SAND2019-8493C

Shock Environments for the Nuclear Fuel Transportation System (Transportation Platform, Cask, Basket, and Surrogate Assemblies) during Heavy-Haul Transport and Handling

Elena Kalinina, Catherine Wright, Lucas Lujan, & Sylvia Saltzstein

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PRESENTED BY

Catherine Wright

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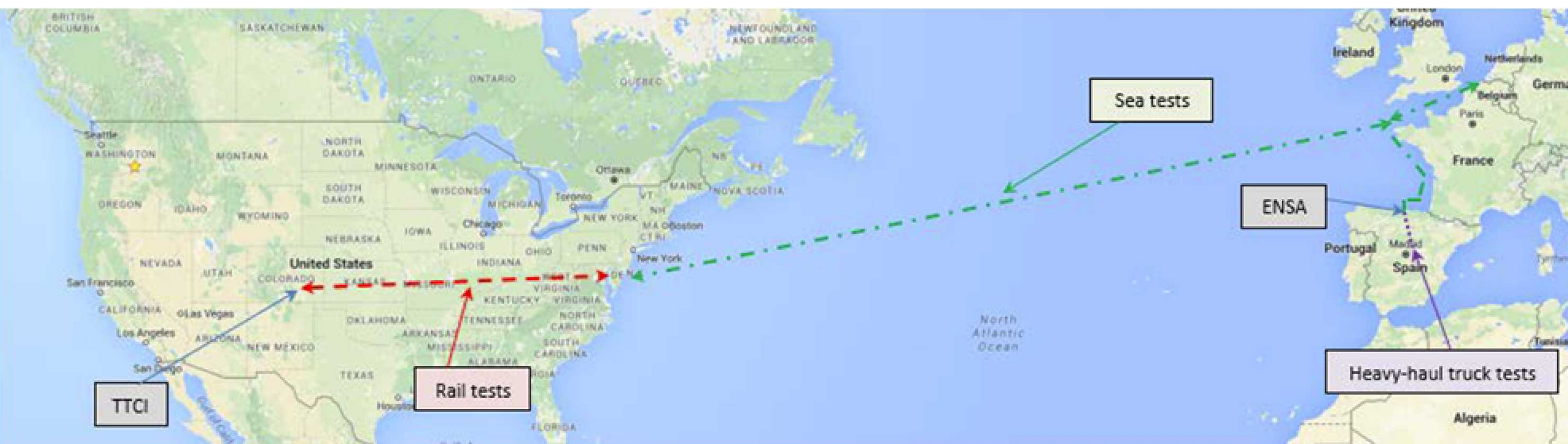
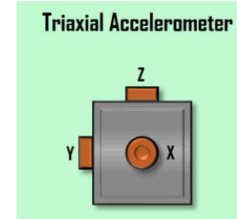
Transportation Test Route *(Transportation Triathlon)*

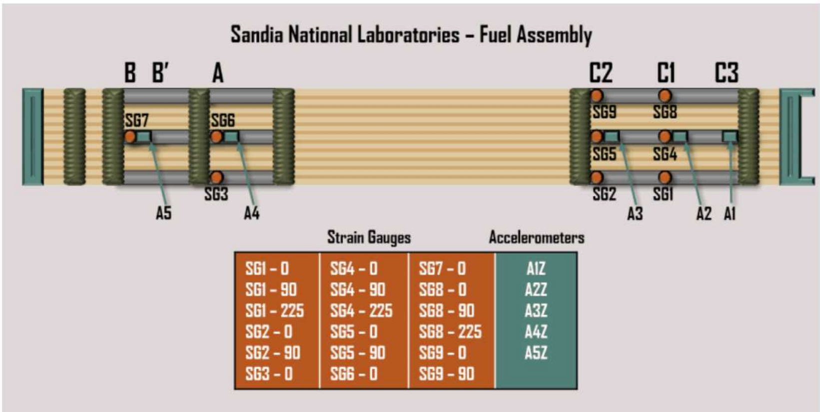
- 54 days of data collection
- 6 terabytes of data
- 4 modes of transportation
- 9,458 miles
- 7 countries
- 12 states



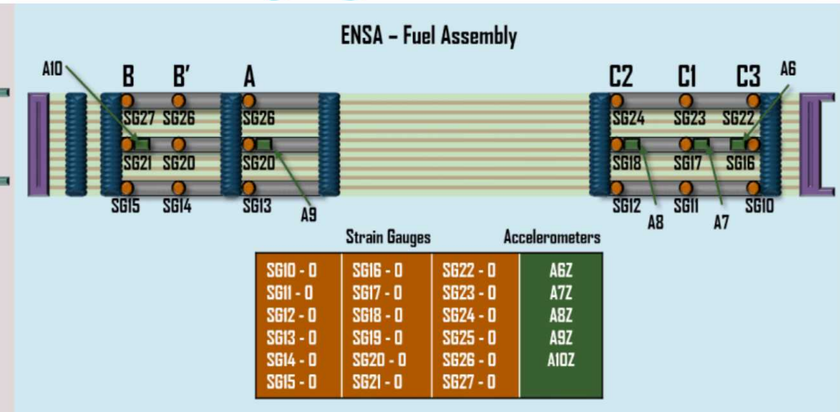
Transportation System Instrumentation



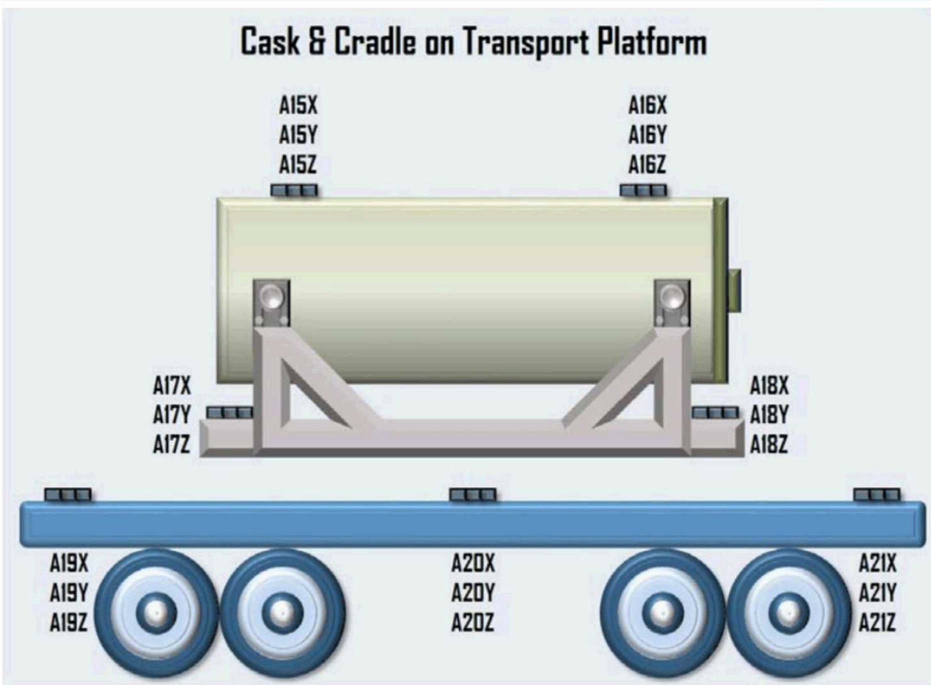
40 accelerometers and 37 strain gauges

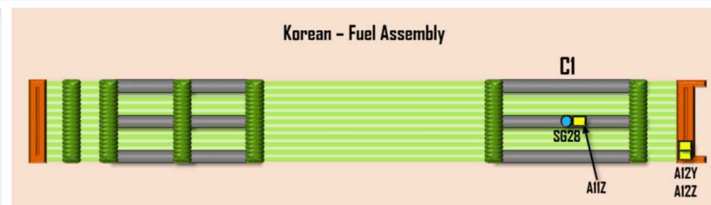


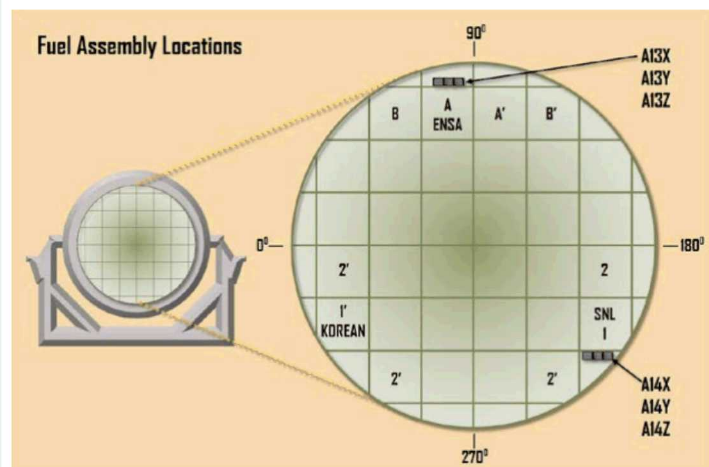
Strain Gauges			Accelerometers
SG1 - 0	SG4 - 0	SG7 - 0	A1Z
SG1 - 90	SG4 - 90	SG8 - 0	A2Z
SG1 - 225	SG4 - 225	SG8 - 90	A3Z
SG2 - 0	SG5 - 0	SG8 - 225	A4Z
SG2 - 90	SG5 - 90	SG9 - 0	A5Z
SG3 - 0	SG6 - 0	SG9 - 90	



Strain Gauges			Accelerometers
SG10 - 0	SG16 - 0	SG22 - 0	A6Z
SG11 - 0	SG17 - 0	SG23 - 0	A7Z
SG12 - 0	SG18 - 0	SG24 - 0	A8Z
SG13 - 0	SG19 - 0	SG25 - 0	A9Z
SG14 - 0	SG20 - 0	SG26 - 0	A10Z
SG15 - 0	SG21 - 0	SG27 - 0	

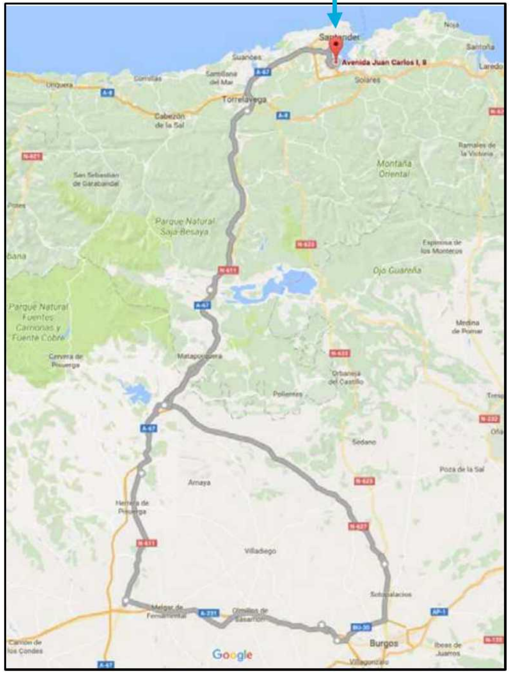






Cask Handling Tests and Heavy-Haul Transport

ENSA facility (Maliaño, Spain)



<u>Dry Storage Cask Handling Tests</u>

- 3 ENSA crane operators
- Lowered onto concrete pad with varying levels of aggressiveness

<u>Heavy-Haul Handling Test</u>

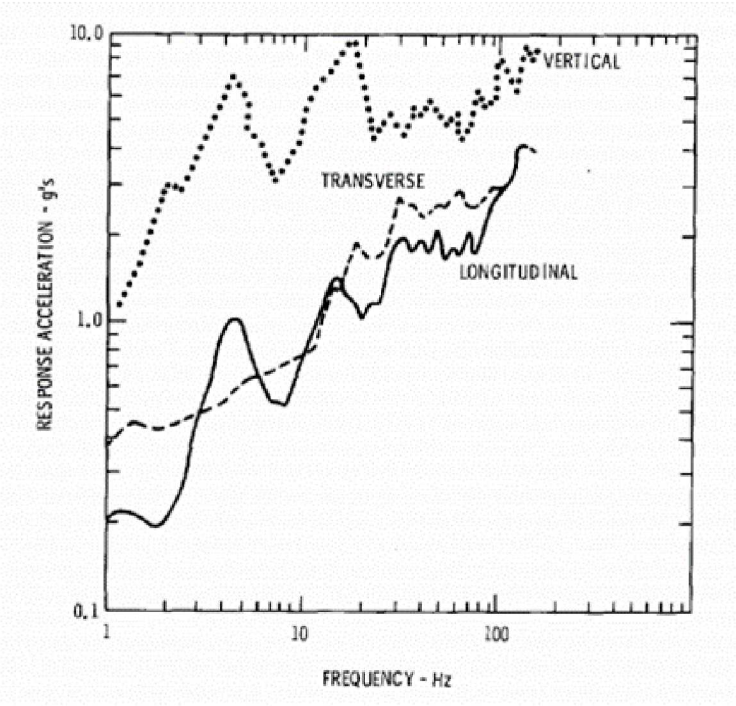
- Cask placed vertically in cradle and lowered to horizontal position for heavy-haul transport

<u>Heavy-Haul Truck Test Route</u>

- 245-mile route
- 13 hours in motion
- 36 shock events

Previous Work

- NUREG 766510 (late 1970's)
- Smaller transportation casks
- Cask interior was not instrumented
- Data collection was not continuous and recorded only some characteristic events

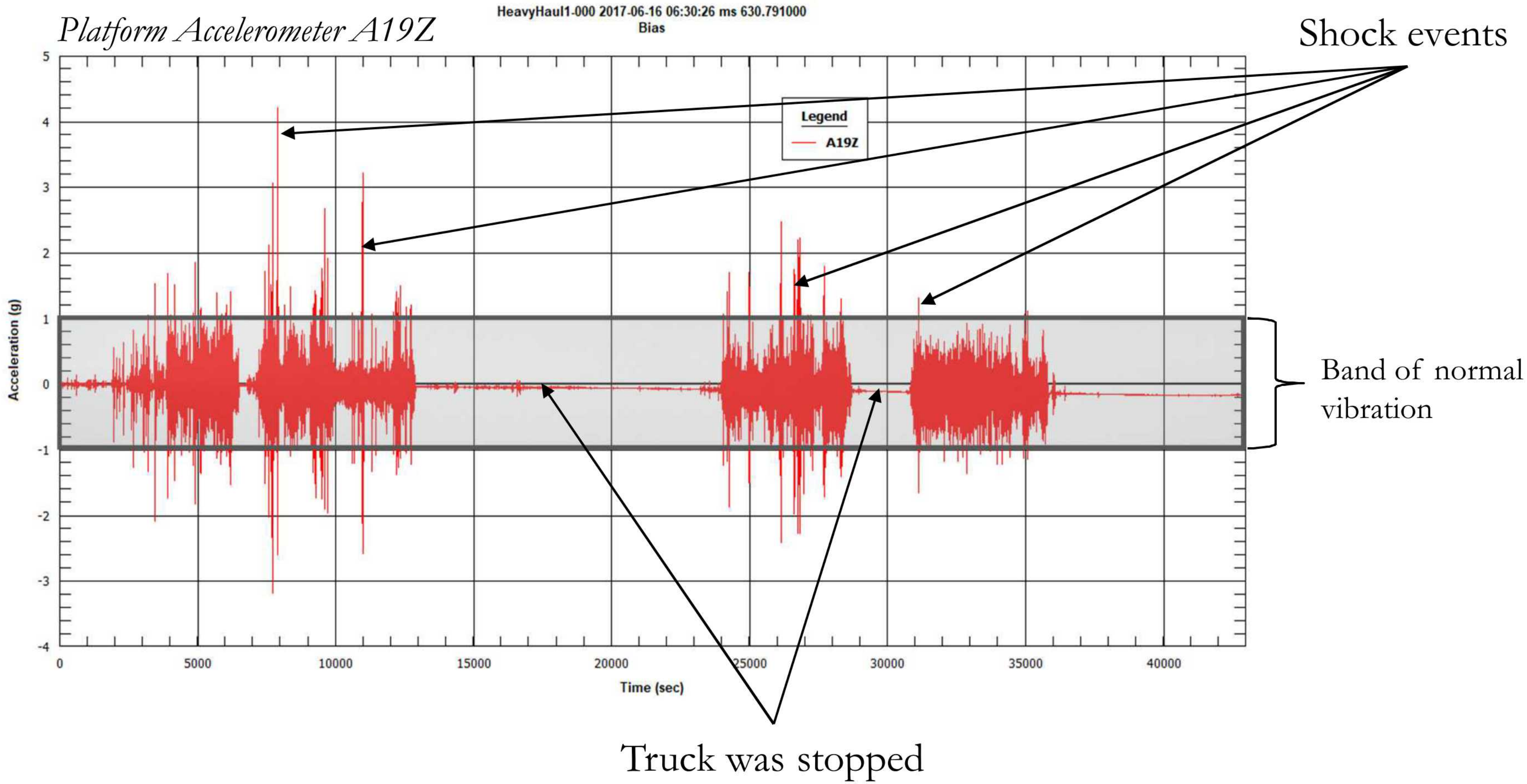


Only the transportation platform and cask were instrumented

Truck Transport Acceleration Shock Response Spectra from NUREG 766510

Shock Event Definition

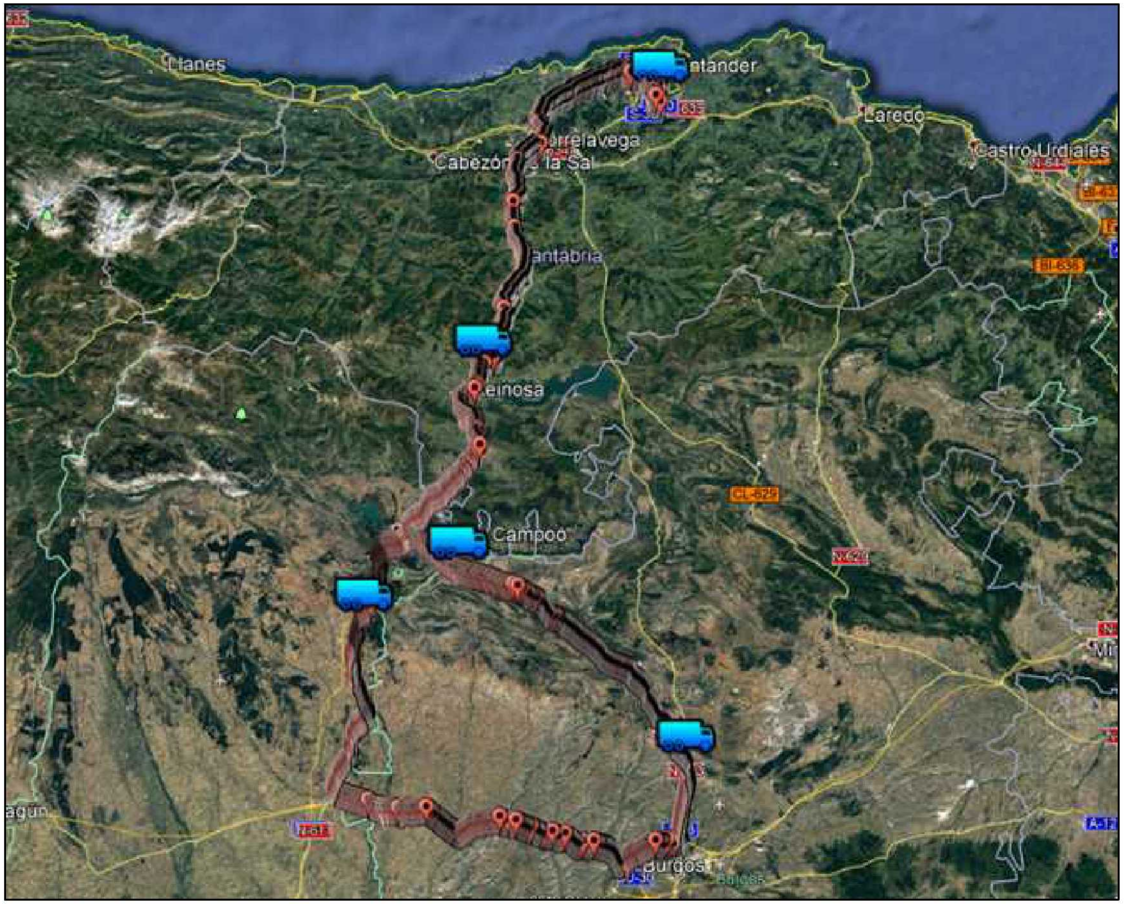
Example of a Time History during Heavy-Haul Transport



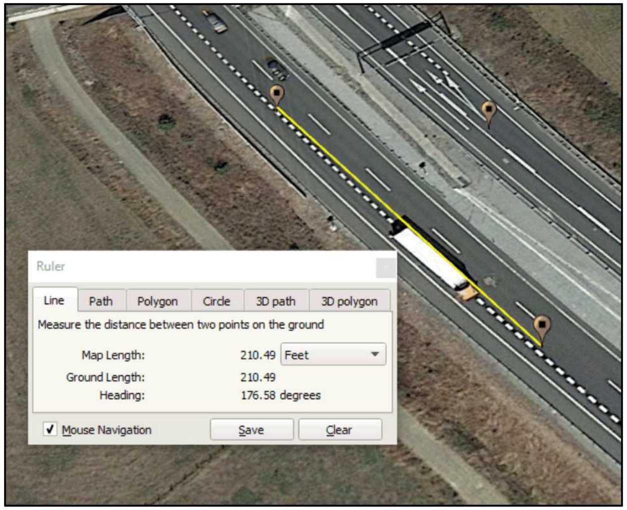
The events with truck platform acceleration equal to or exceeding +/- 1.0 g were classified as shock events.

Heavy-Haul Transport Route

Heavy-haul truck GPS data



 *Location the truck was stopped for a period of time*



Google Earth Ruler tool was used for measuring the ground distance between two points 5 seconds apart.

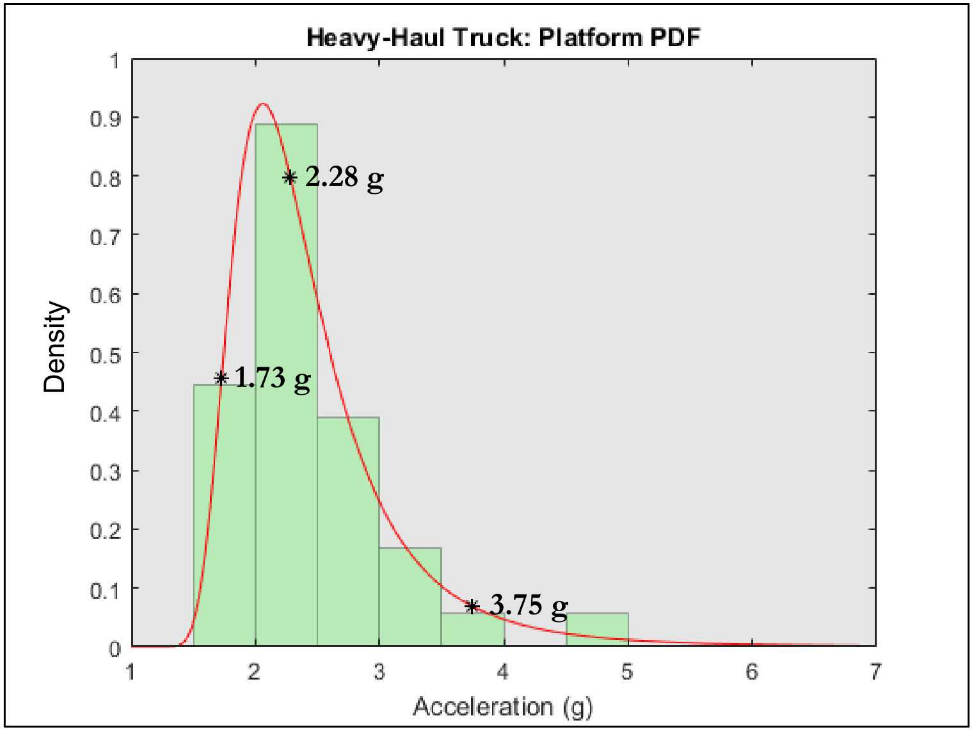
In this example the truck was traveling 29 mph.

Event Analysis

<u>36 shock events</u>

- **28 events** caused by vertical upset
  - Road or bridge abutment
  - Crosswalk
  - Imperfections and uneven road surface
- **4 events** caused by a turn
  - Onto a major road
  - In a roundabout
- **1 event** caused by powerline interference
- **3 events** have undetermined cause
  - Poor image quality
  - Unseen obstruction
  - Overall low acceleration to platform and assembly

Platform Acceleration Histogram and PDF



<u>Fréchet distribution</u>

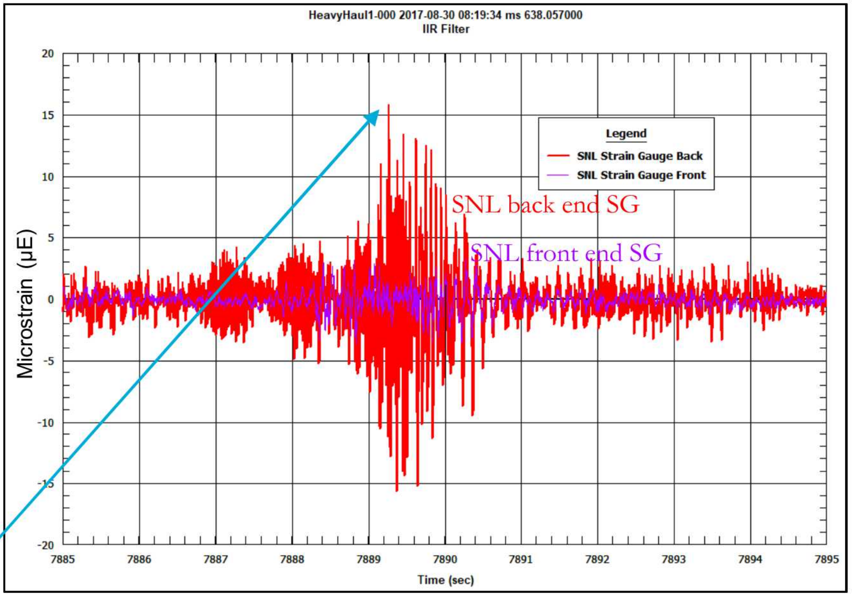
PDF: $f(x;\ \alpha,\sigma,m) = \frac{\alpha}{\sigma}\left(\frac{x-m}{\sigma}\right)^{-1-\alpha} e^{-\left(\frac{x-m}{\sigma}\right)^{-\alpha}}$

$m = 1$ for shock events
$\alpha = 5.3$ $\sigma = 2.1$ calculated using a maximum likelihood estimation

The probability of a shock event with system acceleration greater than 3.75 is less than 5%

Maximum Acceleration and Strain Event

- Occurred in the 3rd hour of transport
- Heavy-haul traveling 24 mph
- Caused by crossing a bridge abutment
- 97th percentile event
- Maximum acceleration: 4.53 g in A19Z
- Maximum assembly acceleration: 0.42 g in A5Z
- Maximum strain: 15.9 μE in SG7-0



Time history of SNL assembly front and back strain gauges during maximum response event

Location of heavy-haul maximum response event

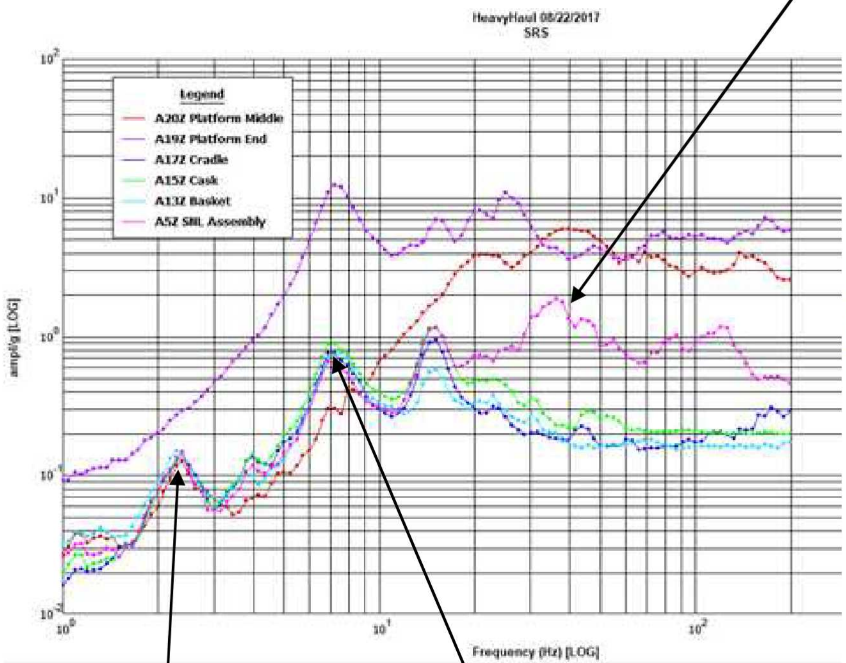
Maximum Acceleration and Strain Event Shock Response Spectra

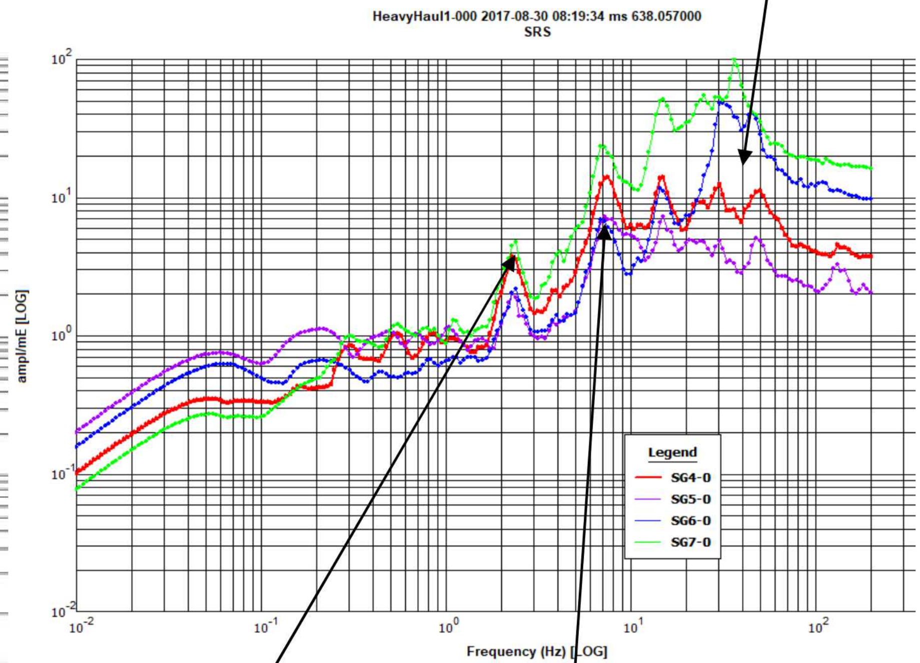
Assembly natural frequency

Assembly natural frequency

System accelerometers

SNL assembly strain gauges





Vertical suspension natural frequency

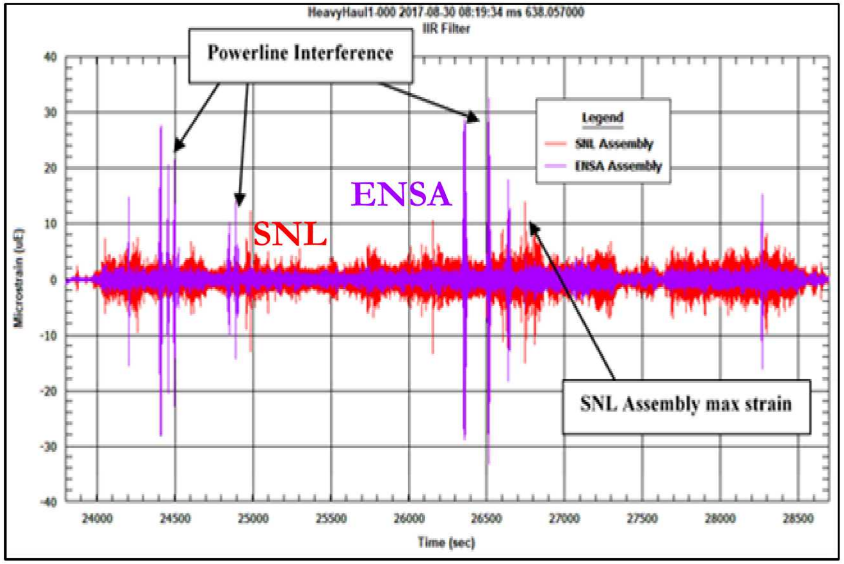
Lateral suspension natural frequency

Vertical suspension natural frequency

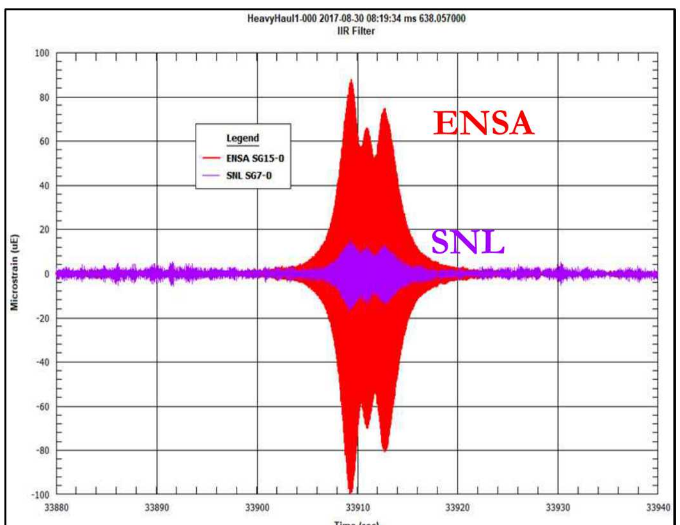
Lateral suspension natural frequency

Powerline Interference

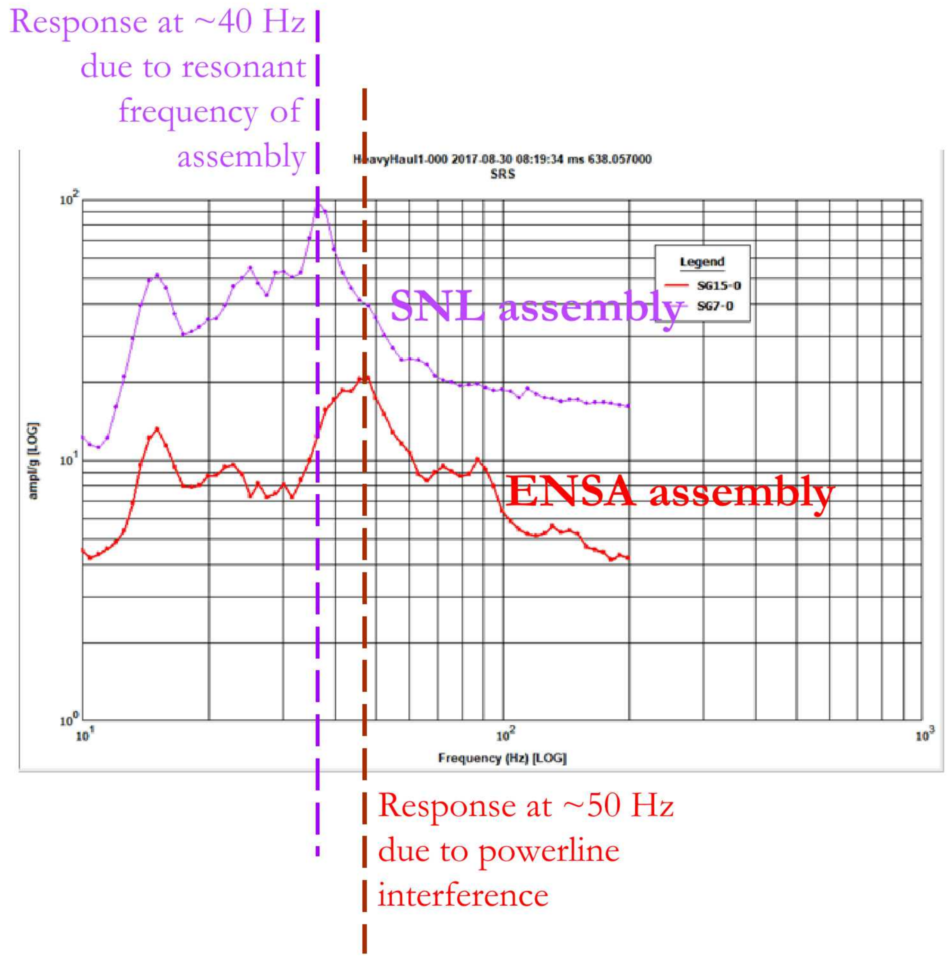
SRS containing SNL assembly max event



More interference in ENSA assembly than SNL assembly



Characteristic shape of powerline interference



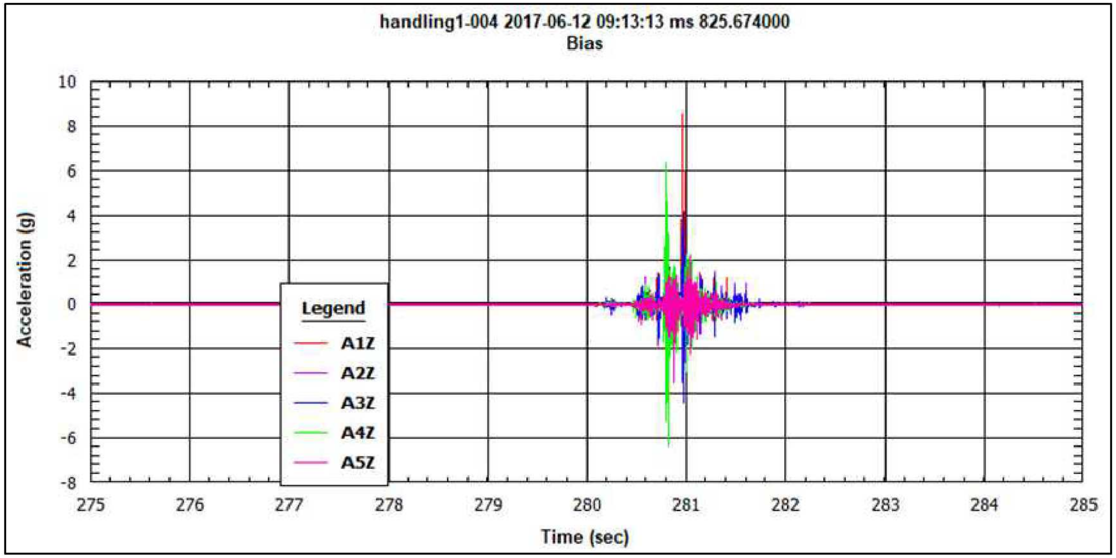
The SNL assembly maximum strain event was not affected by powerline interference

Dry Storage Cask Handling Tests

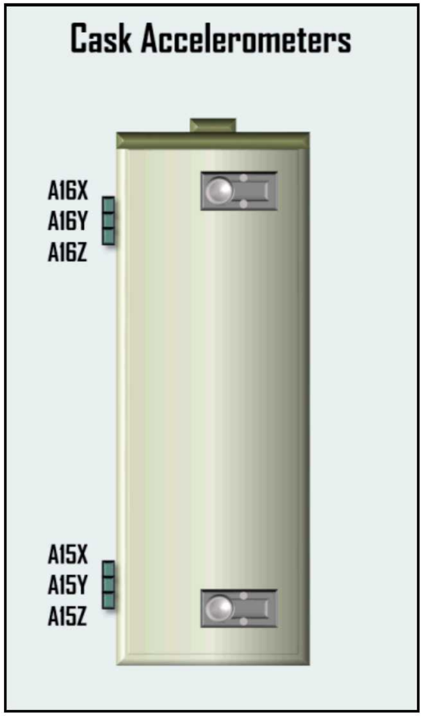
These tests were conducted to understand fuel rod environment during handling

Dry Storage Cask Handling Test

- 3 ENSA crane operators
- 3 test runs (R1, R3, R5)
- 3 drops per run, with varying degrees of crane handling "aggressiveness"



Example of SNL Assembly Acceleration Time Histories for Dry Storage Cask Handling Test (Run 5, Drop 2)



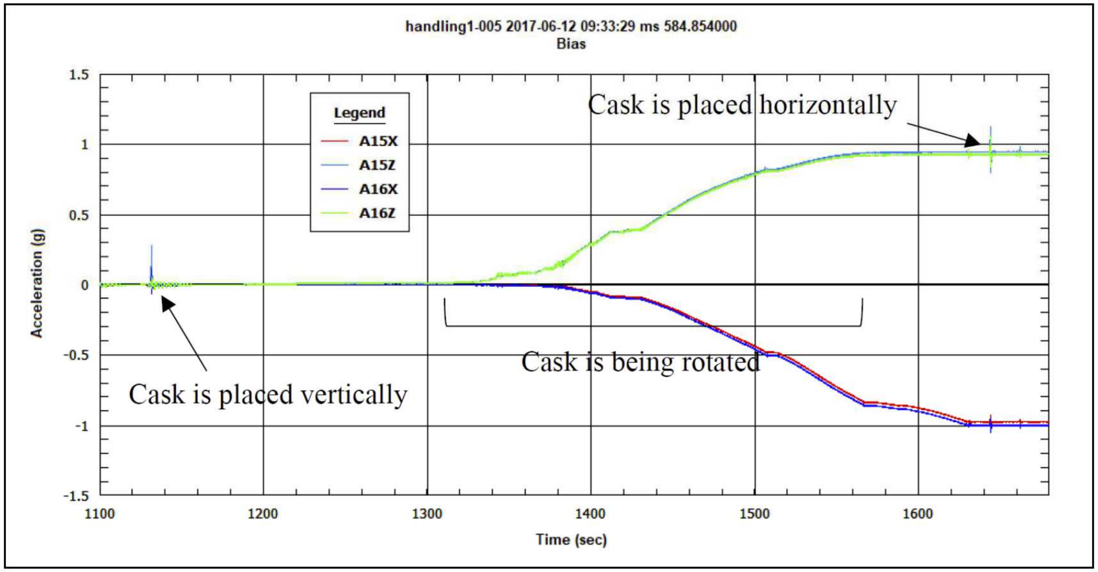
Configuration of cask during dry storage tests

Heavy-Haul Cask Handling Test

These tests were conducted to understand fuel rod environment during handling

Heavy-Haul Handling Test

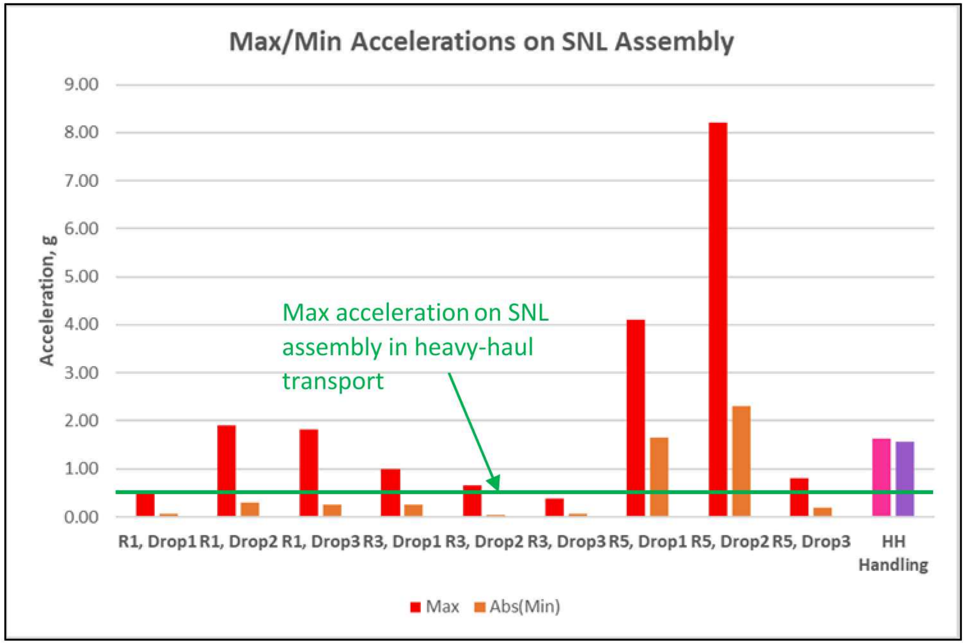
- 1 test
- Cask rotated vertical to horizontal in cradle



Cask accelerometer time history during Heavy-Haul Cask Handling Test.

Cask being lowered into position

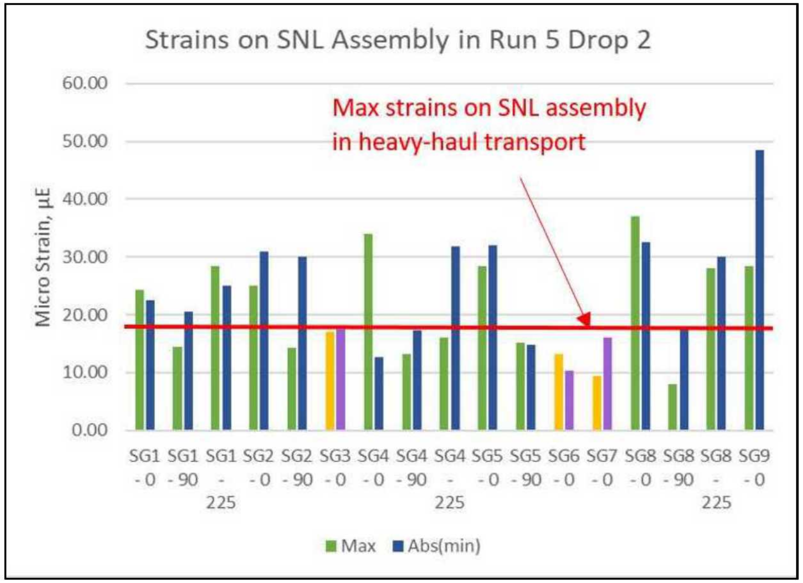
Accelerations and Strains in Cask Handling and Heavy-Haul Handling Tests



Maximum accelerations on the SNL assembly

Accelerations in handling are generally higher than during heavy-haul transport

Max SNL assembly strain: 48.5 μE
Max overall strain: 82 μE (ENSA assembly)



Strain on the SNL assembly during the most severe dry storage handling test

During handling tests strains are higher at the assembly top and generally higher than during heavy-haul transport

Summary

- Heavy-haul transport demonstrated that different system elements behave differently during shock events.
- Higher accelerations and strains generally occur at assembly natural frequency, around 45 Hz.

Heavy-haul Transport (245-mile route) *Analysis of system response during normal heavy-haul transport*

- 36 shock events identified
- Events with greater response were caused by a vertical upset in the road or a turn.
- The maximum observed acceleration in the SNL assembly was 0.5 g, and the maximum observed strain in the SNL assembly was 15.9 µE (with no powerline interference).

Cask Handling Tests (Dry storage and heavy-haul) *Analysis of fuel rod environment during handling*

- 9 dry storage tests and 1 heavy-haul test were conducted.
- Accelerations and strains on the SNL assembly were somewhat higher than during heavy-haul transport shock events.
- Maximum SNL assembly strain was 48.5 µE. The maximum overall was 82 µE.

Only a few handling operations are expected while SNF is in storage and transport

The test results provided a compelling technical basis for the safe transport of spent fuel under normal conditions of transport.

During normal conditions of heavy-haul transport the strain on the assembly are expected to be below 20 µE. During the dry storage handling operations, the strains are expected to be below 100 µE. Consequently, the stress fuel rods experience is far below yield limits for cladding.

Questions?