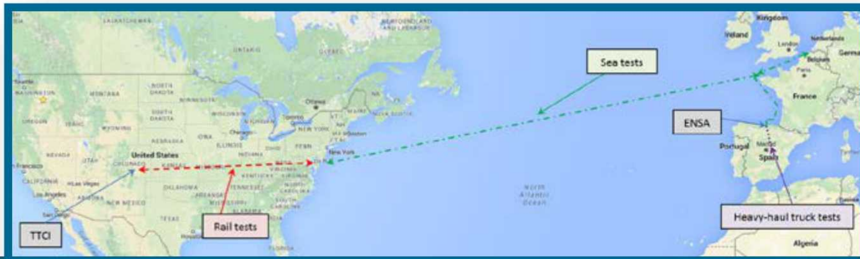

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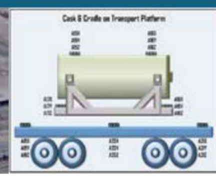
SAND2019-6893PE

Transportation Work Update



Transportation Workshop

July 1-2, 2019

Berlin, Germany

SNL Participants:
Sylvia Saltzstein, Doug Ammerman, and Elena Kalinina

PRESENTED BY

Elena Kalinina

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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.

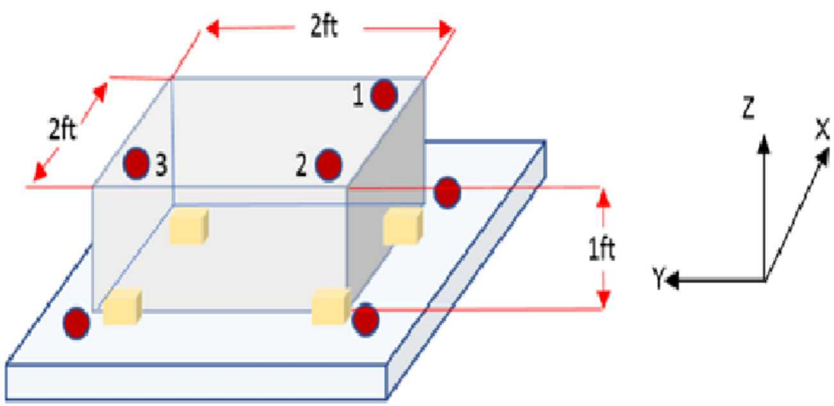
FY18-FY19 Project Reports – SNL and PNNL

- 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, 2018)

- 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.

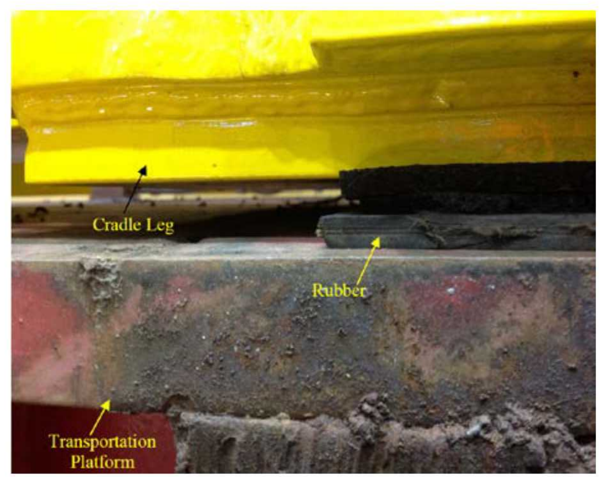
Test Configuration



Rubber, plywood, and steel legs, 1.5"x1.5", 0.5" thick

Triaxial Accelerometer

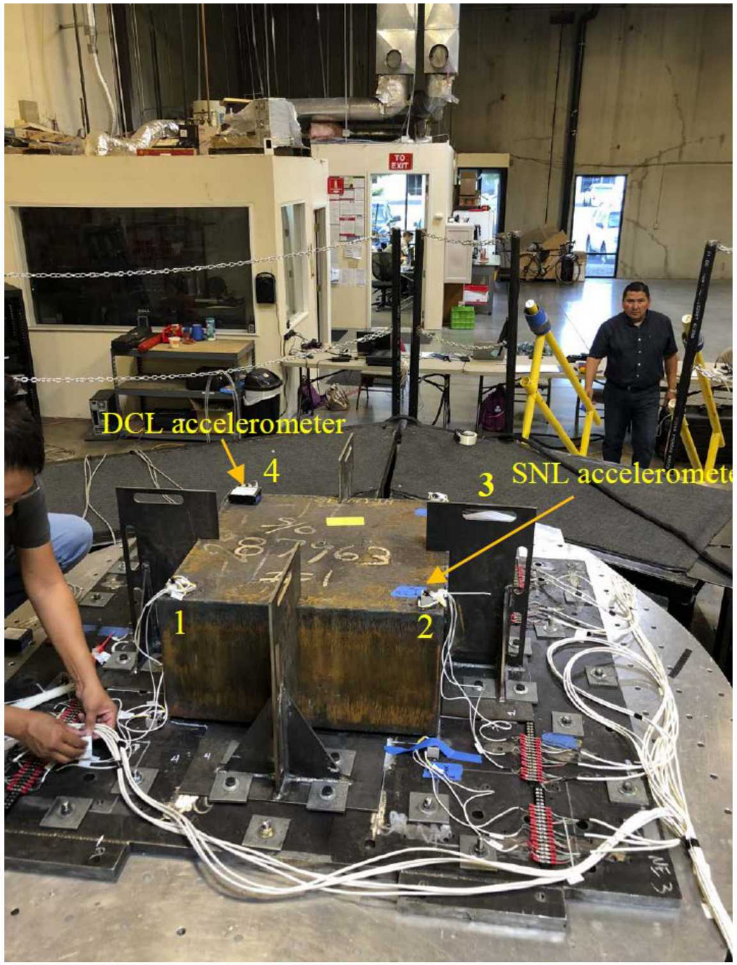
Layer of Rubber Beneath the Cradle



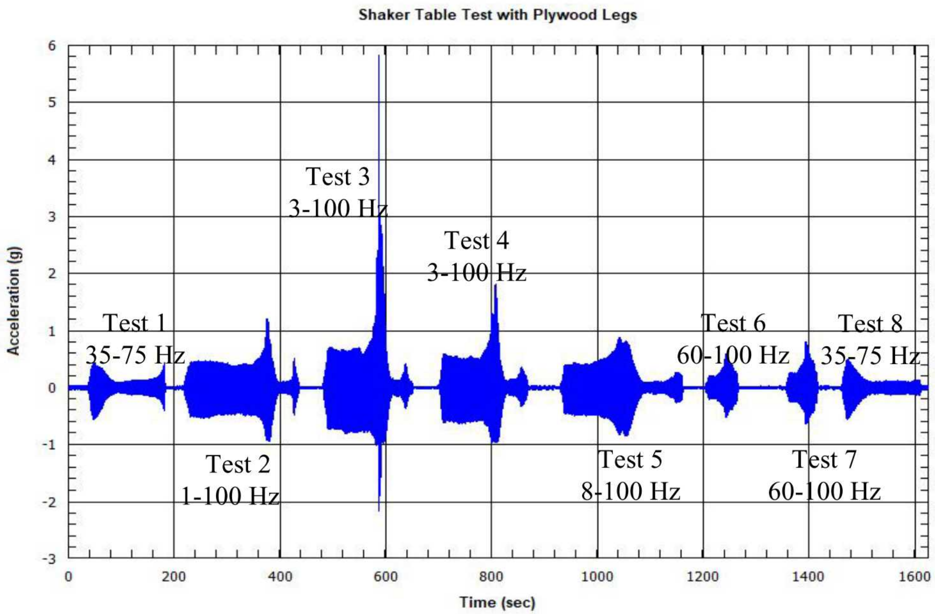
Plywood Leg

Rubber Leg

We shook it!

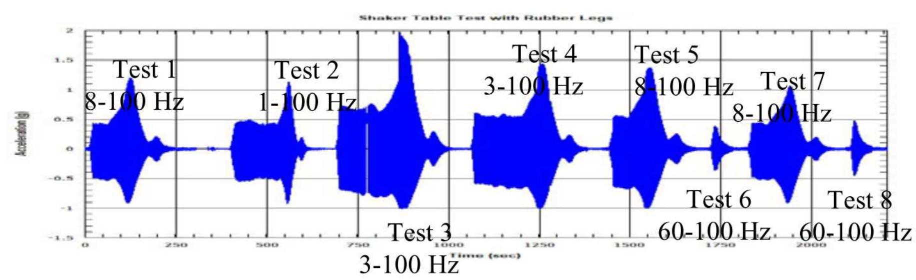


Plywood and Rubber Legs Test Specifications



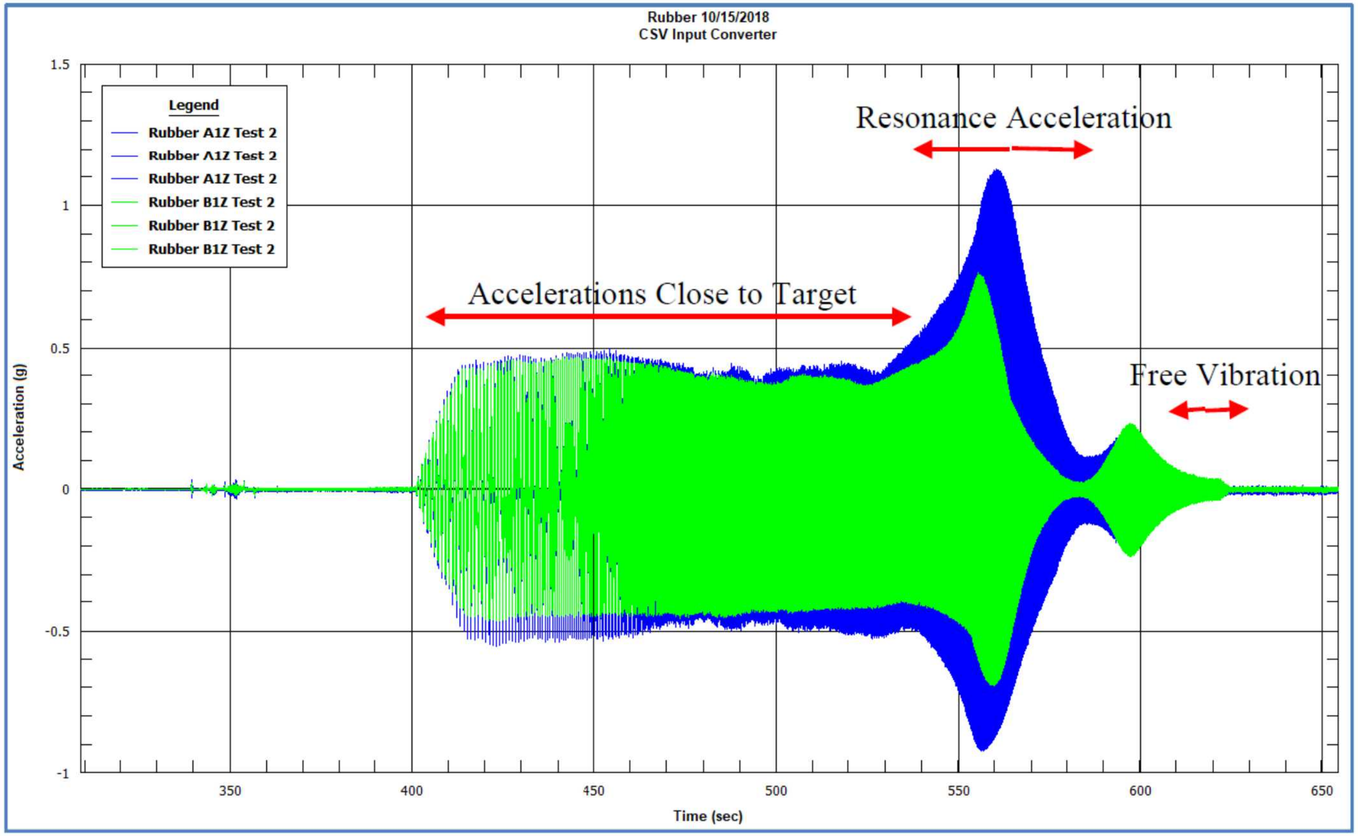
Tests with Plywood Legs

Tests with Rubber Legs



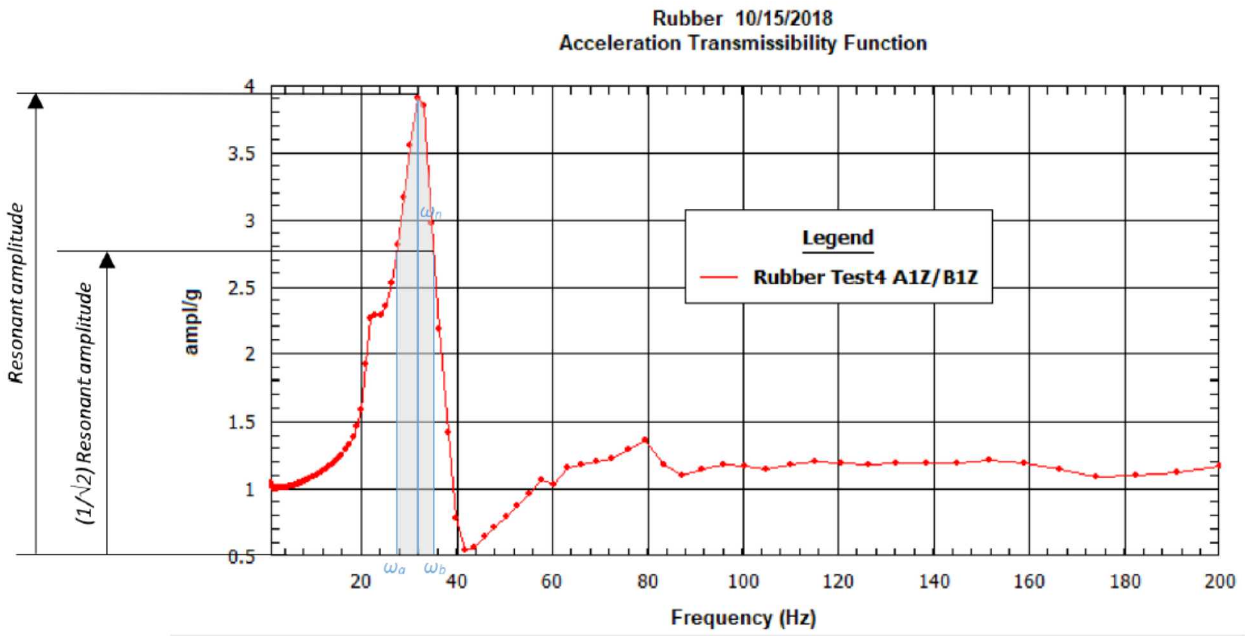
Example of Acceleration Time History

Shaker Table Test 2 with the Rubber Legs



Example of the Half-Power Bandwidth Method

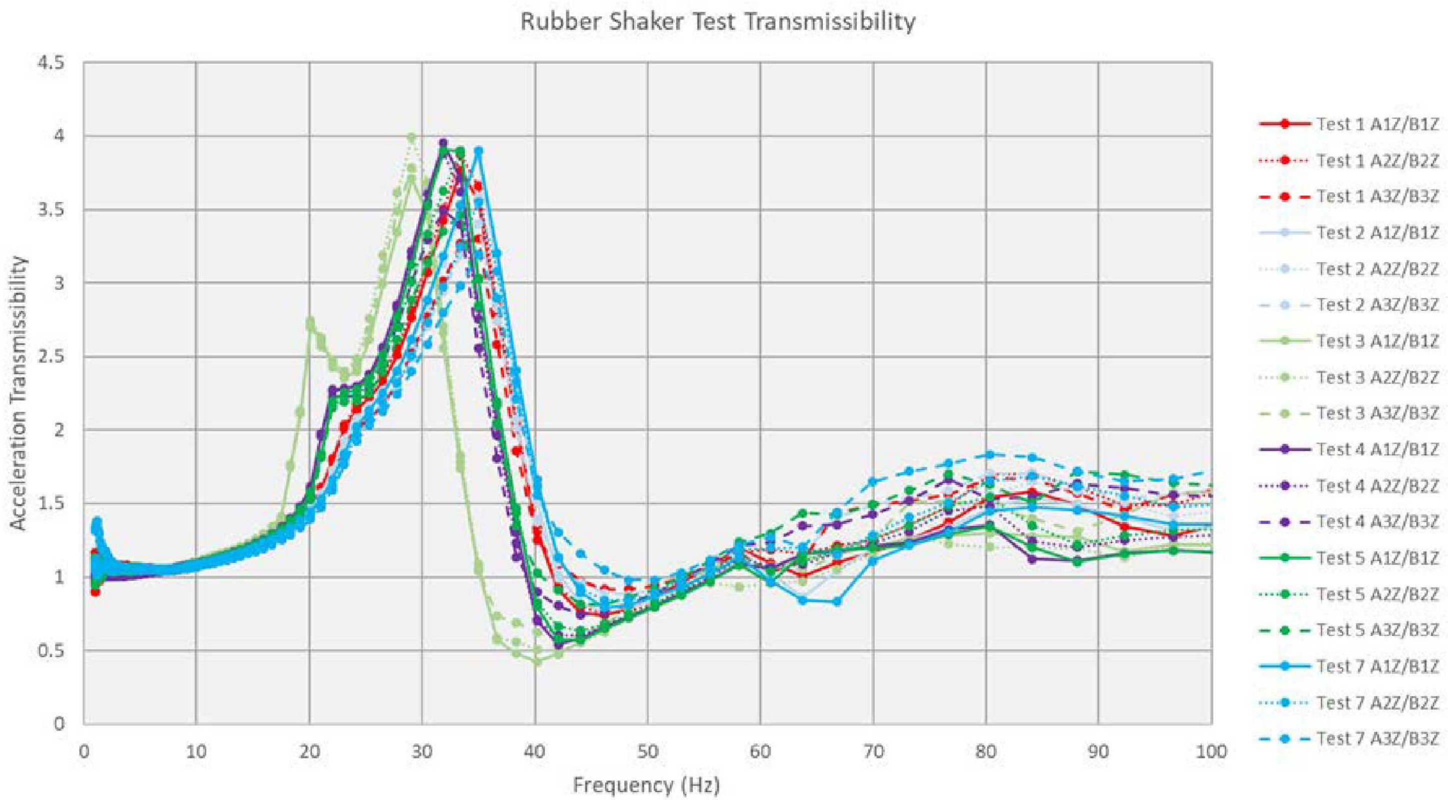
Acceleration Transmissibility Function Calculated from A1Z and B1Z, Rubber Test 4



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

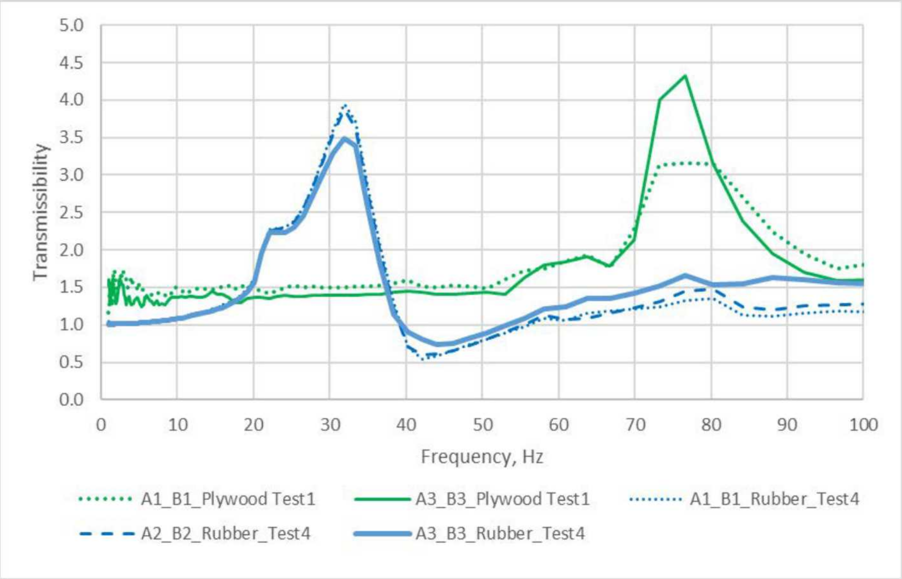
Results of the Rubber Leg Tests

Transmissibility Functions for Rubber Leg Tests

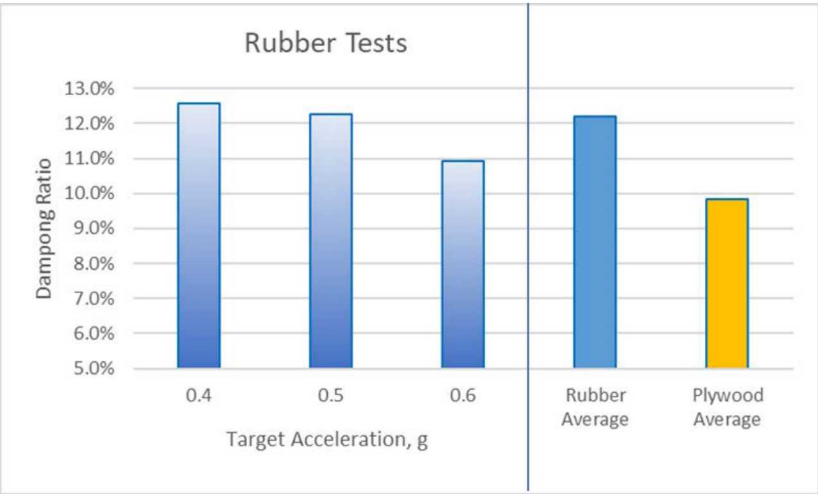


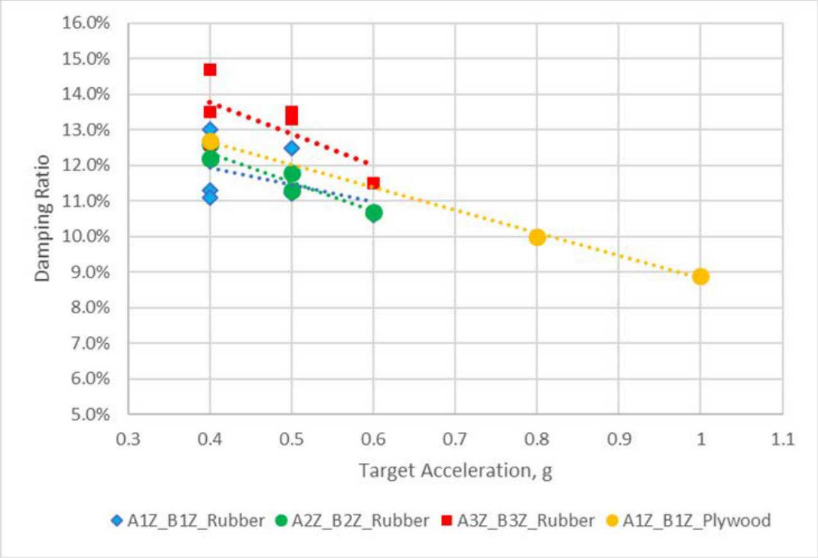
Comparison Between the Plywood and Rubber Leg Tests

Transmissibility Function Comparison



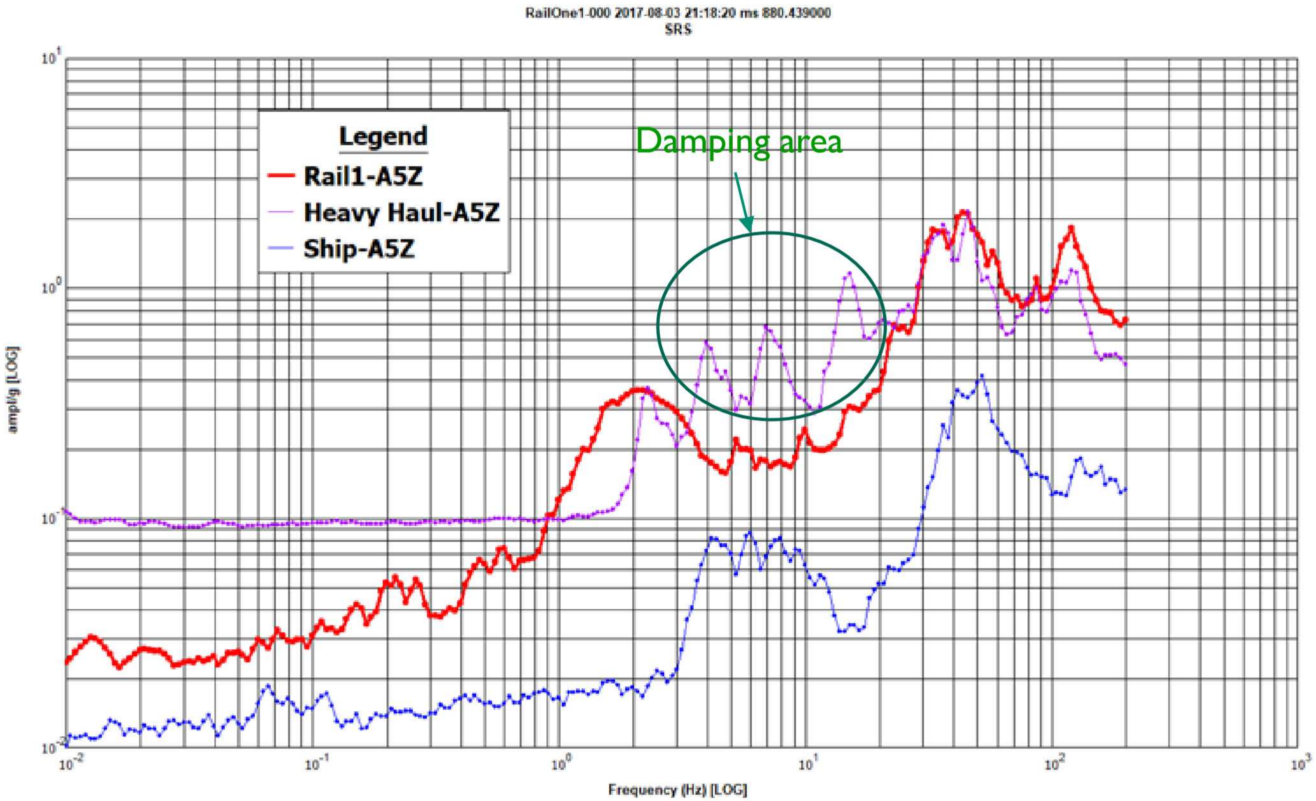
Damping Ratio Comparison





- 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

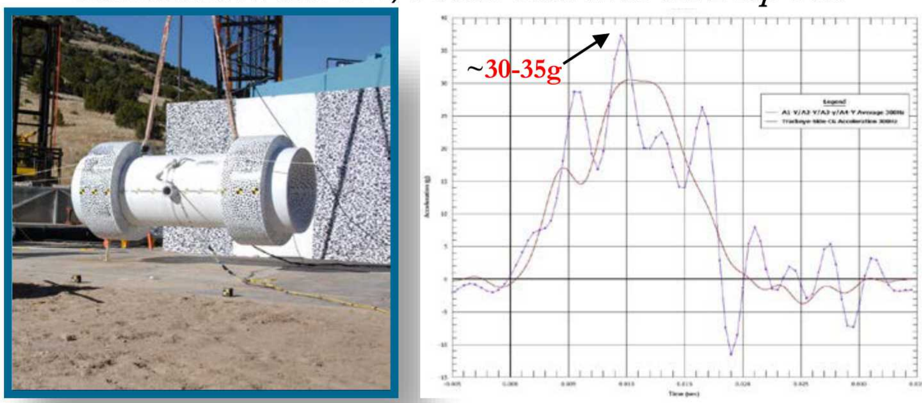
December 2018, BAM Indoor Test Facility, Berlin

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)

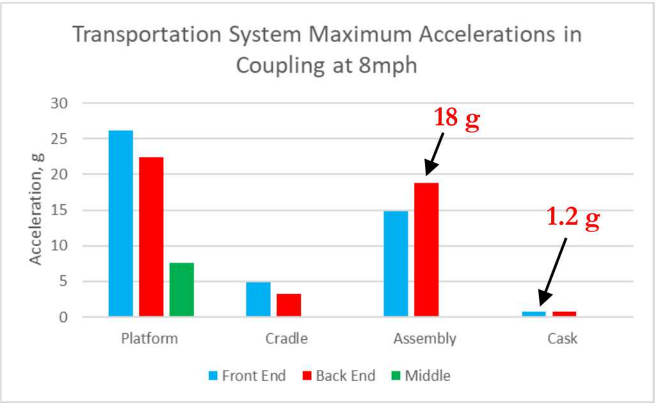
Acceleration Pulse on 1/3 Scale Cask in 30 cm Drop Test

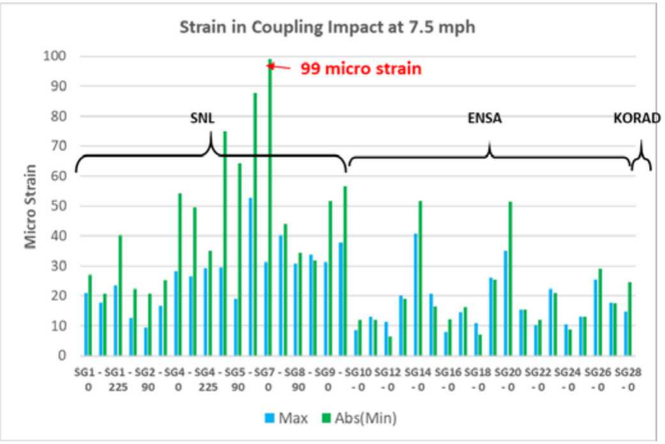


GOALS

- 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

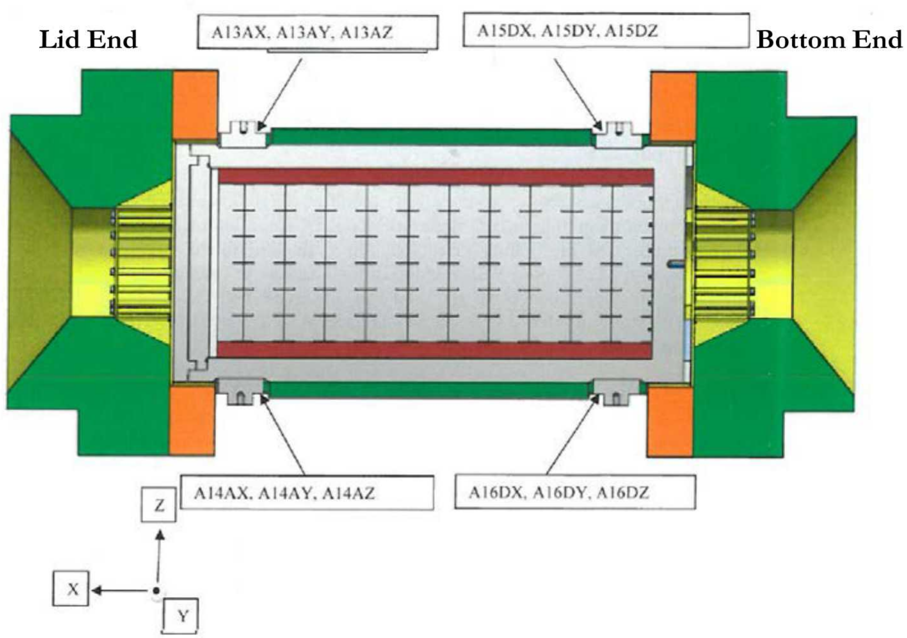
Maximum Accelerations and Strains Measured in Multi-Modal Transportation test (MMTT)

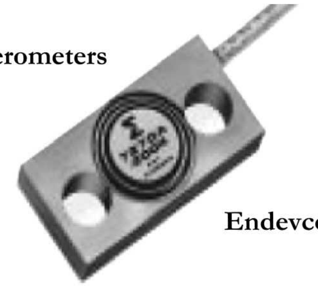




Cask Instrumentation

Accelerometer Locations





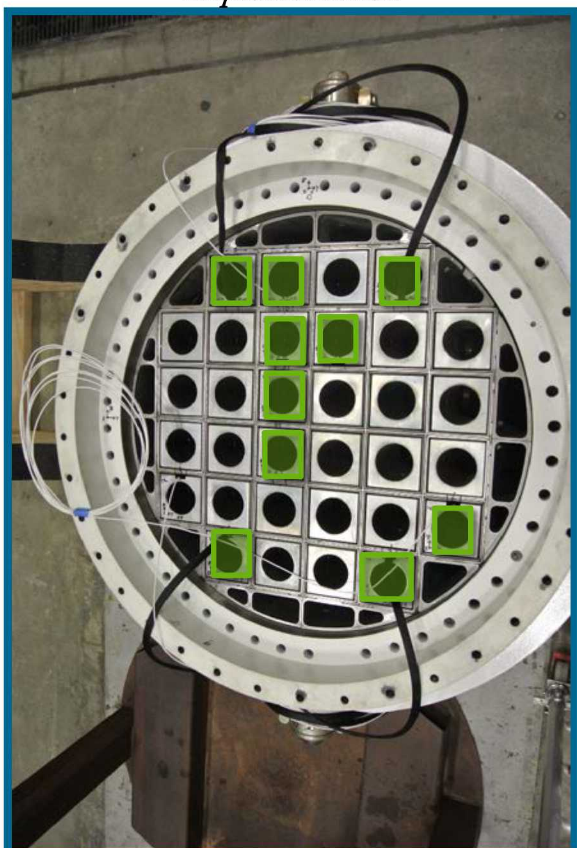
INSTRUMENTATION

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

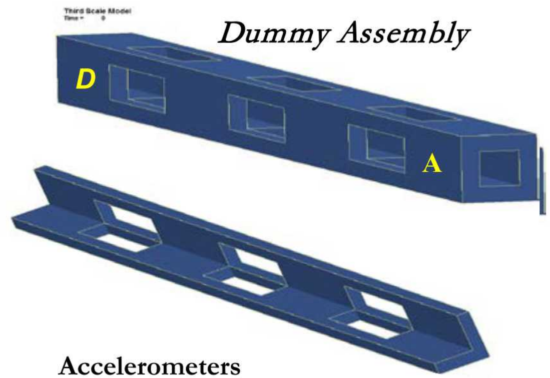
Cask Instrumentation was the same as in 2010 series of tests

Dummy Assembly & Basket Instrumentation

Implementation



Dummy Assembly

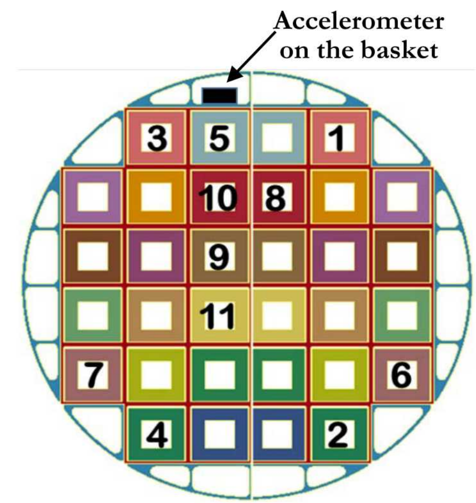


Accelerometers

Endevco Model 727-2K

Endevco Model 7265A

Instrumented Assembly Locations

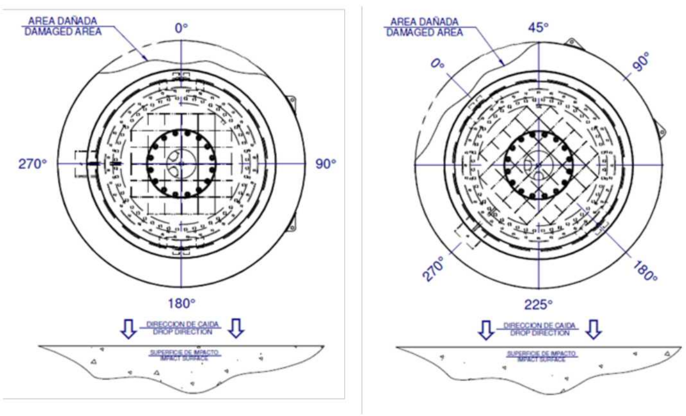


INSTRUMENTATION

- **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**

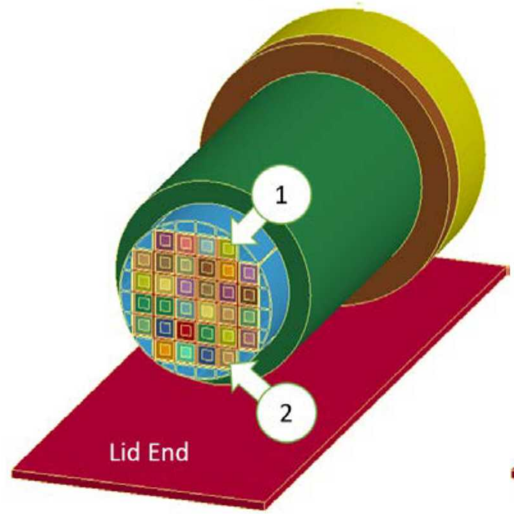
Test Configurations

Impact Limiter Configurations in Two Drop Tests



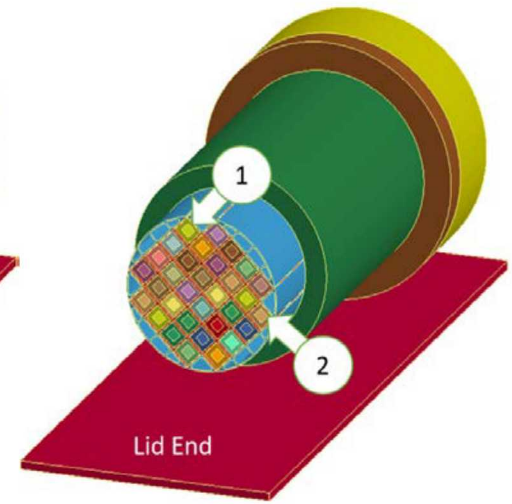
The purpose of Drop Test 2 is to quantify the variation of fuel assembly impact response due to a change in basket orientation.

Drop Orientation 1
Baseplate End



Normal Position

Drop Orientation 2
Baseplate End



45° Degree Axial Rotation

We Dropped It!

Time History of Vertical Accelerations on Cask Filtered to 300 Hz

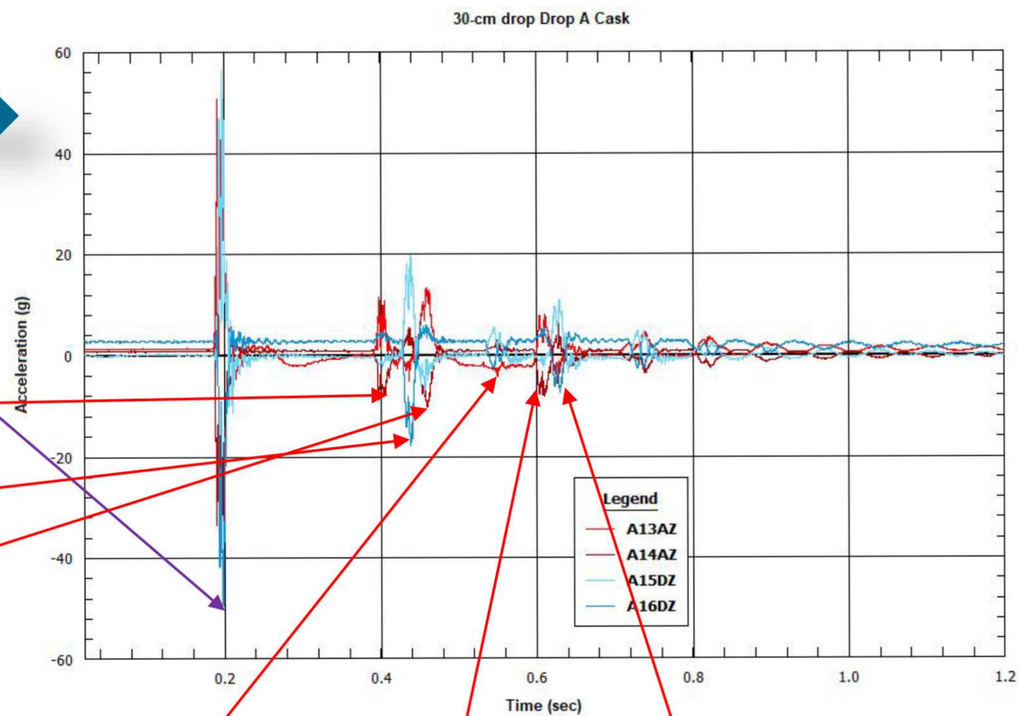
Seven impacts as seen in the video

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

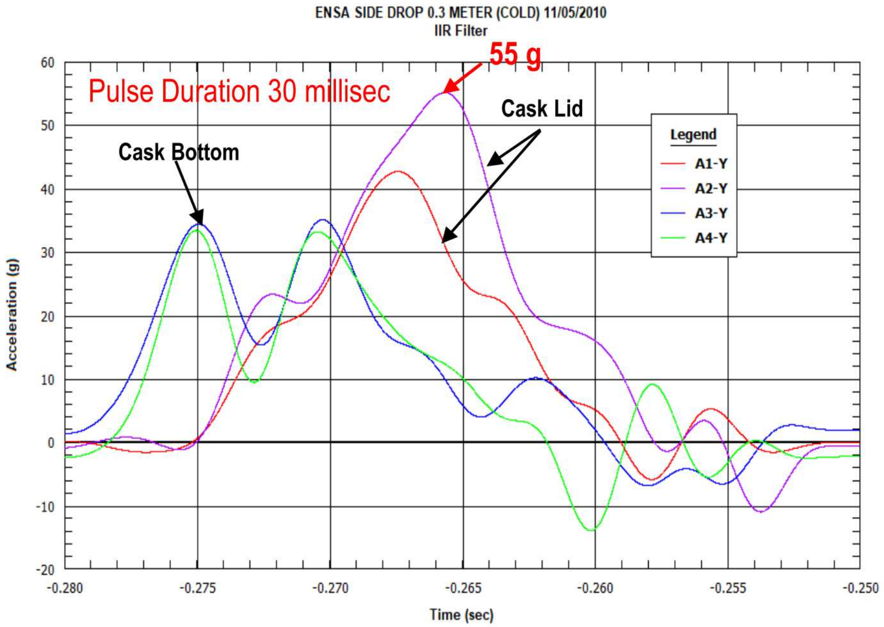
6th Impact: Front end

7th Impact: Back end

Vertical Accelerations on Cask in 2010 & 2018 Tests

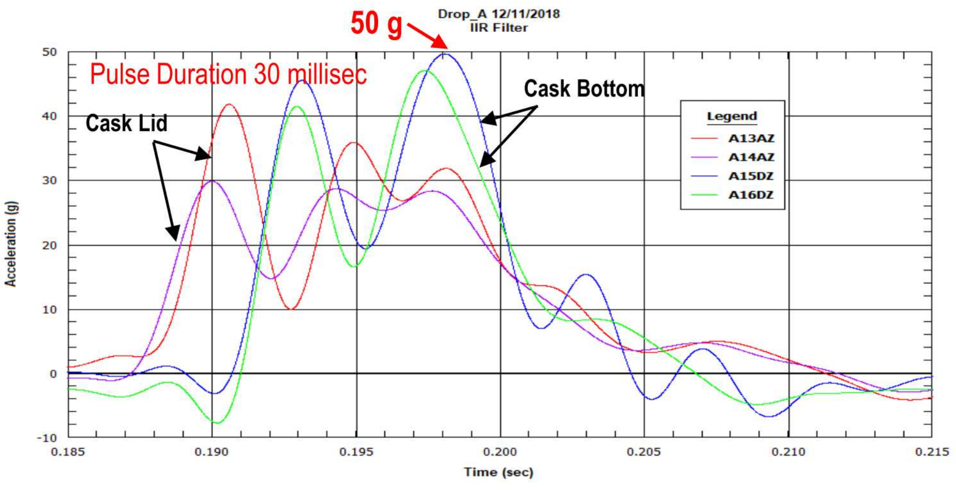
2010 Test

First Impact Time History Filtered to 300 Hz



2018 Test

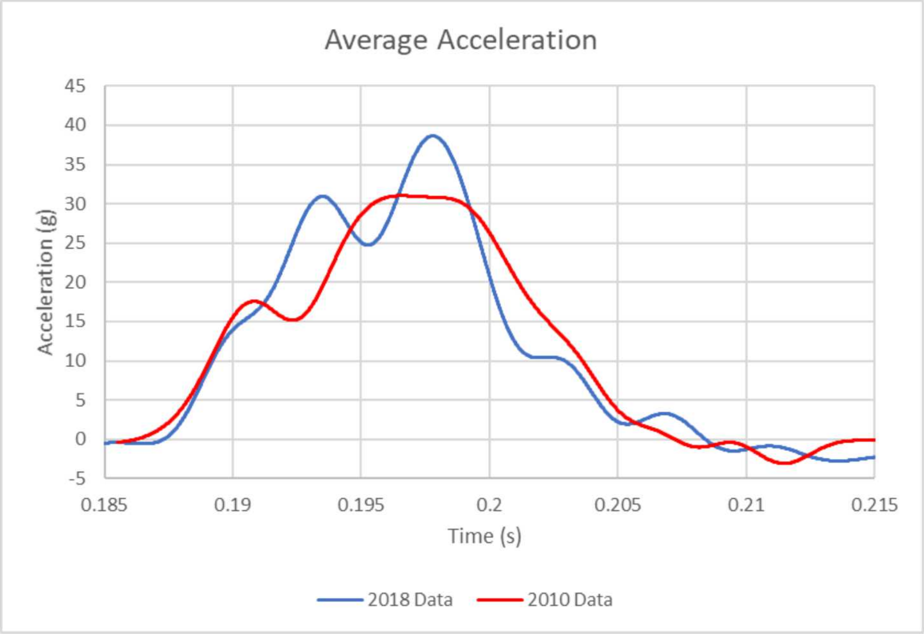
First Impact Time History Filtered to 300 Hz



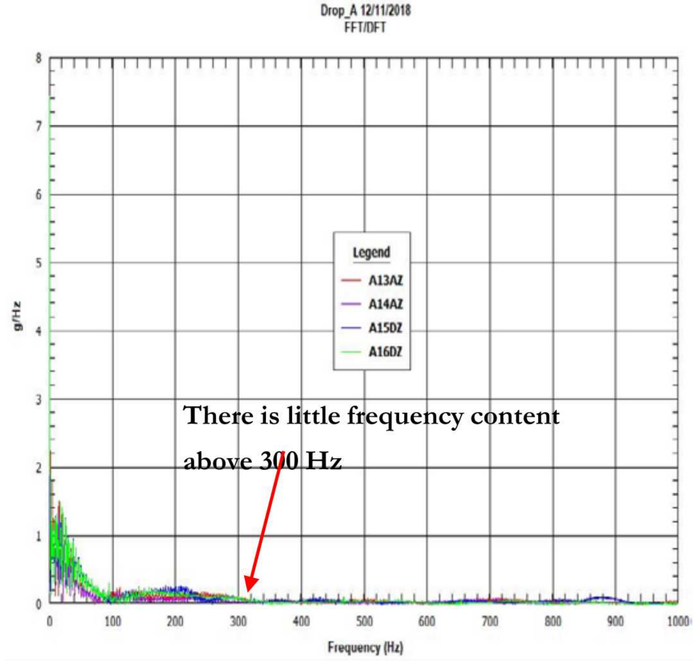
- ***Some differences are due to the fact that the drops are never perfectly horizontal.***

Averaged Vertical Acceleration on Cask in 2010 & 2018 Tests

Averaged Time History Filtered to 300 Hz

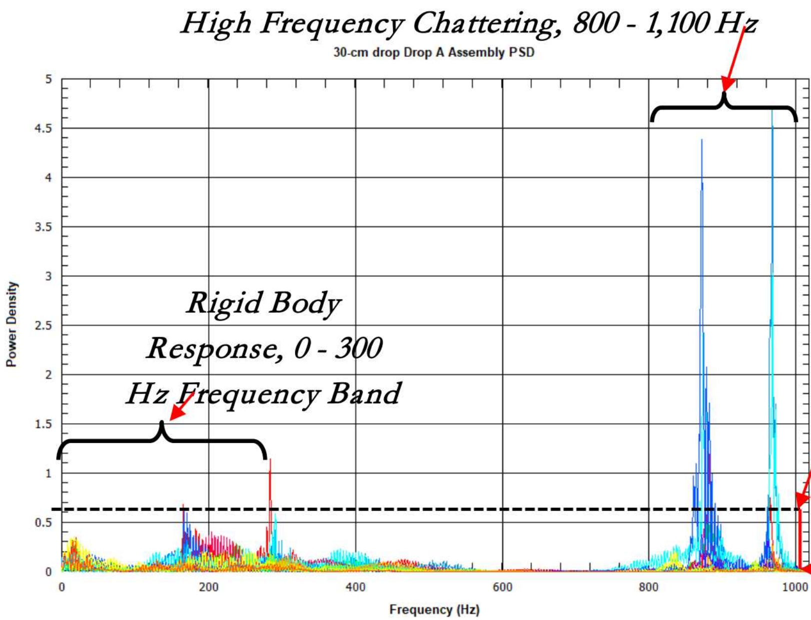


FFT of Cask Acceleration Time Histories (2018 Test)

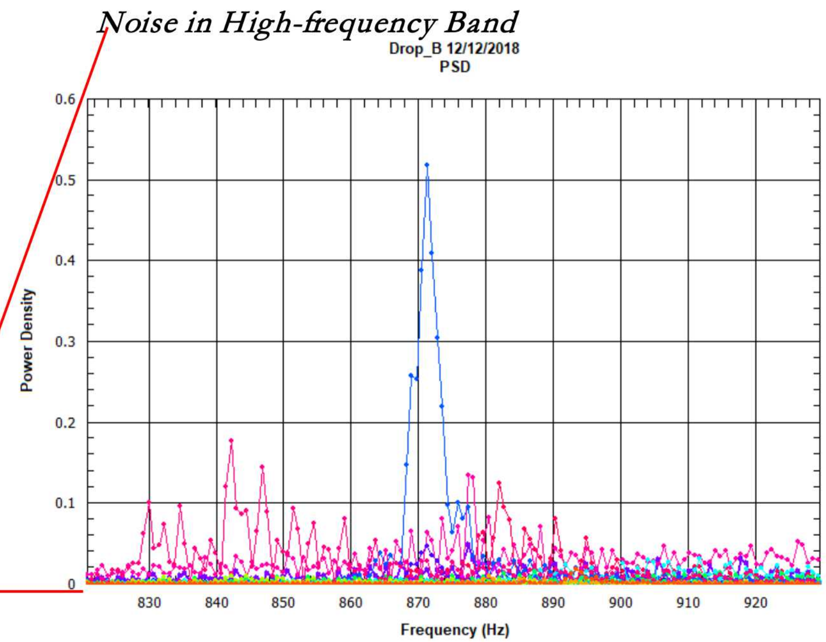


➢ *The cask accelerations measured in 2018 are very similar to the ones measured in 2010.*

Dummy Assembly Frequency Content During 1st Impact



1st Drop

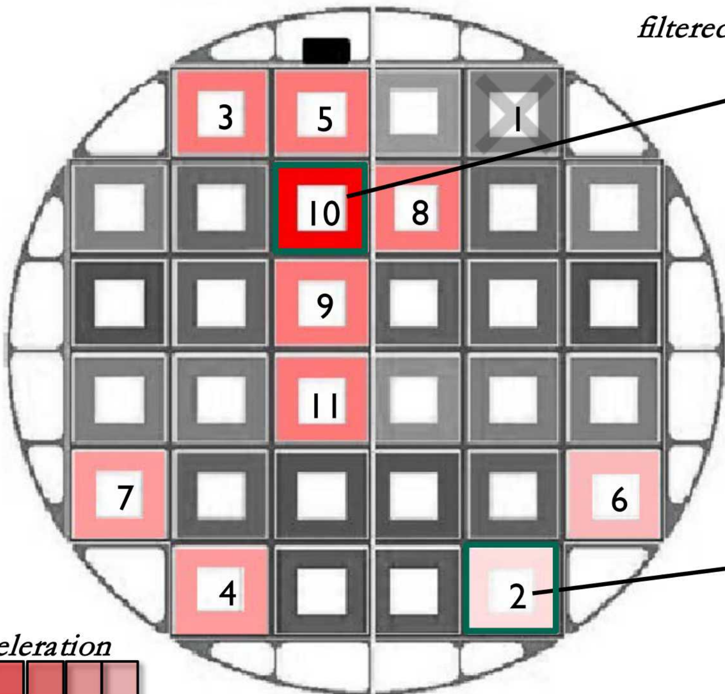


2nd Drop with 45° Degree Axial Rotation

- *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

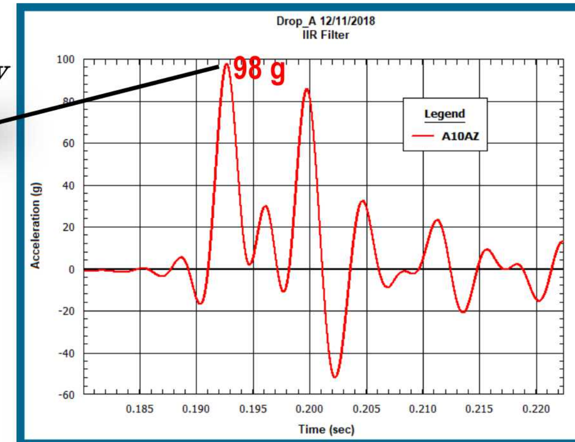
Acceleration Color Map

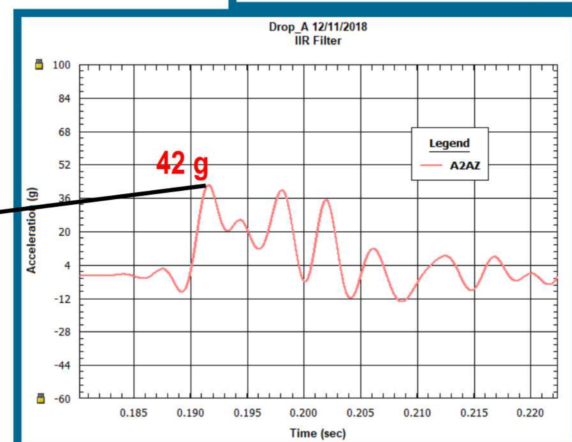


Acceleration

Increasing Acceleration

Assembly #10 time history filtered to 300 Hz

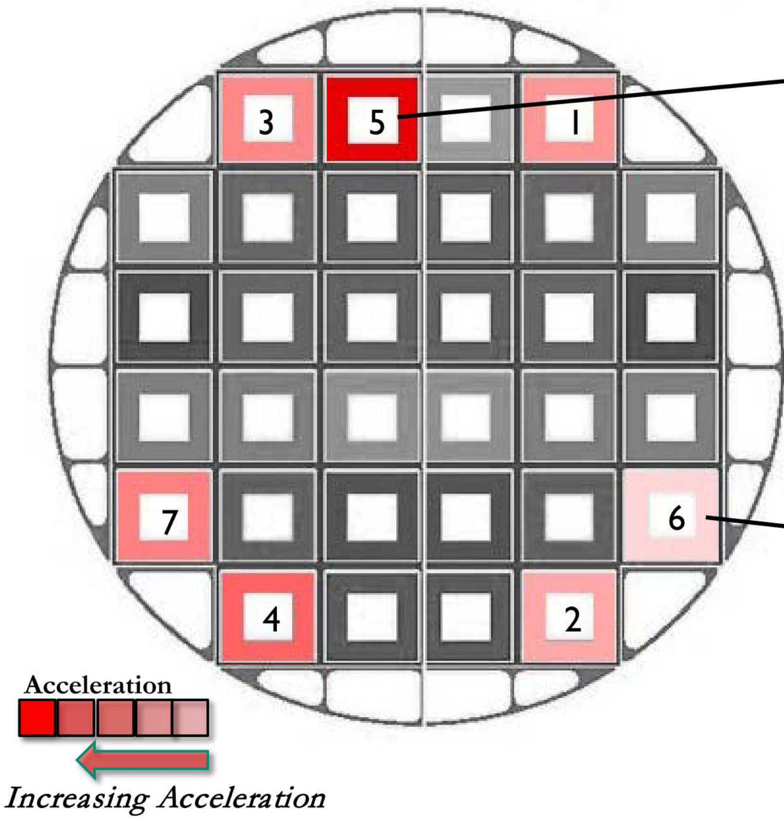




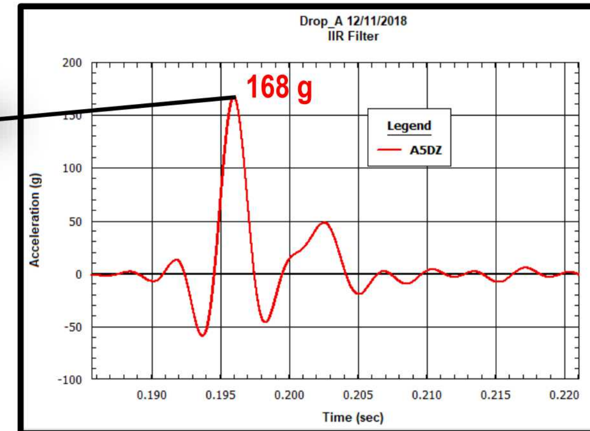
Assembly #2 time history filtered to 300 Hz

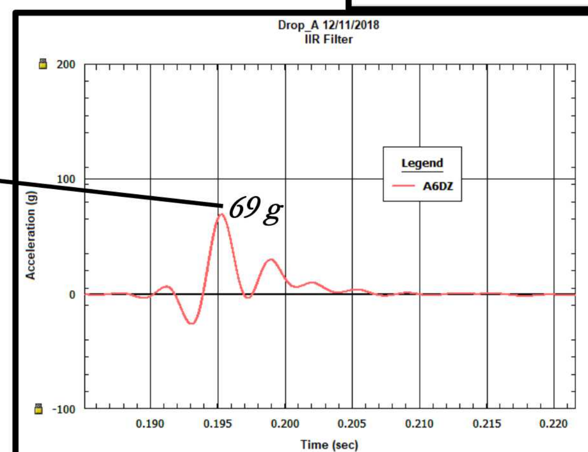
Side D *(Bottom)* Maximum Accelerations on Instrumented Assemblies

Acceleration Color Map



Assembly #5 time history filtered to 300 Hz

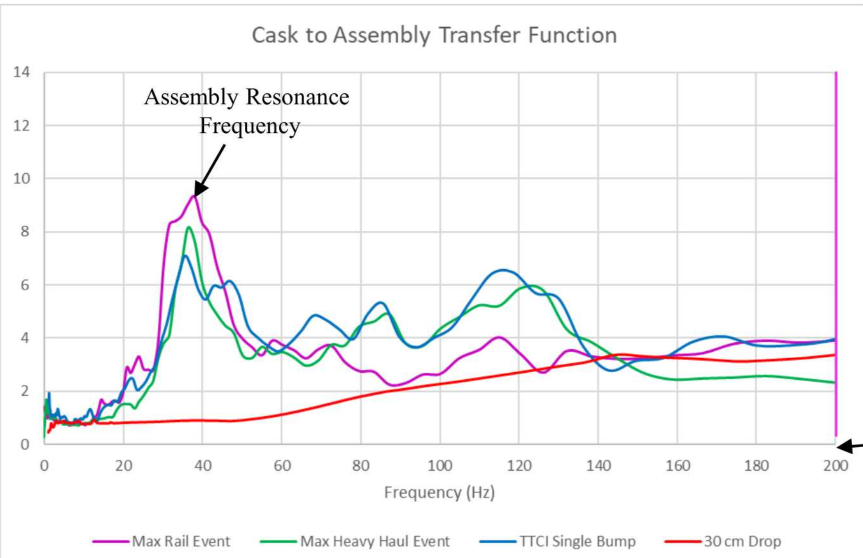




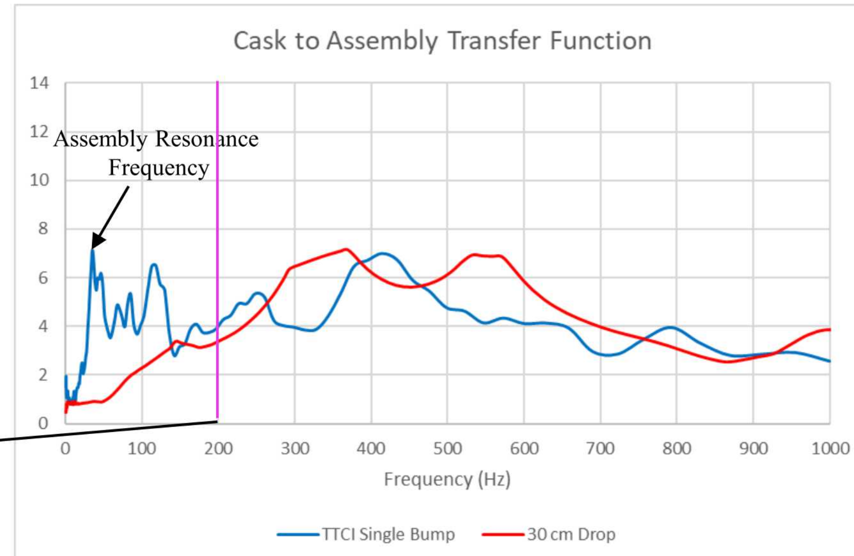
Assembly #6 time history filtered to 300 Hz

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.*

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).*

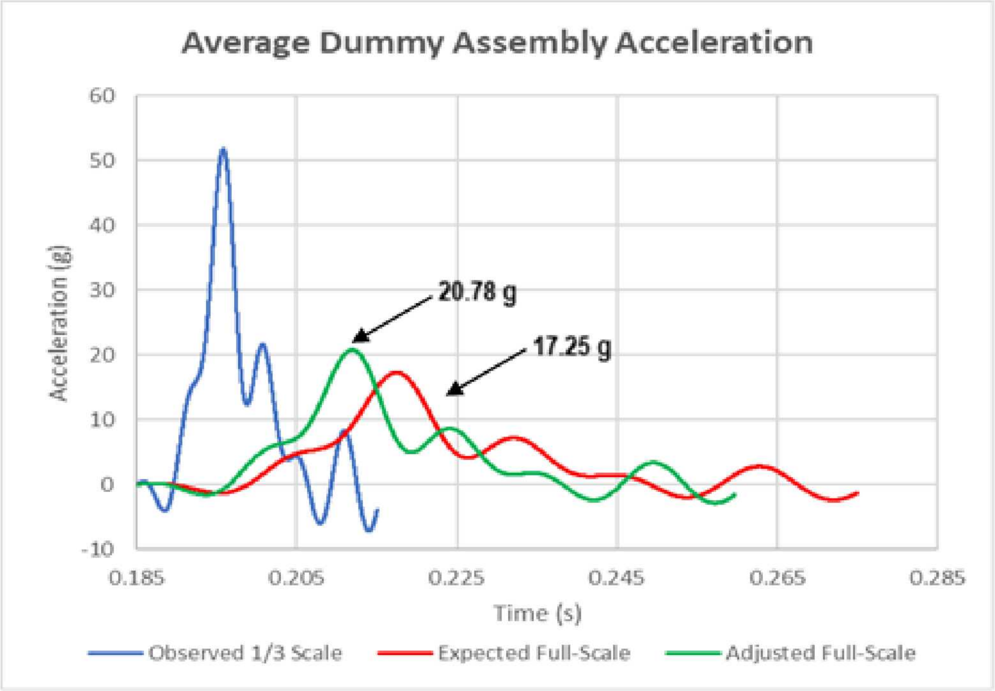
The major inputs from the 1/3 scale cask drop are:

- ❑ 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

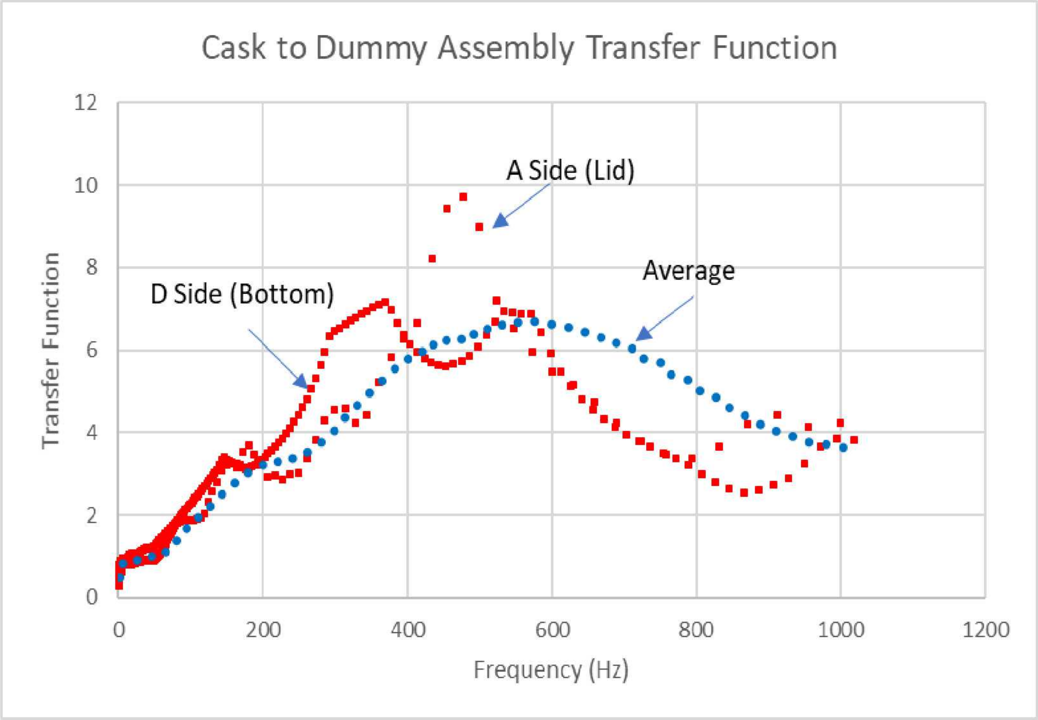
Inputs into 30 cm Drop Test



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

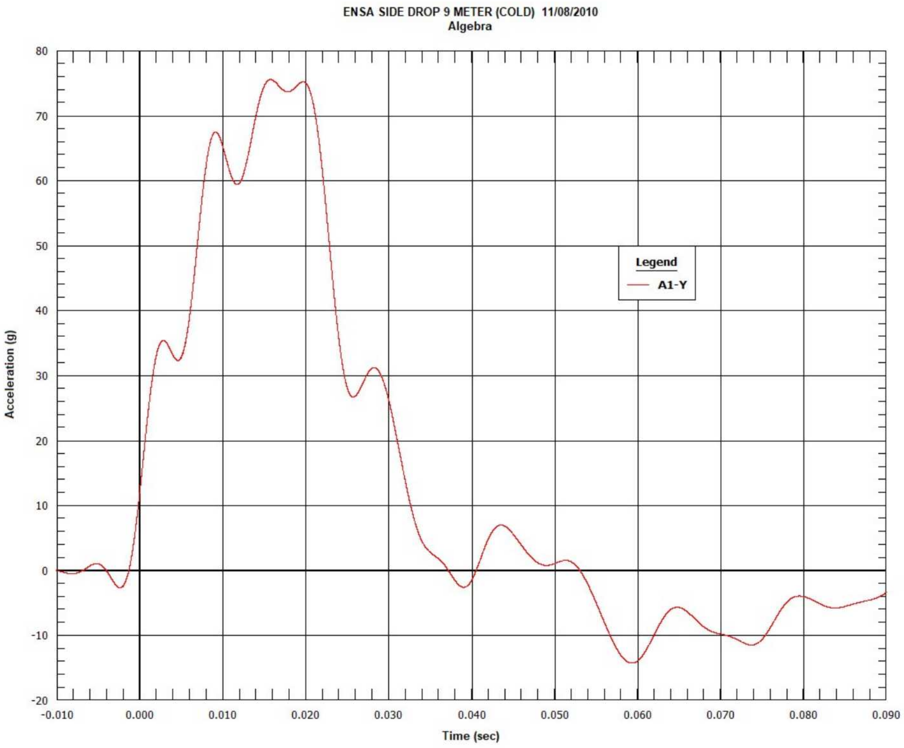
- The average acceleration on the scaled dummy assembly was decreased and the time was increased proportionally to the scale (factor of 3).
- Because the scaling effect may result in underestimating accelerations, the expected accelerations and time were adjusted by 17%.
- Target acceleration in 30 cm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

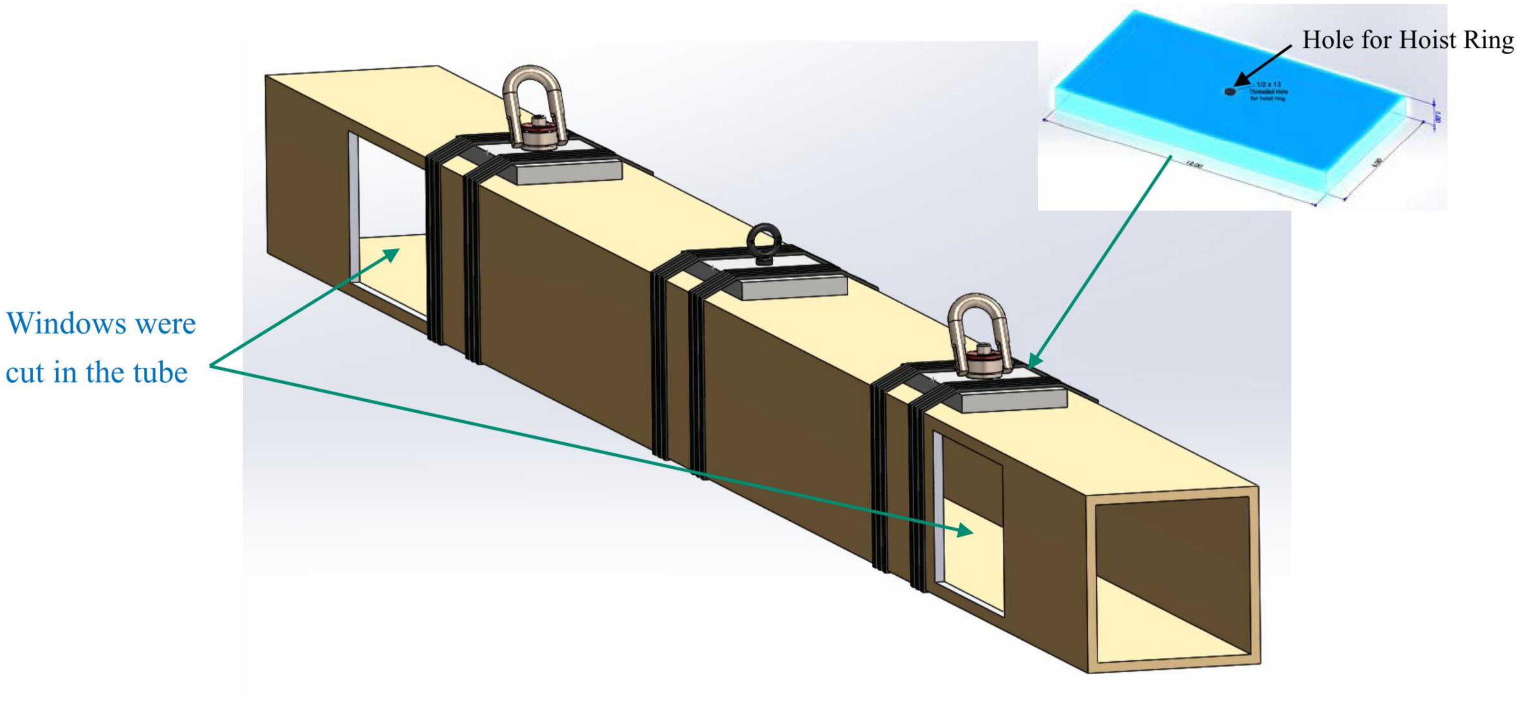
PNNL Finite-Element Model

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

Basket Tube

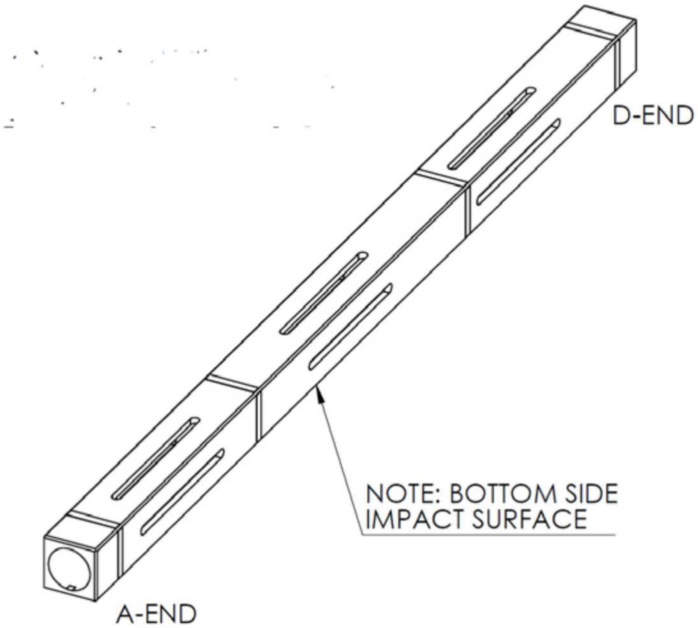
- The full-scale assemblies (dummy and surrogate) will be dropped in the actual 17x17 PWR assembly basket tube.
- It is made of matrix of 'pure' aluminum material with boron carbide insertions
- This is the same basket tube as the ones in the MMTT test.

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.

Installation of Pressure paper

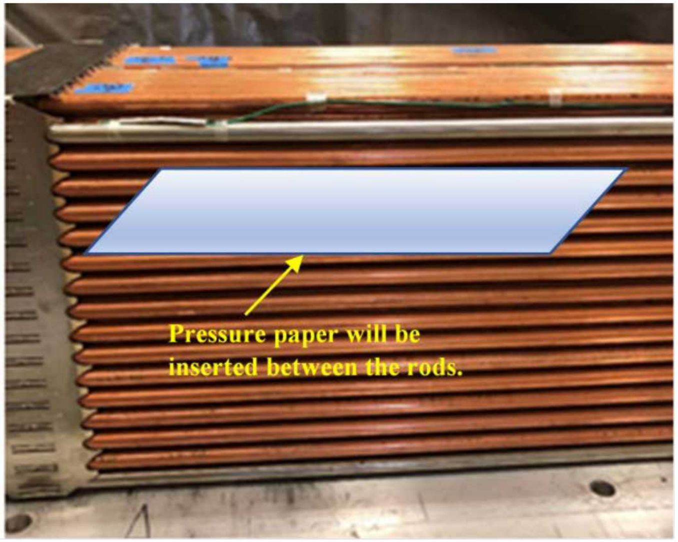
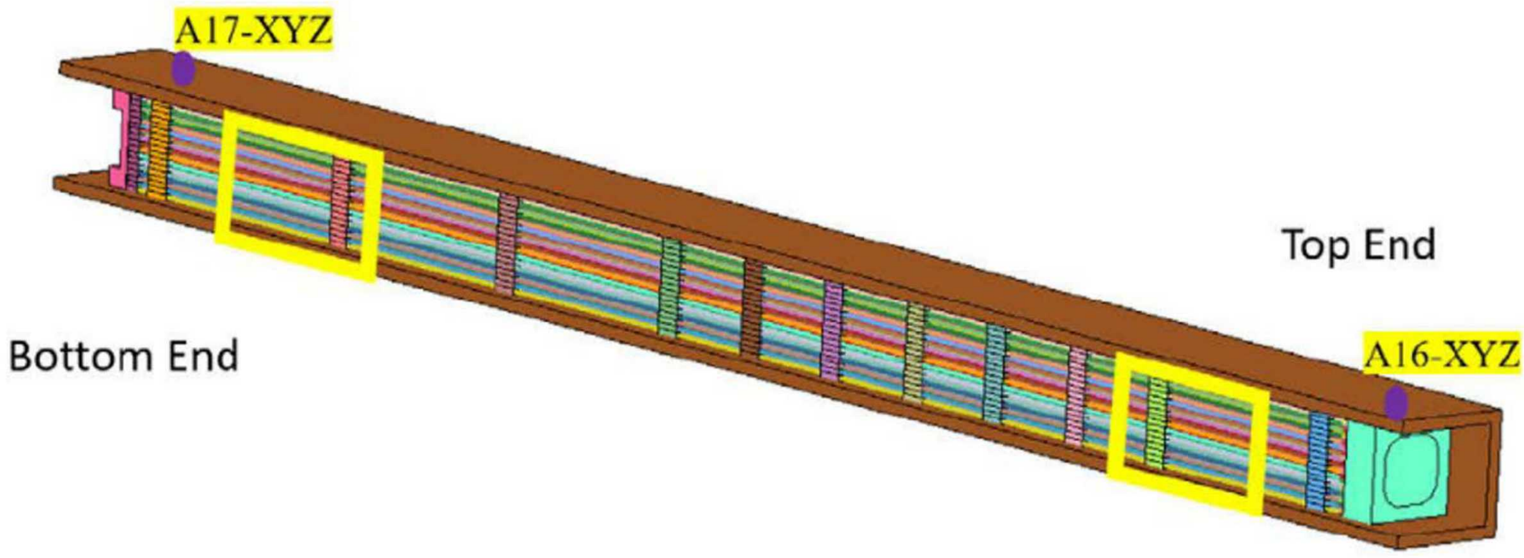


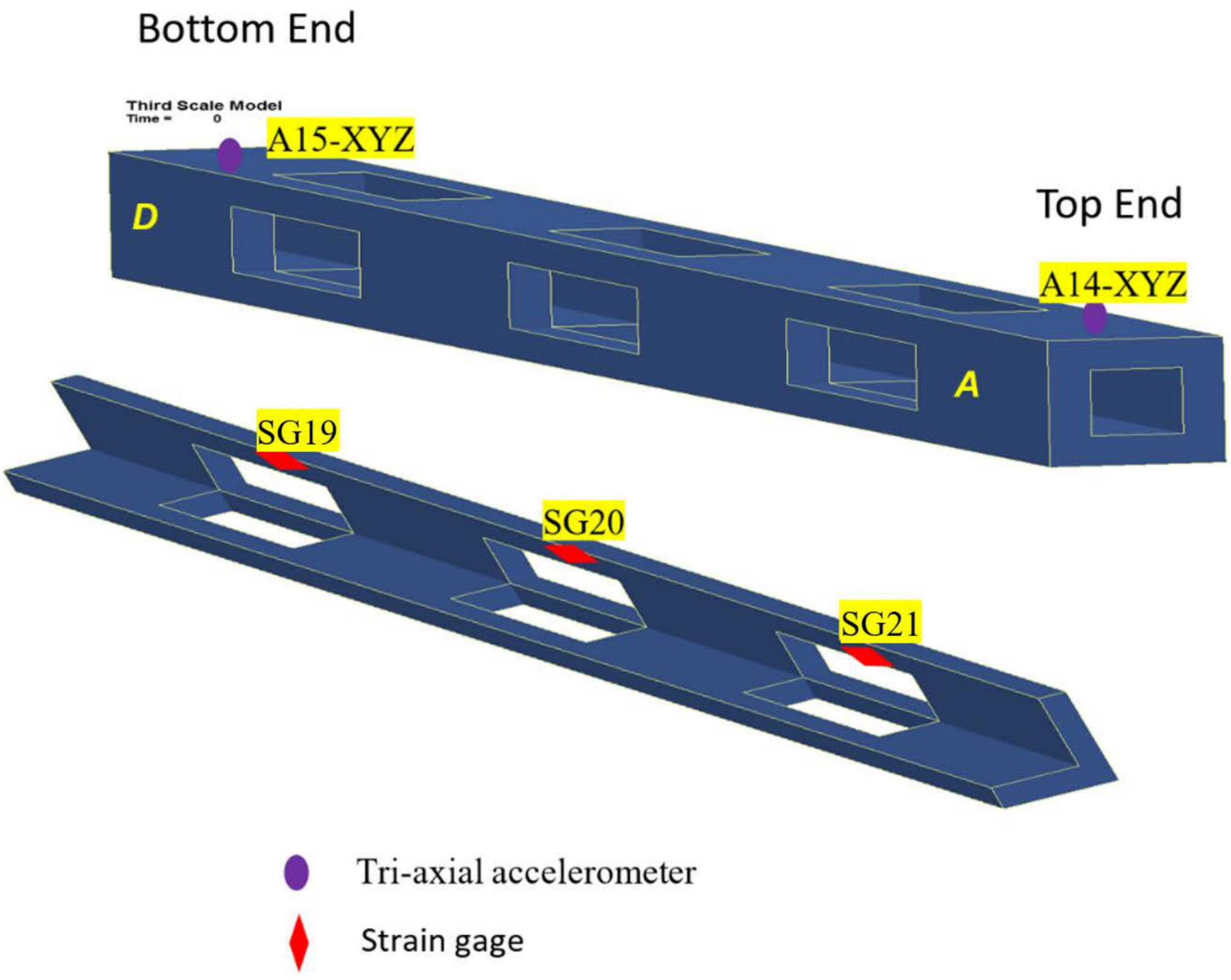
Table 1: Fujifilm Prescale® Specifications		
Film Type	**Roll Dimensions**	**Pressure Range**
Extreme Low (LLLLW/4LW)	9.8 ft × 12.2in (3 m × 310mm)	7.2–28 psi (0.5–1.97 kg/cm^2)
Ultra Low (LLLW)	16.4 ft × 10.6in (5 m × 270mm)	28–85 psi (2–6 kg/cm^2)
Super Low (LLW)	19.7 ft × 10.6in (6 m × 270mm)	70–350 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.

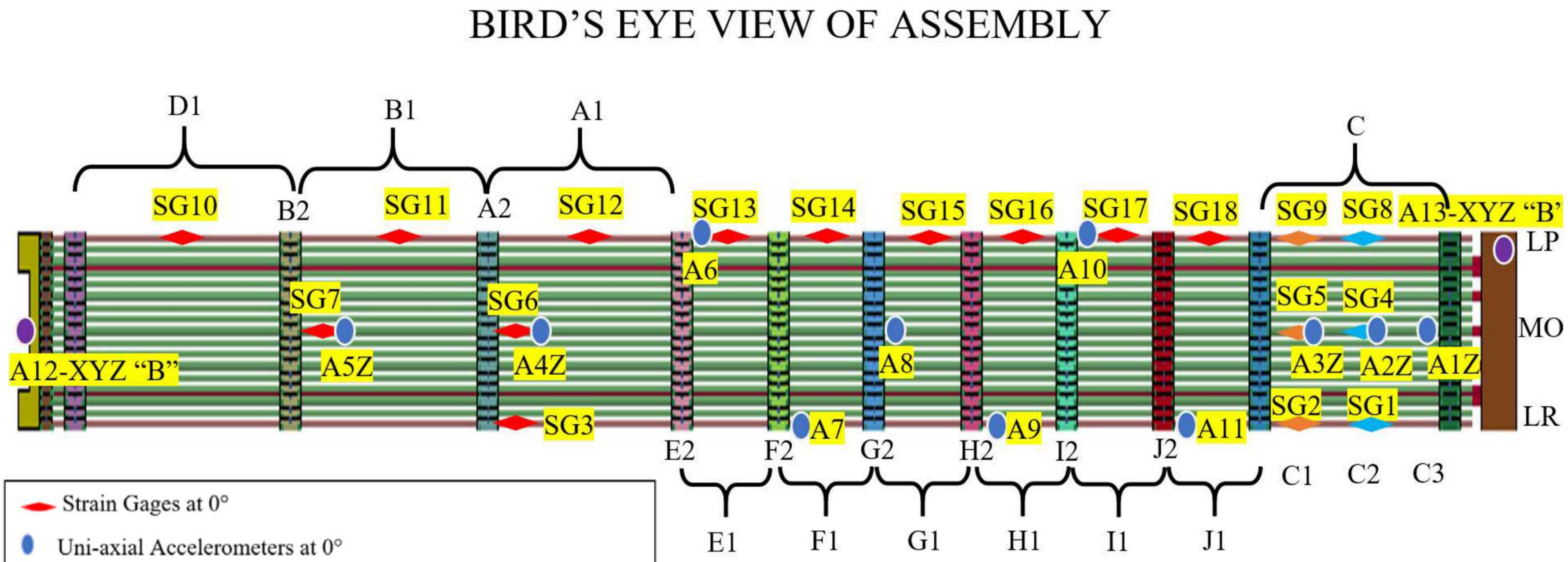
Basket Tube Instrumentation



Dummy Assembly Instrumentation



Surrogate Assembly Instrumentation



- Strain Gages at 0°
- Uni-axial Accelerometers at 0°
- Tri-axial Accelerometers at 0°
- Strain Gages at 0°and 90°
- Strain Gages at 0°, 90°, and 225°

Figure is Bird's eye view of assembly.

Unless otherwise stated, elements are at top of assembly, which is the surface shown in diagram

Labels with a "B" are at the vertical bottom of assembly

LP – Lead Pellets

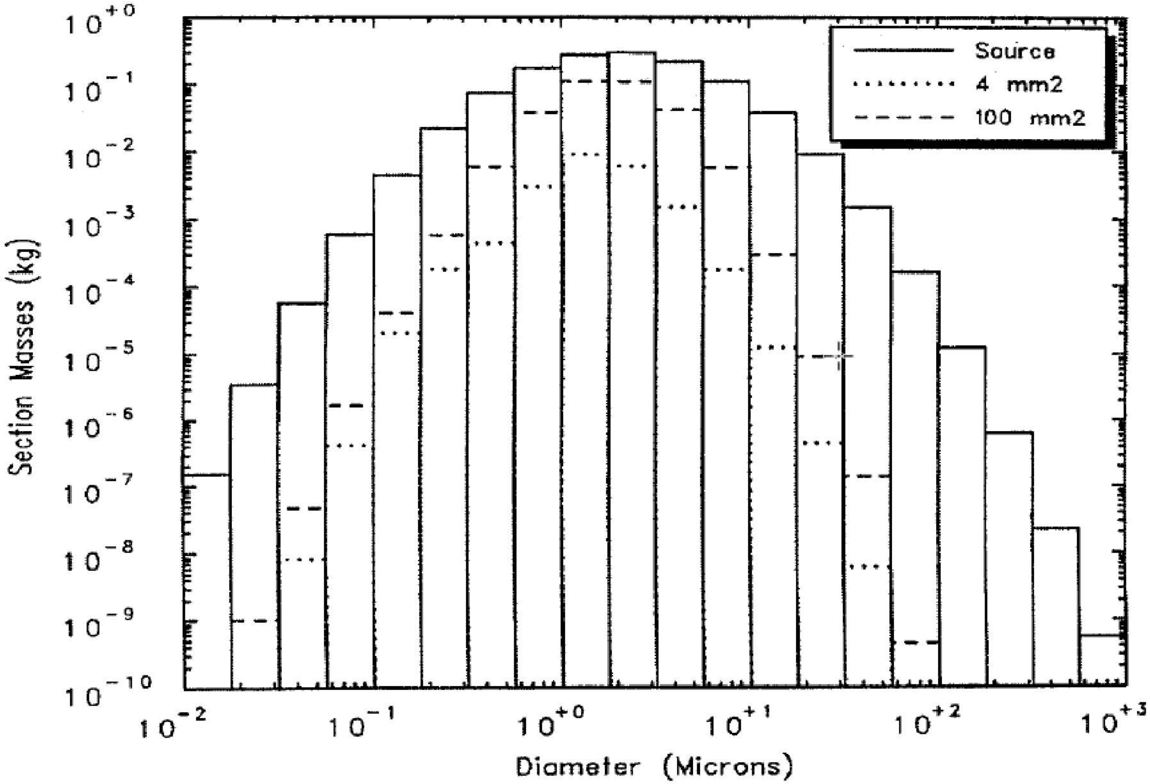
MO – Molg

LR – Lead Rope

Release Fraction Discussion

This is what we have on particle size distribution

Particle size distribution: release from failed fuel to cask

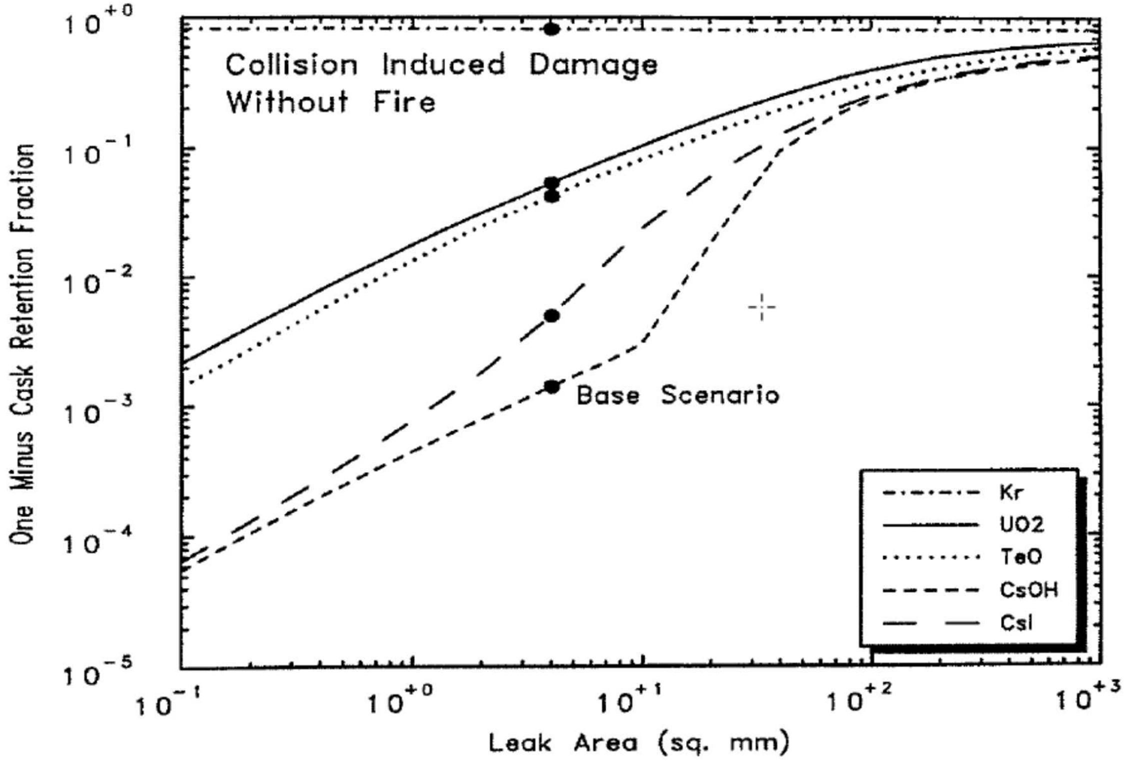


- These data are from NUREG/CR-6672, *Reexamination of Spent Fuel Shipment Risk Estimates* 2000 (Figure 7.10).
- The experiments addressing release through the CICC cracks are on the way.
- There is no data for accident conditions.

Leakage from the Cask

This is what we have on leakage from a cask

Leakage in a Cask at 5 atm Pressure



- These data are from NUREG/CR-6672, Figure 7.11.
- The source is SAND98-1171/2.

Cask-to-Environment Release Fractions

This is what we have on releases from a cask

Parameter	(NRC NUREG-1536, Rev. 1, 2010)	(NRC NUREG-2125, 2014)	(NRC NUREG/CR-6672, 2000)
Cask-to-Environment Release Fraction (Gases)	-	0.8	-
Cask-to-Environment Release Fraction (Volatiles)	-	0.45	8E-4 (CsI vapor) (0.01 cm^2 leak area)
Cask-to-Environment Release Fraction (Fines/ Particles)	-	0.64	0.02 (0.01 cm^2 leak area)
Cask-to-Environment Release Fraction (Crud)	-	0.001	-

- NUREG-2125 identifies NUREG/CR-6672 as the source for release fractions used (with the exception of crud).
- The values in the table are for a corner impact with a leak area of about 600 mm^2.

Effects from Strong Earthquakes

- ❑ We don’t have data for the seismic response of the fuel to strong earthquakes.
- ❑ This can be addressed via a series of shaker table tests.