

International Multi-Modal Spent Nuclear Fuel Transportation Test: The Transportation Test Triathlon



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Conference on the Management
of Spent Fuel from Nuclear
Power Reactors

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PRESENTED BY

Sylvia Saltzstein, Sandia National Labs, USA



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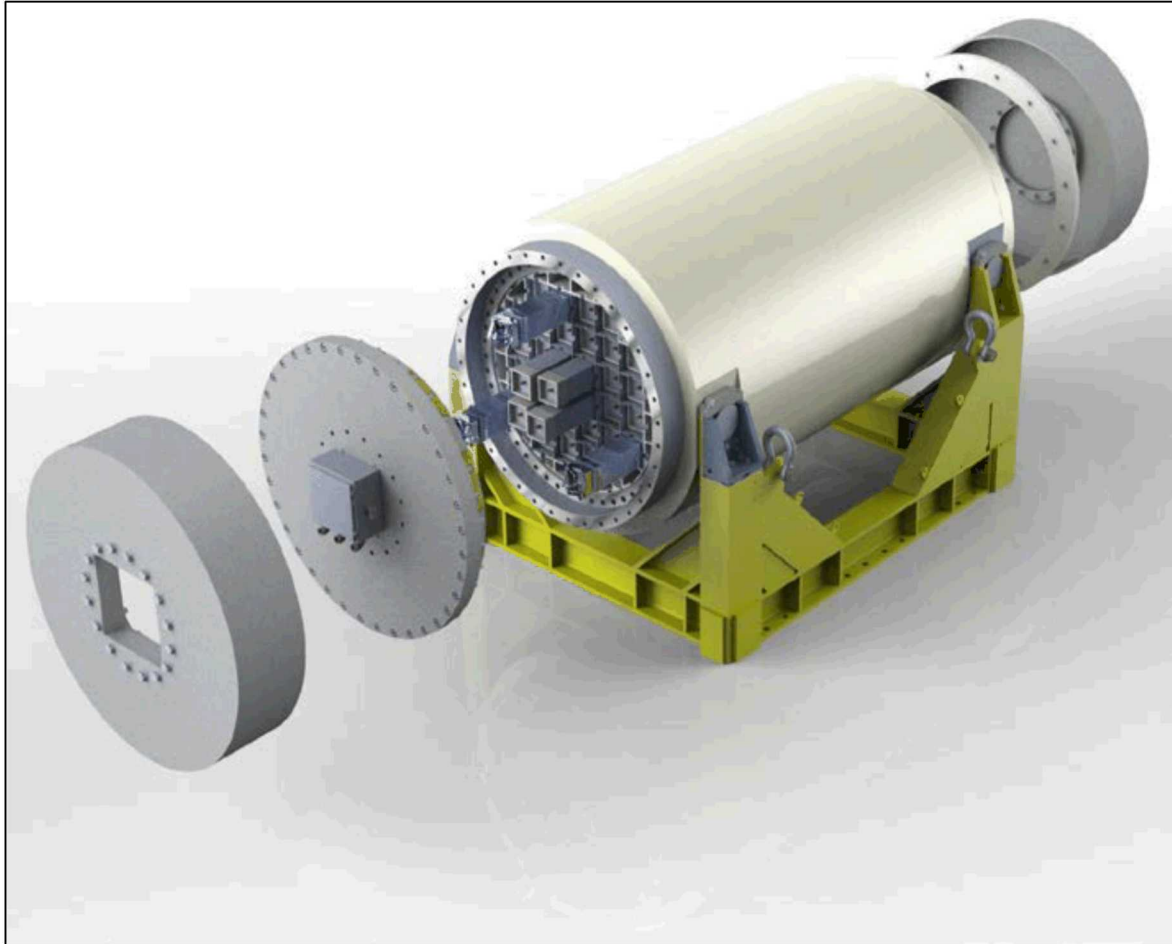
Collaborators

- U.S. Department of Energy
- Pacific Northwest National Laboratory (PNNL)
- Equipos Nucleares Sociedad Anónima (ENSA)
- Korea Hydro and Nuclear Power (KHNP)
- Korea Radioactive Waste Agency (KORAD)
- Korea Atomic Energy Research Institute (KAERI)
- Coordinadora Internacional de Cargas, S.A.
- Empresa Nacional de Residuos Radiactivos S.A. (ENRESA)
- ENUSA Industrias Avanzadas S.A.
- Transportation Technology Center, Inc. (TTCI)
- Sandia National Laboratories (SNL)



Link to video documenting the major test events: <https://www.youtube.com/watch?v=wGKtgrozrGM&feature=youtu.be>

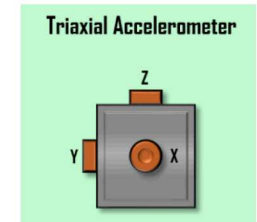
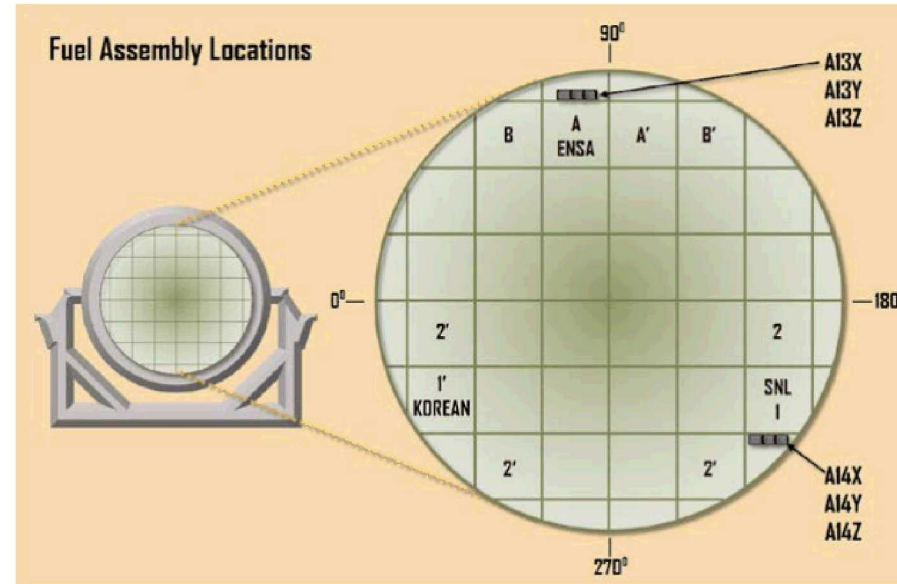
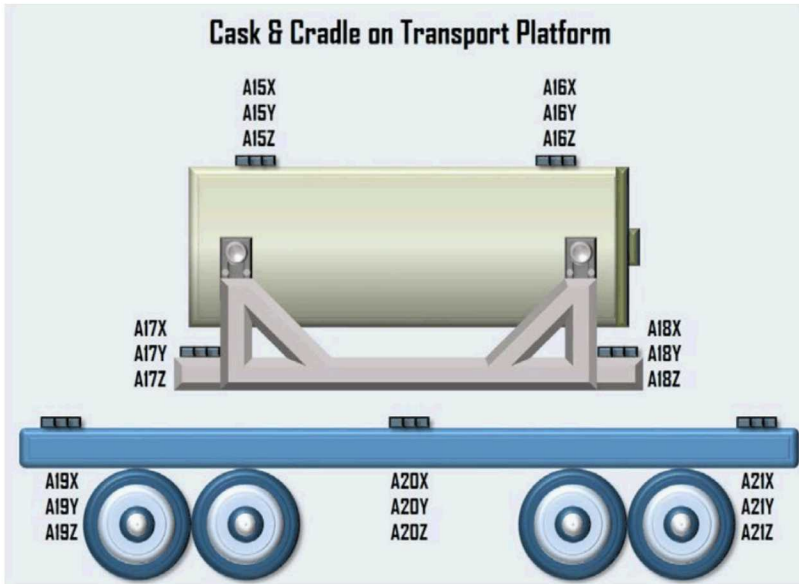
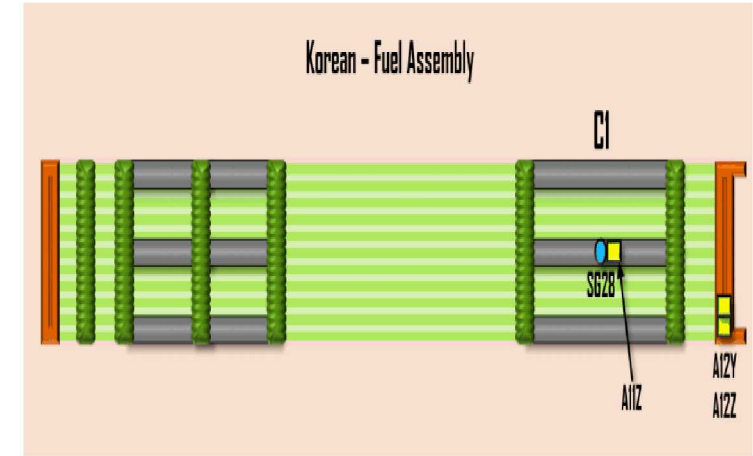
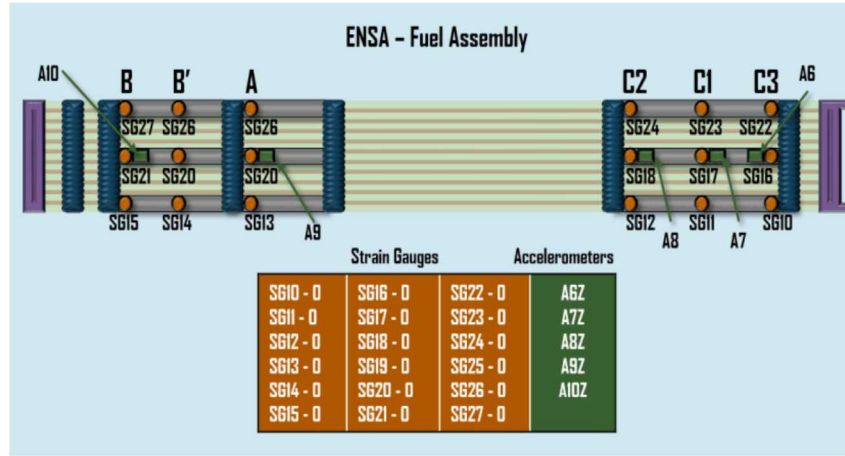
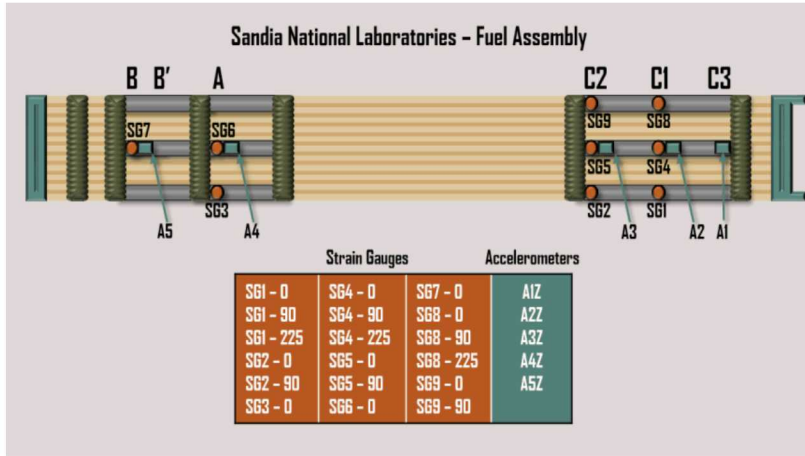
Cask Diagram



- Length: 5 m
- Body diameter: 2.65 m
- Loaded weight of carbon steel cask: 120 tons
- Loaded weight with surrogate impact limiters: 137 tons

Transportation System Instrumentation

40 accelerometers, 37 strain gauges



Transportation Configurations



16-axle heavy haul truck transport through Spain

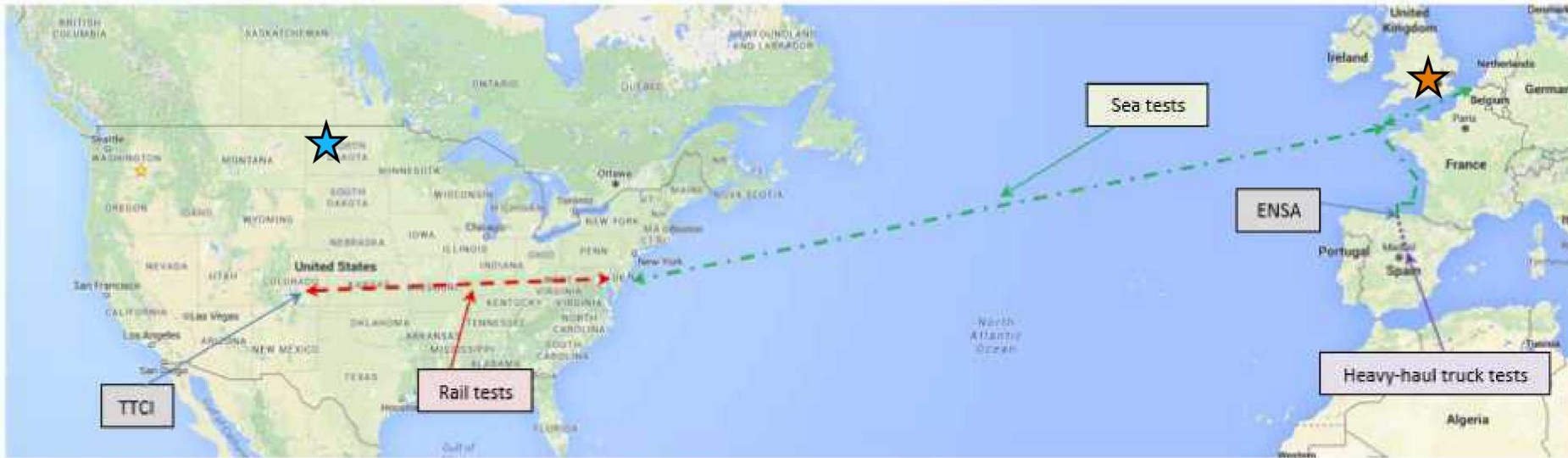


Rail transport and testing in the US – Kasgro 12-axle railcar

Barge and ocean ship transport



Transportation Triathlon Route



- Cask handling tests at ENSA, Santander/Spain ★
- Heavy-haul truck tests in Northern Spain (245 mi/394 km)
- Barge transport from Spain to Belgium (929 mi/1,495 km)
- Ocean ship transport from Belgium to Baltimore (4,290 mi/6,904 km)
- Rail shipment from Baltimore to TCI (Rail 1, 1,950 mi/3,138 km)
- Testing at TCI ★
- Rail shipment from TCI to Baltimore (Rail 2, 1,125 mi/1,811 km)
- Return ocean transport from Baltimore to Spain (not recorded)

Total distance traveled with data acquisition: 8,539 mi (13,742 km)

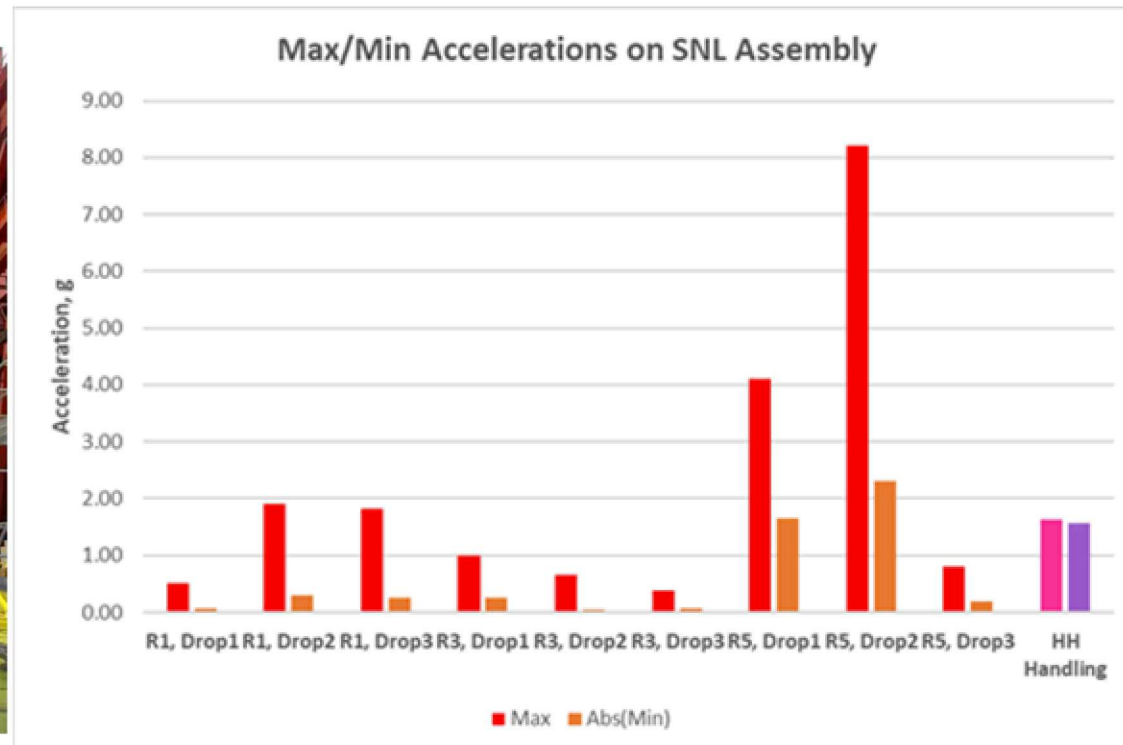
Cask Handling Tests

Dry Storage Cask Handling Tests

- 3 ENSA crane operators conducted one run each (R1, R3, R5) in which each raised and lowered the cask 3 times, with varying levels of “aggressiveness”
- Run 5 (R5) Drop 2 experienced the highest recorded SNL assembly strain: 40 μE

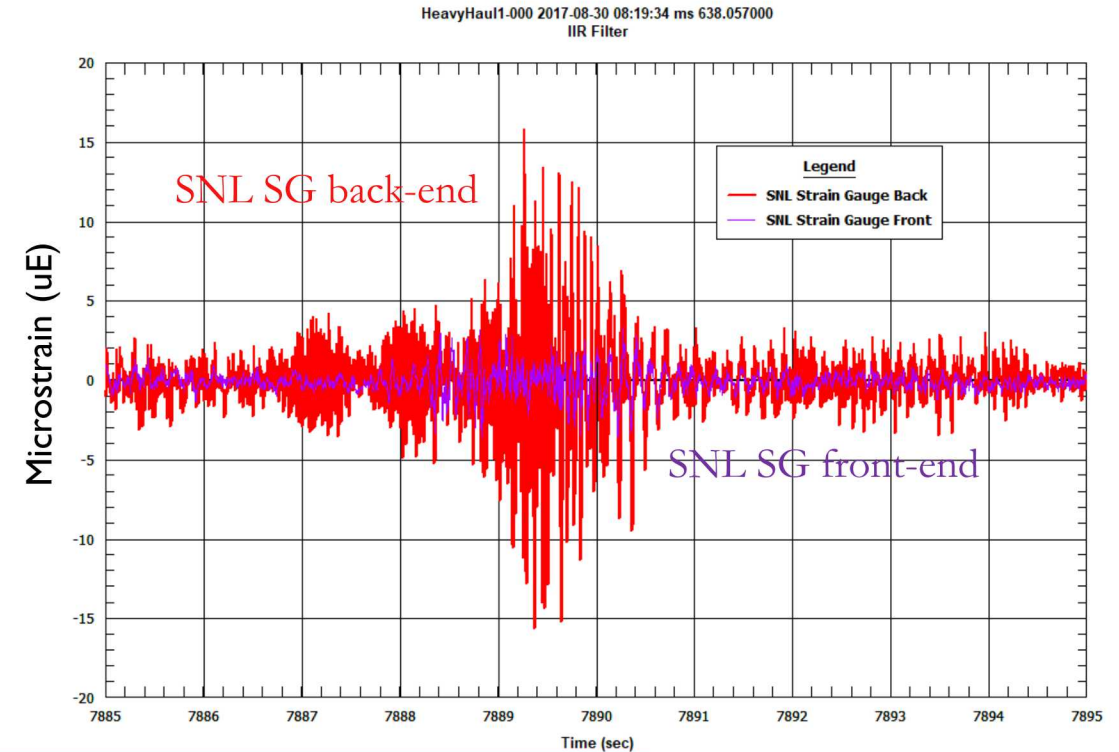
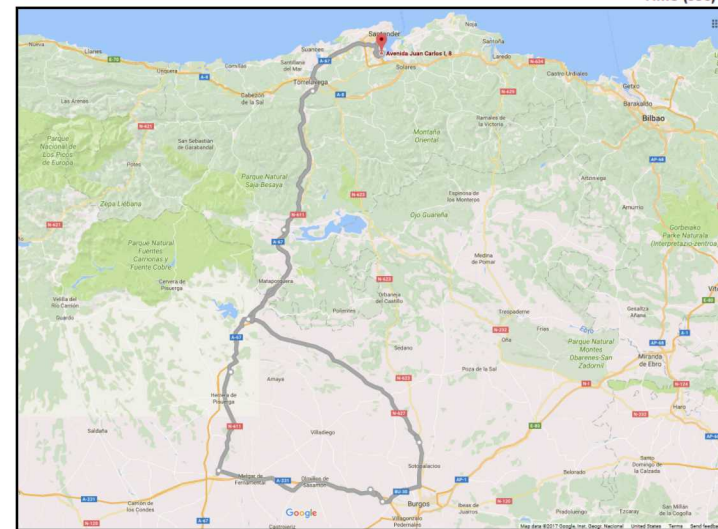
Heavy-Haul Handling Test

- Cask was placed vertically into the cradle and lowered to horizontal position in preparation for heavy-haul truck tests.

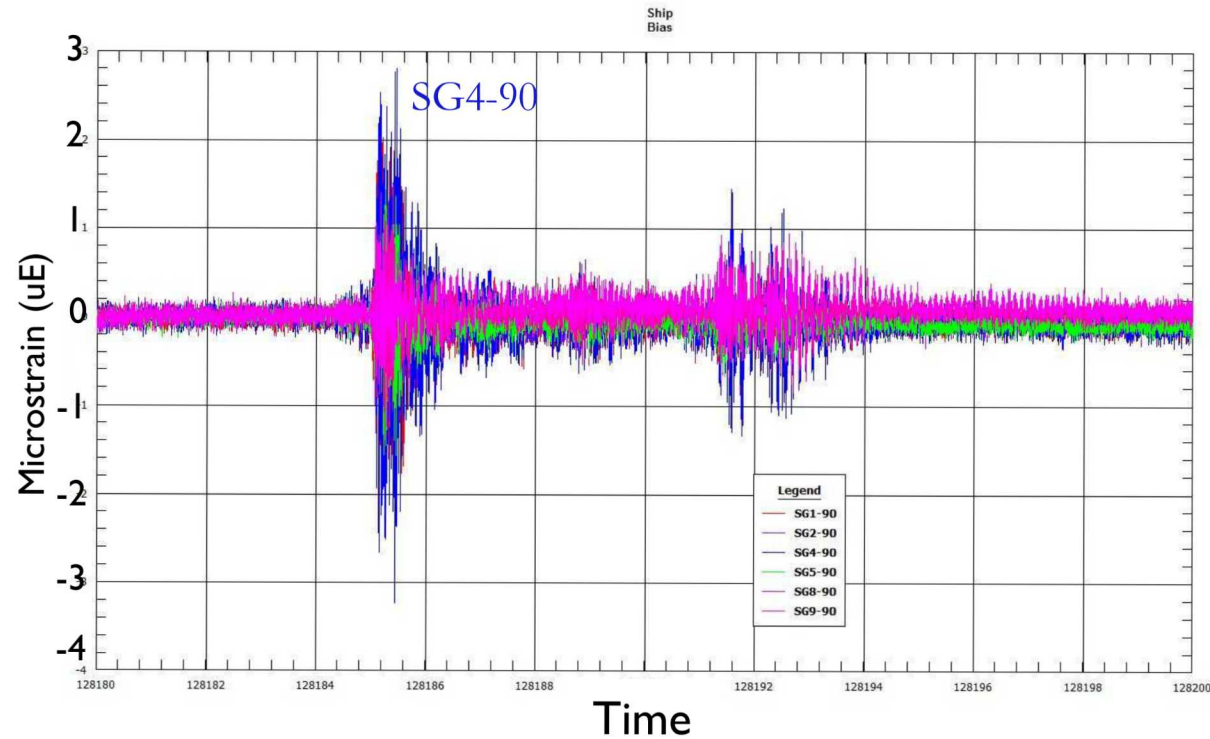


Heavy-Haul Truck Transport

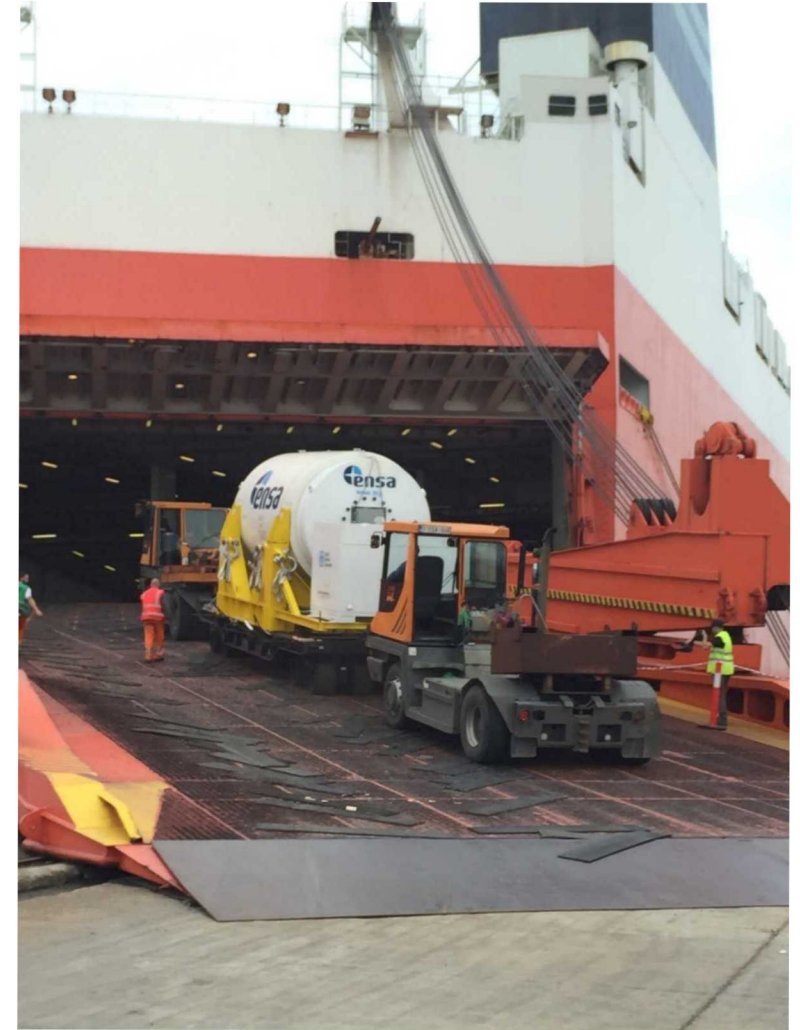
- 36 shock events
- 78% caused by vertical upset in the road, 11% associated with turns, 11% unidentifiable but with low overall response.
- Maximum acceleration:
 - Platform: 4.52 g (back-end)
 - SNL Assembly: 0.52 g
- Maximum SNL assembly strain: 15.6 μE



Barge and Ocean Ship Transport

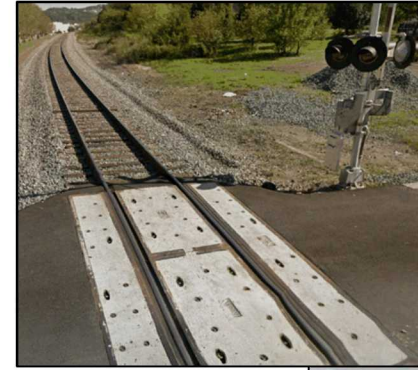


- Observed accelerations and strains were overall very low
- Accelerations (mostly) ≤ 0.3 g, and strains consistently ≤ 4 μ E
- Maximum acceleration:
 - Transport platform: 0.38 g
 - Assembly: 0.12 g
- Maximum strain on the SNL assembly: 3.8 μ E



Rail 1: Baltimore to TTCI (Pueblo, CO)

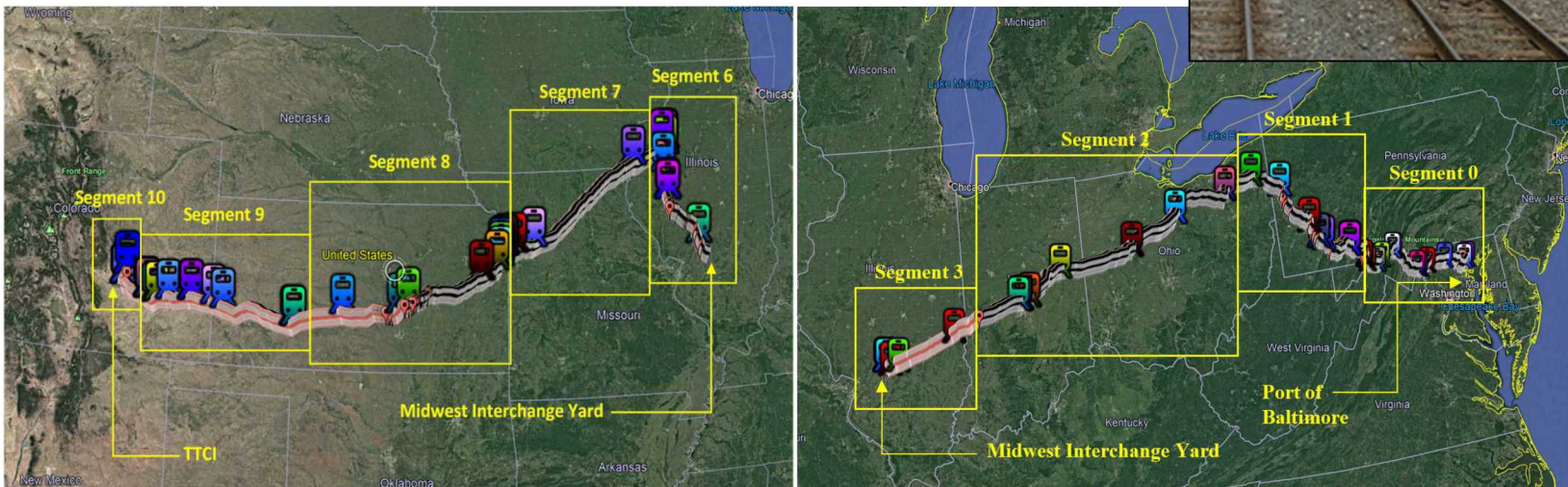
- Total distance: *1,950 miles (3,138 km)*
- Total recording time: *518,400 sec (144 hours)*
- Railcar was moving: *59 hours*
- Number of grade crossing shock events: *1,029*
- Number of track switch shock events: *629*
- Number of coupling events: *1*



Grade crossing



Track switch



Train icons indicated places the train stopped. Rail 1 was recorded over 10 segments of data.

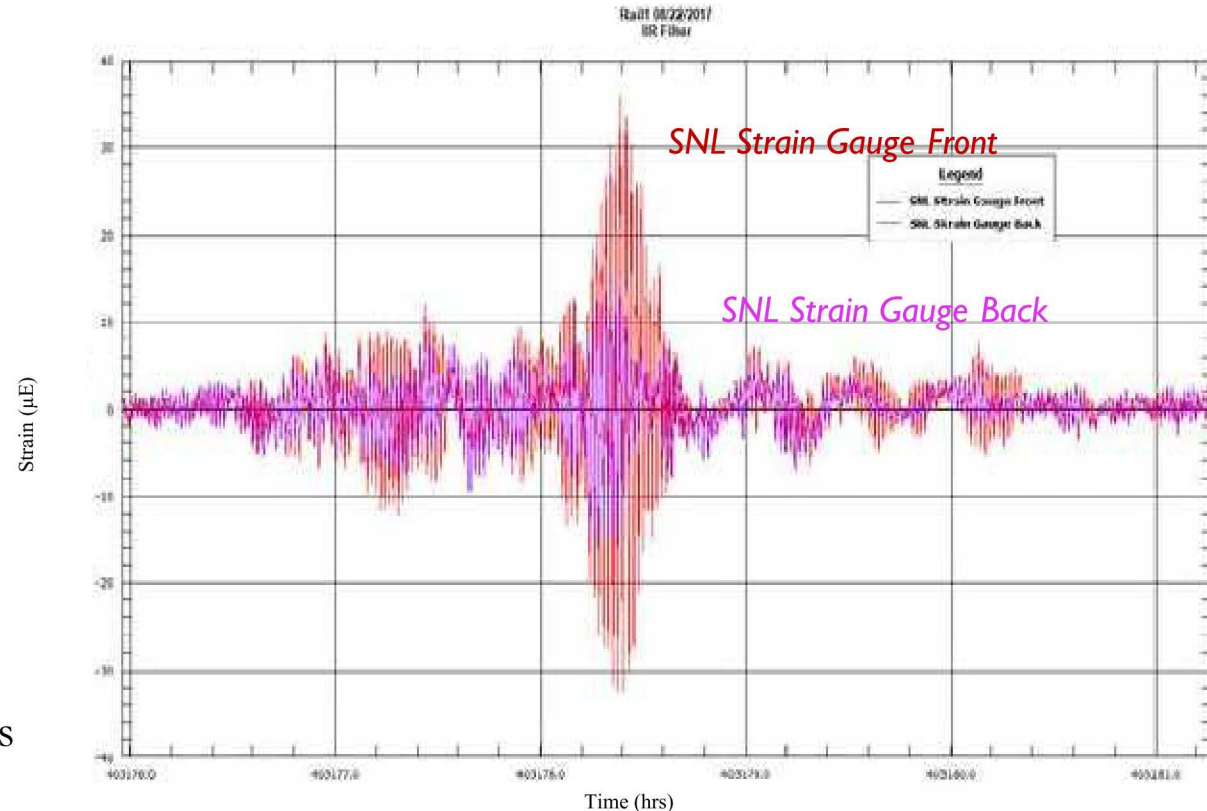
Rail 1: Baltimore to TTCl (Pueblo, CO) - Analysis

Max Acceleration Event

- Caused by a diamond crossing in Jacksonville, Illinois
- Rail 1 traveling 36 mph
- Max absolute acceleration:
 - Platform: 8.68 g (front-end)
 - Assembly: 0.95 g (ENSA)
- Max absolute strain: 20.7 μE in SNL assembly front

Max Strain Event

- Caused by a track switch in Kendall, Kansas
- Rail 1 traveling 45 mph
- Max absolute acceleration:
 - Platform: 3.78 g (front-end)
 - Assembly: 0.66 g (ENSA)
- Max absolute strain: 35.8 μE in the SNL assembly

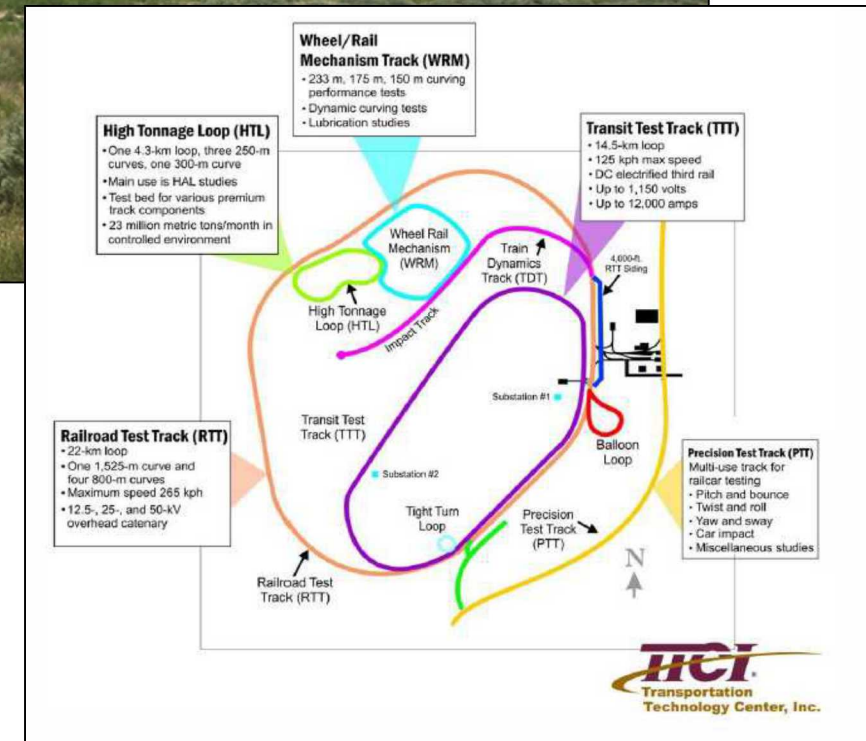


Maximum Strain Event Time History

Rail Tests at the TTCL - Testing

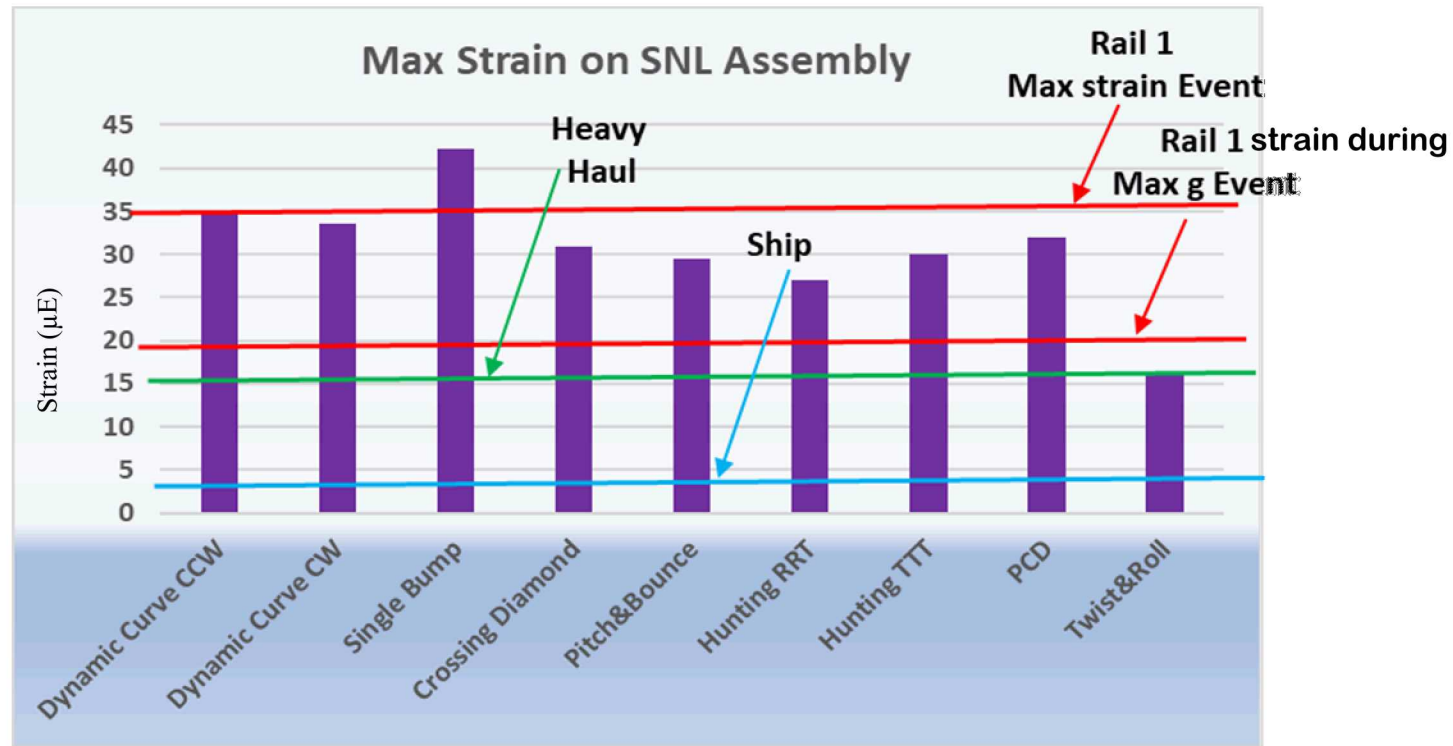
- Short duration tests with known conditions and design parameters more extreme than expected on commercial railroads
- Tests conducted at varying speeds to capture specific resonant speed

Test Description	Number of Tests
Twist and Roll	19
Pitch and Bounce	9
Dynamic Curve	24
Class 2 Rail Track (PCD)	17
Single Bump	8
Crossing Diamond	6
Hunting	23
Coupling Impact	10



Rail Tests at the TTCI - Results

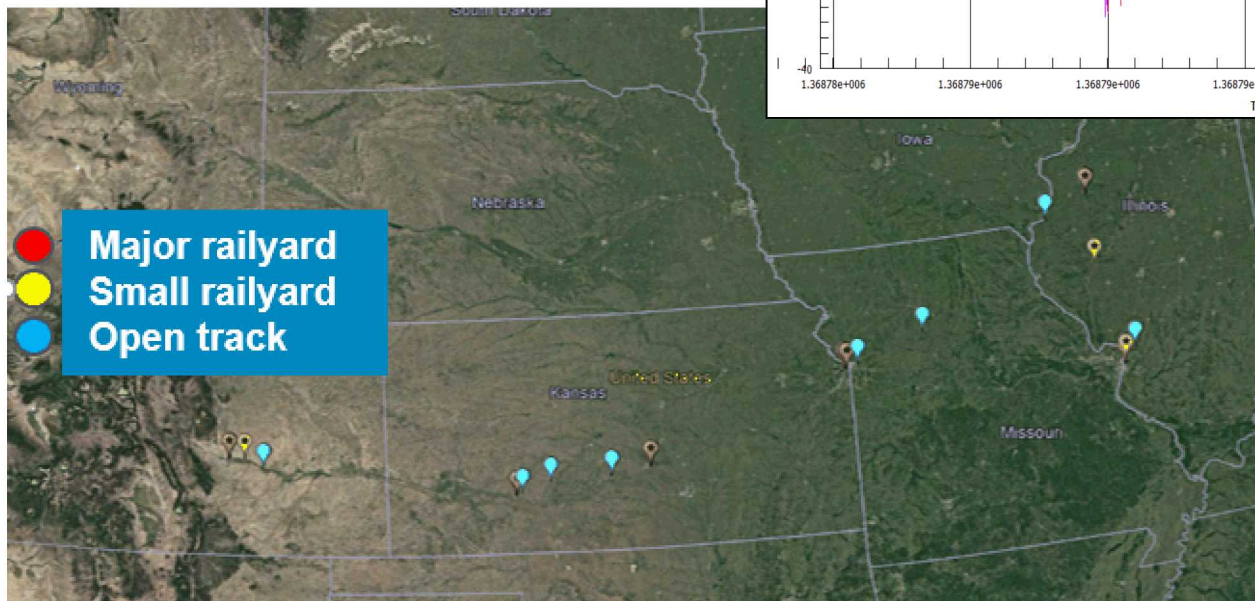
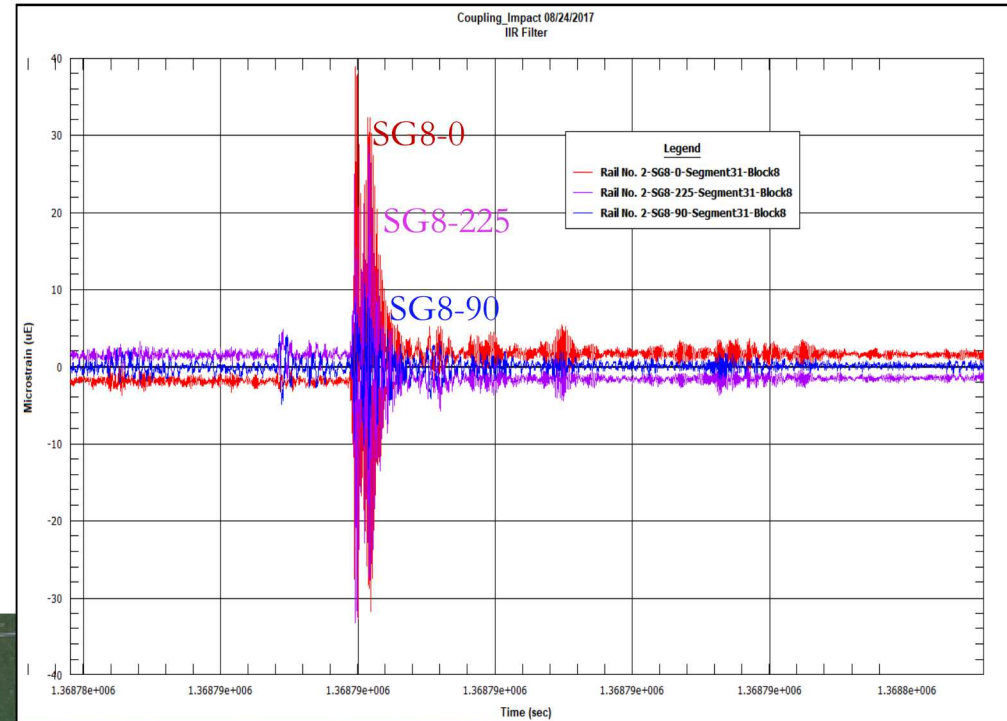
- Testing provided valuable insight of system response to a multitude of transient inputs
- Understanding these inputs made possible the comparison and analysis of rail, heavy-haul, and ship transport data



Maximum strains from TTCI tests compared to maximum strains from different modes of transportation

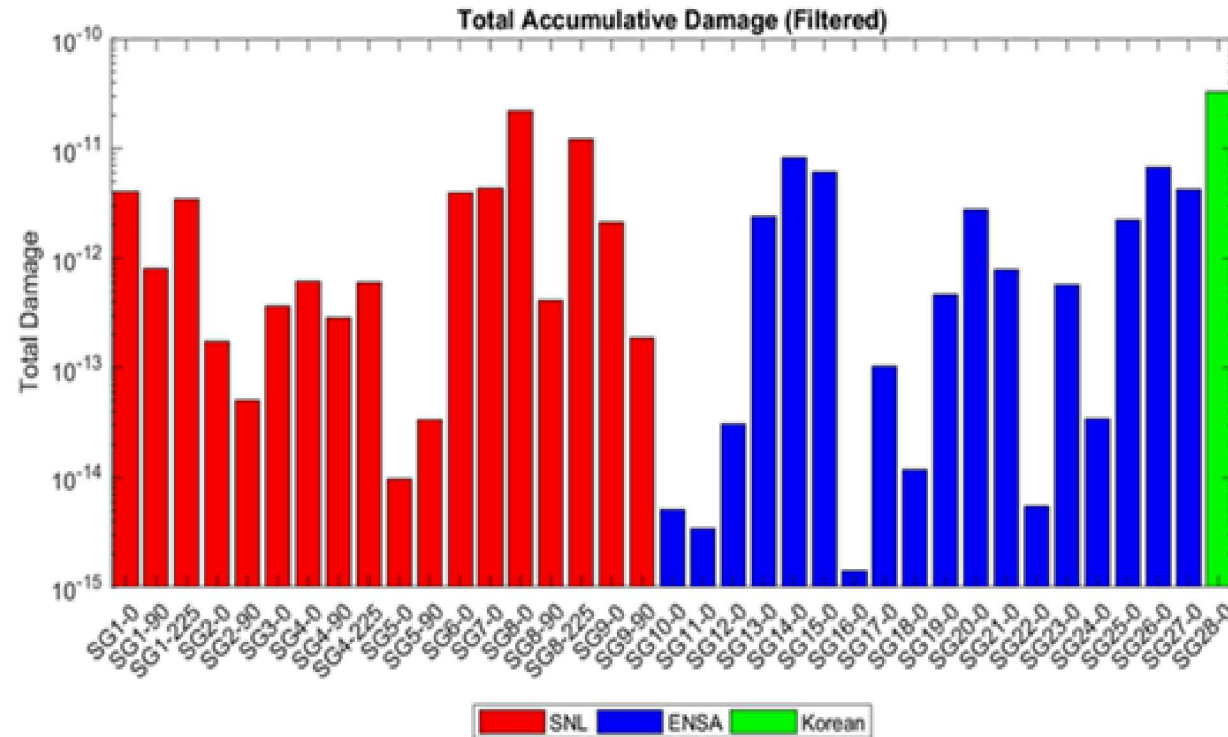
Rail 2: TTCI (Pueblo, CO) to Baltimore

- 18 days (1,125 mi/1,811 km) of data collected from TTCI to near St. Louis, Illinois
- 30 coupling events analyzed at major and minor railyards
- Max SNL acceleration: 1.05 g
- Max SNL strain: 38 μE
- Max TTCI coupling strain: 99 μE at 7.5 mph



Fatigue Analysis

Strain data collected during the multi-modal transportation test were used to perform fatigue analysis on the fuel cladding.



- Damage fraction of 1.0 indicates fatigue failure.
- Accumulated damage in all cases is below $1\text{E}-10$
- This calculation estimates it would take 10 billion cross-country (2,000-mile) trips to challenge the fatigue strength of irradiated fuel cladding.

Summary of What We Learned

1. The 137 ton transportation system is a good cushion.
2. All tested modes of transportation are safe.
3. Fatigue is not a concern.





Questions?

