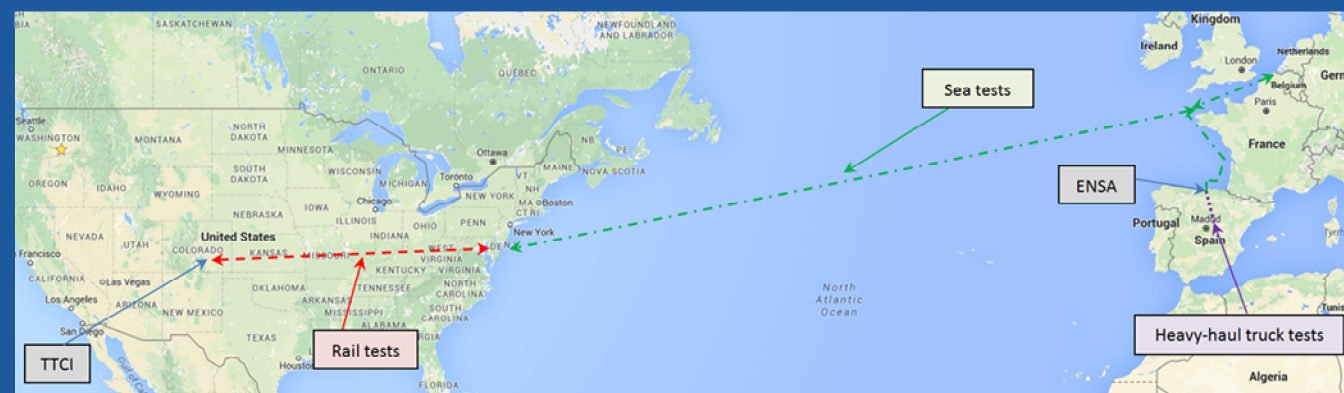




U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

SAND2017-11646C



DOE:NE SPENT FUEL & WASTE SCIENCE & TECHNOLOGY

ENSA ENUN 32P Rail Cask Transport Tests

Presented: REG CON 2017

White Flint, MD
October 31, 2017

Sylvia J. Saltzstein, Ken Sorenson, Paul McConnell* & Steven Ross**

***Sandia National Laboratories **Pacific Northwest National Laboratories**



Sandia National Laboratories is a multi-mission 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. SAND Number: SAND2017-XXXXXX.



What are the Strains and Accelerations Experienced when Transporting Spent Nuclear Fuel?

How do stresses on fuel during Normal Conditions of Transport compare to failure limits of zirconium-alloy tubes?

Could vibrations or shocks result in fatigue failure?

- Based on previous SNL tests, the stresses fuel rods experience due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding.
- But previous tests are only simulations of the configuration of actual SNF transport modes.





Transporting Spent Nuclear Fuel: *How do Stresses on Fuel During Normal Conditions of Transport Compare to Failure Limits?*

THREE SERIES OF TESTS USING SURROGATE PWR ASSEMBLY

- 1) *Truck data on vertical acceleration shaker table*
- 2) *Over-the-road truck test*
- 3) *Truck/rail data on commercial seismic shaker with 6° of freedom*



McConnell et al, 2016, SNL and PNNL



Why Did We Do These Tests?

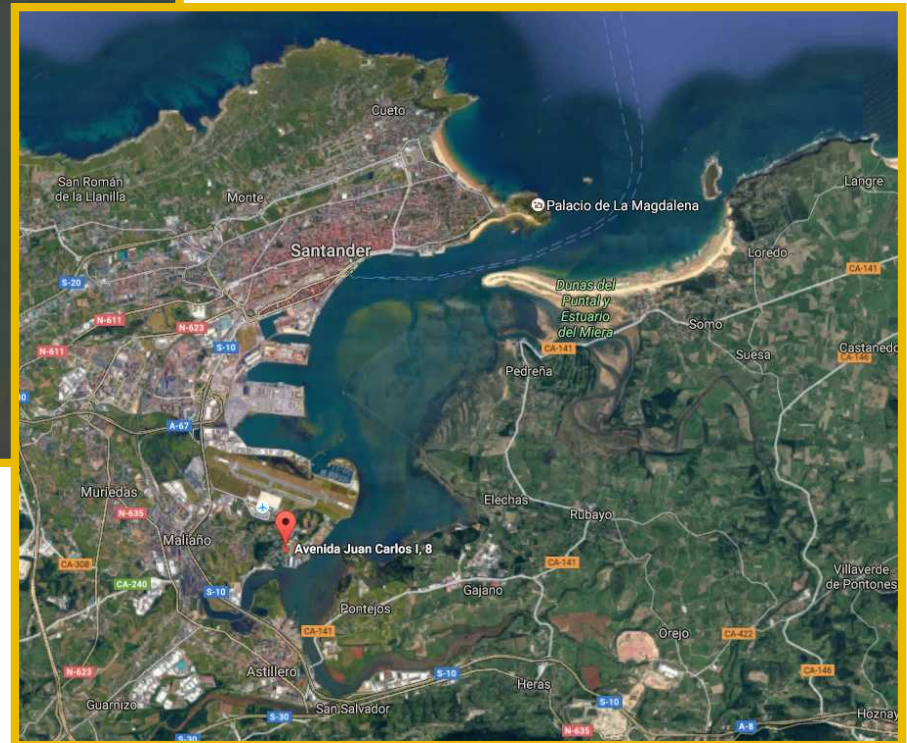
- The objective was to validate our hypothesis that spent fuel will maintain integrity during Normal Conditions of Transport.
 - *We didn't have data for rail transport or during the transfer of the cask between transport modes*
 - *We also obtained more realistic data for truck transport*
- We had international partners who contributed valuable hardware, expertise, and shared in the cost.



U.S. DEPARTMENT OF
ENERGY

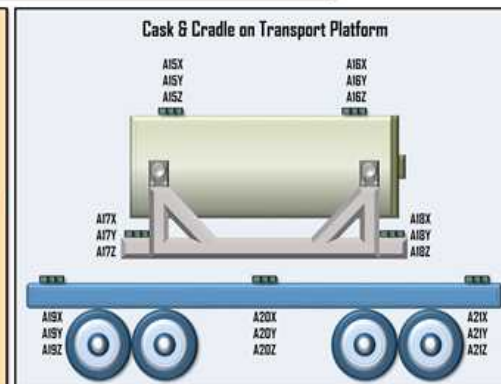
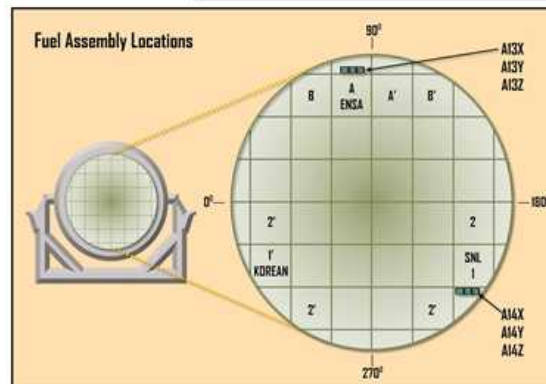
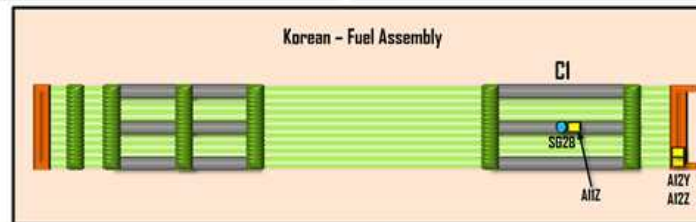
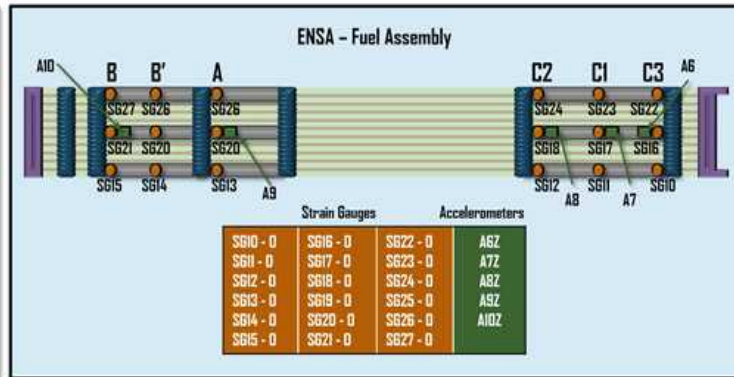
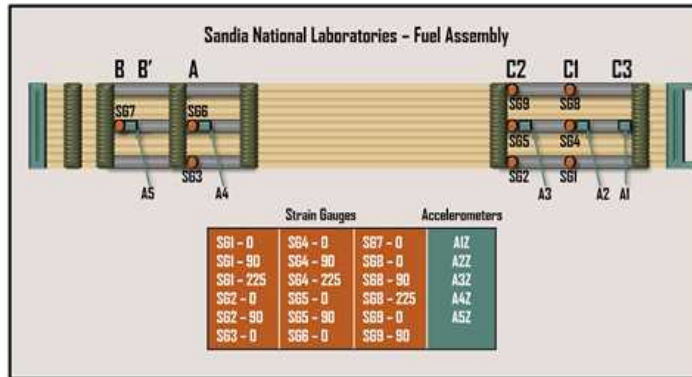
Nuclear Energy

Equipos Nucleares S.A. Supplied an ENSA ENUN 32P Rail Cask for a Series of Transport Tests





3 Surrogate Assemblies and Cask System Instrumented with 77 Accelerometers/Strain Gauges

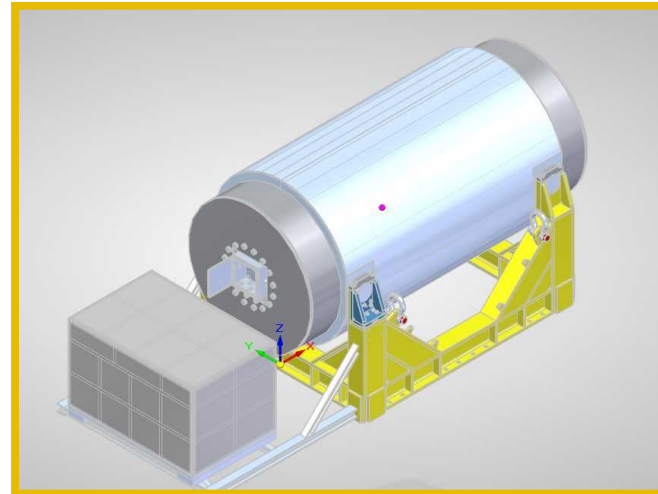




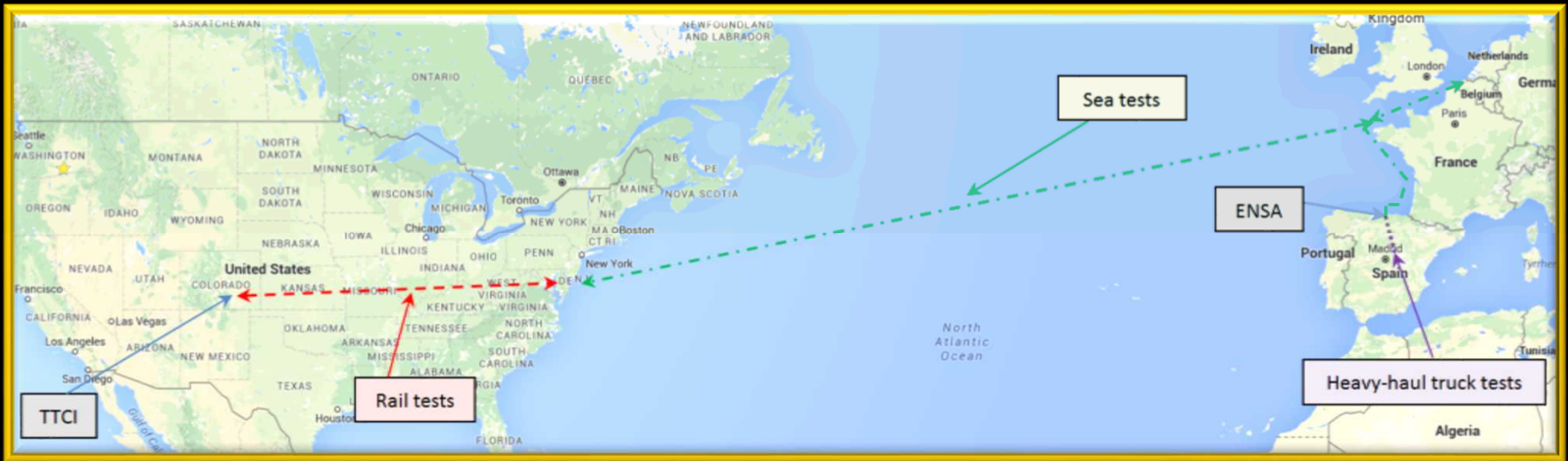
U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Instrumentation/Battery Box: *Two 40-channel Data Acquisition Systems, 20 Batteries, 1.25 Miles of Cable*



Routing of Cask



- Cask handling tests
- Heavy-haul truck from in northern Spain, June, 2017
- Coastal sea shipment from Santander to Zeebrugge, June, 2017
- Ocean transport from Europe to Port of Baltimore, July, 2017
- Commercial rail shipment from Baltimore to Pueblo, Colorado, July, 2017
- Testing at the Transportation Technology Center, Inc. August, 2017
- Return trip to ENSA will be the same.

Data was collected throughout all legs of the transport as well as transfers between legs.



54 Days of Data Collection, 8 Terrabytes of Data, 9458 Miles, 7 Countries, 12 States

TEST	ROUTE					TRAVEL or TEST TIME (days)	DISTANCE (miles)
Cask Handling						1	
Heavy-Haul Truck	Northern SPAIN					2	245
Ship 1 "Autosky"	Santander, SPAIN	Pasajes, SPAIN	Rotterdam, NETHERLANDS	Zeebrugge, BELGIUM		4	929
Ship 2 "Tarago"	Zeebrugge, BELGIUM	Bremerhaven, GERMANY	Le Havre, FRANCE	Southampton, UK	Baltimore, USA	14	4222
Rail 1	Baltimore, Maryland	Pueblo, Colorado				6	~ 2000
TTCI	9 test days; 8 types of tests; 125 separate events						
Rail 2	Pueblo, Colorado	Baltimore, Maryland				43 18 test days	2062 1125 test miles
Return Ship	Baltimore, USA	Santander, SPAIN	October 22 – November 20; no data collection				
TOTAL TEST DAYS / MILES						54	9458



Rail Tests Conducted at TTCI

- 1) ***TWIST & ROLL TEST*** – determines the car's ability to negotiate oscillatory cross-level perturbations.
- 2) ***PITCH & BOUNCE TEST*** – determines the car's ability to negotiate parallel vertical rail perturbations.
- 3) ***DYNAMIC CURVING TEST*** – determines the car's ability to negotiate curving over jointed track with a combination of lateral misalignment at the outer rail joints and cross-level due to low joints on the staggered rails.
- 4) ***TESTS AT U.S. ARMY PUEBLO CHEMICAL DEPOT*** – determines performance over FRA Class-2 railroad track and tests through No. 8 turnout and No. 8 crossovers.
- 5) ***SINGLE BUMP TEST*** – determines performance at grade crossings. The test zone consists of a 1" bump on tangent track. The bump is a flat topped ramp that rises up over 7', has a steady elevation over 20', and drops back down over 7'. Test speeds are 40-75 mph in 5 mph increments. Railroad industry experience is that vertical dynamic response at grade crossings is a significant source of large vertical accelerations and shock and vibration in freight cars.
- 6) ***LOADED HUNTING ON RAILROAD TEST TRACK*** – determines the vehicle's lateral stability at higher speeds.
- 7) ***LOADED HUNTING ON TRANSIT TEST TRACK*** – determines stability at 30, 40, 50-75 mph at 5 mph increments
- 8) ***COUPLING IMPACT TEST*** – determines longitudinal inputs from coupling at higher than normal speeds.

The ENSA ENUN 32P cask was loaded with three surrogate assemblies and 29 concrete masses. Here, accelerometers are attached to the basket.





The cask, cradle, and assemblies are very large, but the accelerometers, strain gauges, and leads are very small and require a careful and steady hand. Out of 78 connections, we only lost one.

On June 12, 2017, we completed cask handling tests performed by three different crane operators who are experienced in dry cask movement. Each crane operator performed 3 tests.



Placement of the battery and data acquisition box onto the cradle extension.



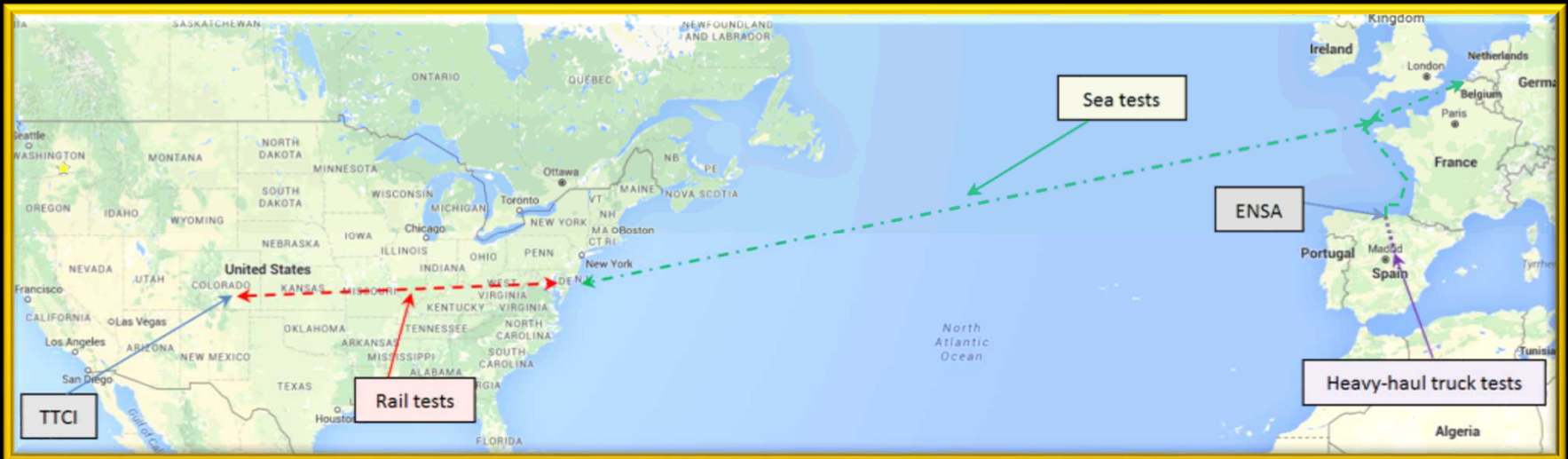
*Accelerometers
were placed on
the basket,
cask, cradle,
and car, as well
as on the
surrogate fuel.*





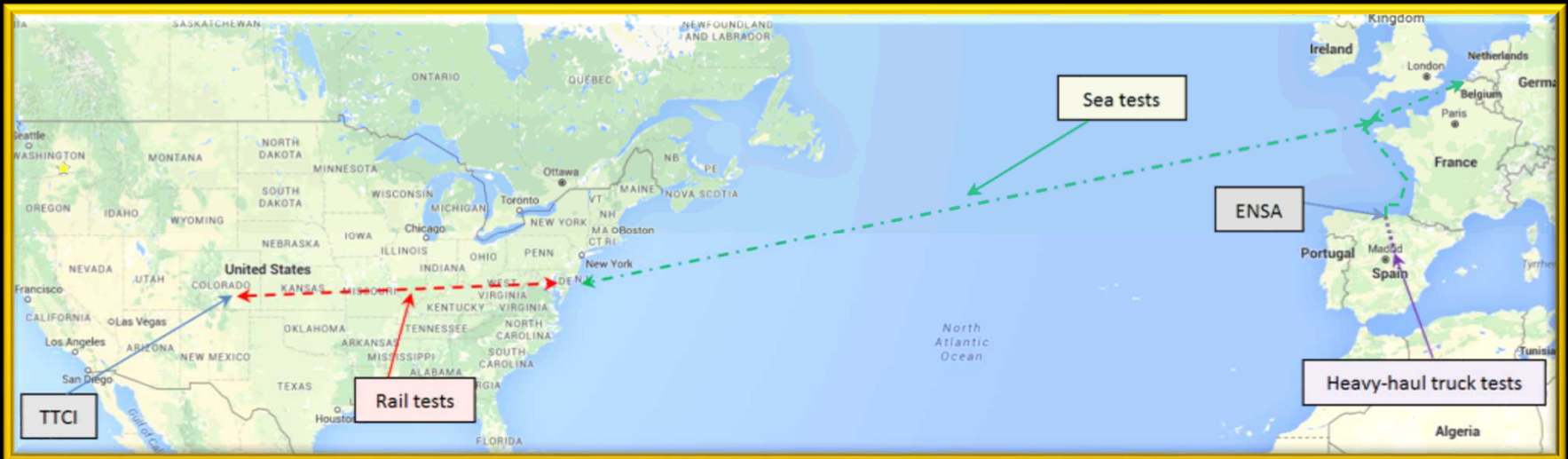
Loading on the 16-axle, 110 foot-long truck. The truck had 3 sets of tri-axial accelerometers on the bed.

Routing of Cask



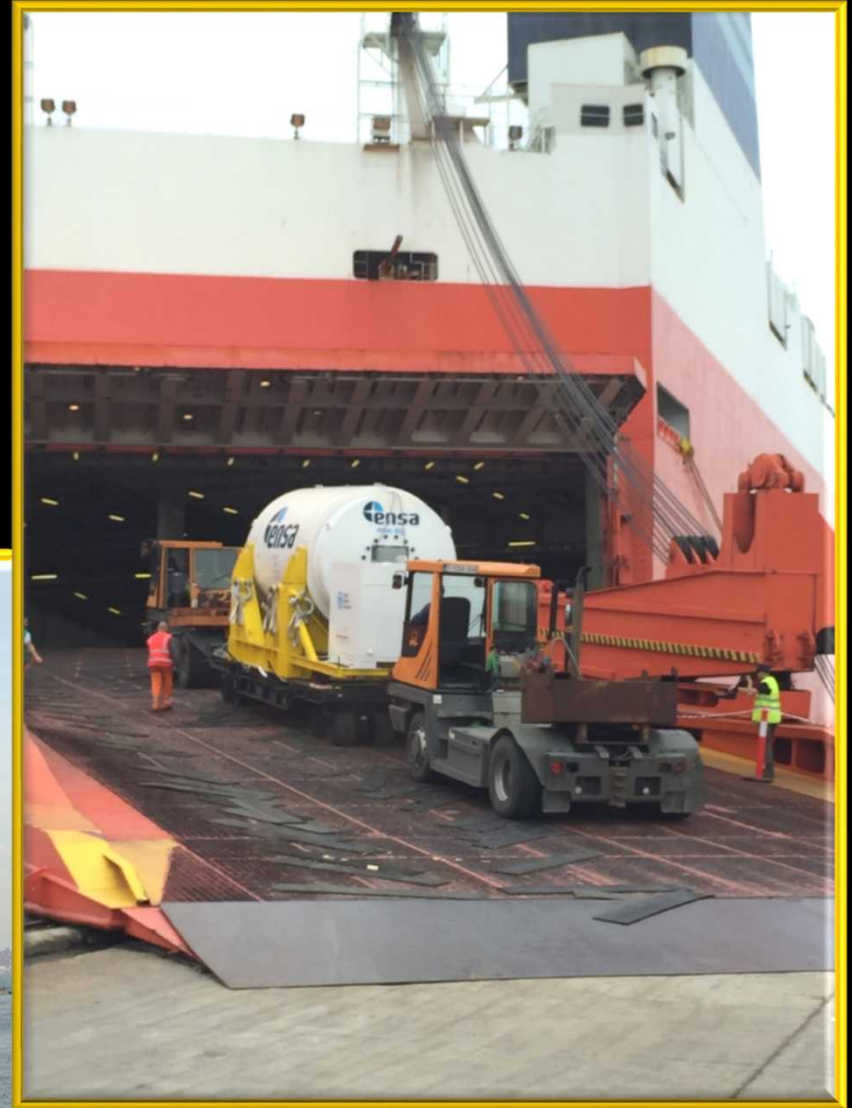


Routing of Cask





*The system being loaded
onto the ship in Belgium
to go to the US.*



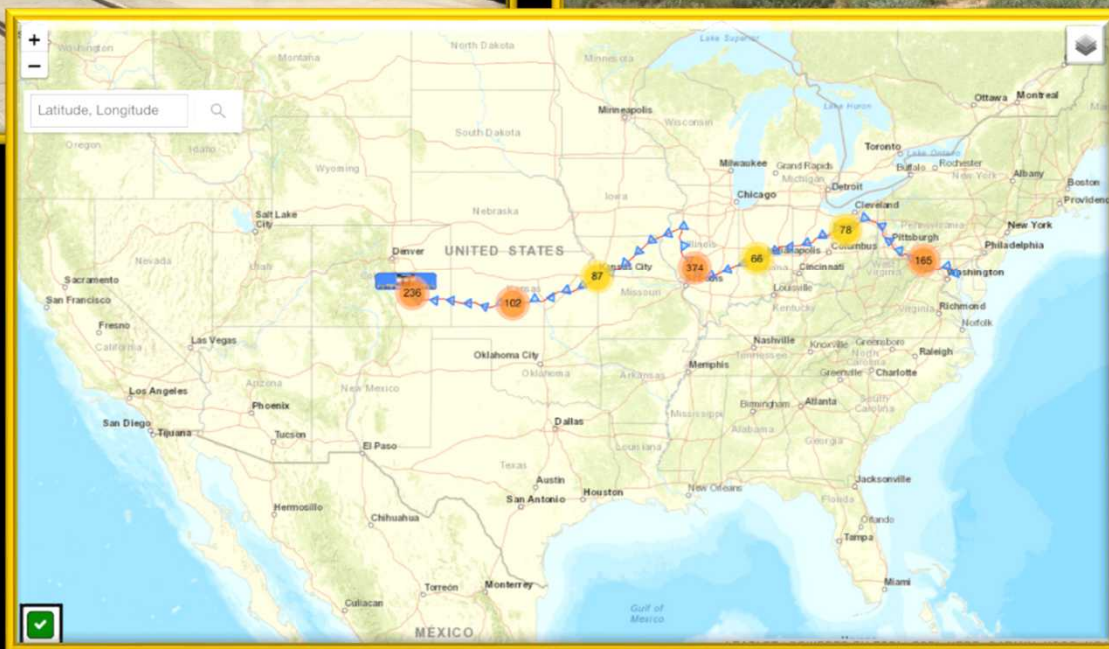
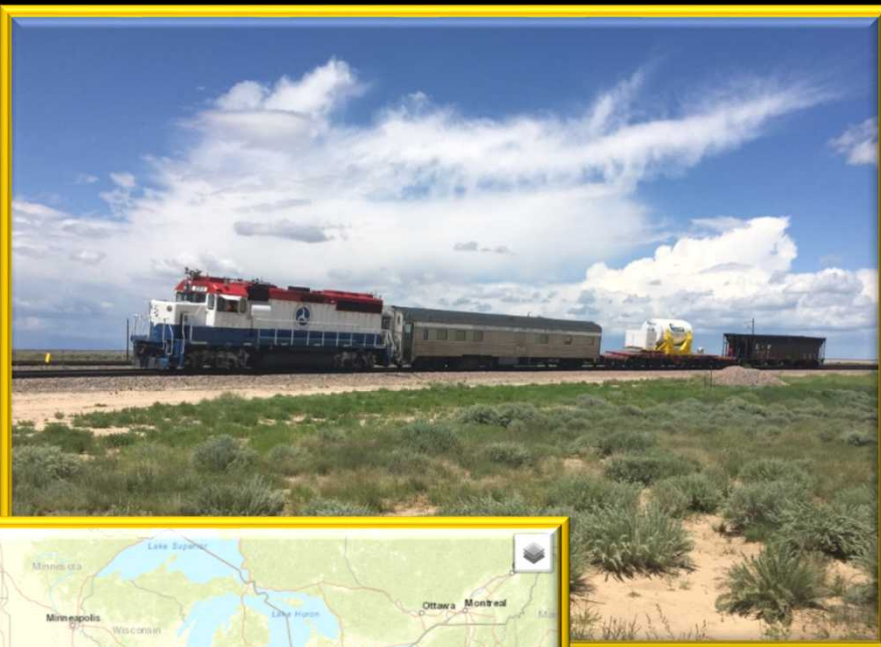
Cask Transfer onto 12-axle railcar in Baltimore



Cask on Railcar



ENSA Cask after being transferred by crane from Samson trailer to Kasgro 12-axle railcar. This picture is prior to lashing (welding) and reconnection of instrumentation system.



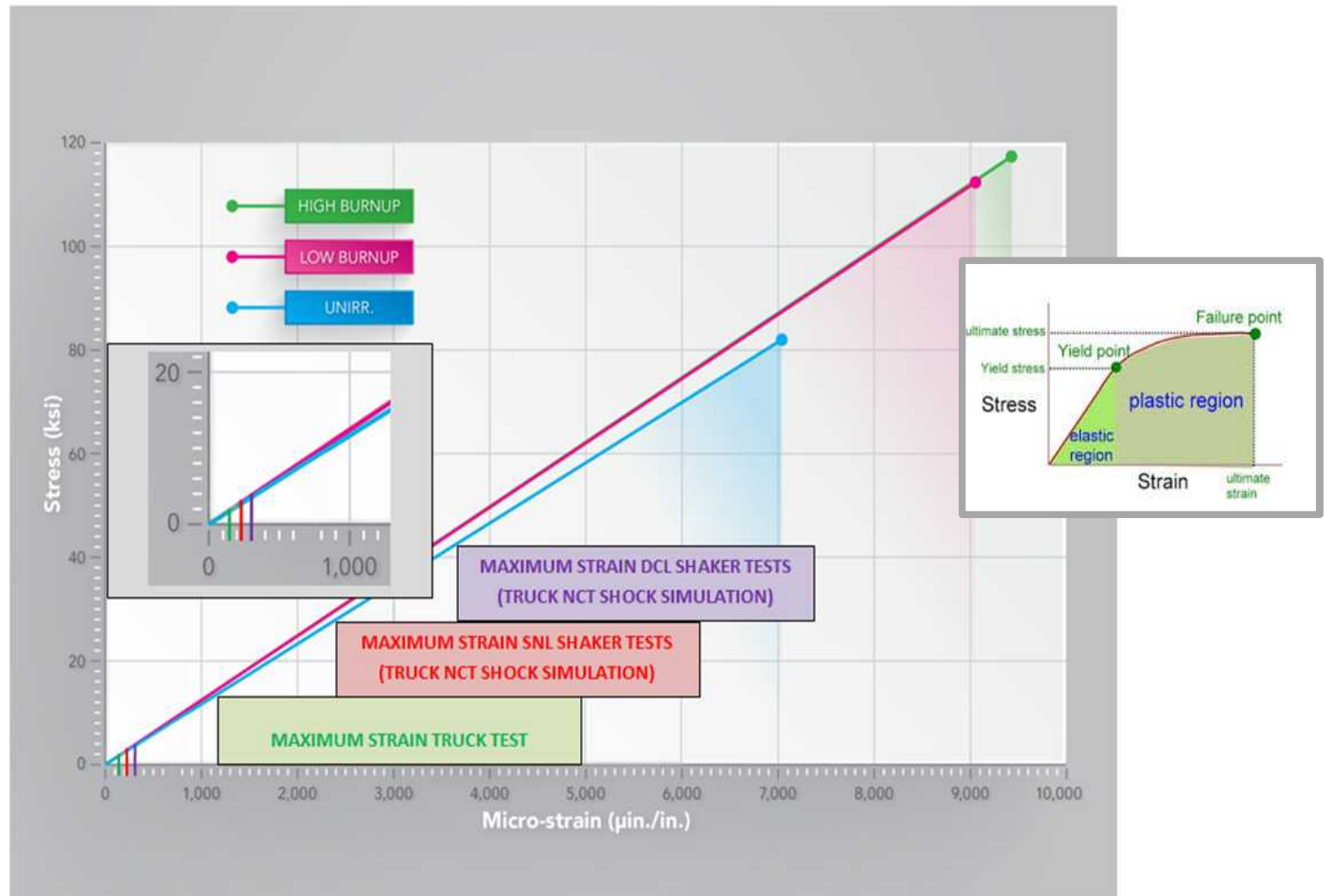
Comparison of Maximum Strains Measured in all Assembly Tests.

Data for the Rail-cask Tests is Preliminary

	SNL Assembly Vertical Shaker FY13	SNL Assembly Truck Test FY14	SNL Assembly Multi-axis Shaker FY15	ENSA Cask Heavy-Haul Truck Test FY17
Maximum truck shock micro-strain ($\mu\text{m}/\text{m}$)	119	143	160 - 301	97



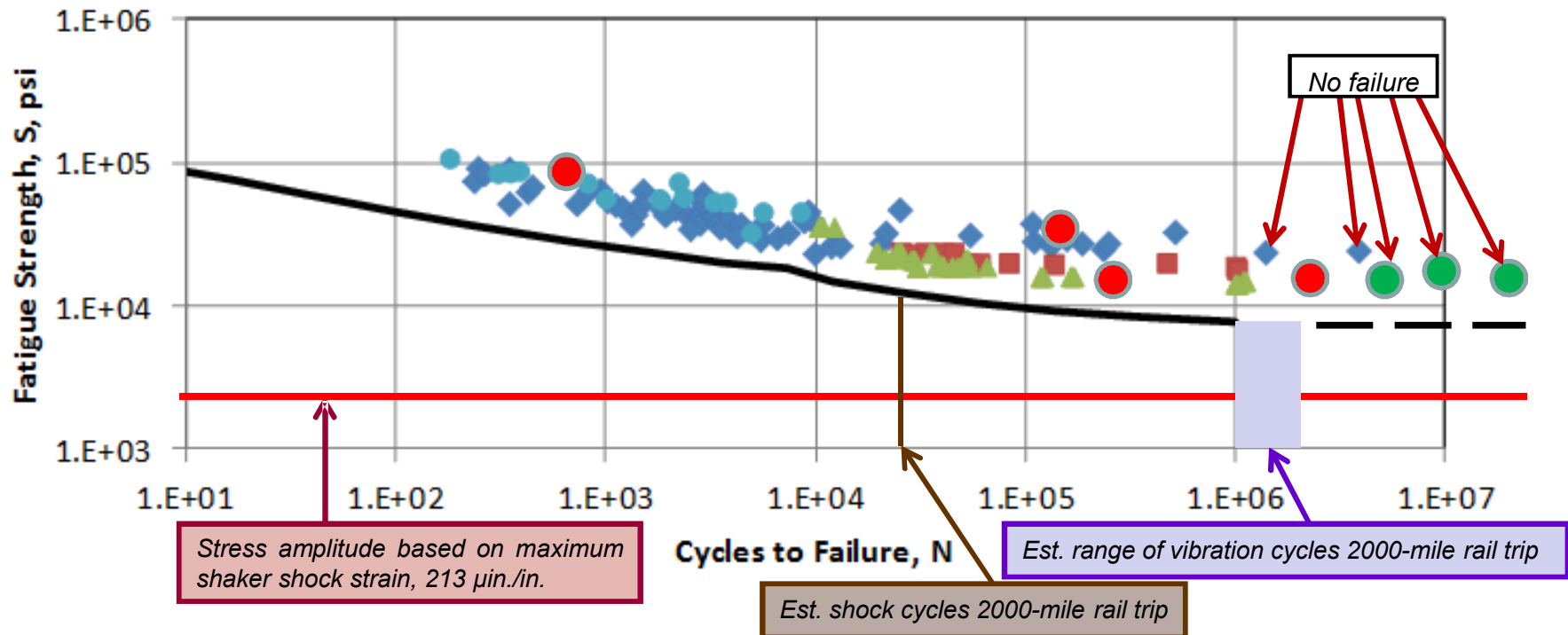
Transporting Spent Nuclear Fuel: *How do Stresses on Fuel During Normal Conditions of Transport Compare to Yield Points?*



McConnell et al, 2016, SNL and PNNL



Transporting Spent Nuclear Fuel: *Could Vibrations or Shocks Result in Fatigue Failure?*



Fatigue design curve (—): O'Donnel and Langer, "Fatigue Design Basis for Zircaloy Components," Nucl. Sci. Eng. 20, 1, 1964. (cited in NUREG-0800, Chapter 4)

Data plot courtesy of Ken Geelhood, PNNL
The large circles are ORNL HBR data

CONCLUSIONS

The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding. We only have limited rail data, which most likely will be the prevailing transportation mode.



Questions?

- The next year will be spent analyzing the data and developing a model that will allow us to relate these results to different storage and transportation systems.

Questions?