National Laboratory, Richland, WA, 2018.
- Sandia National Laboratories, Cask Transportation Test (2018), https://www.youtube.com/watch?v=wGKtgrozrGM&feature=youtu.be

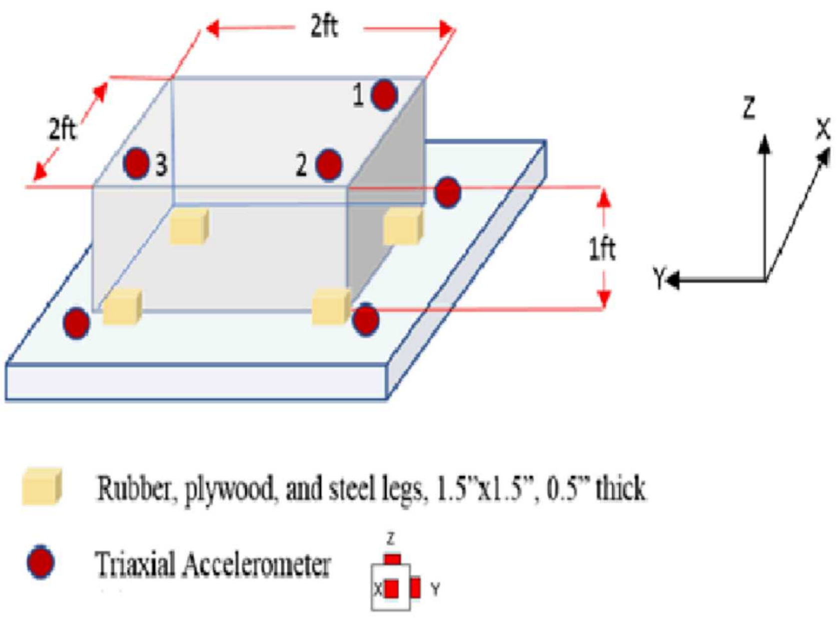
# Shaker Table Test (September 12, 2019)

- The attenuation in the transportation system observed during MMTT was assumed to be partially related to the damping caused by the rubber placed under the cradle leg.
- The purpose of the Shaker Table Test was to verify this assumption.

Layer of Rubber Beneath the Cradle

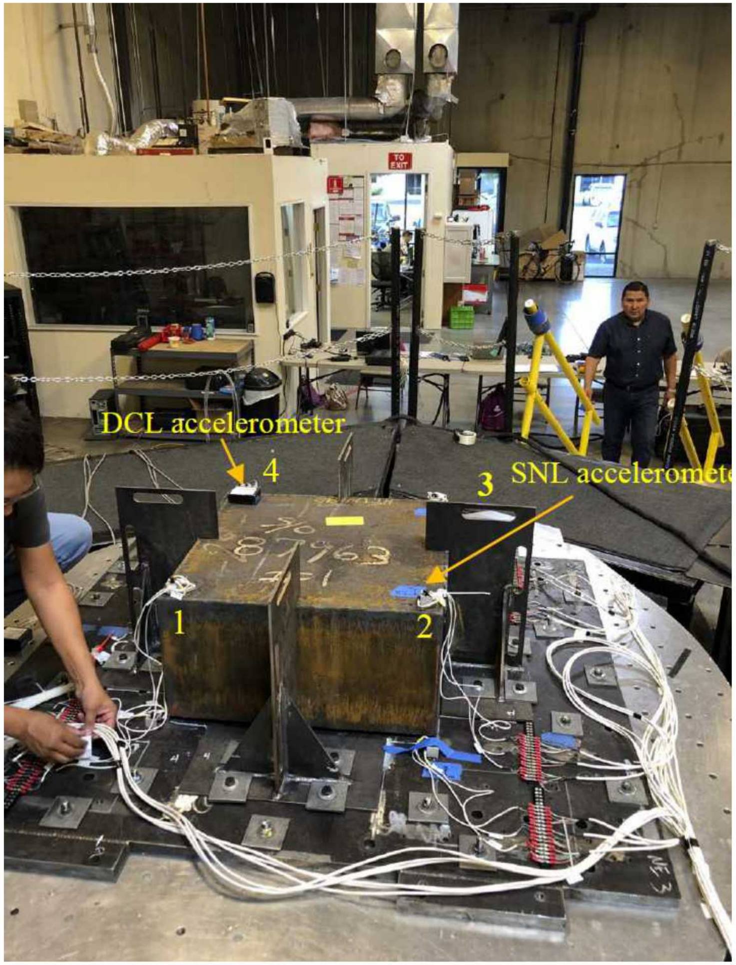

**Test Configuration**

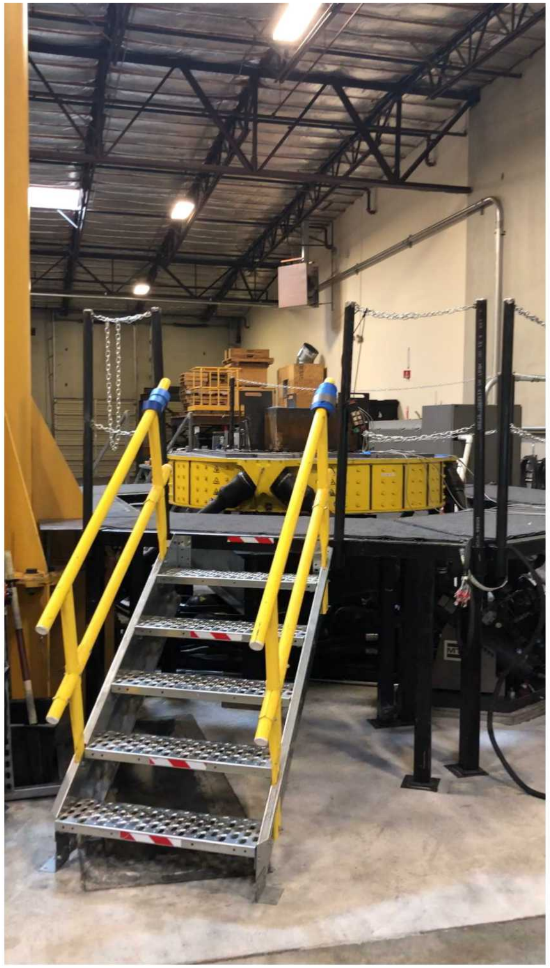



Plywood Leg

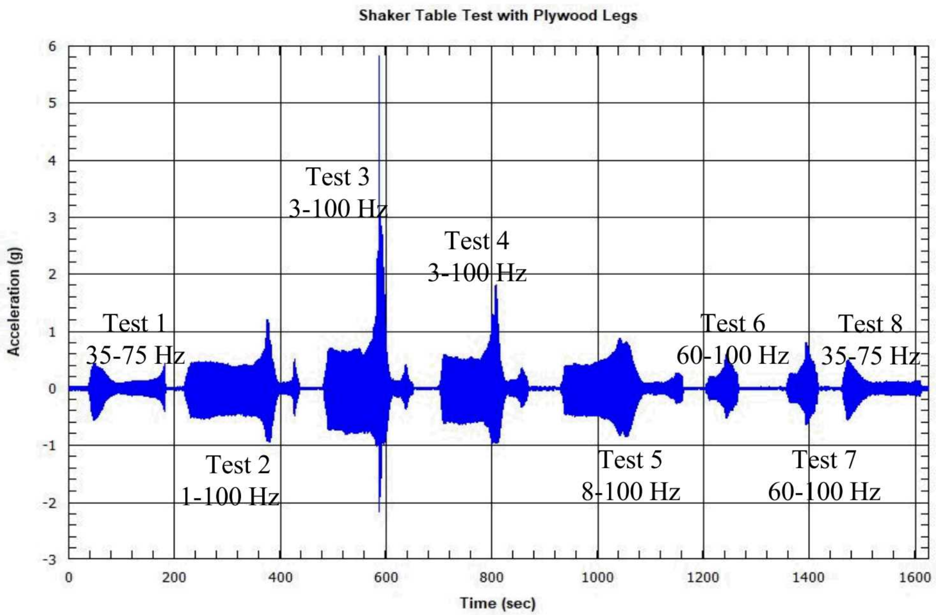
Rubber Leg

# WE SHOOK IT!



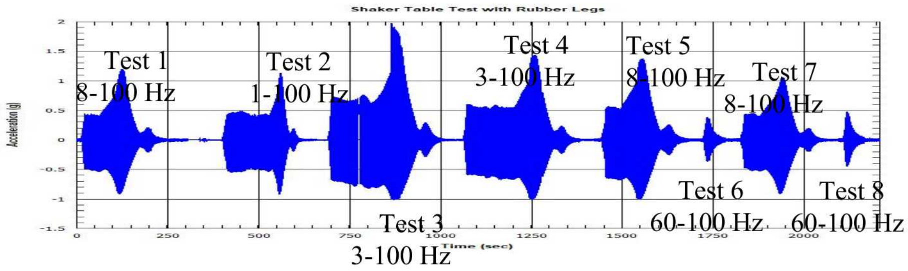



# VERTICAL ACCELERATION TIME HISTORY



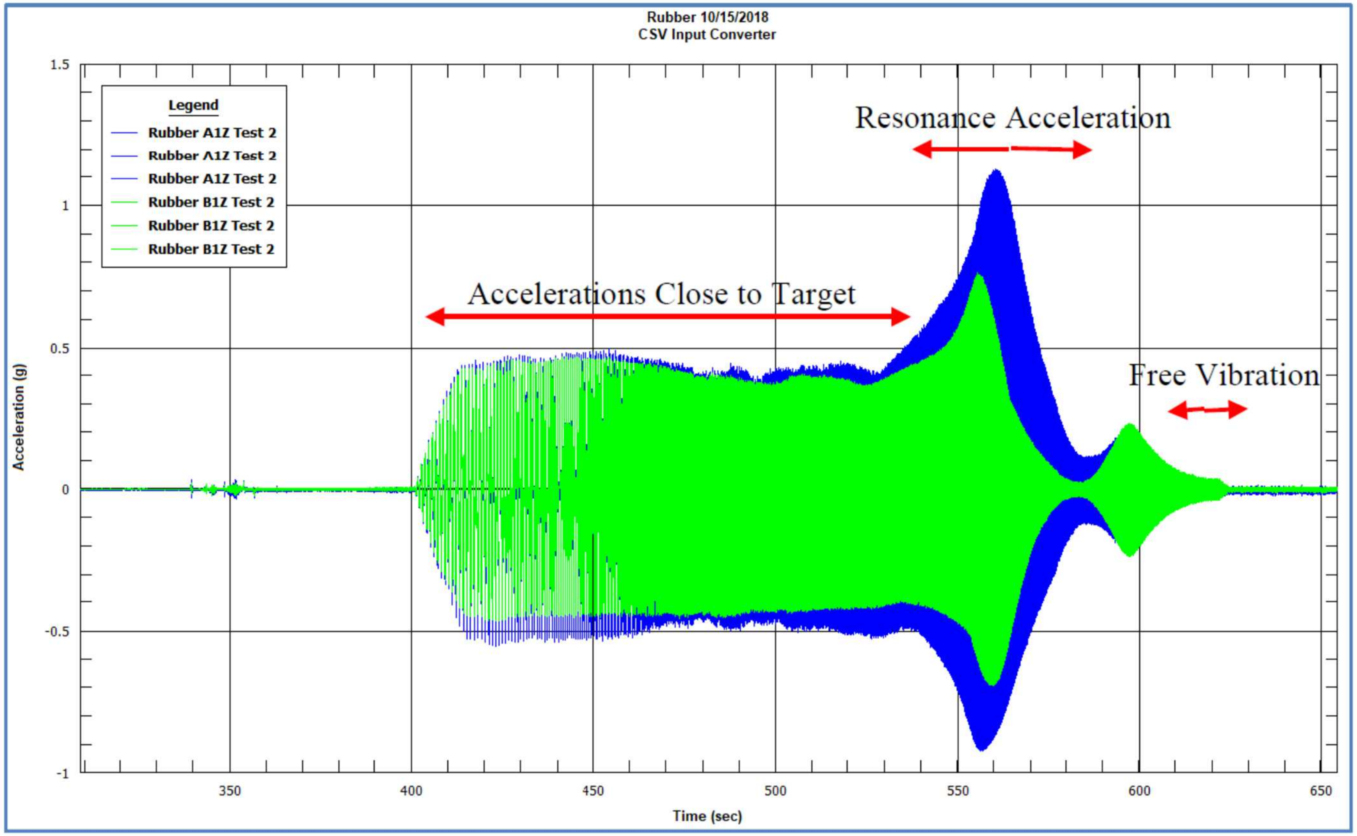

Tests with Plywood Legs

Tests with Rubber Legs



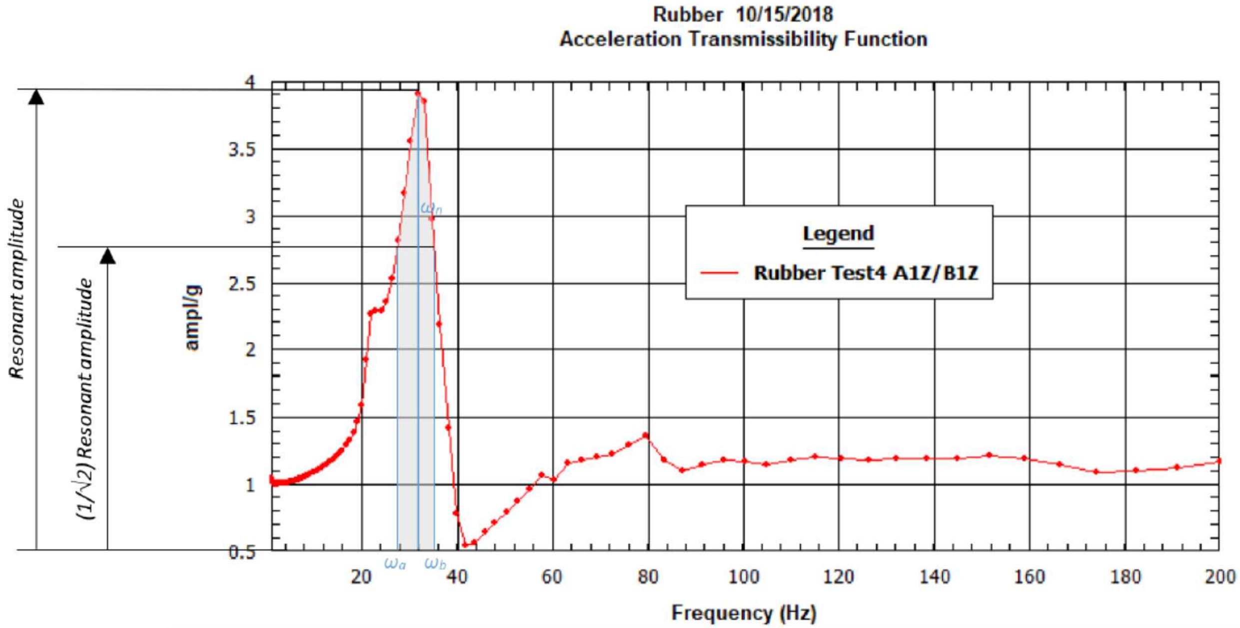
# Example of Acceleration Time History

Shaker Table Test 2 with the Rubber Legs



# Example of the Half-Power Bandwidth Method

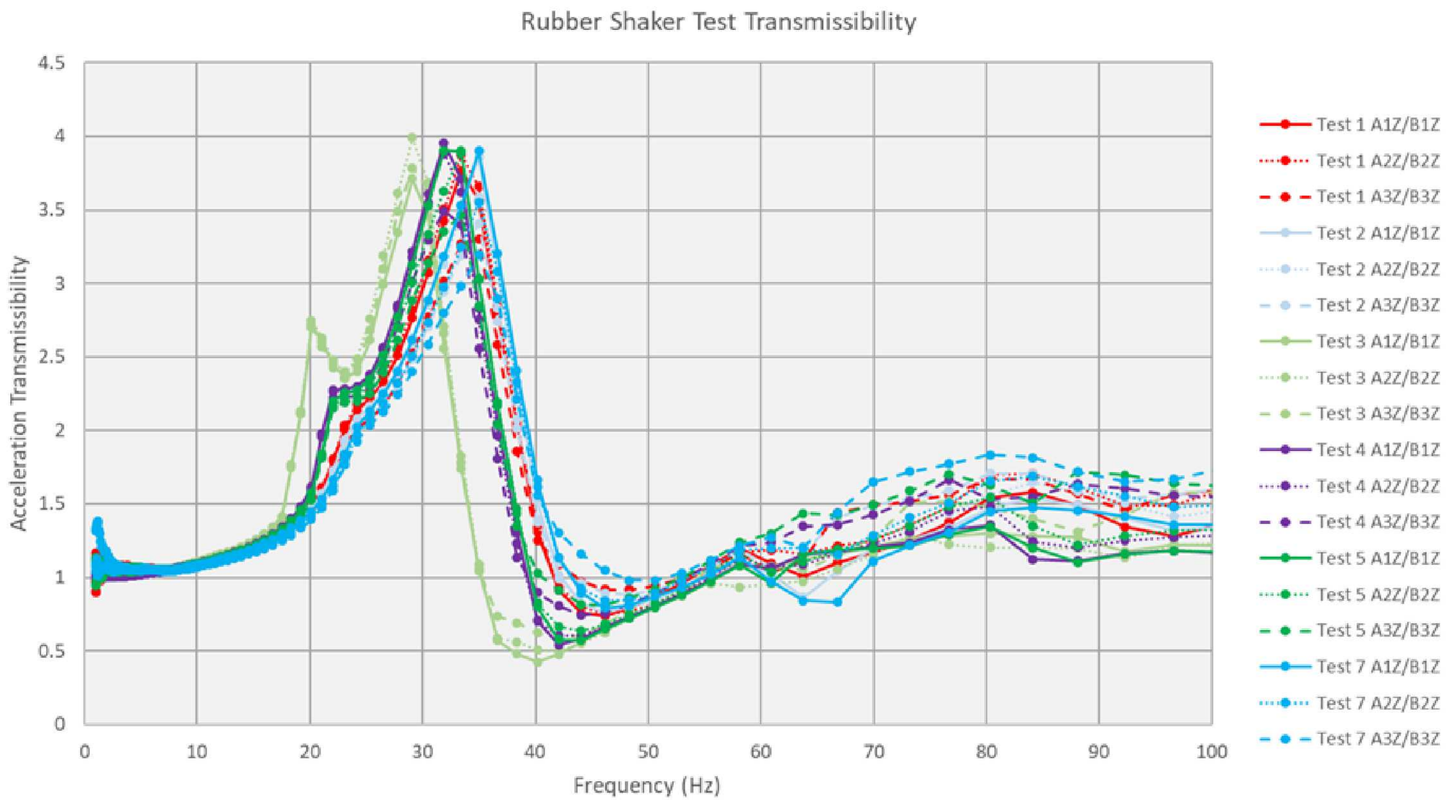
Acceleration Transmissibility Function Calculated from A1Z and B1Z, Rubber Test 4




$$\zeta = \frac{\omega_b - \omega_a}{2\omega_n}$$

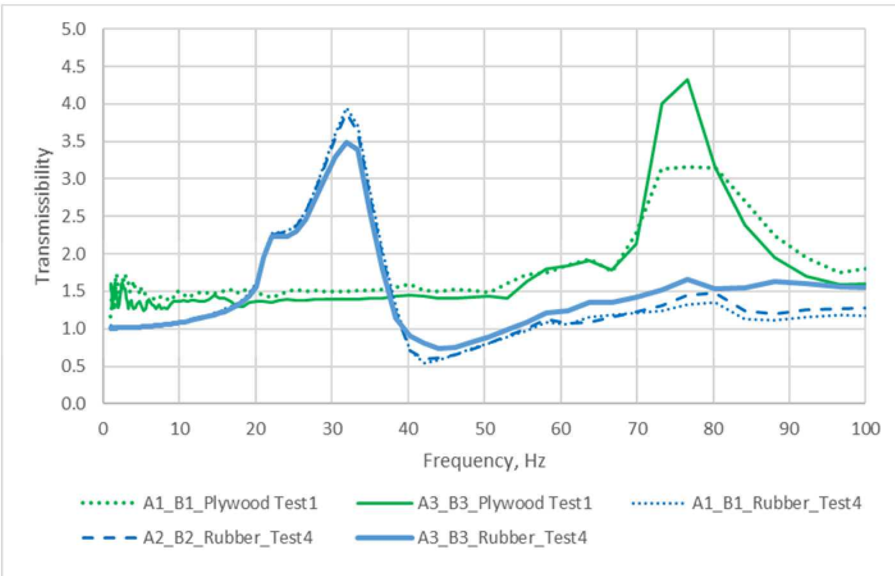
# Results of the Rubber Leg Tests

Transmissibility Functions for Rubber Leg Tests

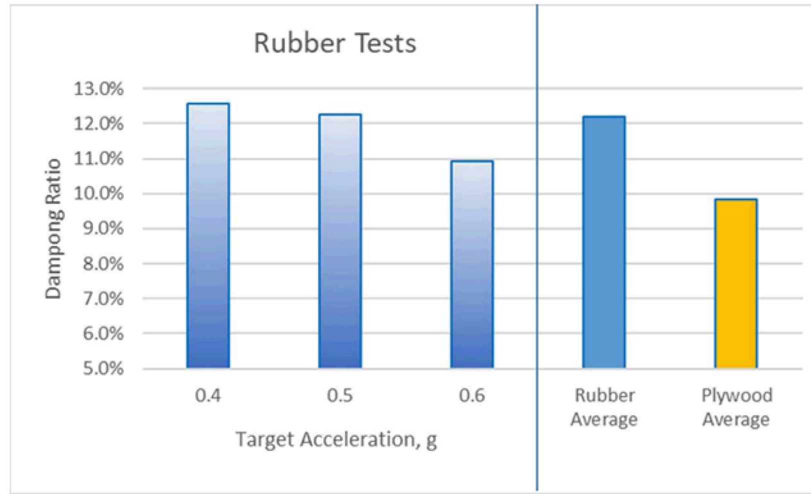


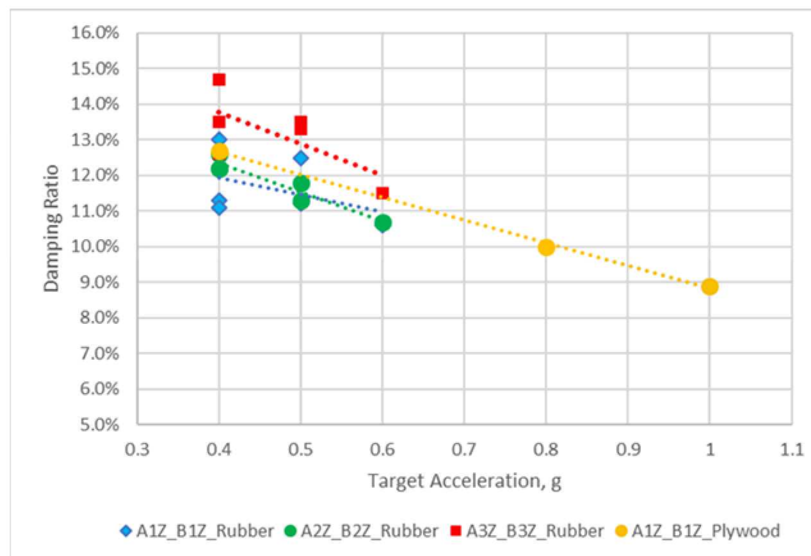
# Comparison Between the Plywood and Rubber Leg Tests

## Transmissibility Function Comparison



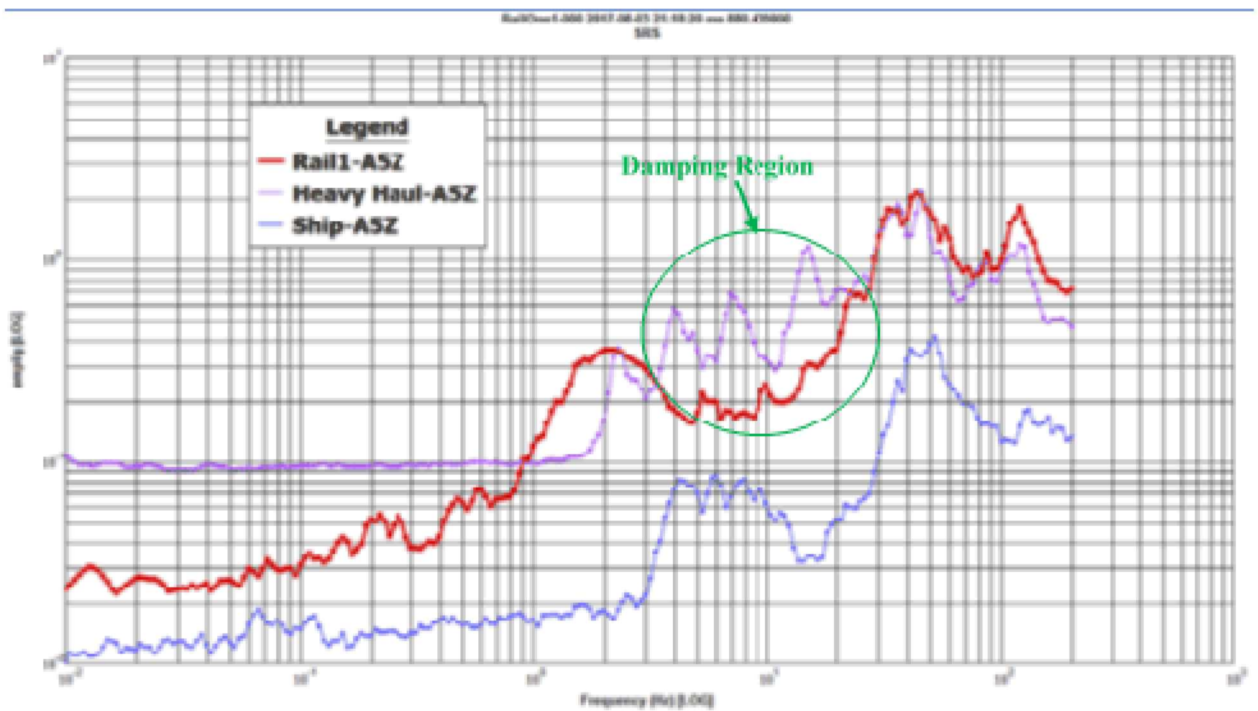

## Damping Ratio Comparison




- The transmissibility functions are very similar, except the natural frequencies are different.
- The damping ratios are – 12% (rubber) and 10% (plywood).
- The damping ratio decreases with increase in target acceleration.

# Shaker Table Test Summary




The Shaker Table Test made it possible to:

- Estimate damping ratios of rubber and plywood;
- Demonstrate that the rubber was partially responsible for the observed attenuation;
- Explain the differences in the responses between the heavy-haul and rail transport:
- Confirm that rubber and plywood have similar damping properties and will provide similar damping when used in rail transport.

# 30 cm Drop of 1/3 Scale ENUN 32P Cask (December 2018)

*In collaboration with…*

Sandia National Laboratories

E. Kalinina, D. Ammerman, C. Grey, M. Arviso, S. Saltzstein, C. Wright

**Test Design & Instrumentation**

Pacific Northwest National Laboratory

N. Klymyshyn, S. Ross

**Pre-test Modeling Predictions Transportation Logistics**

BAM Bundesanstalt für Materialforschung und -prüfung

F. Wille, T. Quercetti

**Test Facility & Data Acquisition**

ensa

Equipos Nucleares, S.A S.M.E.

A. Palacio, I. Fernandez, G. Calleja

**1/3 Scale Rail Dual Purpose Cask, Impact Limiters, & Modified Lid**

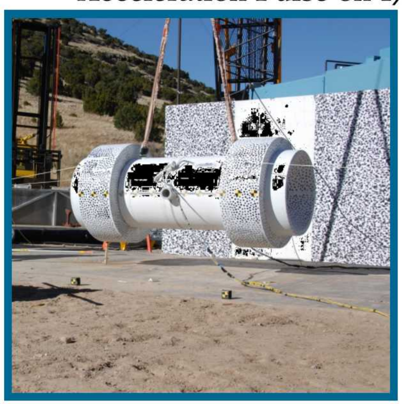

*December 2018, BAM Indoor Test Facility, Berlin*

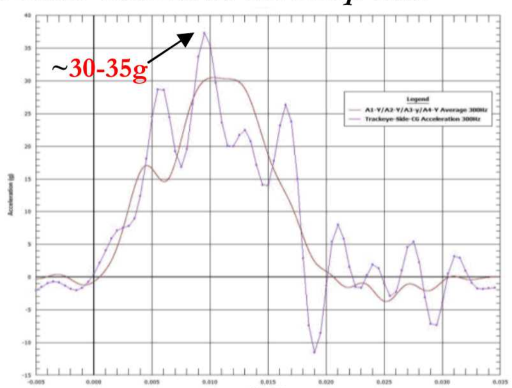
# 30 CM DROP TEST PURPOSE & GOALS

**PURPOSE: MEASURE ACCELERATIONS ON THE DUMMY ASSEMBLIES**

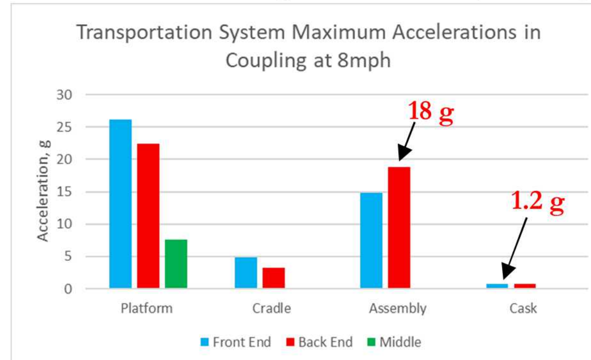
- These data do not exist for 30 cm drop
- Tests in 2010 provided accelerations on the cask only
- Expected acceleration on full scale cask is ~ 12g
- Max acceleration on the cask in MMTT was 1.2 g (coupling at 8 mph)

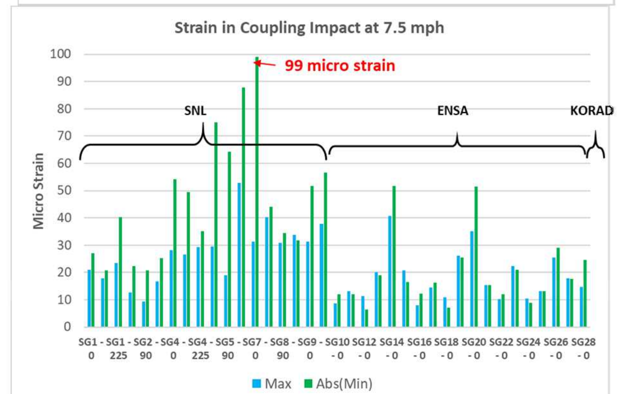
*Acceleration Pulse on 1/3 Scale Cask in 30 cm Drop Test*






*Maximum Accelerations and Strains Measured in Multi-Modal Transportation test (MMTT)*



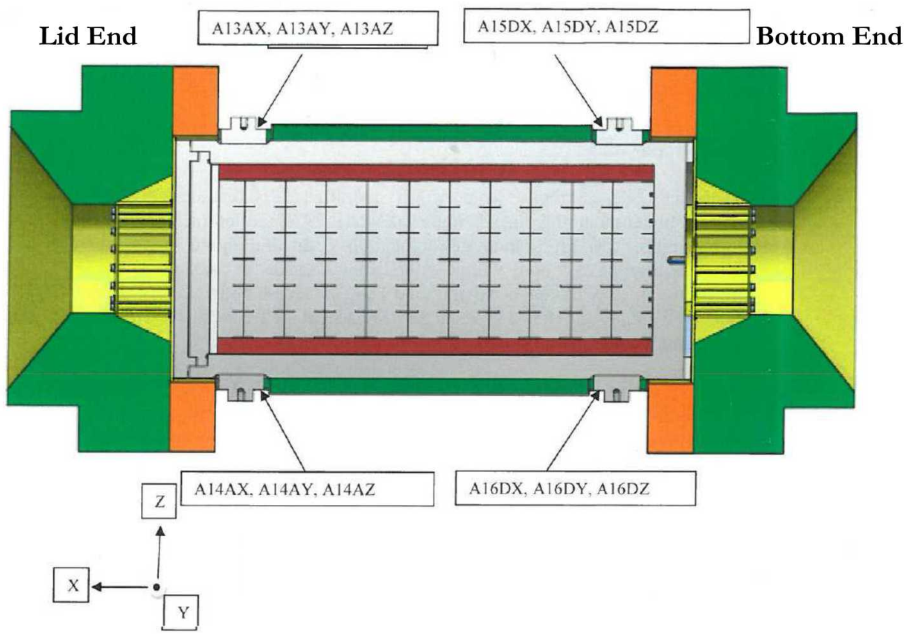




**GOALS**

- Complete the NCT mechanical testing environment
- Better understand the potential implications of handling incidents
- Define transfer function from the cask to the fuel for more severe impacts

# Cask Instrumentation

*Accelerometer Locations*





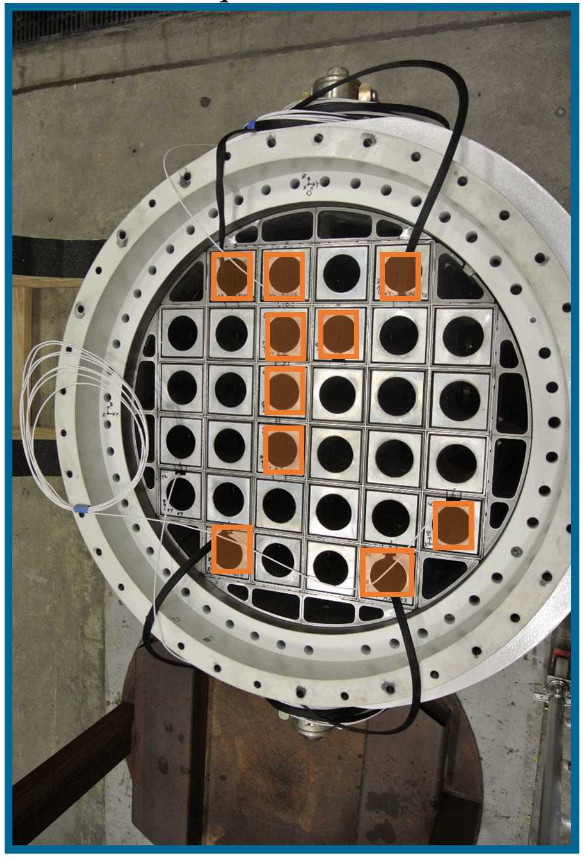
**Instrumentation**

- 12 of model 7270A accelerometers
- Two tri-axial accelerometer blocks on the cask top
- Two tri-axial accelerometer blocks on the cask bottom

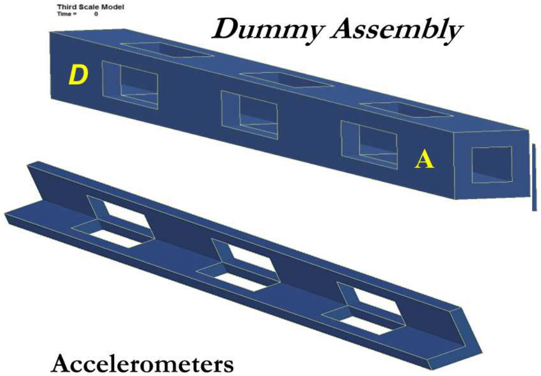
***Cask Instrumentation was the same as in 2010 series of tests***

# Dummy Assembly & Basket Instrumentation

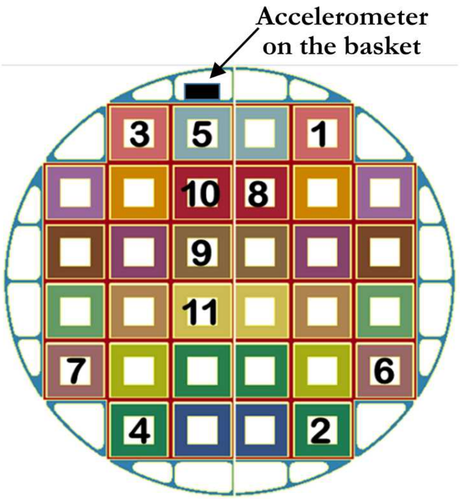
*Implementation*



*Dummy Assembly*




*Instrumented Assembly Locations*




Accelerometers

Endevco Model 727-2K

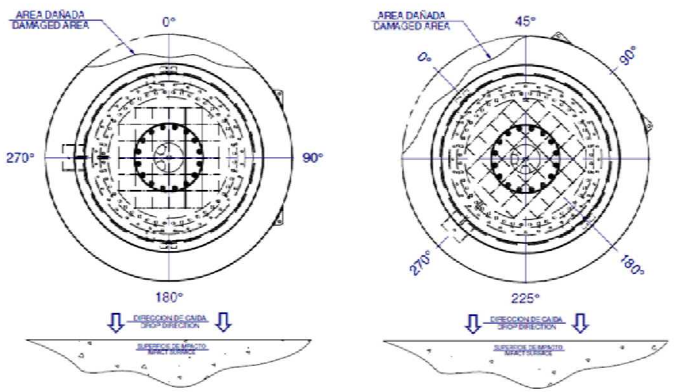
Endevco Model 7265A


## Instrumentation

- 11 instrumented assemblies on A (lid) side: tri-axial accelerometers in locations 1-4, uniaxial (vertical). accelerometers in locations 5-11
- 7 instrumented dummy assemblies on D (bottom) side: tri-axial accelerometers in locations 1-4, uniaxial (vertical). accelerometers in locations 5-7
- One tri-axial accelerometer on basket

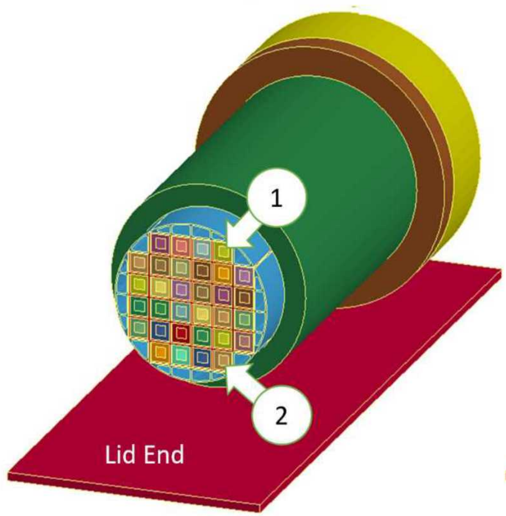
# Test Configurations

*Impact Limiter Configurations in Two Drop Tests*



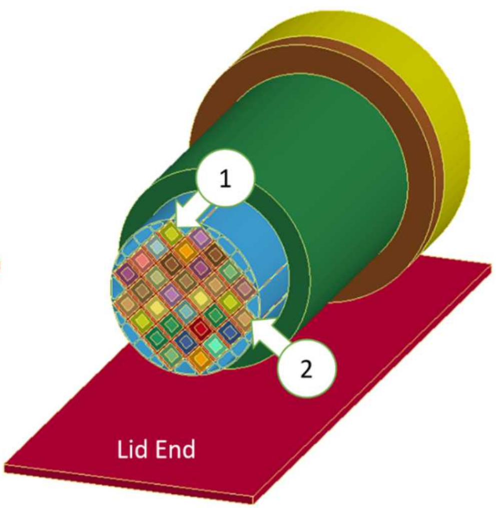

*The purpose of Drop Test 2 is to quantify the variation of fuel assembly impact response due to a change in basket orientation.*

*Drop Orientation 1*
*Baseplate End*




**Normal Position**

*Drop Orientation 2*
*Baseplate End*




**45° Degree Axial Rotation**

# Cask Handling

SNL Steel Frame

Wooden Cradle Manufactured by ENSA

# We Dropped It!

# Time History of Vertical Accelerations on Cask Filtered to 300 Hz

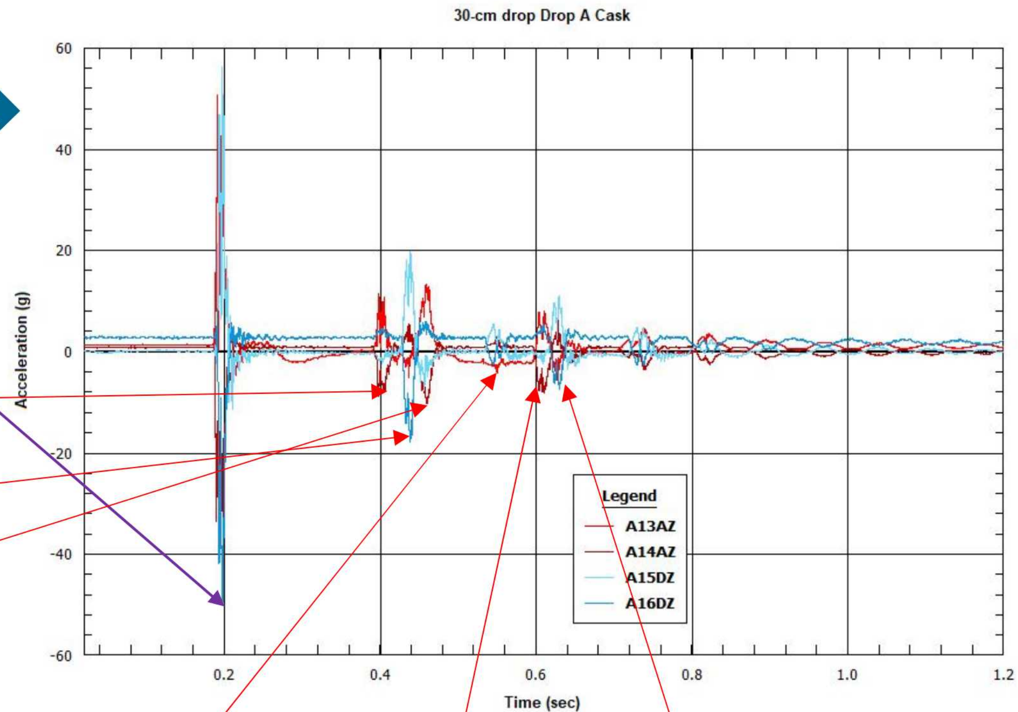
***Seven impacts as seen in the video***

*1st Impact:*
*At approximately the same time*
*Front end hit ~2 millisec earlier than the back end*

***2nd Impact:***
***Front end***

***3rd Impact:***
***Back end***

***4th Impact:***
***Front end***




***5th Impact:***
***Small,***
***Back end***

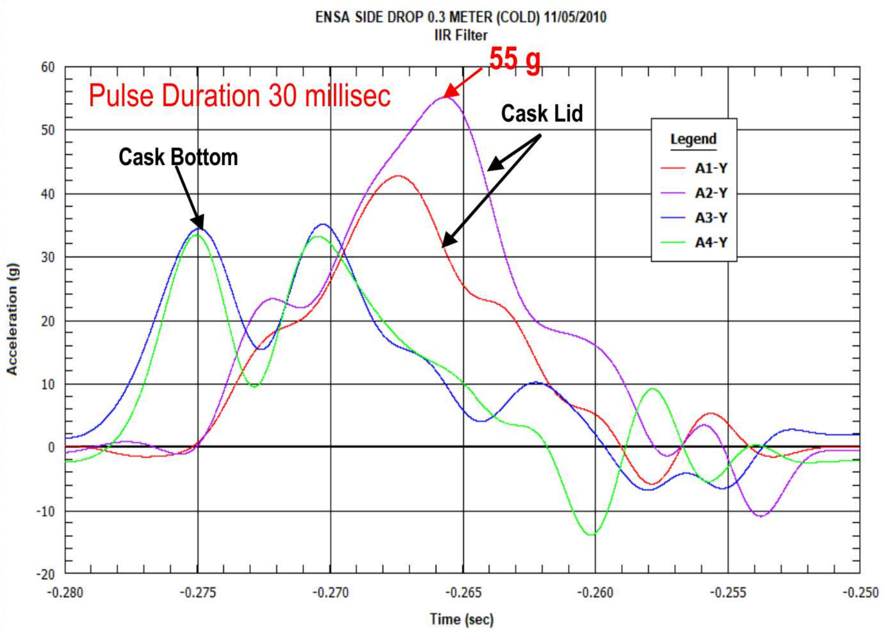
***6th Impact:***
***Front end***

***7th Impact:***
***Back end***

# Vertical Accelerations on Cask in 2010 & 2018 Tests

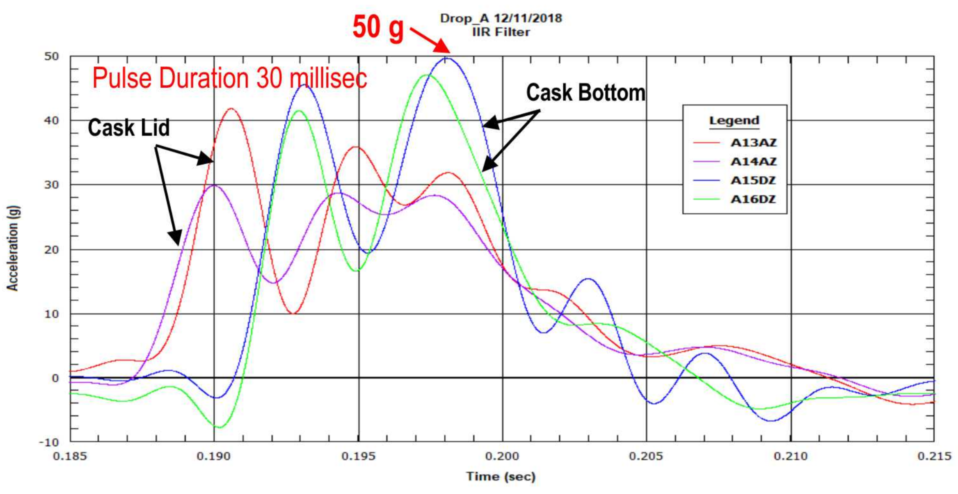
*2010 Test*

*First Impact Time History Filtered to 300 Hz*




*2018 Test*

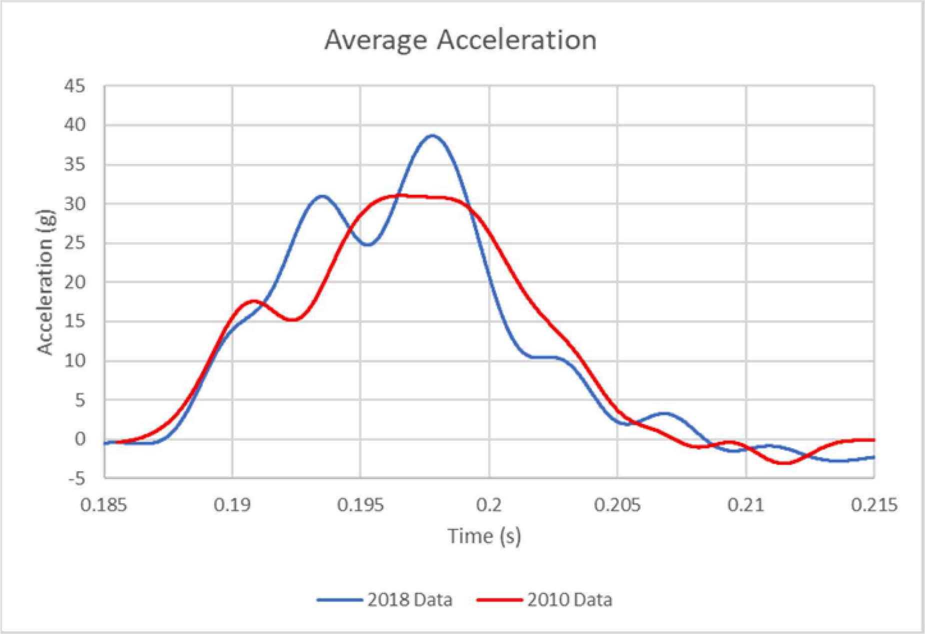
*First Impact Time History Filtered to 300 Hz*



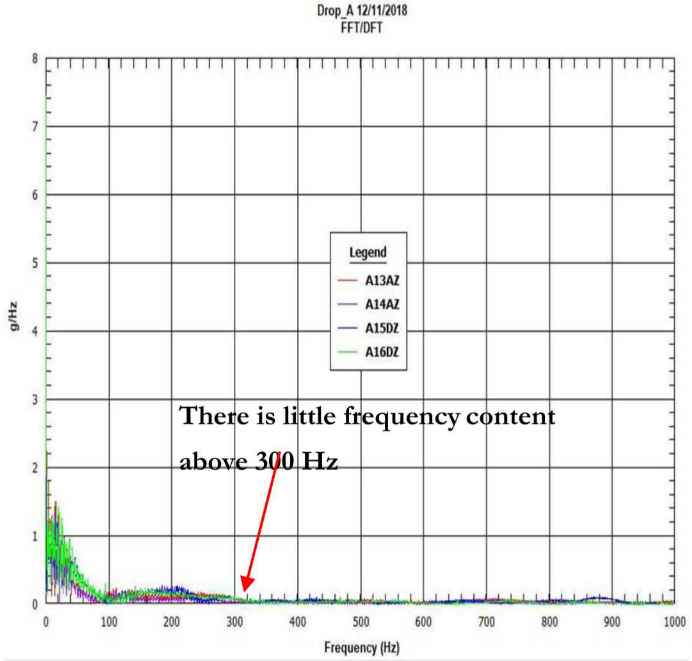

- *Some differences are due to the fact that the drops are never perfectly horizontal.*

# *Averaged* Vertical Acceleration on Cask in 2010 & 2018 Tests

*Averaged Time History Filtered to 300 Hz*

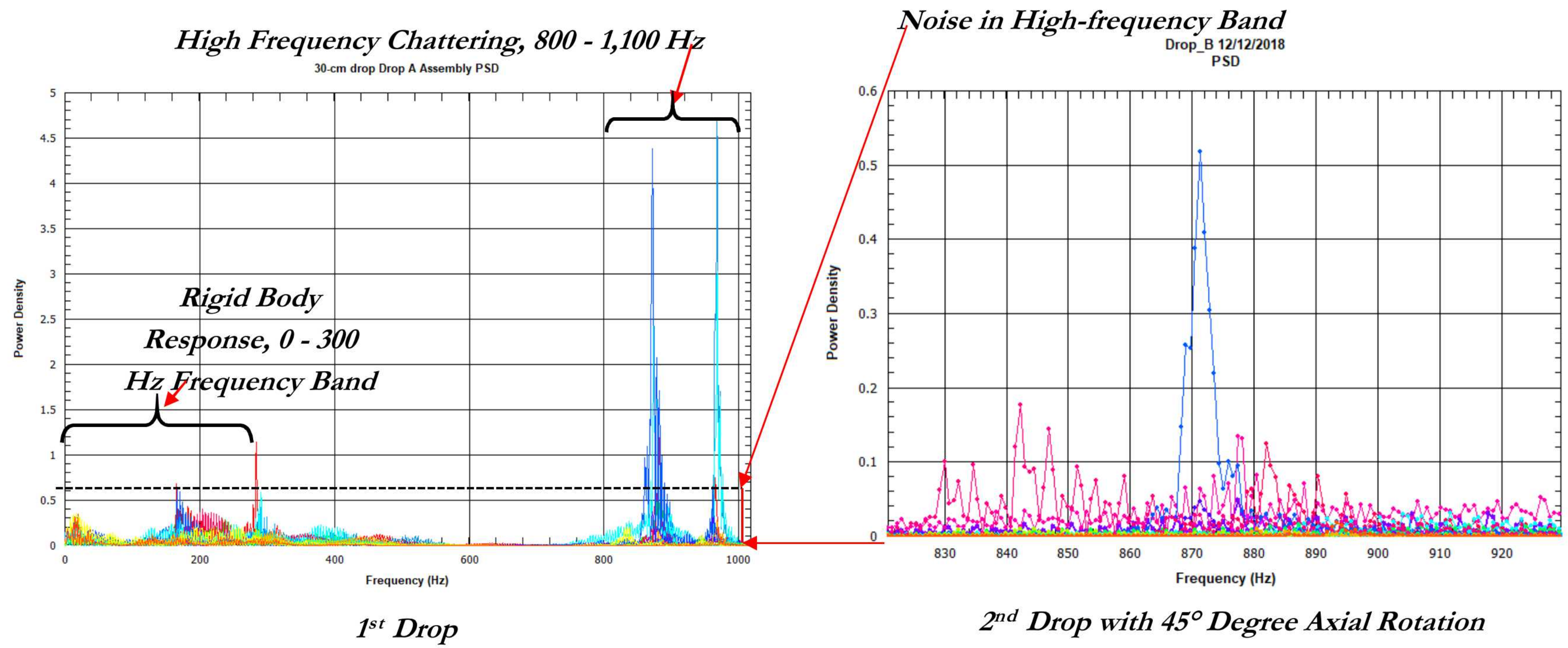



*FFT of Cask Acceleration Time Histories (2018 Test)*




- *The cask accelerations measured in 2018 are very similar to the ones measured in 2010.*

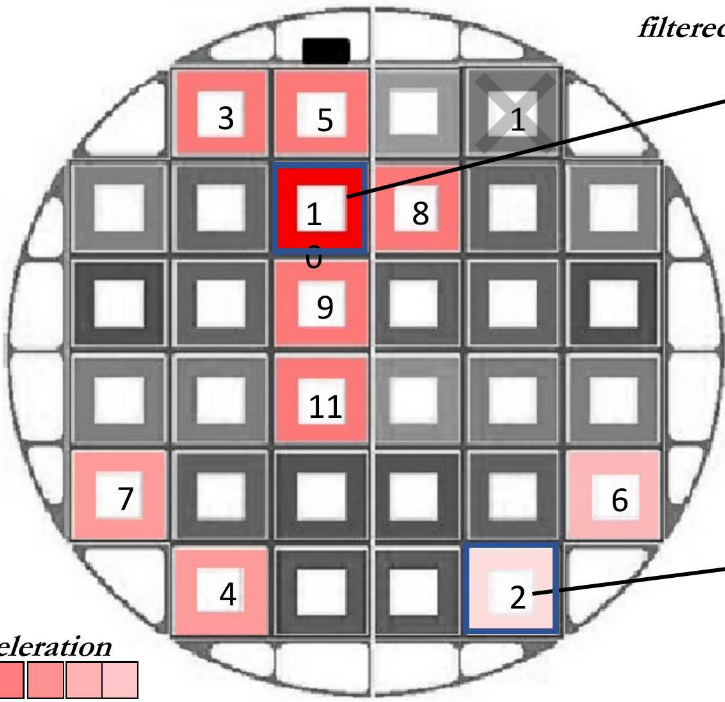
# Dummy Assembly Frequency Content During 1st Impact




- *The high-frequency response was only observed in the 1st drop and was attributed to the dummy assembly vibration inside the basket tube. The vibration was limited when the basket was rotated.*

# SIDE A (LID) MAXIMUM ACCELERATIONS ON INSTRUMENTED ASSEMBLIES

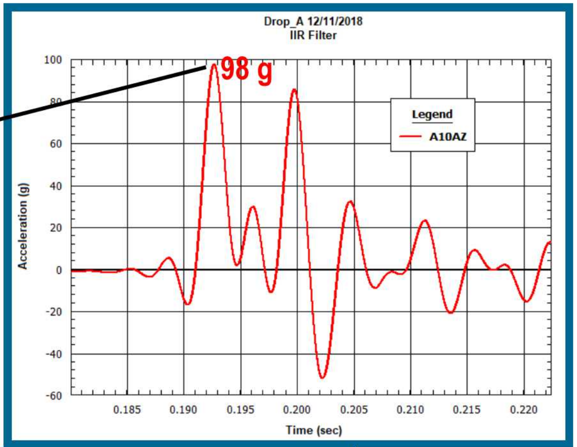
*Acceleration Color Map*

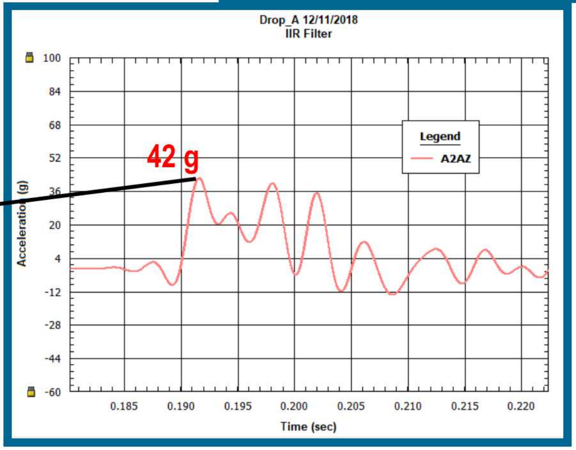



*Acceleration*

*Increasing Acceleration*

*Assembly #10 time history filtered to 300 Hz*

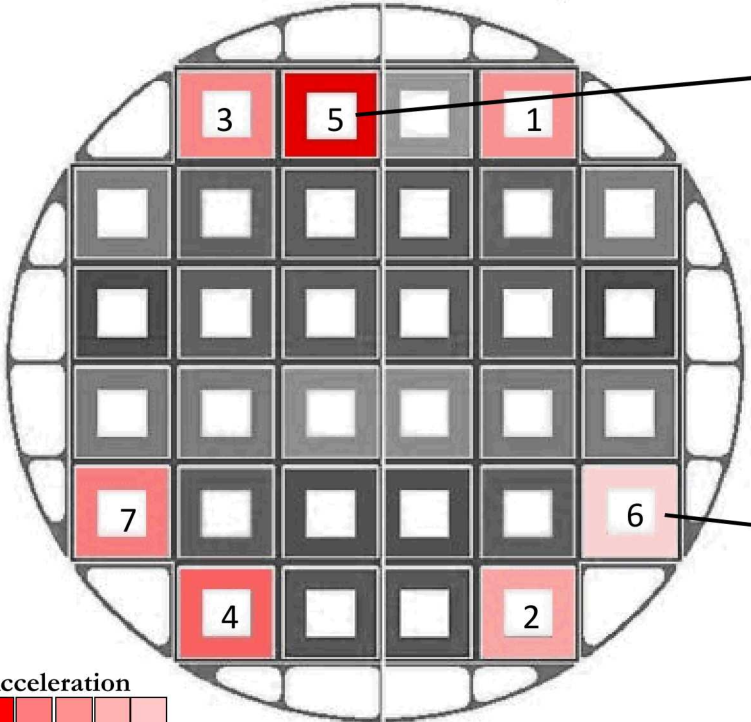



*Assembly #2 time history filtered to 300 Hz*

# Side D (Bottom) Maximum Accelerations on Instrumented Assemblies

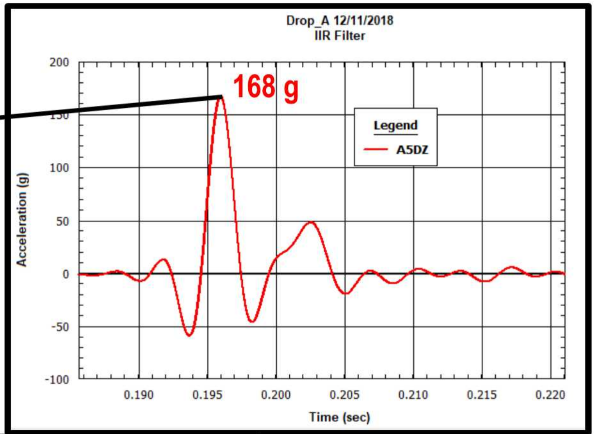
*Acceleration Color Map*

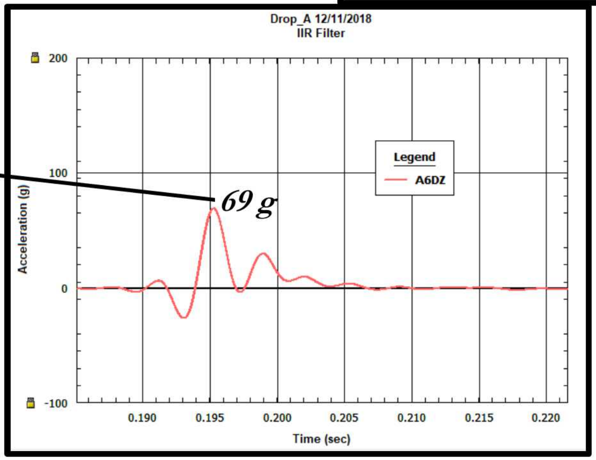



**Acceleration**

*Increasing Acceleration*

*Assembly #5 time history filtered to 300 Hz*

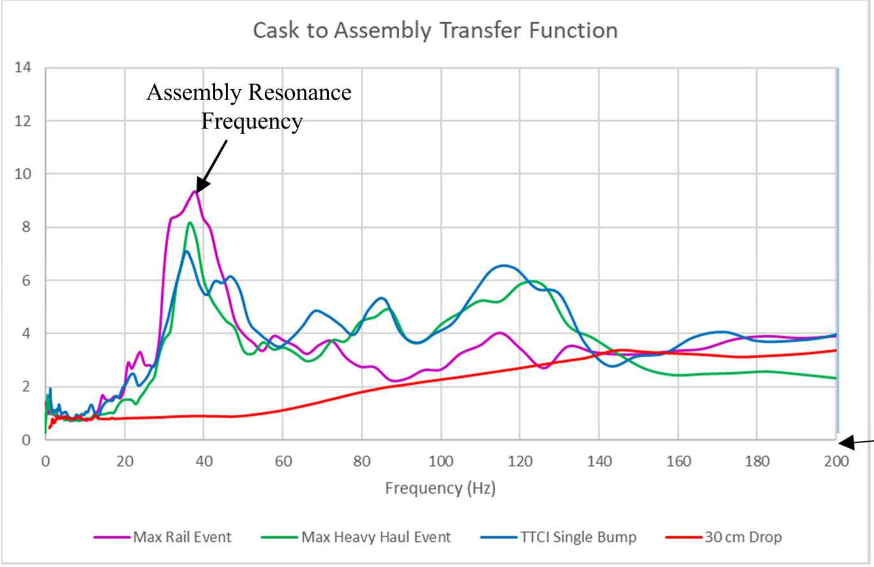


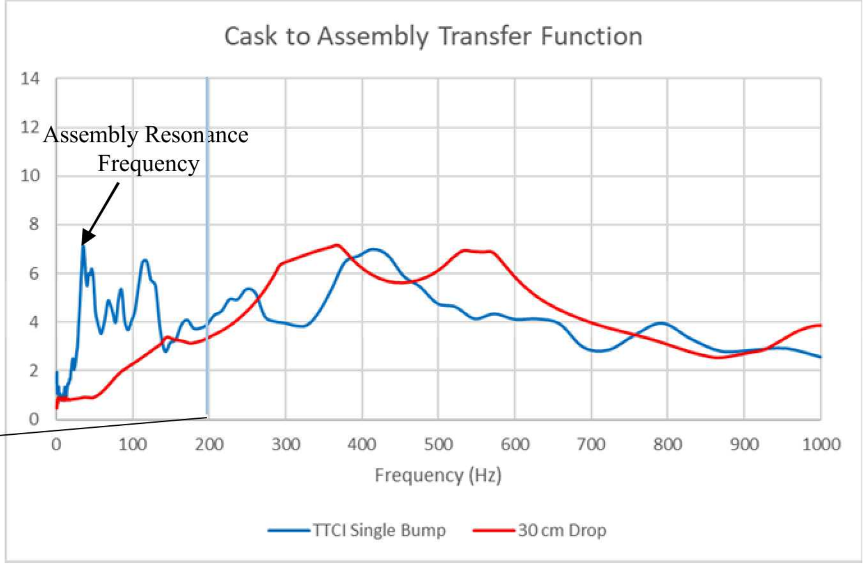

*Assembly #6 time history filtered to 300 Hz*

# CASK TO ASSEMBLY TRANSFER FUNCTIONS IN MMTT & 30 CM DROP

*0 to 200 Hz Frequency Band*




*0 to 1,000 Hz Frequency Band*

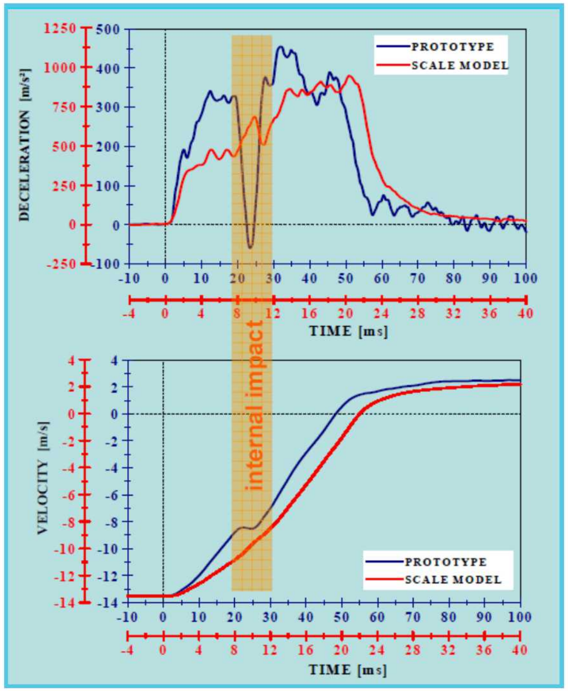



- ***In the low frequency band the major differences between the dummy and surrogate assemblies are due to the surrogate assembly resonance frequency around 40 Hz.***

- ***In the high band frequency the differences between the surrogate and dummy assemblies are relatively small.***

# Scale Versus Prototype Cask Results in 9 m Vertical Drop Tests

***Deceleration and Velocity***




***Prototype***


***Scale Model***

***From "Comparison of Experimental Results from Drop Testing of a Spent Fuel Package Design Using a Full-Scale Prototype Model and a Reduced-Scale Model", Quercetti et al, 2007.***

# Scaling Effects per Quercetti (2007)

**Rigid body impact response of the scaled model**

- Maximum tranlation ↑+9 %
- Impact duration ↑+24 %
- Maximum and average deceleration ↓-17 %

The scaled model tends to represent the impact of the prototype model as softer

**Structural impact response of scaled model**

- cask body axial strain ↓-26 %
- primary lid bending strain ↓-80 %
- primary lid bolt axial strain ↓-94 %

The scaled model undervalues the response of the prototype

### Why Are There Differences?

- ❑ Impact limiter material grain size is not scaled.
- ❑ Scale model should be tested in a scaled acceleration field.
- ❑ Compressed time in the scale model means that timing of secondary impacts is incorrect (the larger the gaps in the model, the more significant this difference is).

### How This Affects the Drop of 1/3 Scale Model

- ➢ 1/3-scale drop test will not provide cladding strains.
- ➢ This can be obtained by dropping an instrumented full-scale assembly onto programming material to provide the same shock pulse as the dummy assemblies experienced in the 1/3-scale cask drop test.

# FULL-SCALE ASSEMBLY DROP TESTS

The drop tests will be conducted at the SNL drop tower.

***The major goal** is to obtain the data on **accelerations** and **strains** on the **full-scale surrogate fuel assembly** during **30 cm** horizontal drop (normal conditions of transport) and **9 m** horizontal drop (accident conditions of transport).*

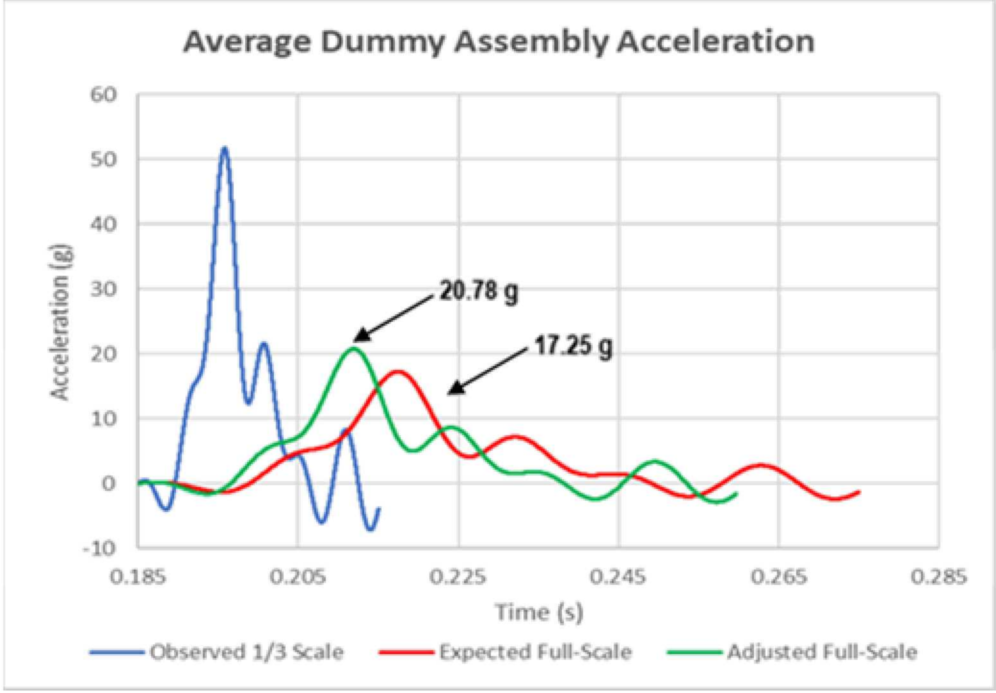
The major inputs from the 1/3 scale cask drop are:

- ❑ Accelerations on the dummy assembly
- ❑ Transfer function from the cask to the dummy assembly

The programming material will be felt (30 cm drops) and aluminum honeycomb (9 m drops).

The programming material acts to simulate the impact limiters on the cask

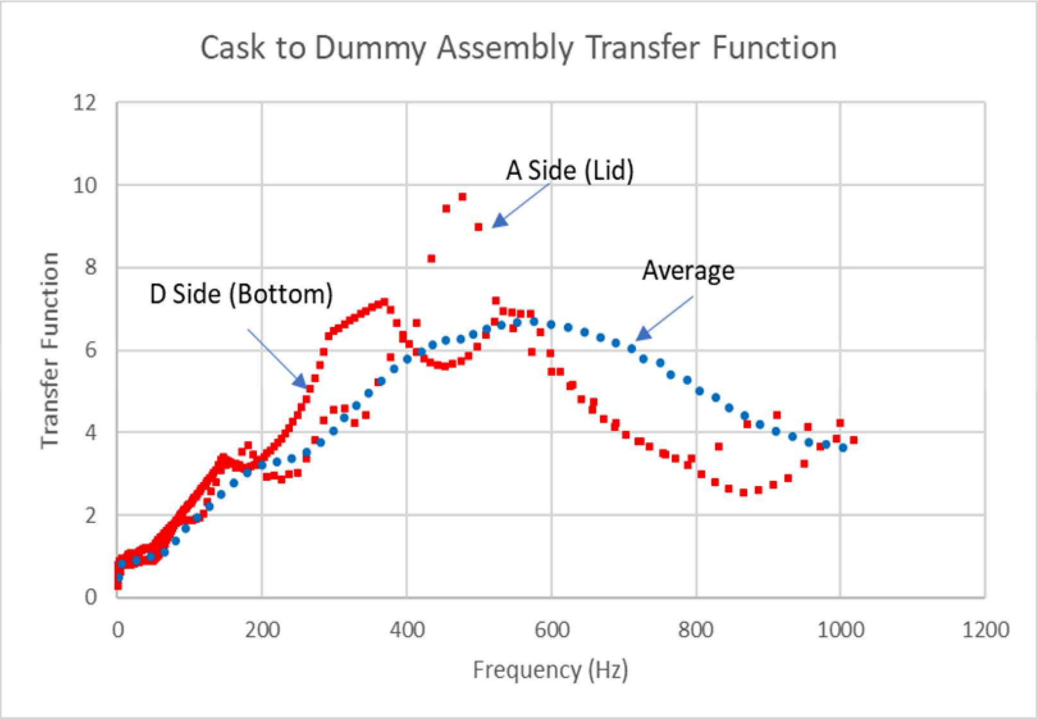
# INPUTS INTO 30 CM DROP TEST




**Expected acceleration on the full-scale dummy assembly during 30 cm drop:**

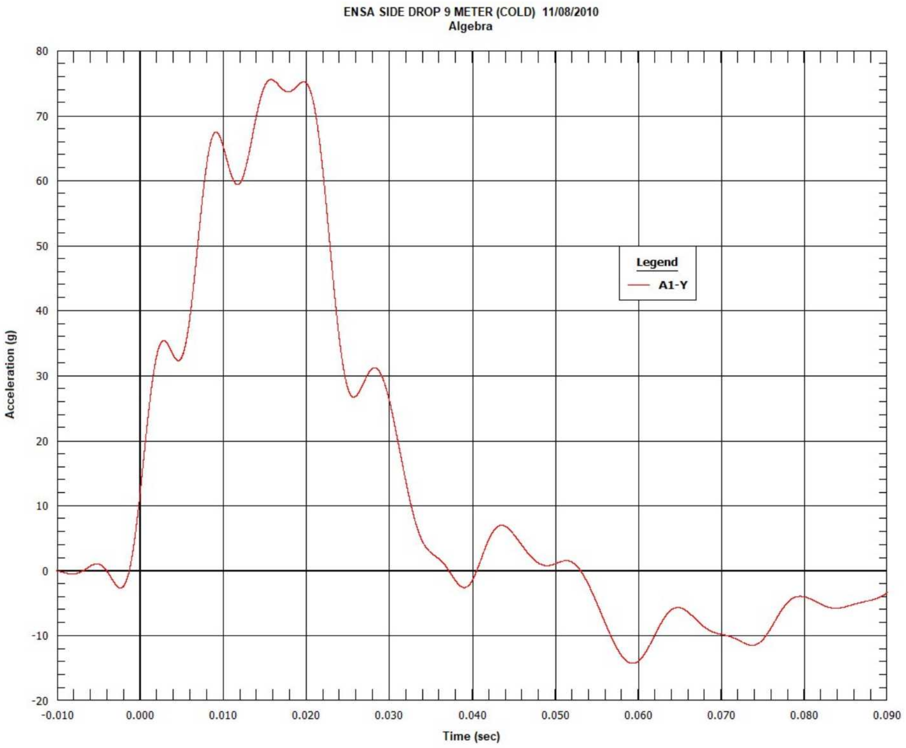
- The average acceleration on the scaled dummy assembly was decreased and the time was increased proportionally to the scale (factor of 3).
- Because the scaling effect may result in underestimating accelerations, the expected accelerations and time were adjusted by 17%.
- Target acceleration in 30 cm drop test will be 20.8 g

# Inputs into 9 m Drop Test




- There is no test data related to the accelerations on the 1/3 scale dummy assembly for the 9 m drop
- The average transfer function was used in predicting the maximum acceleration on the dummy assembly in the 9 m drop.

# EXPECTED ACCELERATION IN 9 M DROP TEST




The expected accelerations on full-scale dummy assembly in 9 m drop were calculated from:

- Average acceleration transfer function
- Accelerations on the 1/3 scale cask from 2010 9 m drop test
- Because the scaling effect may result in underestimating accelerations, the acceleration was adjusted by 17%.
- The target acceleration on the full-scale dummy assembly in 9 m drop test will be 76 g.

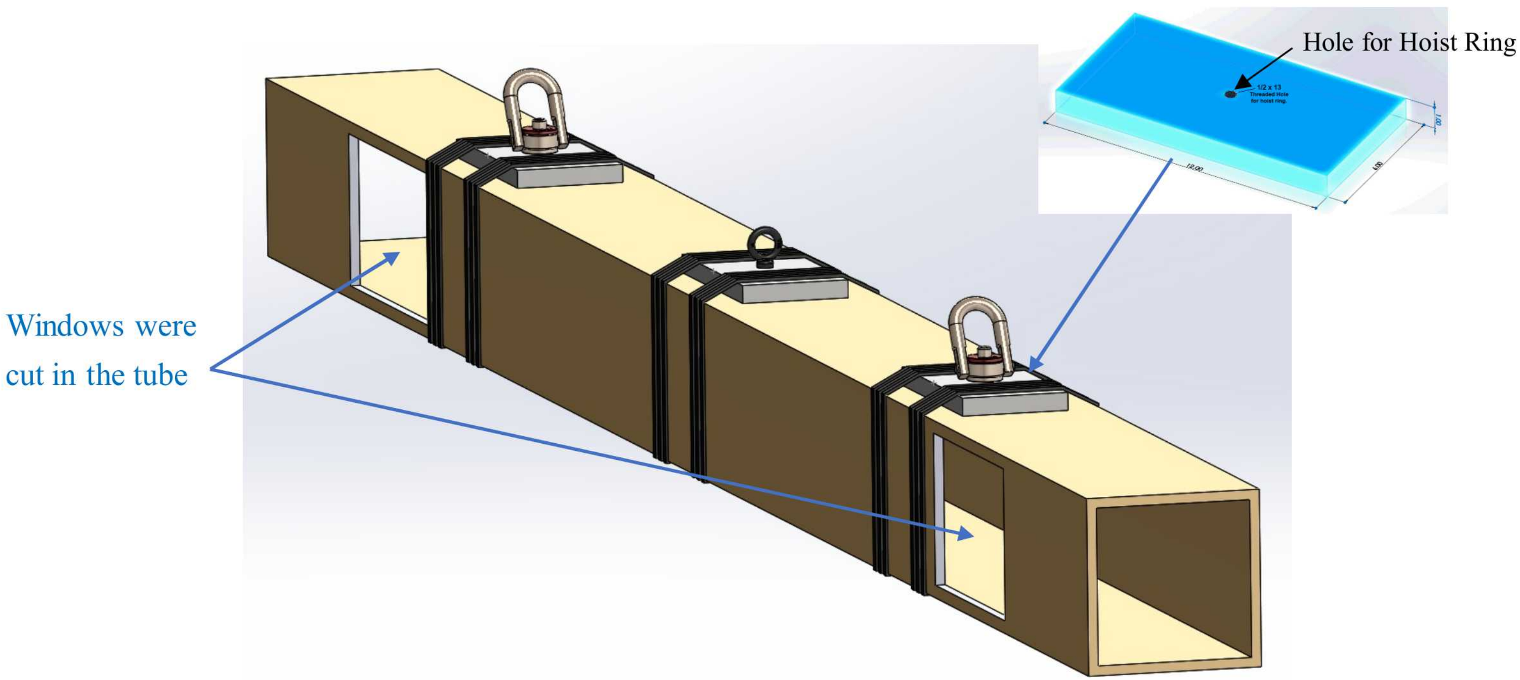
**PNNL Finite-Element Model**

- The predicted acceleration on the dummy assembly in 9 m drop filtered to 200 Hz is 72.5 g.

# Basket Tube

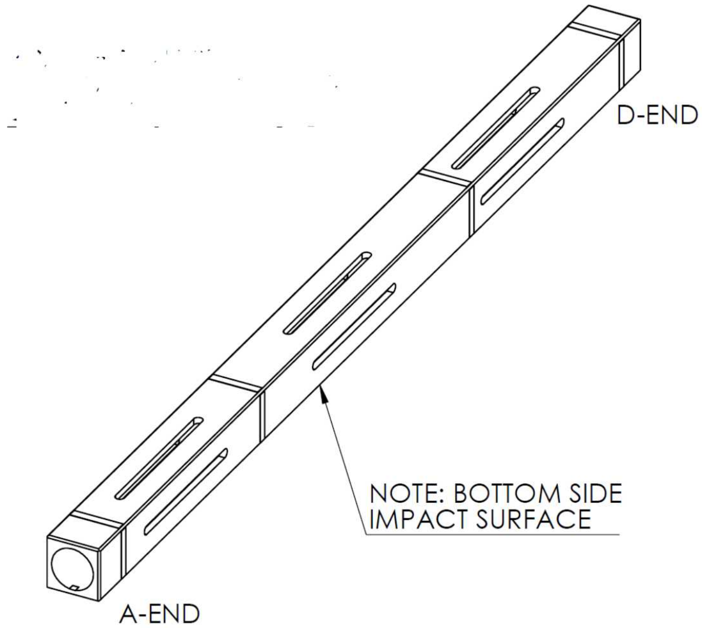
- The full-scale assemblies (dummy and surrogate) will be dropped in the actual 17x17 PWR assembly basket tube.
- It is made of matrix of 'pure' aluminum material with boron carbide insertions
- This is the same basket tube as the ones in the MMTT test.

# Basket Tube Handling




- ❑ The proposed handling is to use 3 steel plates with the hoist rings that are attached to the basket tube by wrapped around metal bands.
- ❑ The windows are for video recording of the rods behavior during the drops.

# FULL-SCALE DUMMY ASSEMBLY



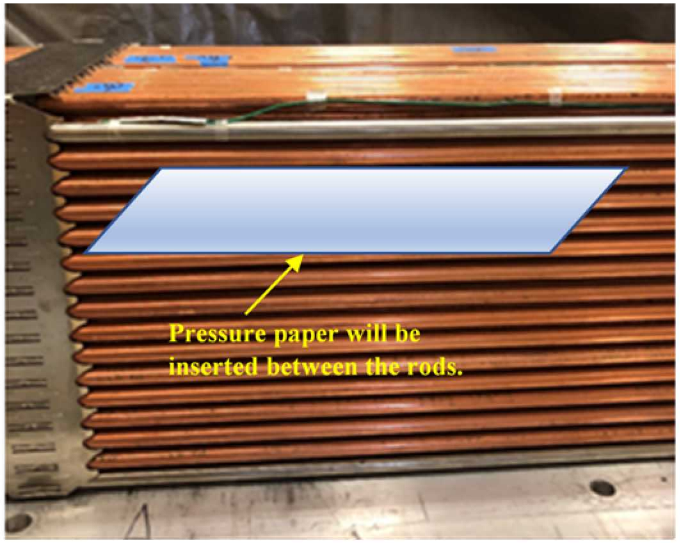

- The full-scale dummy assembly is the enlarged by 3 times equivalent of the 1/3 scale dummy assembly.

# Full-Scale Surrogate Assembly

- The full-scale surrogate assembly is the same assembly that was used in MMTT.

The instrumentation is in progress

# Installation of Pressure paper

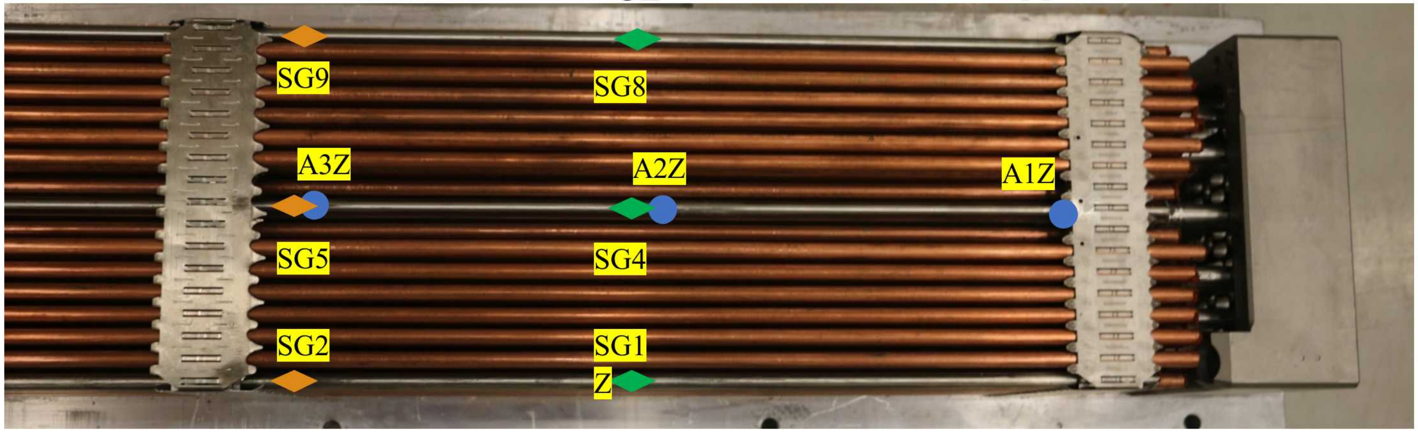



| Table 1: Fujifilm Prescale® Specifications | | |
|---|---|---|
| **Film Type** | **Roll Dimensions** | **Pressure Range** |
| Extreme Low (LLLLW/4LW) | 9.8 ft × 12.2in (3 m × 310mm) | 7.2–28 psi (0.5–1.97 kg/cm$^2$) |
| Ultra Low (LLLW) | 16.4 ft × 10.6in (5 m × 270mm) | 28–85 psi (2–6 kg/cm$^2$) |
| Super Low (LLW) | 19.7 ft × 10.6in (6 m × 270mm) | 70–350 psi (5–25 kg/cm$^2$) |
| Low (LW) | 39.4 ft × 10.6in (12 m × 270mm) | 350–1,400 psi (25–100 kg/cm$^2$) |
| Medium (MS) | 39.4 ft × 10.6in (12 m × 270mm) | 1,400–7,100 psi (100–500 kg/cm$^2$) |
| High (HS) | 39.4 ft × 10.6in (12 m × 270mm) | 7,100–18,500 psi (500–1,300 kg/cm$^2$) |
| Super High (HHS) | 39.4 ft × 10.6in (12 m × 270mm) | 18,500–43,200 psi (1,300–3,000 kg/cm$^2$) |

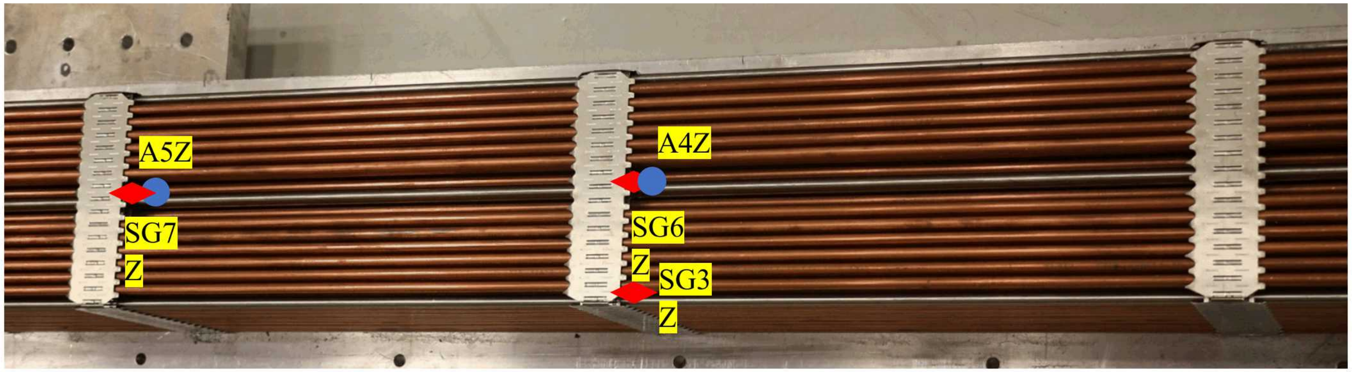
- The pressure paper will be inserted between each layer of the rods (16 layers in total) in two locations (two longest segments between the spacer grids)
- For the 30 cm drop test, the **Extreme Low** and **Super Low** layers will be alternated.
- For the 9 m drop test, all four types will be alternated.

# SURROGATE ASSEMBLY INSTRUMENTATION

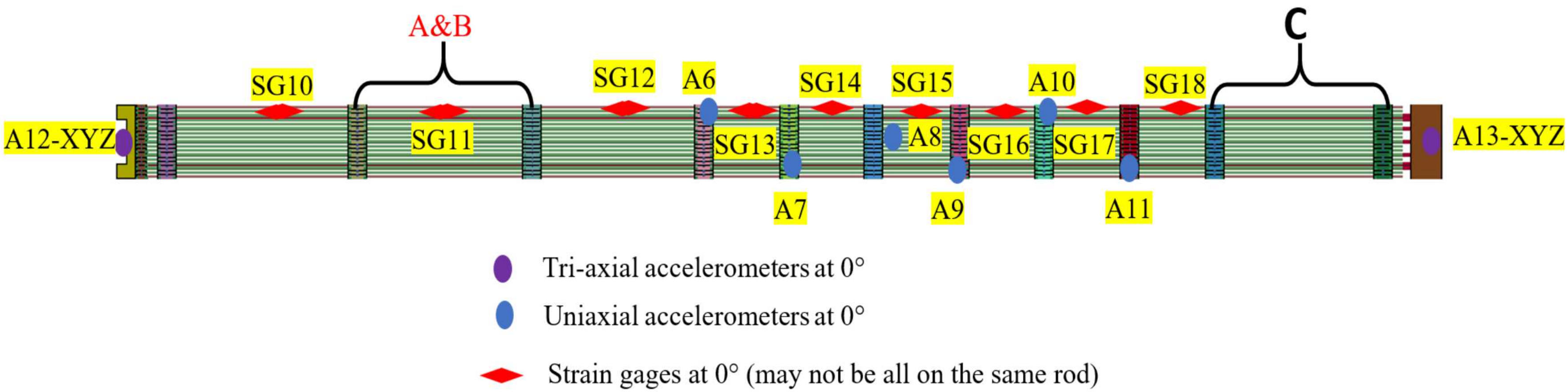
**TOP-NOZZLE END**



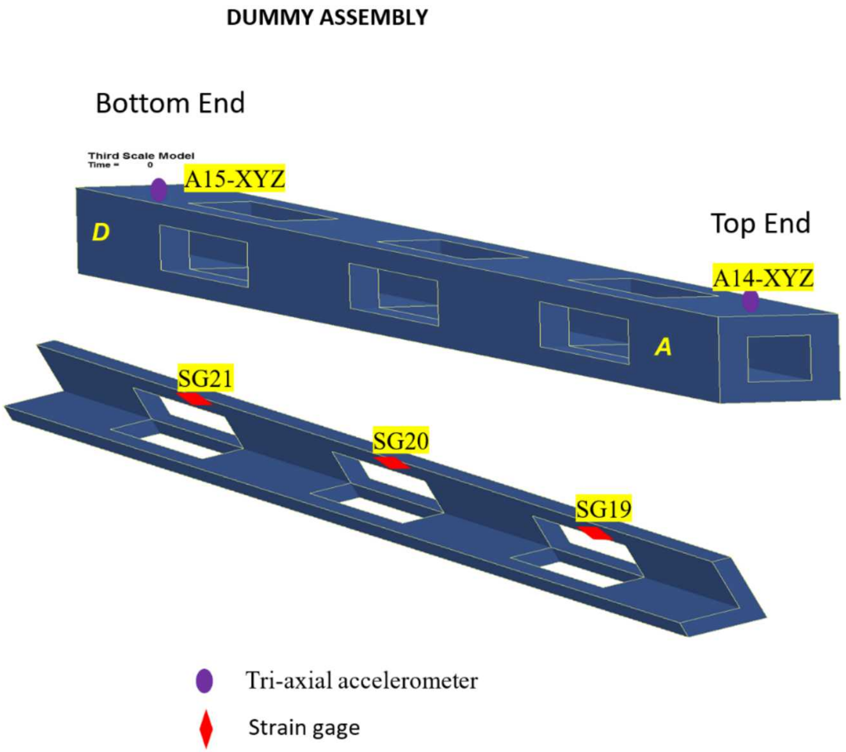

**BOTTOM-NOZZLE END**



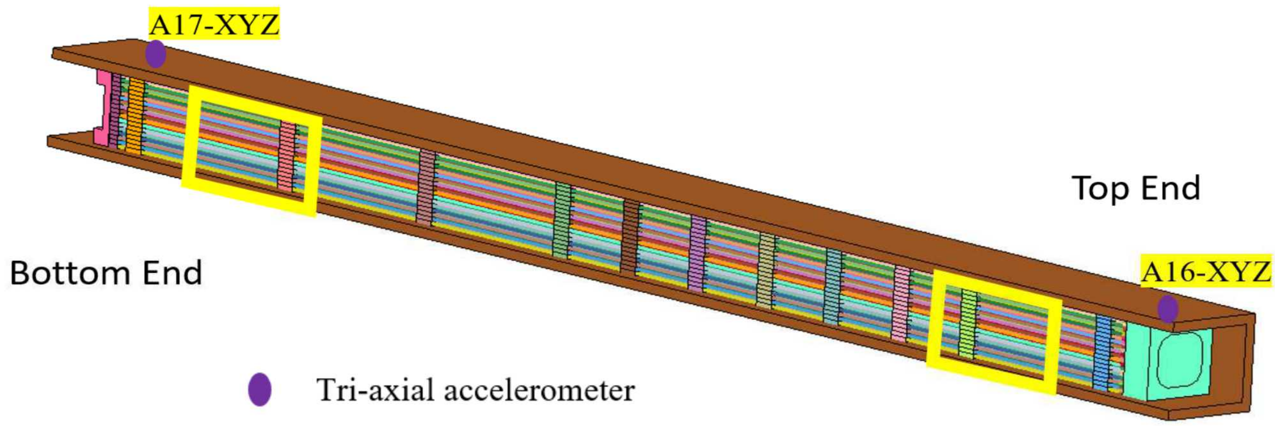
# Surrogate Assembly Additional Sensors

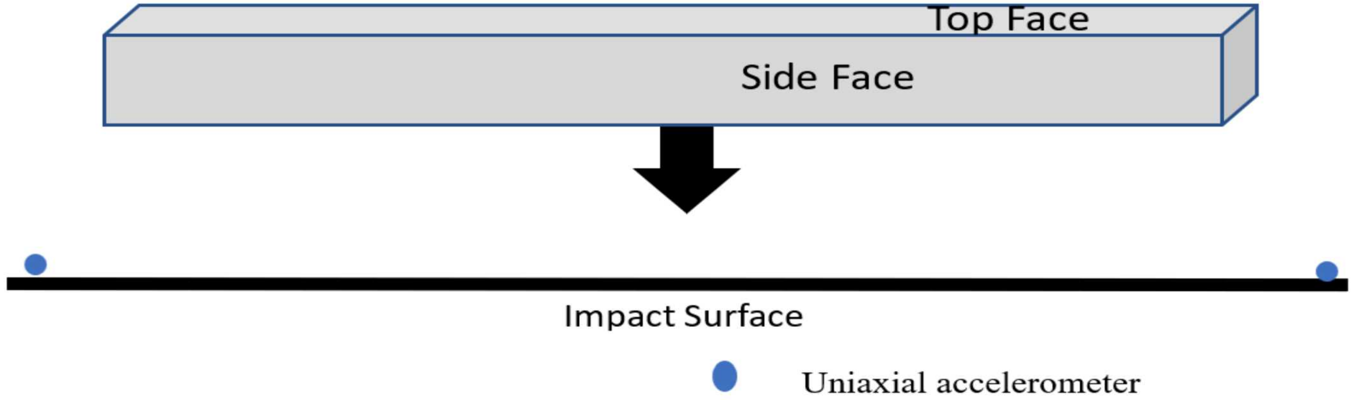


# Dummy Assembly Instrumentation



# BASKET TUBE AND IMPACT TARGET INSTRUMENTATION



# PROPOSED DROP TEST SCHEDULE

## 2019 JUNE

DROP TEST SCHEDULE

| Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|
| 10<br>▪ Transfer basket tube with the dummy assembly to the drop test facility.<br>▪ Test set up and practicing lifts. | 11<br>▪ First 30 cm drop with the dummy assembly.<br>▪ Analyze the data and decide if the second drop is needed. If the second drop is needed, modify the programming material. | 12<br>▪ Second 30 cm drop with the dumy assembly if needed.<br>▪ If second drop is not needed, then transfer the surrogate assembly to the drop facility. Pull out the dummy assembly, install pressure paper on the surrogate assembly, insert the surrogate assembly into the basket tube, and conduct 30 cm drop with the surrogate assembly. | 13<br>▪ 30 cm drop with the surrogate assembly if there was a second 30 cm drop with the dummy assembly on June 12.<br>▪ Otherwise preliminary analysis of the 30 cm drop data. | 14<br>▪ Drop facility is closed.<br>▪ Pull out the surrogate assembly and insert the dummy assembly. Collect the pressure paper from the surrogate assembly and document the results. |
| 17<br>▪ First 9 m drop with the dummy assembly.<br>▪ Analyze the results and modify the programming material. | 18<br>▪ Second 9 m drop with the dummy assembly.<br>▪ Analyze the results and modify the programming material. | 19<br>▪ Pull out the dummy assembly, install pressure paper on the surrogate assembly, and insert the surrogate assembly into the basket tube.<br>▪ Conduct one 9 m drop with the surrogate assembly.<br>▪ Pull out the surrogate assembly. Collect the pressure paper from the surrogate assembly and document the results. | 20<br>▪ Reserved to accommodate the schedule slip and for the data analysis. | 21<br>▪ Reserved to accommodate the schedule slip and for the data analysis. |

# QUESTIONS?

SFWD

SPENT FUEL & WASTE DISPOSITION

*Annual Working Group Meeting*
*May 21-23, 2019*

UNLV-SEV – *Las Vegas, Nevada*