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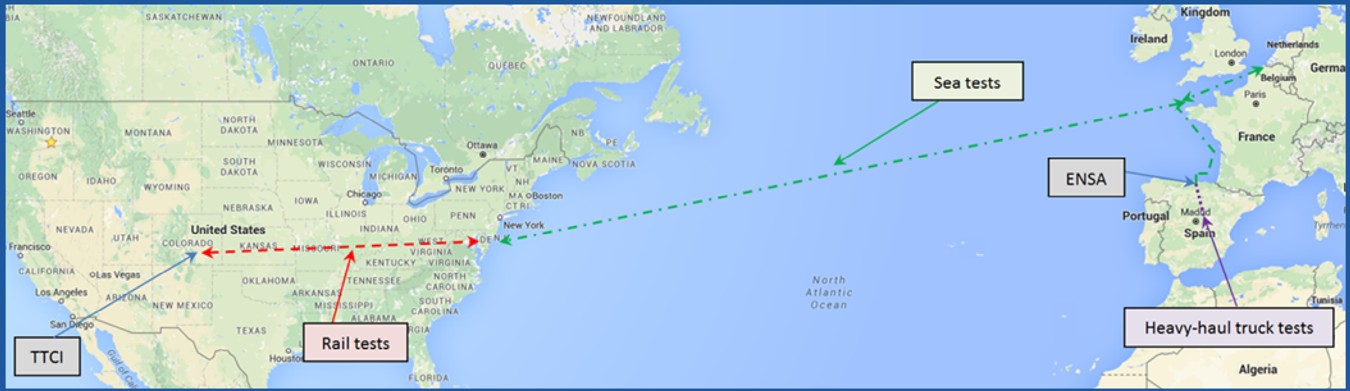
SAND2017-12057PE



DOE:NE SPENT FUEL & WASTE SCIENCE & TECHNOLOGY

ENSA / DOE transportation test summary:
Preliminary cask handling and rail coupling test results

EPRI ESCP

Charlotte, 14 November 2017

ENSA ENUN 32P Rail-Cask Test Team:

Sandia National Laboratories, Equipos Nucleares S.A., Pacific Northwest National Laboratory, Transportation Technology Center, Inc.

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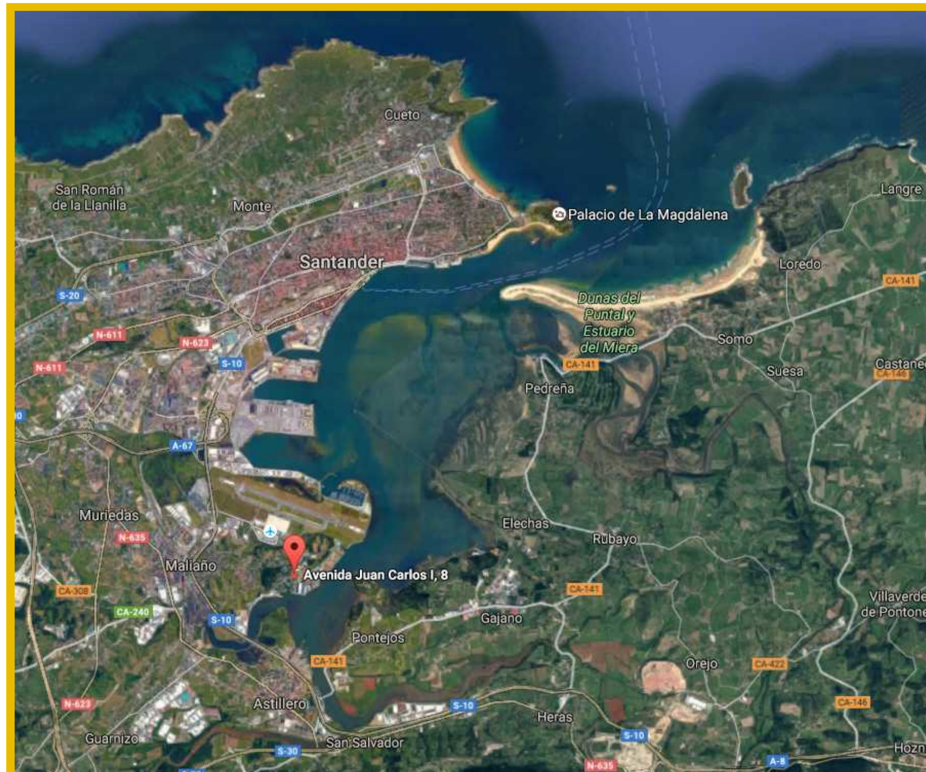
Equipos Nucleares S.A. Supplied an ENSA ENUN 32P Rail Cask for a Series of Transport Tests



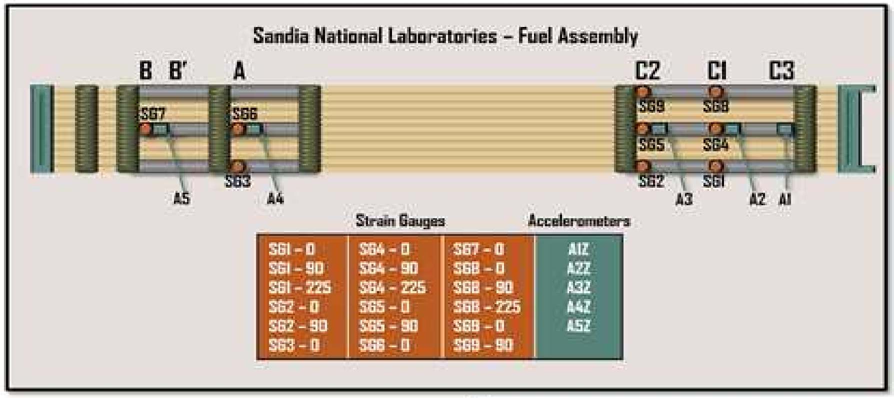
Why?
To measure strains and accelerations on a cask system when transporting fuel assemblies?

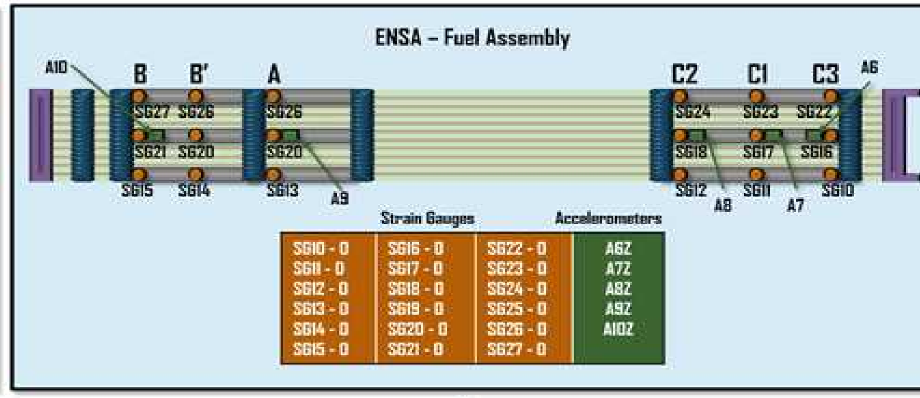
How do strains on fuel rods during Normal Conditions of Transport compare to failure limits of zirconium-alloy tubes?

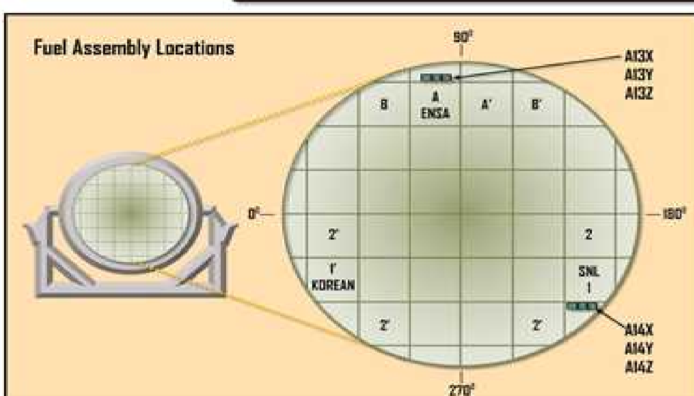
Could vibrations or shocks result in fatigue failure?

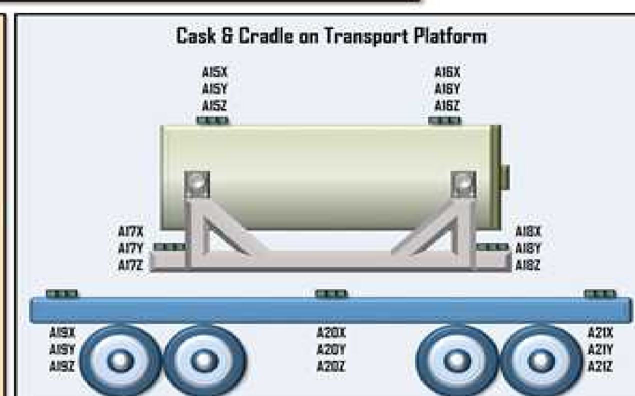
- Based on previous SNL tests, the stresses fuel rods experience due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding.
- But previous tests are only simulations of the configuration of *actual* SNF transport modes.

Surrogate assemblies from three countries and the cask system were instrumented with 77 accelerometers / strain gauges





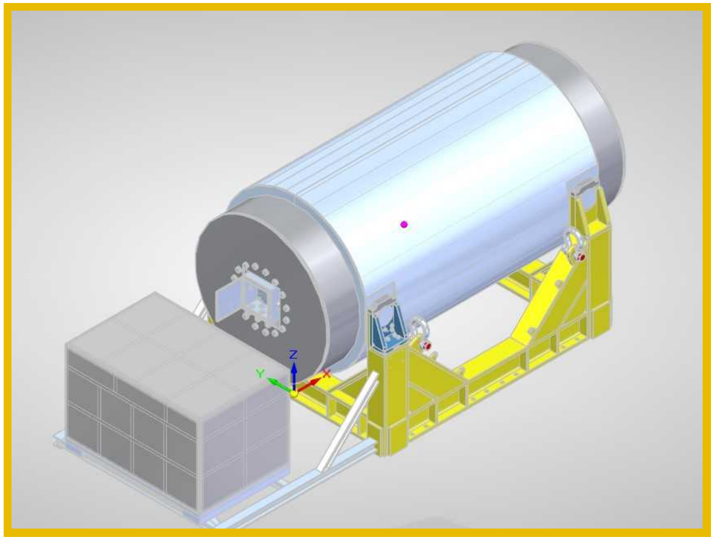




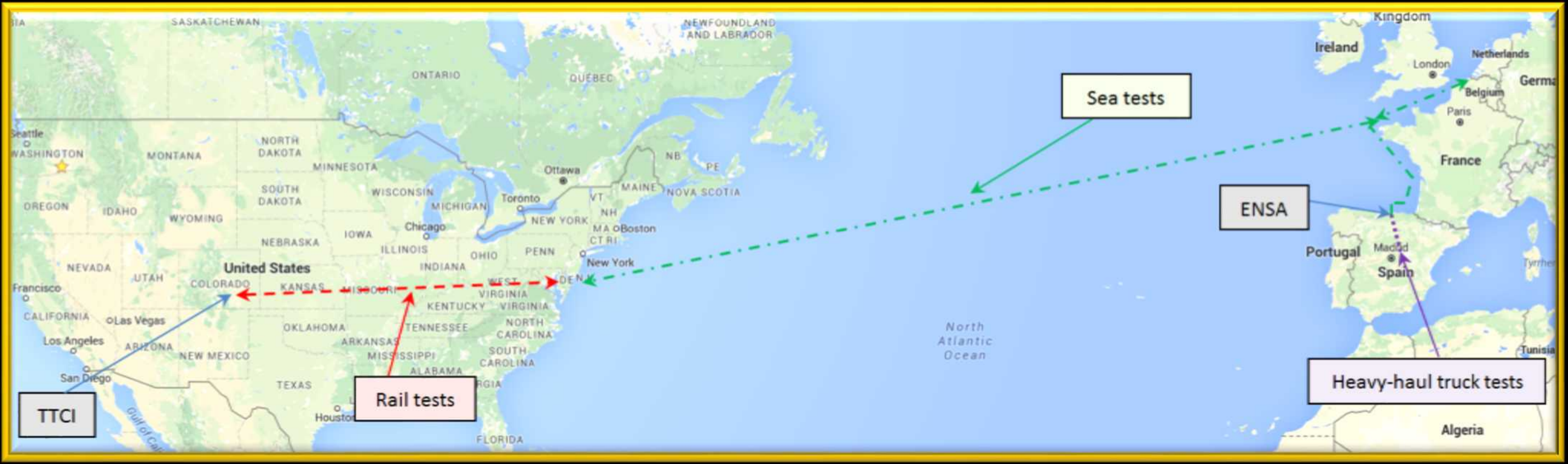
Instrumentation/Battery Box

Two 40-channel Data Acquisition Systems,
4000 lbs of Batteries, 1.17 Miles of Cable





Cask Test Route



- Cask handling tests at ENSA, June 2017
- Heavy-haul truck in northern SPAIN, June 2017
- Coastal sea shipment from Santander SPAIN to Zeebrugge BELGIUM, June 2017
- Ocean transport from Europe to Port of Baltimore, July 2017
- Commercial rail shipment from Baltimore to Pueblo, Colorado, July – August 2017
- Testing at the Transportation Technology Center, Inc., August 2017
- Commercial rail shipment back to Baltimore, August – October 2017
- Cask shipped to ENSA, October – November, 2017

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54 Days of Data Collection
101,857 ASCII data files; 6 Terrabytes of Data
9458 Miles, 7 Countries, 12 States

TEST	ROUTE					TRAVEL or TEST TIME (days)	DISTANCE (miles)
Cask Handling			ENSA Maliaño SPAIN			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	Avondale Colorado				6	~ 2000
TTCI	9 test days; 8 types of tests; 125 tests						
Rail 2	Pueblo Colorado	Baltimore Maryland				43 18 test days	2062 1125 test miles
Return Ship “Tarago”	Baltimore USA	Santander SPAIN via Zeebrugge BELGIUM	October 22 – November 02 – November 23, 2017 no data collection				
TOTAL TEST DAYS / MILES						54	9458

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. The cask was placed onto the concrete pad with varying degrees of force.

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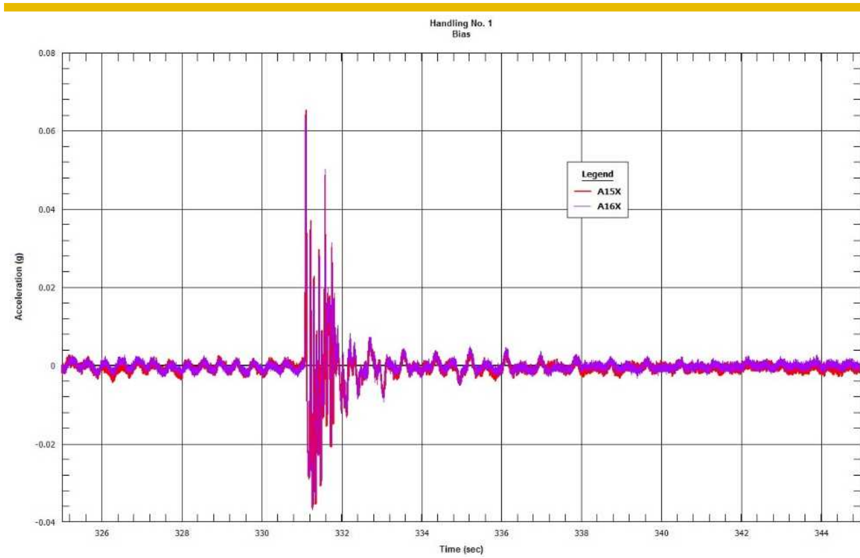
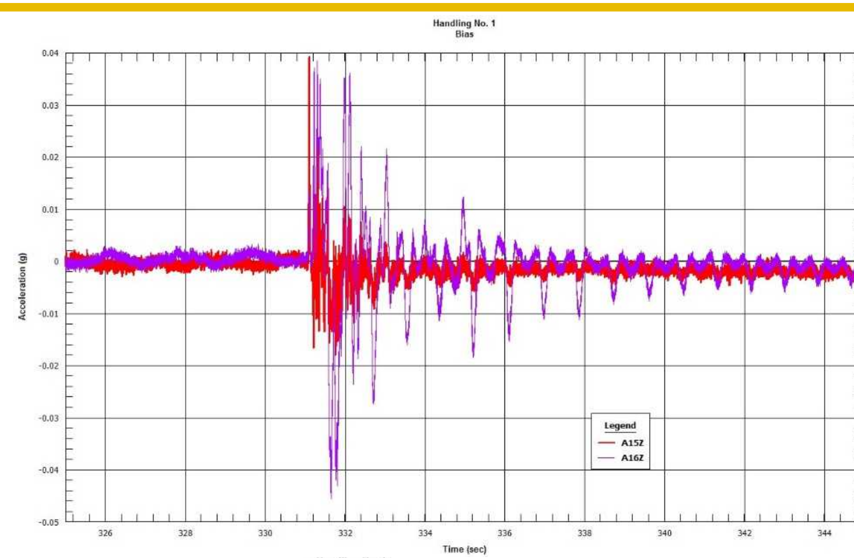
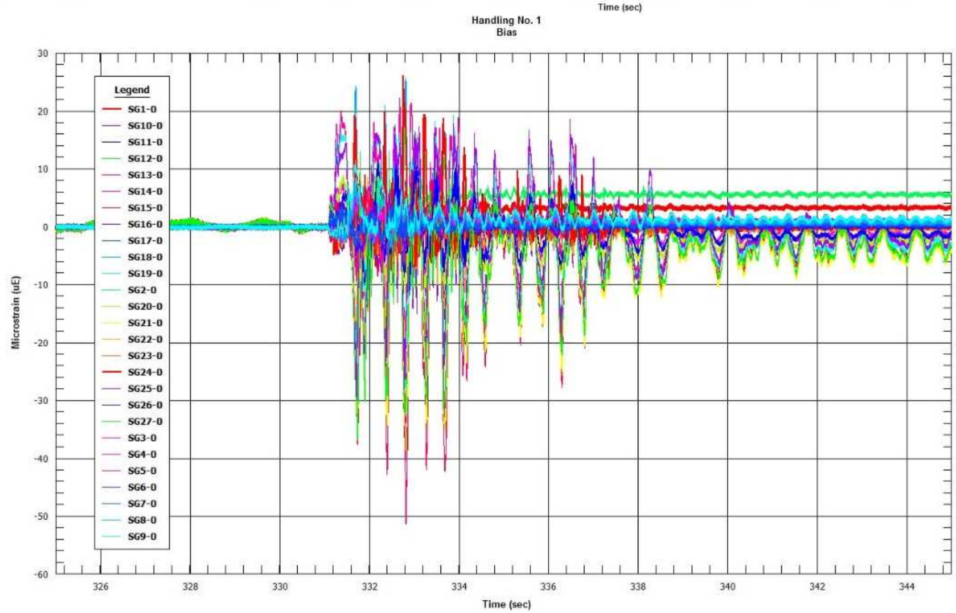
Cask Handling Test 1
accelerometer and strain gauge data

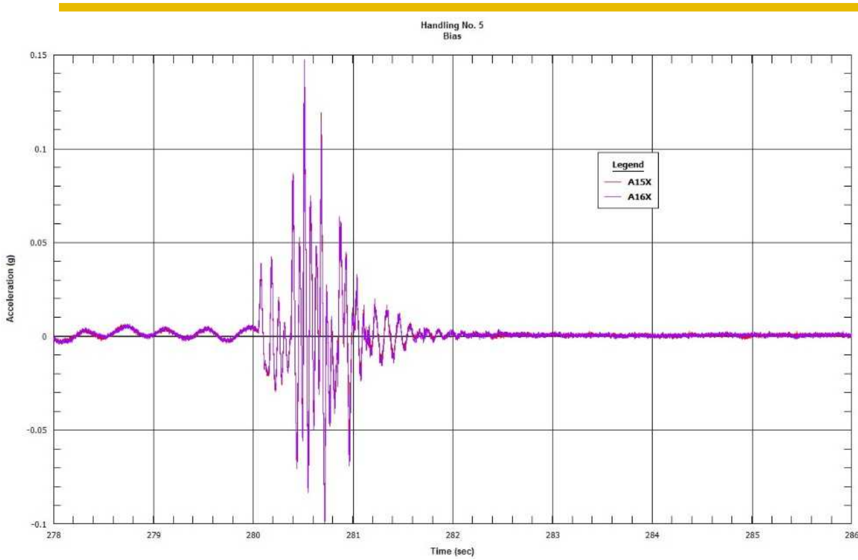
maximum cask acceleration = 0.08 g
maximum strain = 51 µm/m

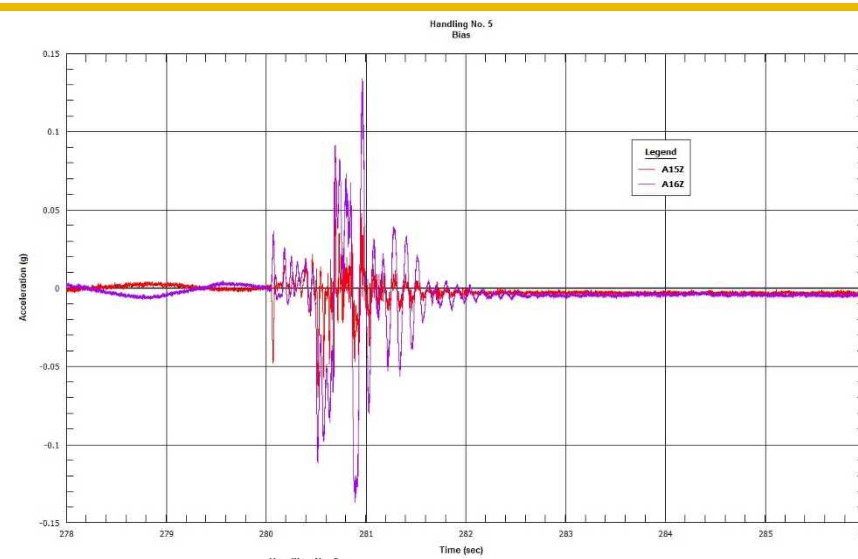


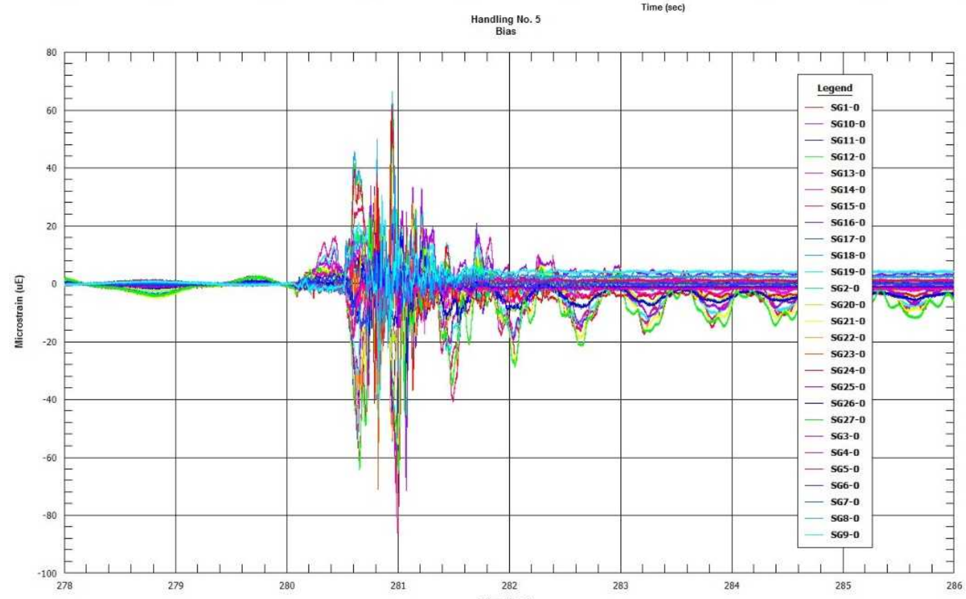




Cask Handling Test 5
accelerometer and strain gauge data
maximum cask acceleration = 0.15 g
maximum strain = 87 µm/m





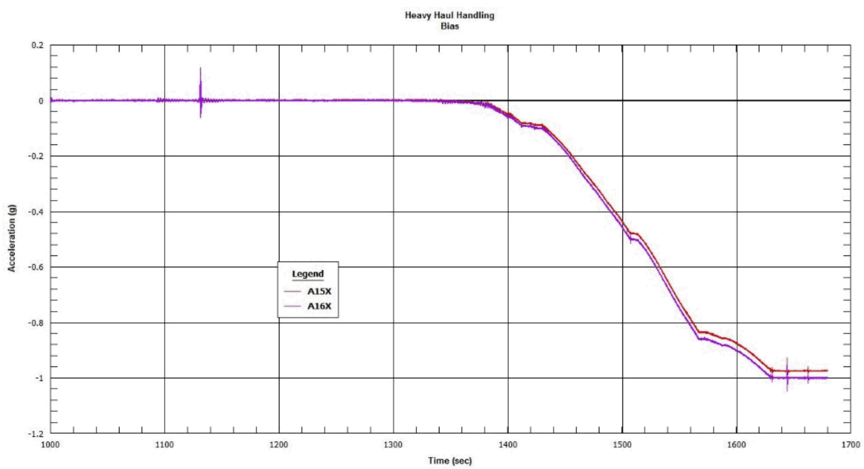


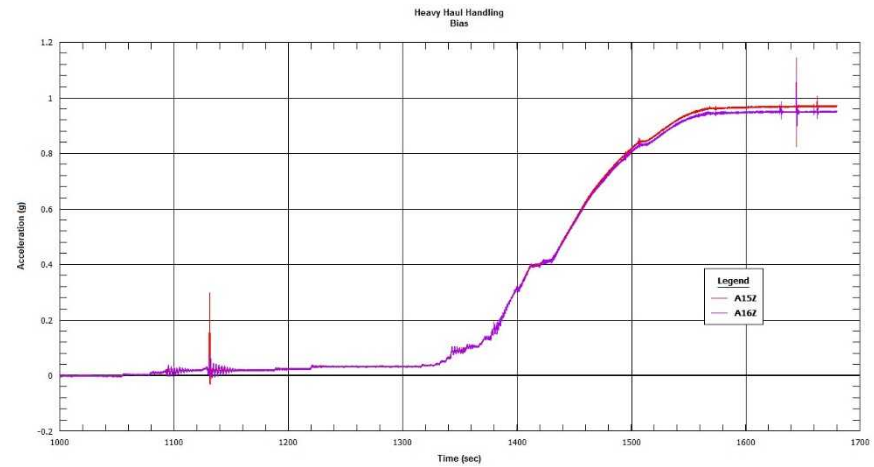
Placement of the battery and data acquisition box onto the cradle extension after placing cask onto cradle.

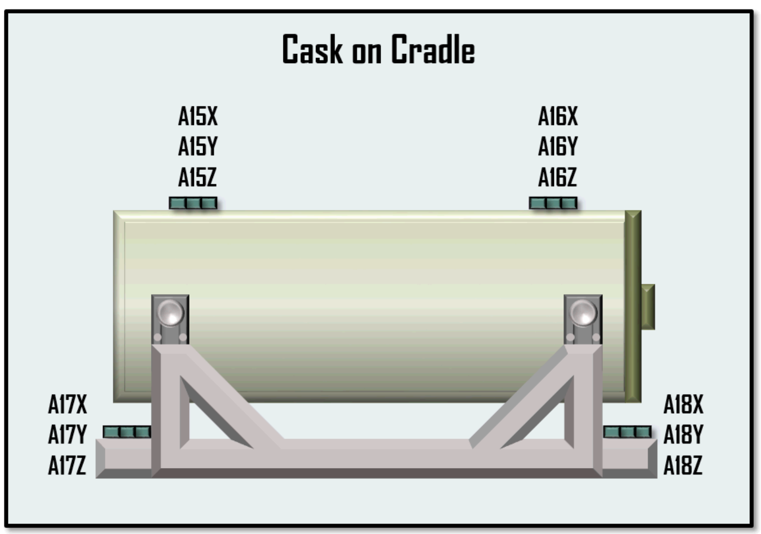
Cask onto Cradle Test accelerometer and strain gauge data

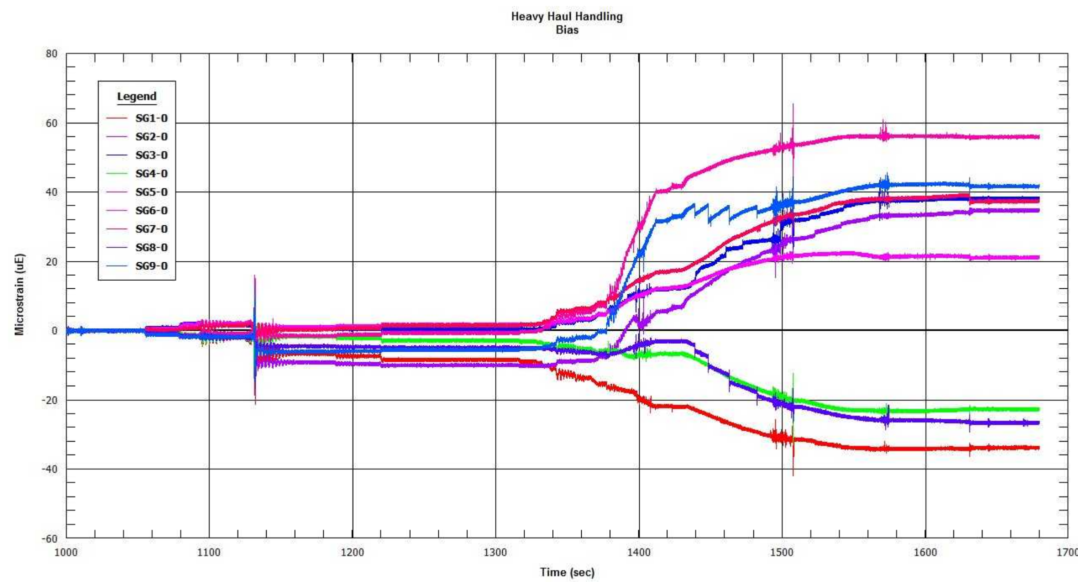
maximum cask acceleration = 1.30 g

maximum strain = 66 μm/m









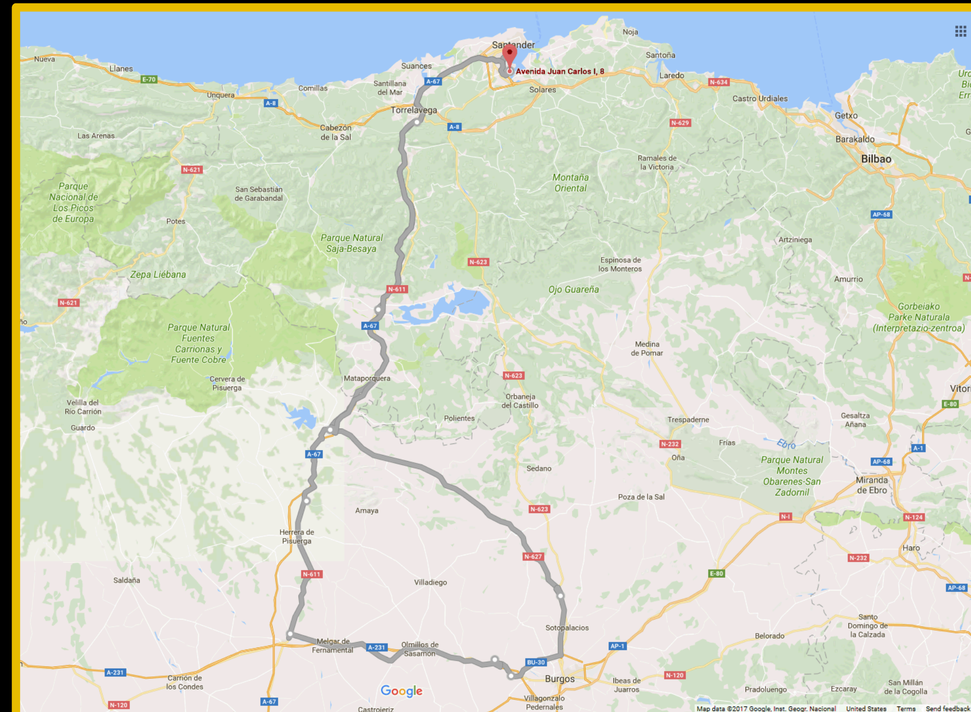
Summary of Cask Handling Test Data

	Handling Test 1	Handling Test 5	Cask onto Cradle
assembly	2.38 g / 51 με	9.68 g / 87 με	1.77 g / 66 με
nozzle	7.90 g	23.30 g	4.08 g
basket	1.76 g	8.50 g	1.90 g
cask	0.08 g	0.15 g	1.30 g

Accelerometers were placed on the basket, cask, cradle, and transport platforms as well as on the surrogate fuel assemblies.

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

Heavy-haul truck route through scenic northern SPAIN, Maliaño to Burgos



Many rotondas *needed to be negotiated…*

…and tiny villages

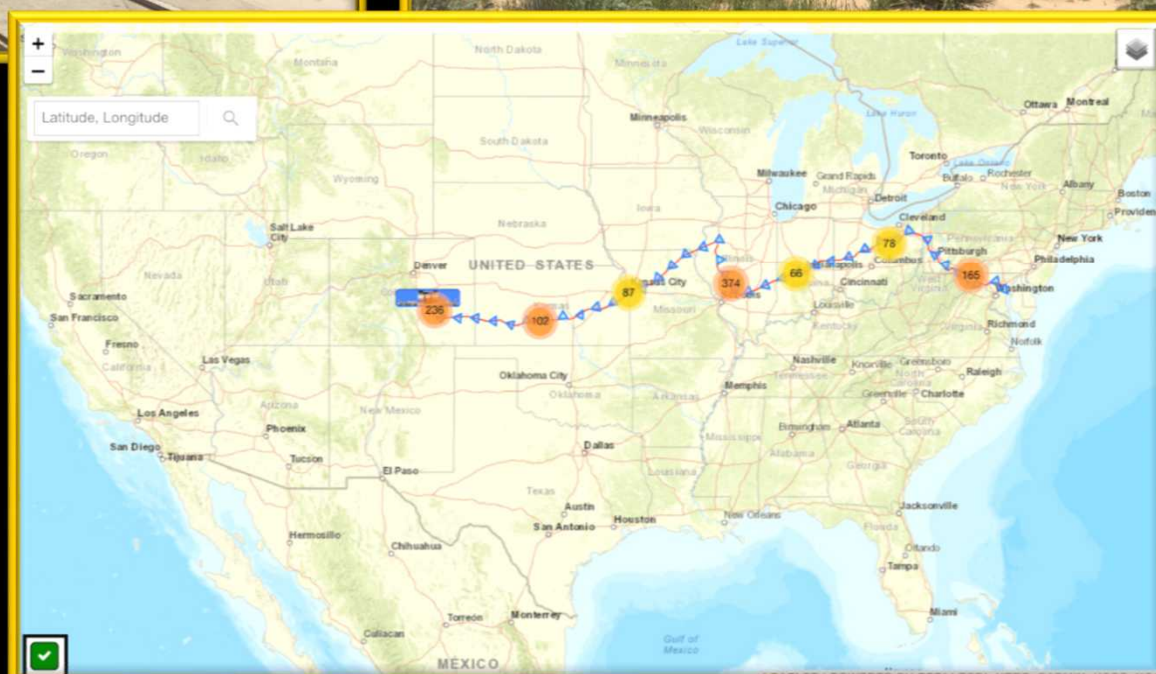
After heavy-haul truck test, cask was loaded onto the "Autosky" at Port of Santander

The system was then loaded onto “Tarago” at Port of Zeebrugge for transport to the USA.

Cask was then transferred onto a 12-axle Kasgro railcar at Mid-Atlantic Terminal, Baltimore

Witnessed by DOE, NRC, USCG

Cask was transported by rail to TTCI for a series of rail tests



Map from ANL
Traveler *GPS*

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Rail Tests Conducted at TTCI

- ***TWIST & ROLL TESTS (18)*** – determines the car's ability to negotiate oscillatory cross-level perturbations.
- ***PITCH & BOUNCE TESTS (9)*** – determines the car's ability to negotiate parallel vertical rail perturbations.
- ***DYNAMIC CURVING TESTS (25)*** – 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.
- ***TESTS AT U.S. ARMY PUEBLO CHEMICAL DEPOT (17)*** – determines performance over FRA Class-2 railroad track and tests through No. 8 turnout and No. 8 crossovers.
- ***SINGLE BUMP TESTS (12)*** – 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.
- ***CROSSING DIAMOND TESTS (6)*** – determines the vehicle's behavior when crossing diamonds (or "frogs'), a leading cause of derailments.
- ***LOADED HUNTING ON RAILROAD TEST TRACK AND ON TRANSIT TEST TRACK (30)*** – determines stability at 30, 40, 50-75 mph at 5 mph increments
- ***COUPLING IMPACT TESTS (10)*** – determines longitudinal inputs from coupling at higher than normal speeds.

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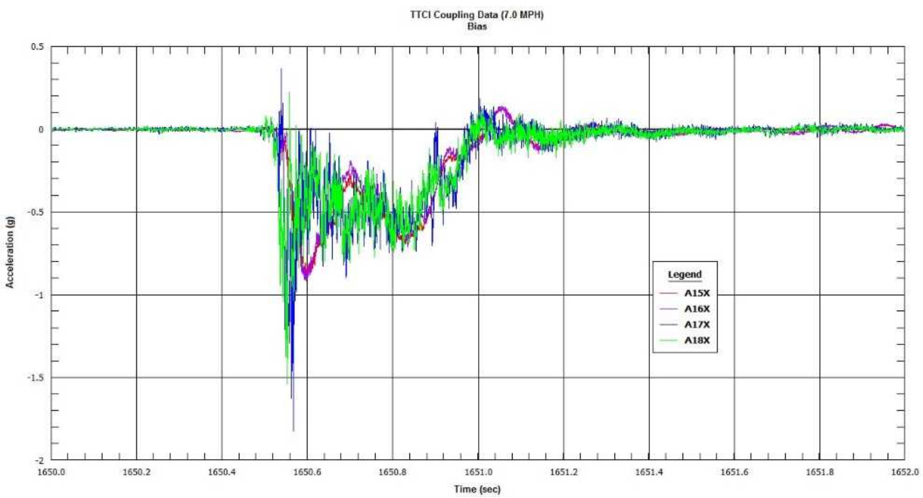
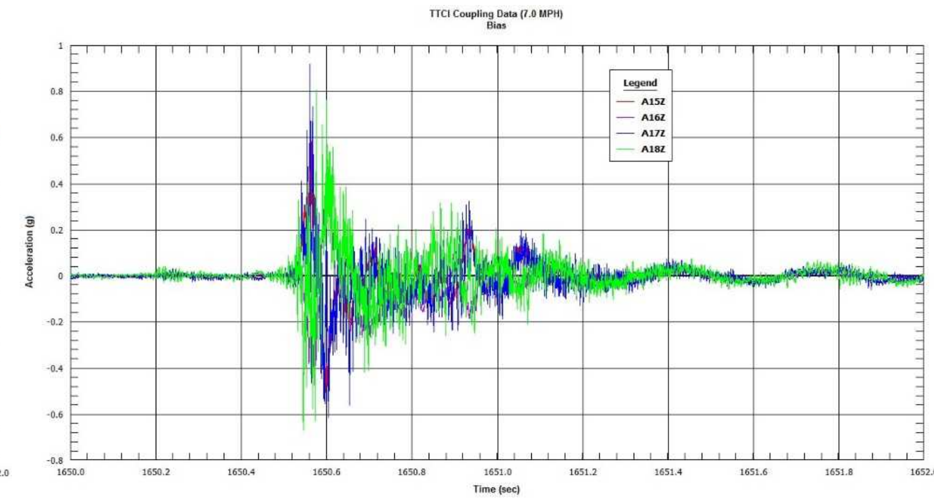
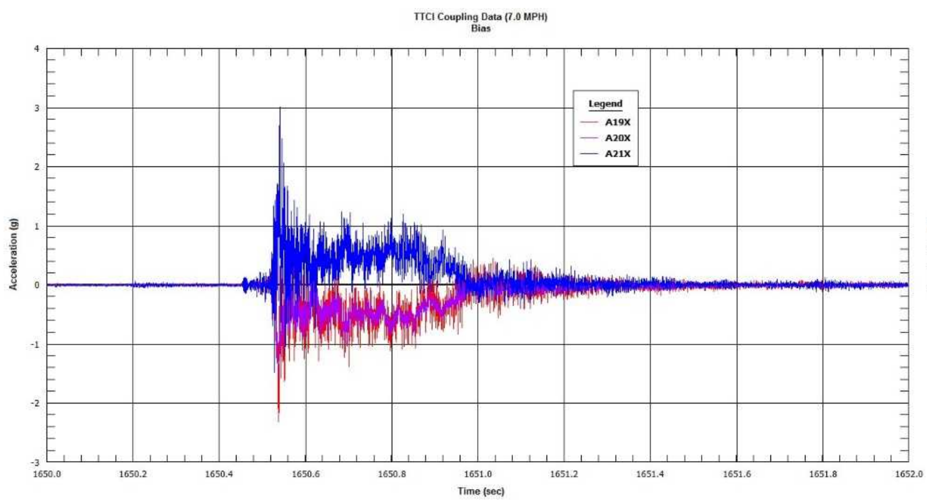
Railcar Coupling 7 mph accelerometer data

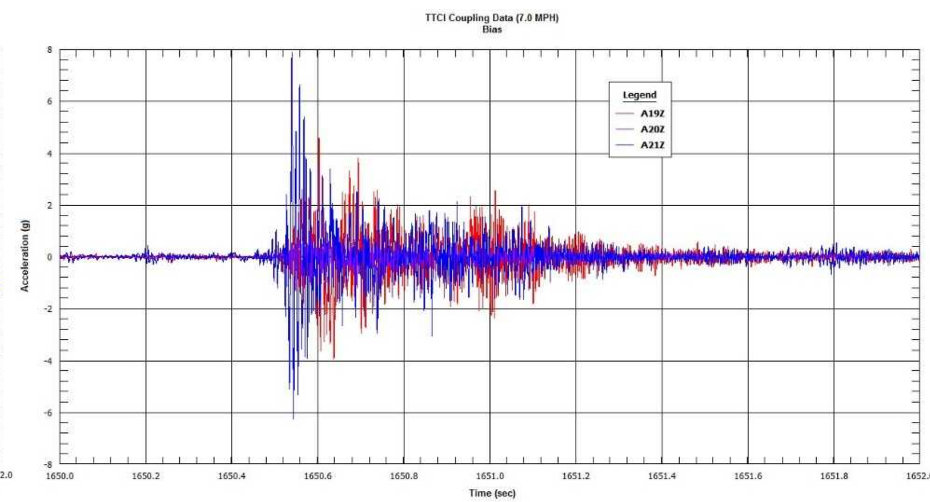
maximum cask acceleration = 0.92 g

maximum railcar acceleration = 7.90 g



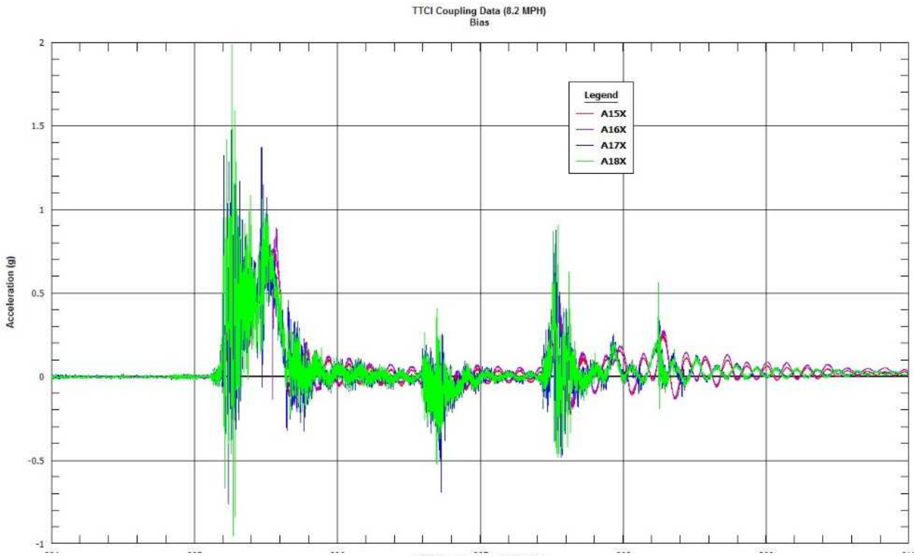


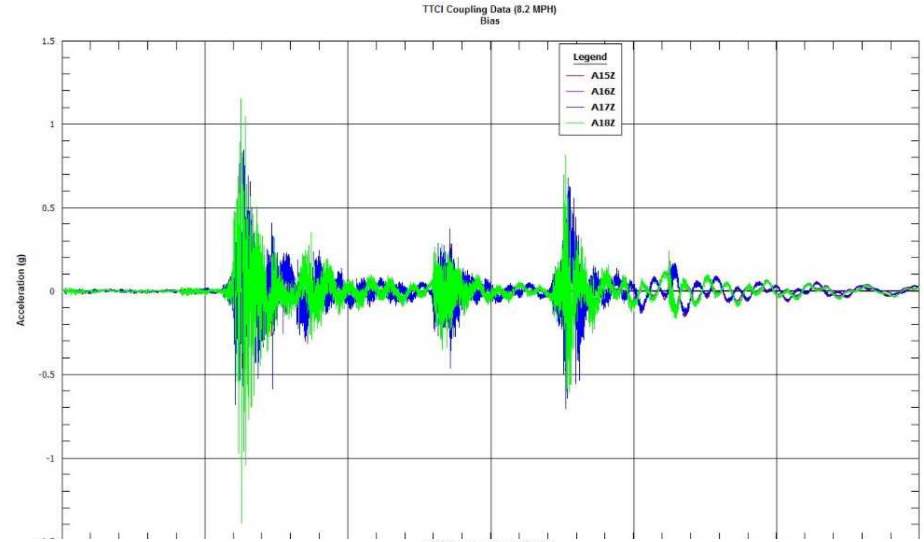


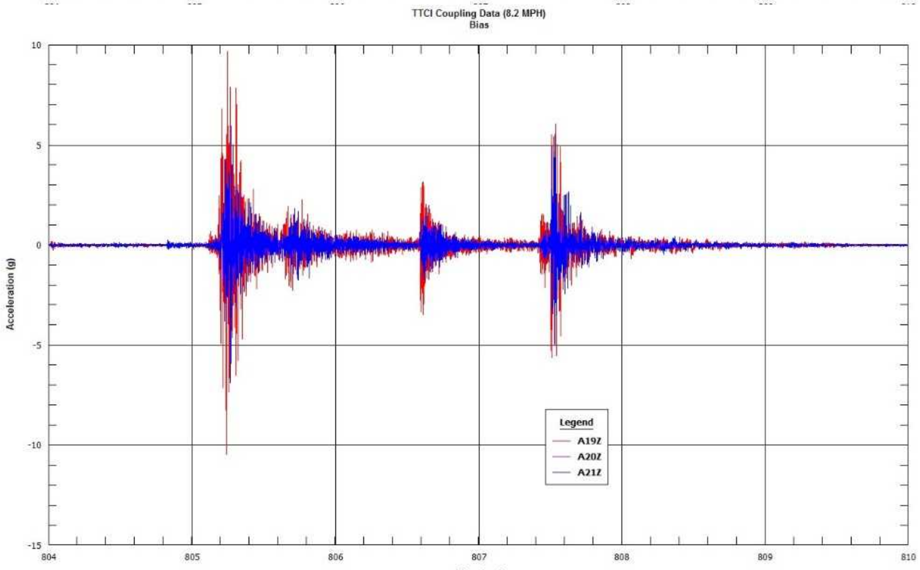


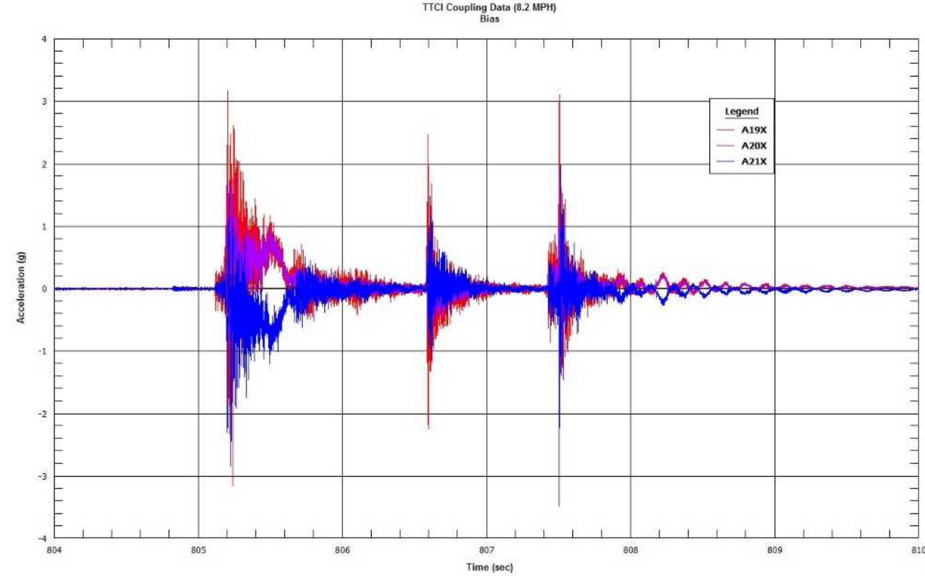
Railcar Coupling 8.2 mph accelerometer data

maximum cask acceleration = 0.89 g
maximum railcar acceleration = 10.40 g



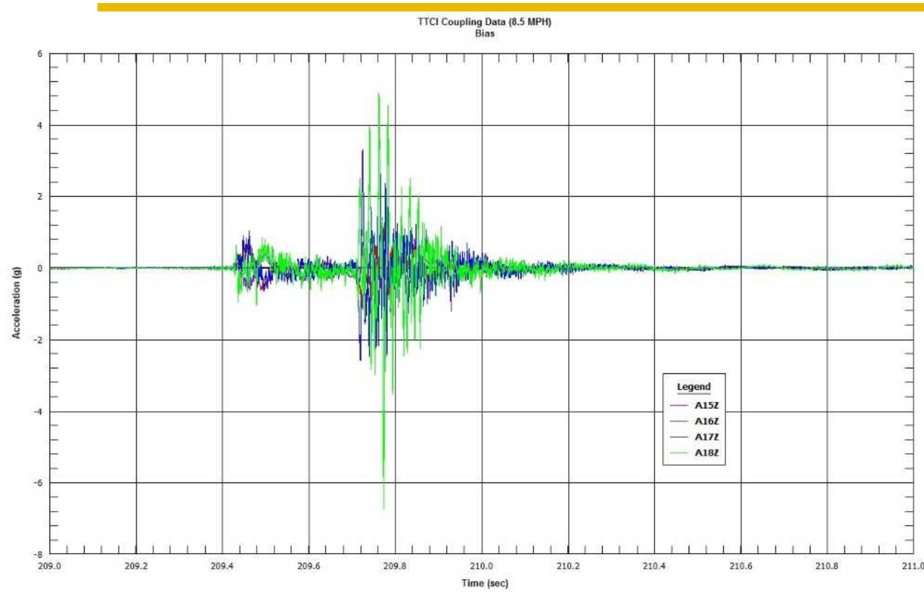


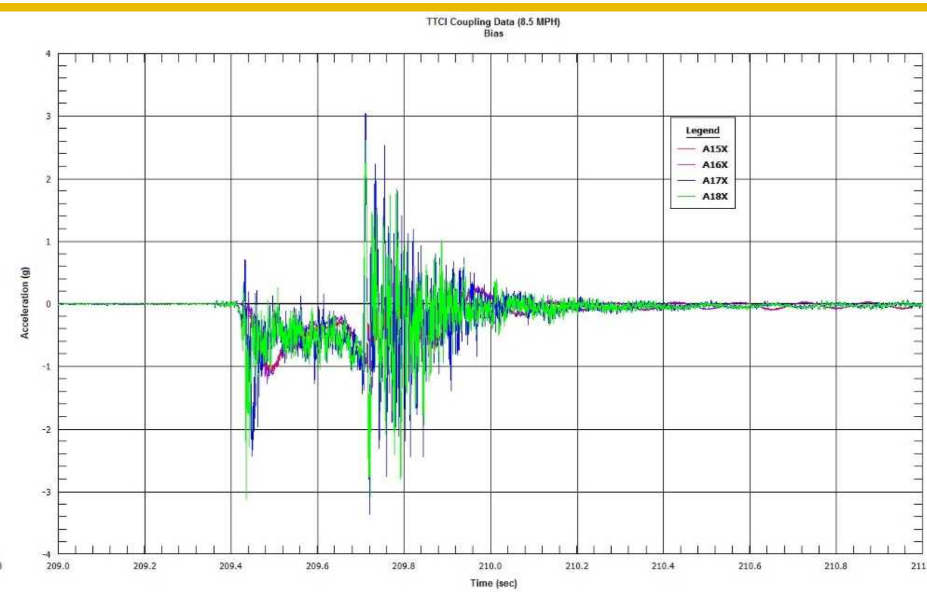


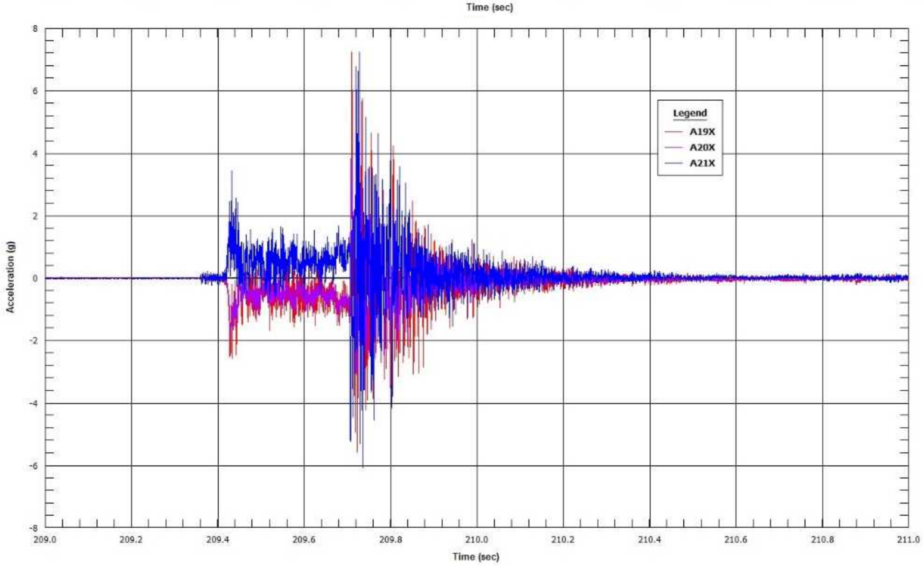


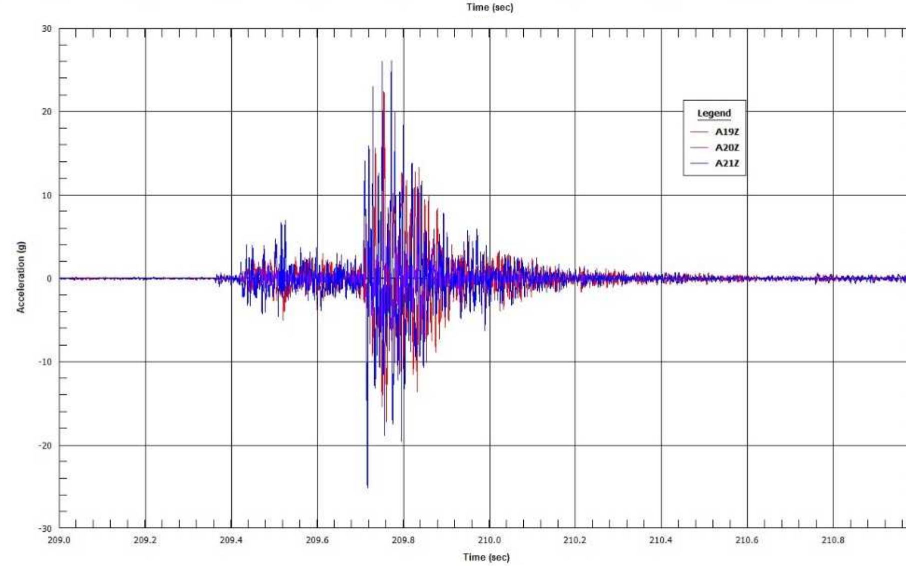
Coupling 8.5 mph accelerometer data

maximum cask acceleration = 1.40 g
maximum railcar acceleration = 26.1 g









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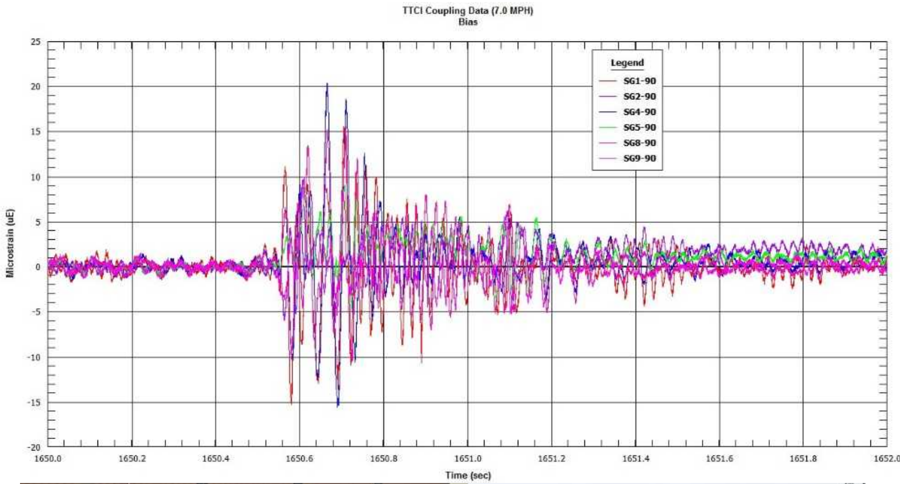
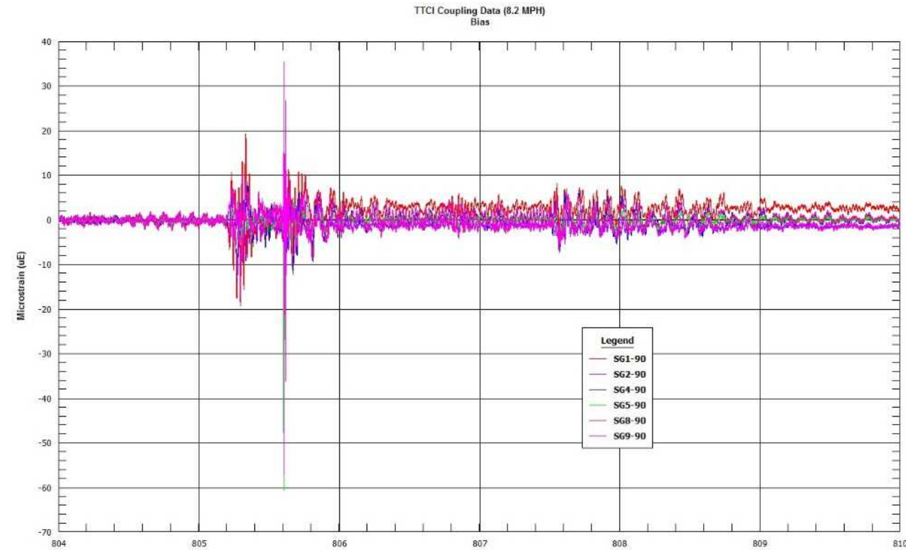
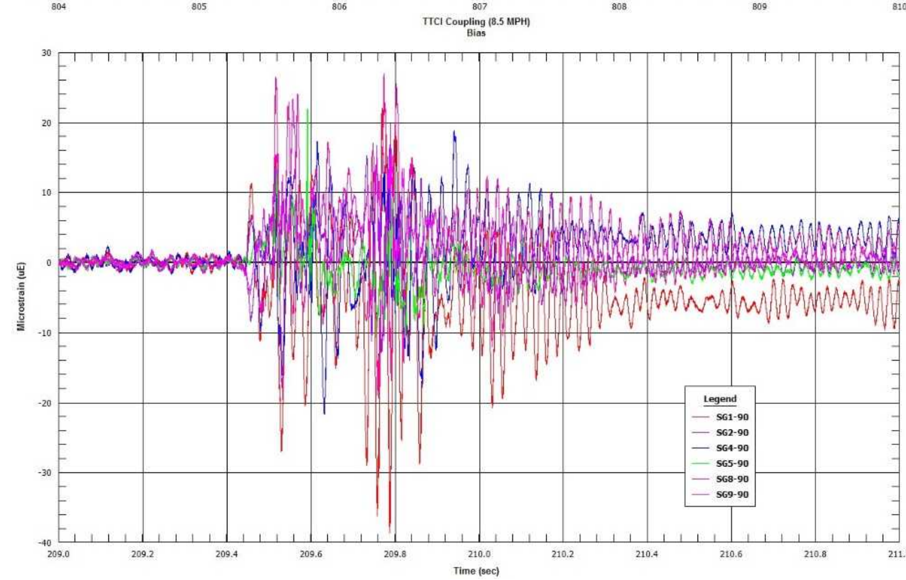
Railcar Coupling at 7, 8.2, 8.5 mph
SNL assembly strain gauge data
maximum strains = 39, 92, 77 μm/m







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Accelerations on system during three rail coupling tests, g

	7.0 MPH	8.5 MPH	8.2 MPH
assembly	1.72	10.60	10.10
basket	0.82	1.80	0.76
cask	0.59	1.30	0.89
cradle	0.92	6.70	1.99
railcar			
19X	2.31	7.30	3.18
19Z	4.60	22.4	10.40
20X	1.57	3.90	1.89
20Z	1.55	7.60	2.67
21X	3.00	7.20	3.50
21Z	7.90	26.1	6.90

8.2 MPH test was “backward” i.e., top of the cask was pointed away from coupling impact

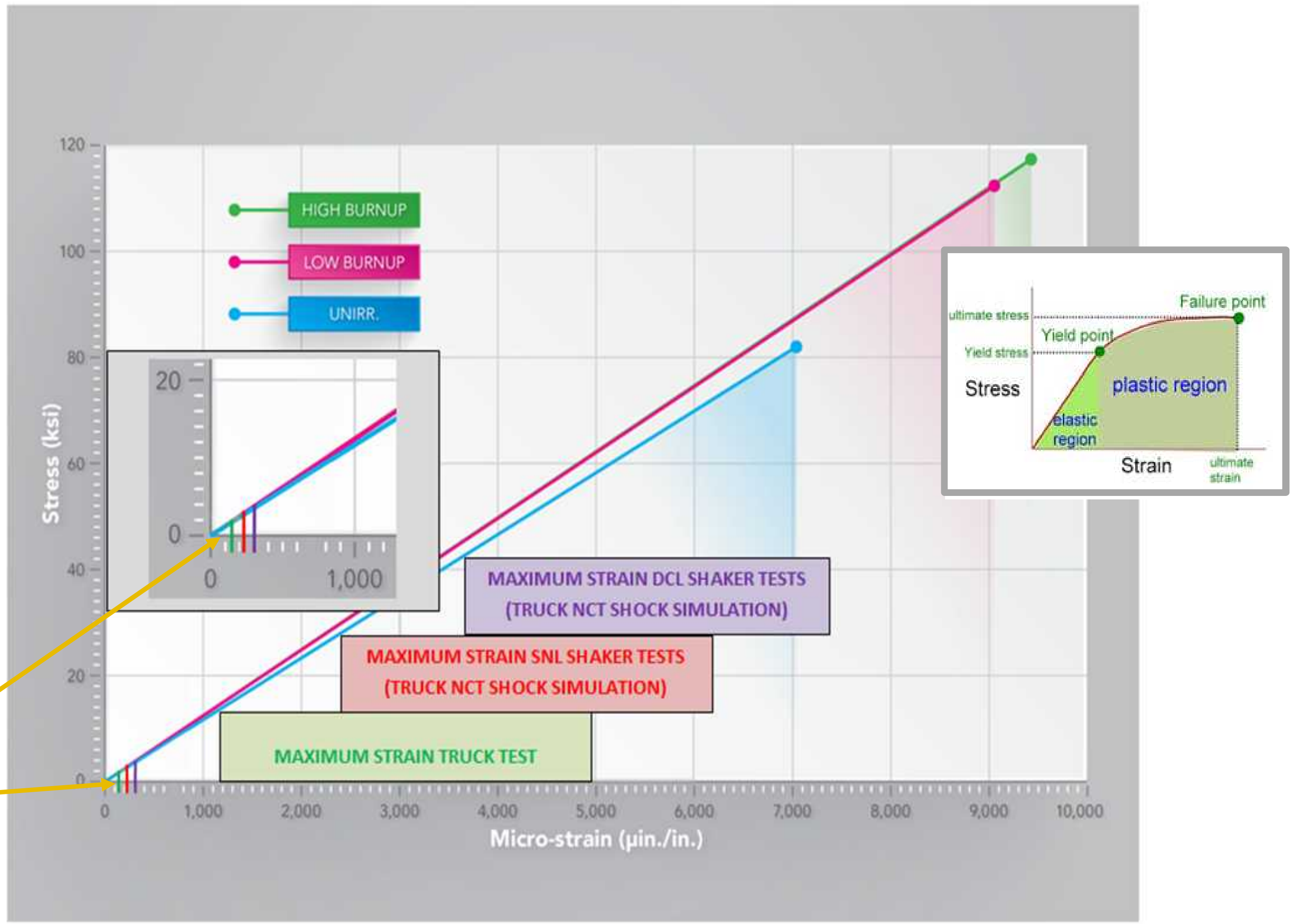
Comparison of Maximum Strains Measured in all Assembly Tests

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 (μm/m)	119	143	160 - 301	97*

** The 97 με is the maximum strain observed in all of the ENSA ENUN 32P tests. Measured during heavy-haul truck test.*

Strains in Rail-Cask Tests All Less than 100 µm/m
Similar to previous assembly tests



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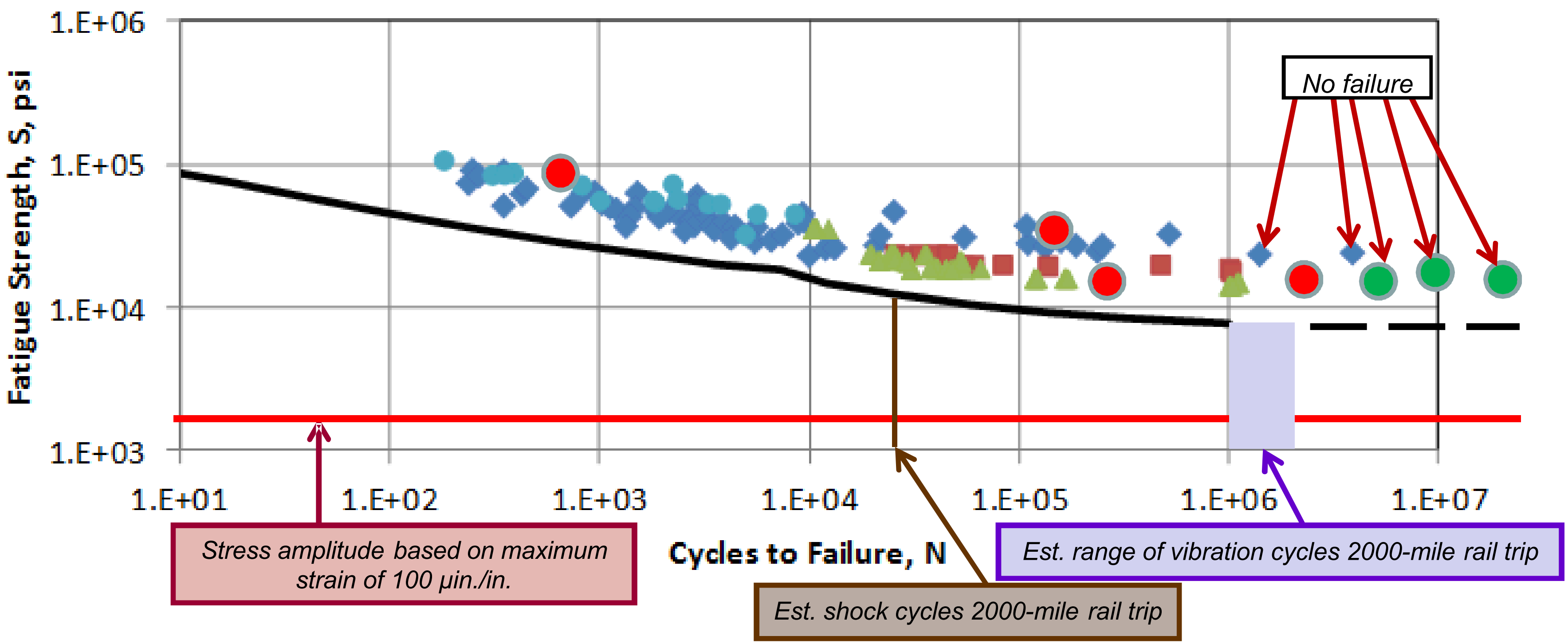
Transporting Spent Nuclear Fuel: *Could Vibrations or Shocks Result in Fatigue Failure?*



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

The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding.

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FY18 will be spent analyzing the data and modeling that will allow us to relate these results to different casks and transportation systems.

Questions?