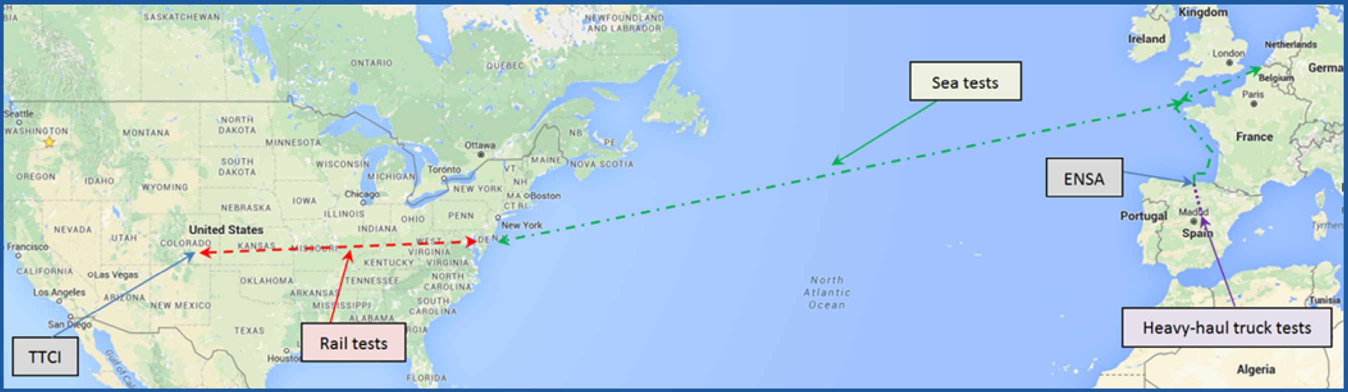
U.S. DEPARTMENT OF ENERGY | Nuclear Energy

SAND2018-2594PE



DOE:NE SPENT FUEL & WASTE SCIENCE & TECHNOLOGY

ENSA/DOE Multi Modal Transportation Tests Preliminary Results

BAM/SNL Collaboration Meeting

Sylvia Saltzstein, **Paul McConnell, Steve Ross, Doug Ammerman, Brady Hanson, Elena Kalinina, Alejandro Palacio, Woo Seok Choi, et al.**

Sandia National Laboratories,

Equipos Nucleares S.A.,

Pacific Northwest National Laboratory, Transportation Technology Center, Inc.

Korea Radioactive Waste Agency (KORAD) & KAERI

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. SAND2018-0677C

• 54 Days Data Collection (101,857 ASCII Files) •
• 8 Terabytes of Data • 4 Transport Modes •
• 9458 Miles • 7 Countries • 12 States •

The ENSA/DOE Multi-Modal Transportation Test using the ENSA ENUN 32P Cask

Why These Tests?

Measure Strains/Accelerations on Cask System Transporting Fuel Assemblies

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

- **Data will provide technical basis for asserting safety inherent in transporting spent fuel under normal conditions of transport.**
- **Could vibrations or shocks result in fatigue failure?**
  - ✓ ***Based on previous SNL tests, strains fuel rods experience due to vibration and shock during normal conditions of transport are far below yield strength and fatigue limits for cladding.***
- **Previous tests only simulations of configuration of actual SNF transport modes.**

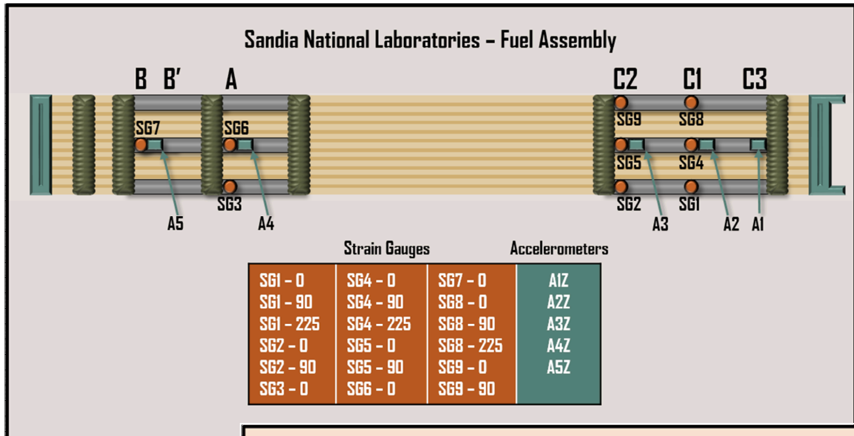
U.S. DEPARTMENT OF
ENERGY
Nuclear Energy

Cask Test Participants

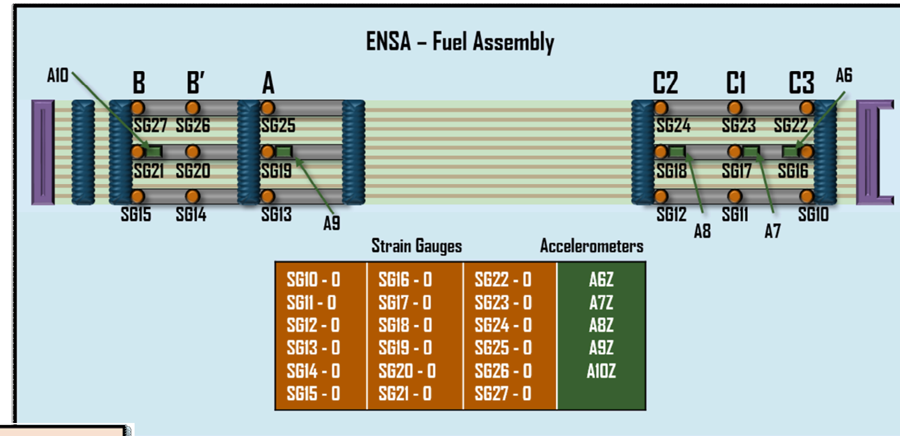
- U.S. Department of Energy
- Equipos Nucleares Sociedad Anónima (ENSA)
- Empresa Nacional de Residuos Radiactivos S.A. (ENRESA)
- ENUSA Industrias Avanzandas S.A.
- Coordinadora Internacional de Cargas, S.A.
- Sandia National Laboratories (SNL)
- Pacific Northwest National Laboratory (PNNL)
- Transportation Technology Center, Inc.
- Korea Radioactive Waste Agency (KORAD)
- Korea Atomic Energy Research Institute (KAERI)
- Korea Nuclear Fuel Company Ltd. (KNFC)
- Argonne National Laboratory (ANL)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

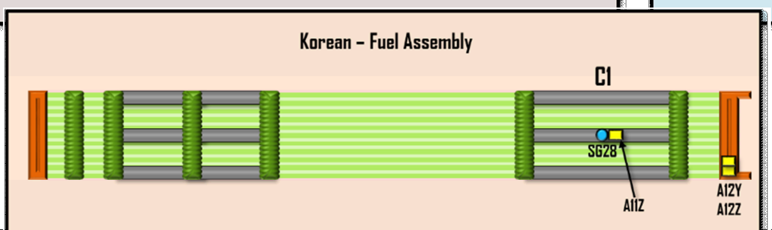
Accelerometer and Strain Gauge Locations

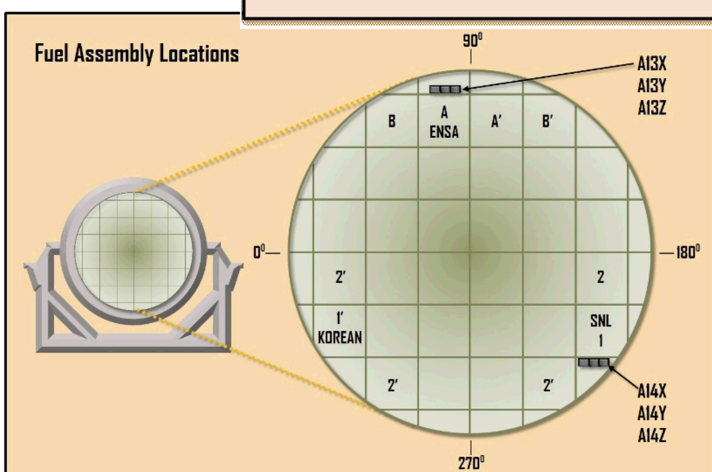


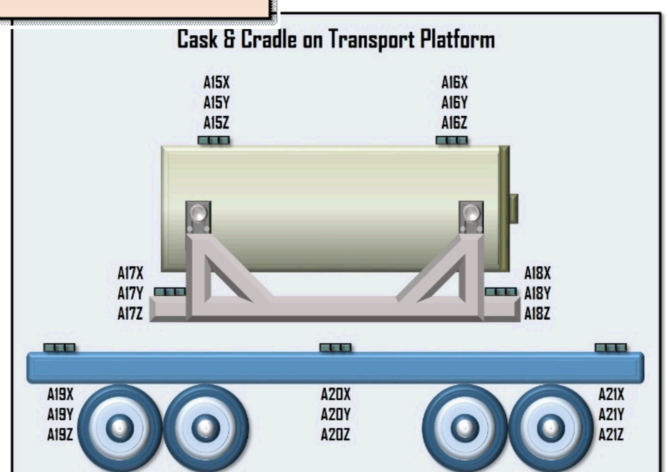
Strain Gauges			Accelerometers
SG1 - 0	SG4 - 0	SG7 - 0	A1Z
SG1 - 90	SG4 - 90	SG8 - 0	A2Z
SG1 - 225	SG4 - 225	SG8 - 90	A3Z
SG2 - 0	SG5 - 0	SG8 - 225	A4Z
SG2 - 90	SG5 - 90	SG9 - 0	A5Z
SG3 - 0	SG6 - 0	SG9 - 90	



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	

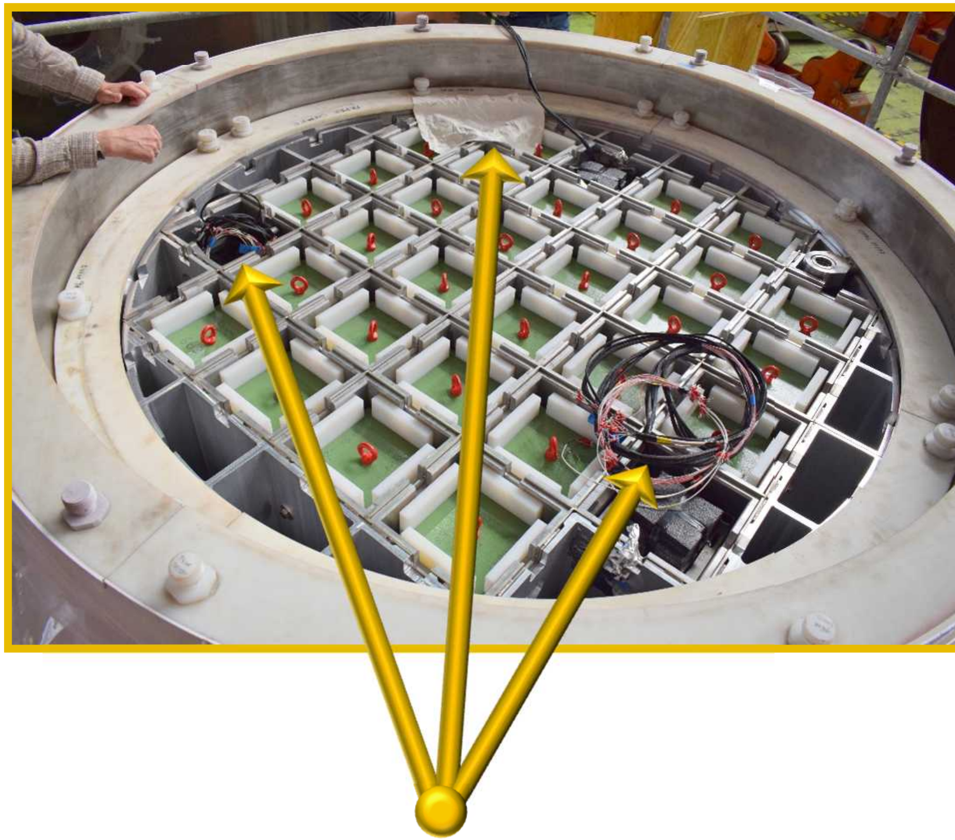






Assemblies & Cask System Instrumented with 77 Accelerometers & Strain Gauges

32P Cask Basket

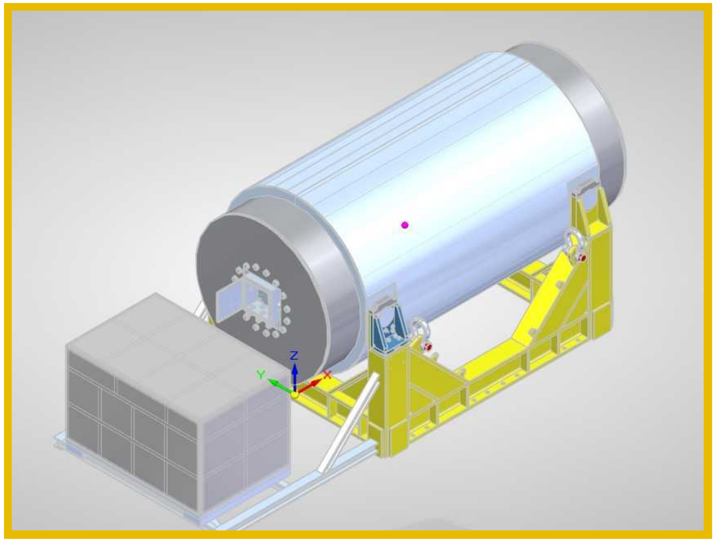


Locations of the 3 PWR assemblies plus 29 dummy assemblies
(Informed by PNNL Modeling)

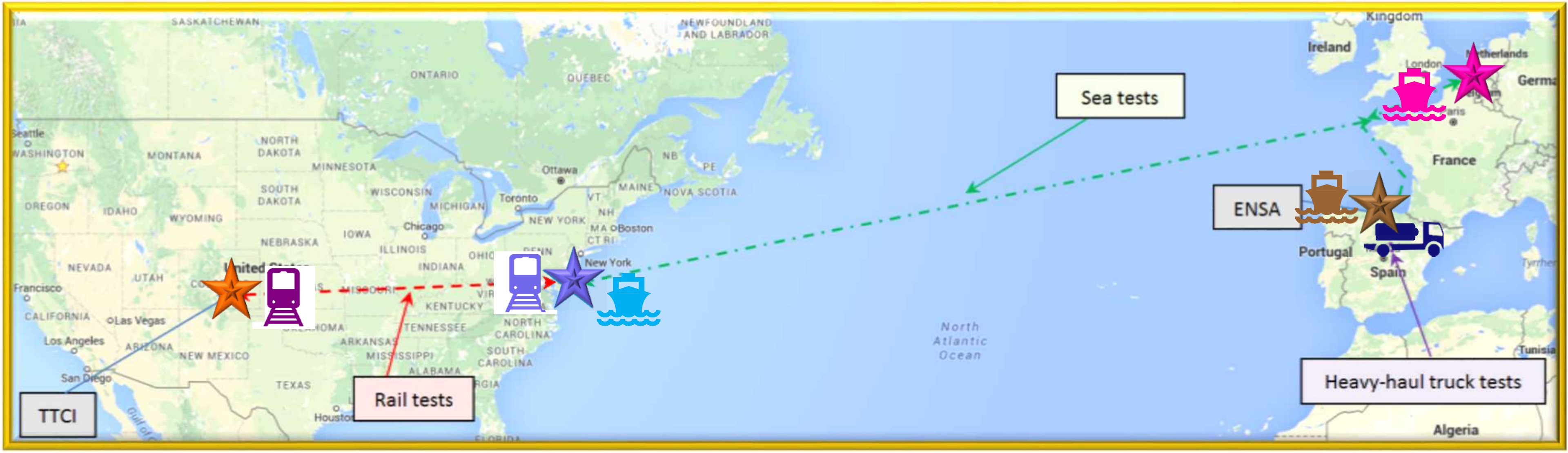
Lid being placed on cask

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, Santander/Spain (JUN 2017, 1 day)

Heavy-haul truck tests in northern Spain (JUN 2017, 2 days, 245 miles)

Ocean transport from Spain to Belgium (JUN 2017, 4 days, 939 miles)

Ocean transport from Belgium to Baltimore (JUL 2017, 14 days, 4222 miles,)

Rail shipment from Baltimore to Pueblo (AUG 2017, 6 days, 2000 miles)

Testing at Transportation Technology Center, Inc., Pueblo (AUG 2017, 9 test days; 8 types of tests; 125 tests)

Rail shipment from Pueblo to Baltimore (OCT 2017, 43 travel days, 18 test days, 1125 test miles)

Ocean transport from Baltimore to Spain (DEC 2017, no data collected)

Cask handling tests performed in Spain by three different crane operators experienced in dry cask movement.

Each operator performed three tests.

Cask placed onto concrete pad with varying degrees of force.

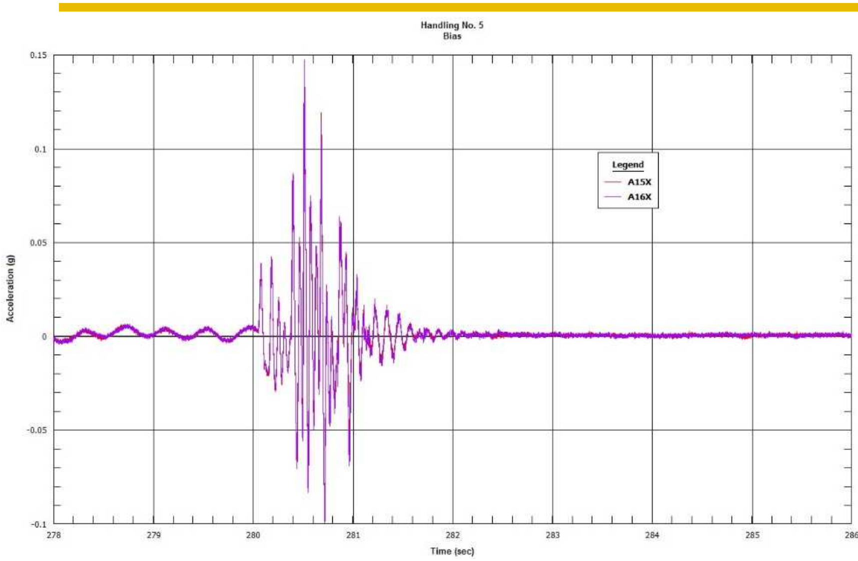
Preliminary Cask Handling Test Accelerometer & Strain Gauge Data

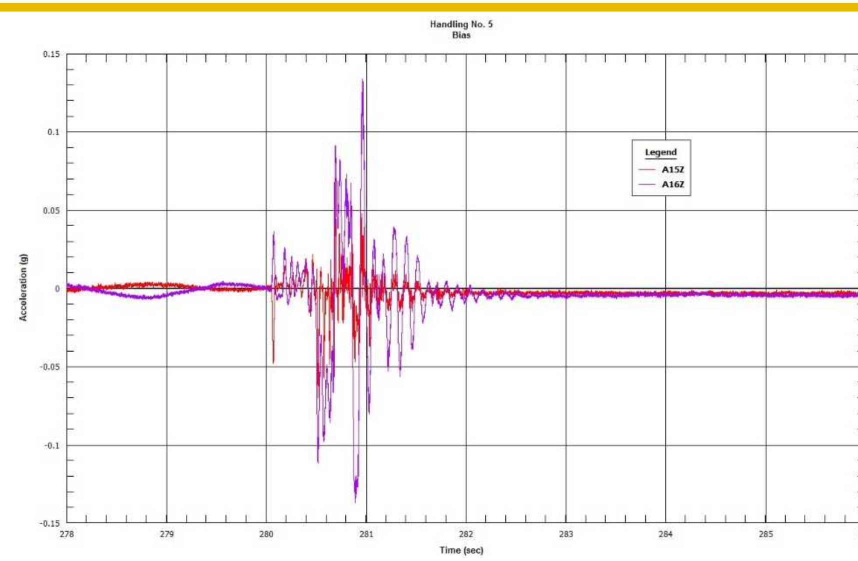
Maximum Cask Acceleration = 0.15 g

Maximum Assembly Strain = 87 µm/m

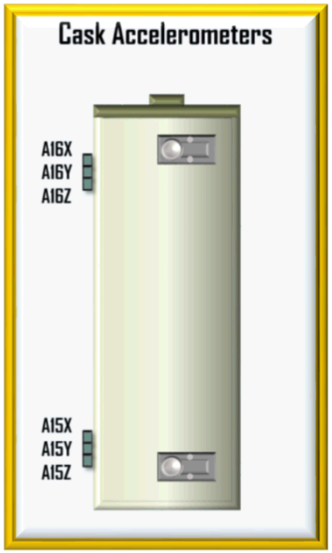
U.S. DEPARTMENT OF ENERGY

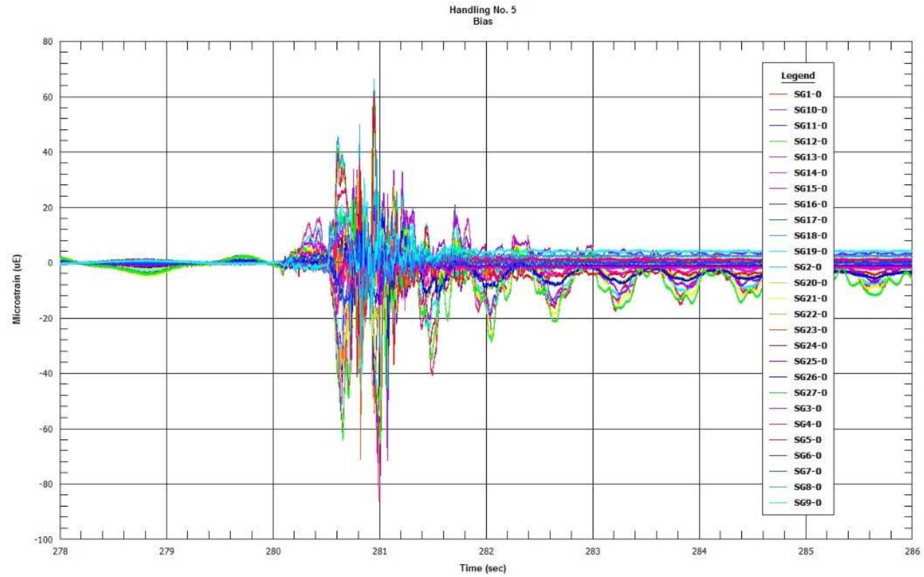
Nuclear Energy





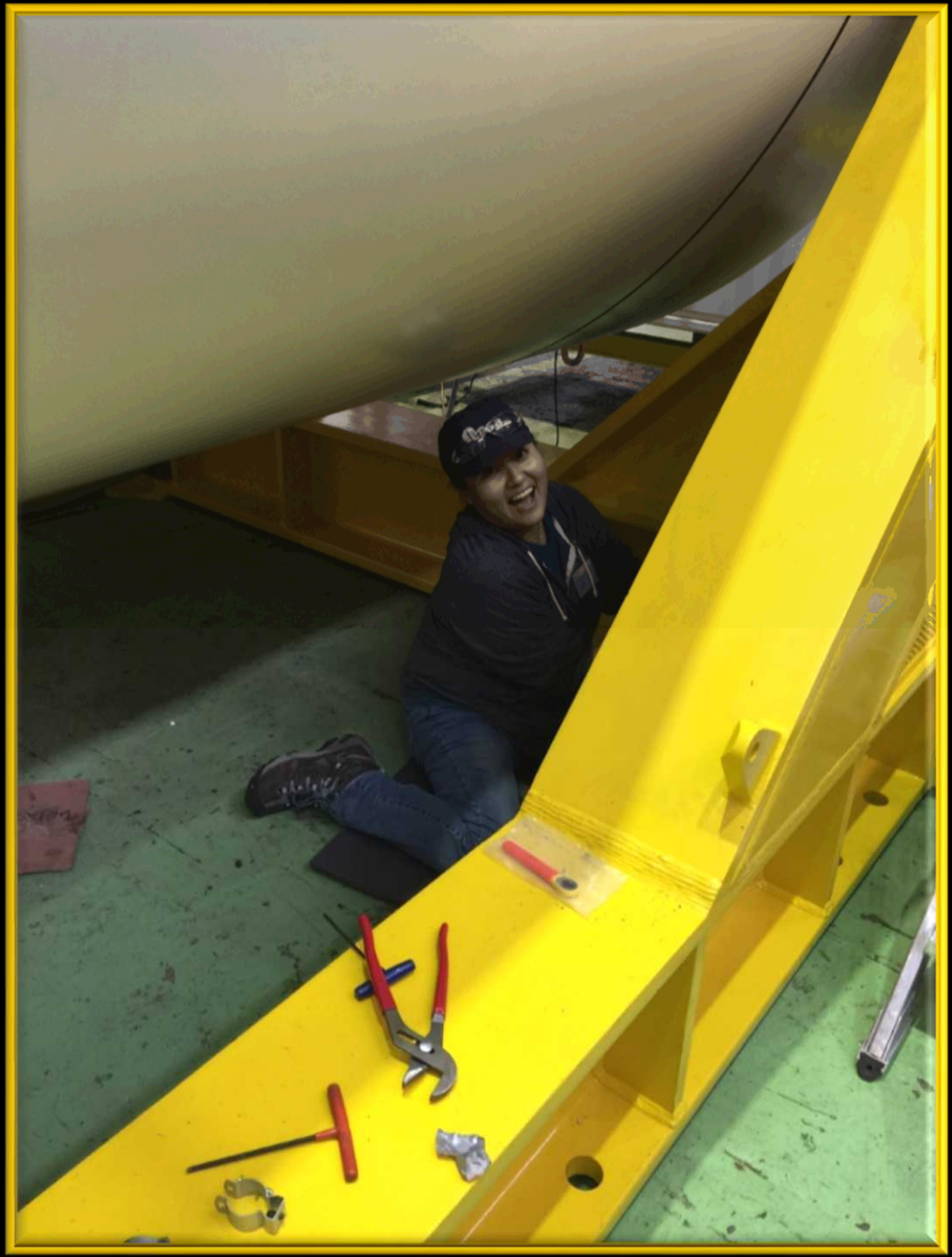
FY18 will examine frequency transmission, instantaneous loading v. gross loading, etc.





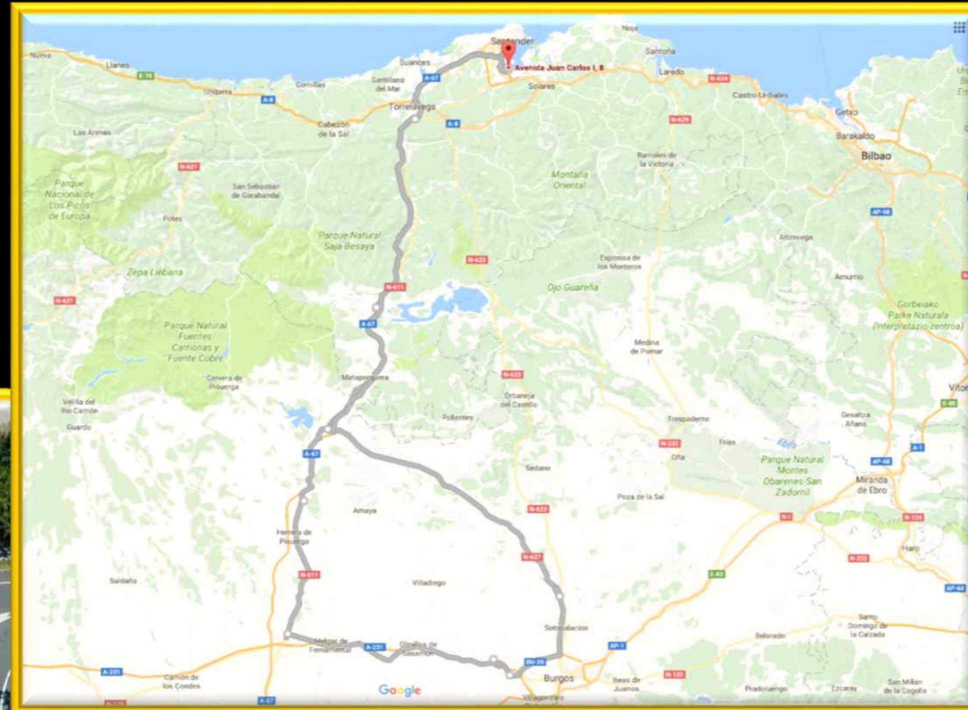
After the handling tests, the cask was connected to the battery and data acquisition box on a cradle extension.

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



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

Heavy-haul truck route through northern Spain – Burgos to Maliaño and back.



Many *rotondas*…

… and tiny villages negotiated.

Preliminary Heavy-Haul Truck Test Data

Maximum Assembly Acceleration = 0.74 g

Maximum Assembly Strain = 86 μm/m

Maximum Assembly Strain, μm/m	Maximum Platform Acceleration, g	Maximum Cask Acceleration, g	Maximum Cradle Acceleration, g	Maximum Basket Acceleration, g	Maximum Assembly Acceleration, g
86	4.2	≤0.2	≤0.2	≤0.2	0.74

After heavy-haul truck test, cask loaded onto “Autosky” at Port of Santander.

Preliminary Intercoastal Ship Test Data

Maximum Assembly Acceleration = ≤0.3 g

Maximum Assembly Strain = ≤20 μm/m

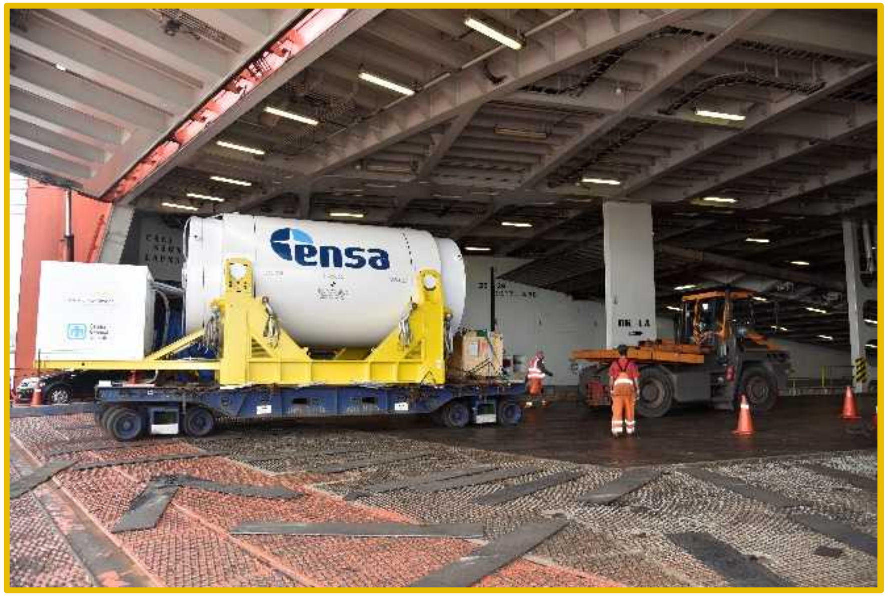
Maximum Assembly Strain, μm/m	Maximum Platform Acceleration, g	Maximum Cask Acceleration, g	Maximum Cradle Acceleration, g	Maximum Basket Acceleration, g	Maximum Assembly Acceleration, g
≤20	0.86	≤0.3	≤0.3	≤0.3	≤0.3

Cask system then loaded onto "Tarago" at Port of Zeebrugge for transport to Baltimore, MD, USA.

Preliminary Transoceanic Ship Test Data

Maximum Assembly Acceleration = ≤0.2 g

Maximum Assembly Strain = ≤ 20 μm/m



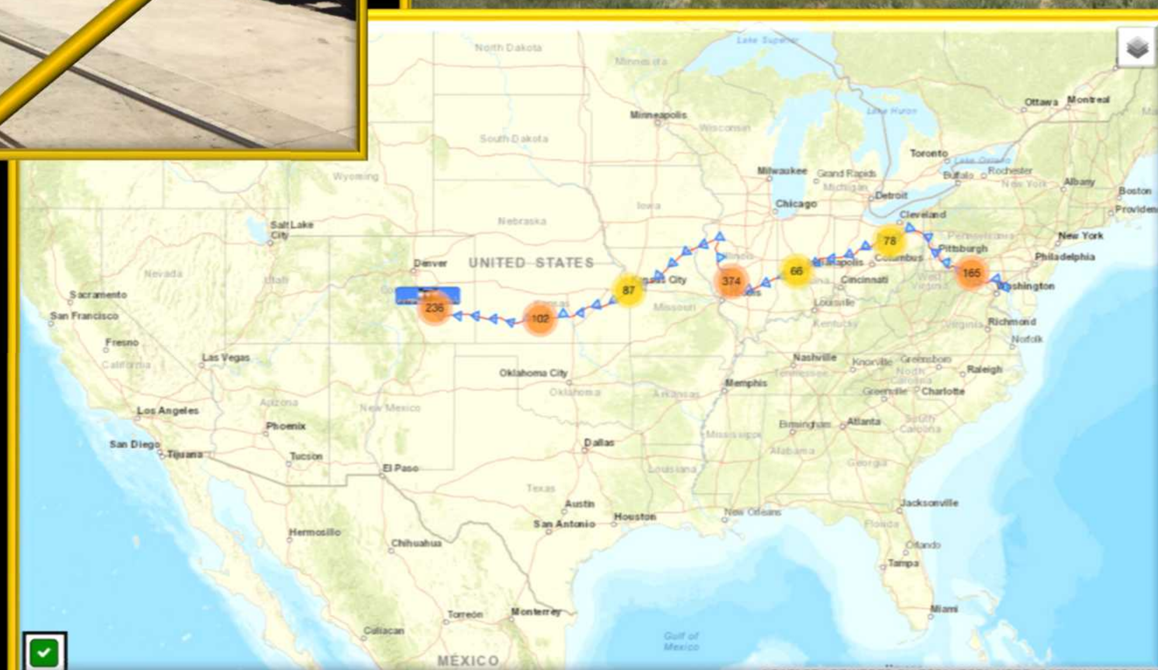
Maximum Assembly Strain, μm/m	Maximum Platform Acceleration, g	Maximum Cask Acceleration, g	Maximum Cradle Acceleration, g	Maximum Basket Acceleration, g	Maximum Assembly Acceleration, g
≤20	0.38	≤0.2	≤0.2	≤0.2	≤0.2

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

Witnessed by DOE, NRC, USCG

While not a 2043 railcar, the 12-axle Kasgro railcar is expected to bound the strains and accelerations seen in a 2043.

Cask transported by rail to TTCI for series of rail tests.



Map from ANL Traveler GPS

Preliminary Cross-Country Rail Test Data

Maximum Assembly Acceleration = 1.3 g
Maximum Assembly Strain = 47 μm/m

Maximum Assembly Strain, μm/m	Maximum Platform Acceleration, g	Maximum Cask Acceleration, g	Maximum Cradle acceleration, g	Maximum Basket Acceleration, g	Maximum Assembly Acceleration, g
47	8.40*	0.42	0.70	0.40	1.30

** This platform acceleration does not appear in other accelerometers. This will be investigated further, but appears to be a local, instantaneous load which does not correspond to significant structural loading.*

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Rail Tests Conducted at TTCI

8 Types of Tests
125 Separate Tests

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

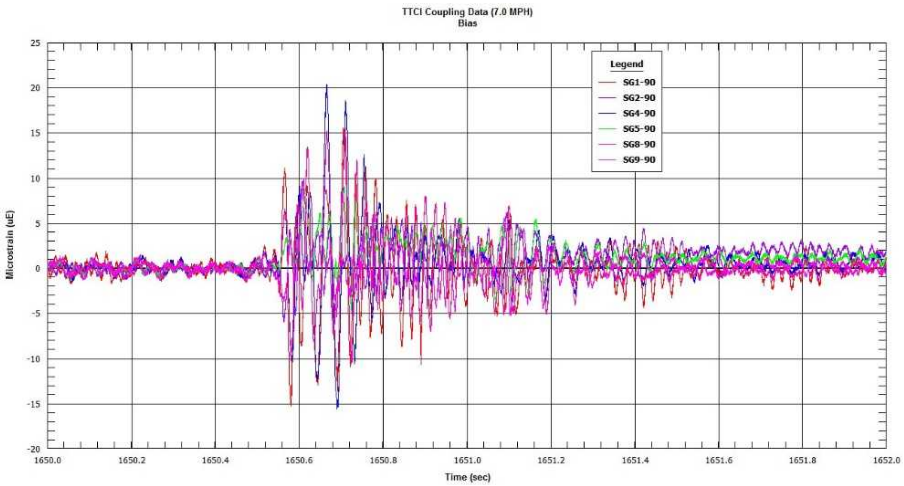
U.S. DEPARTMENT OF ENERGY

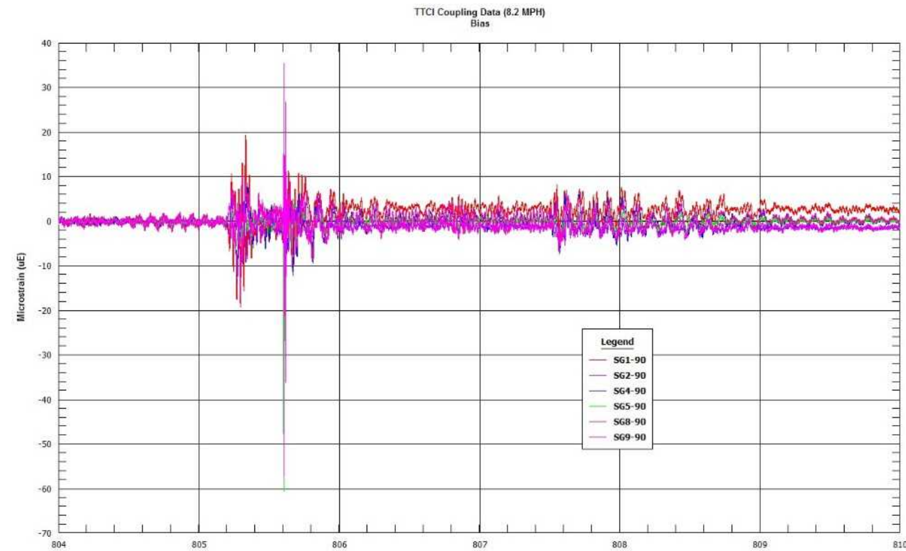
Nuclear Energy

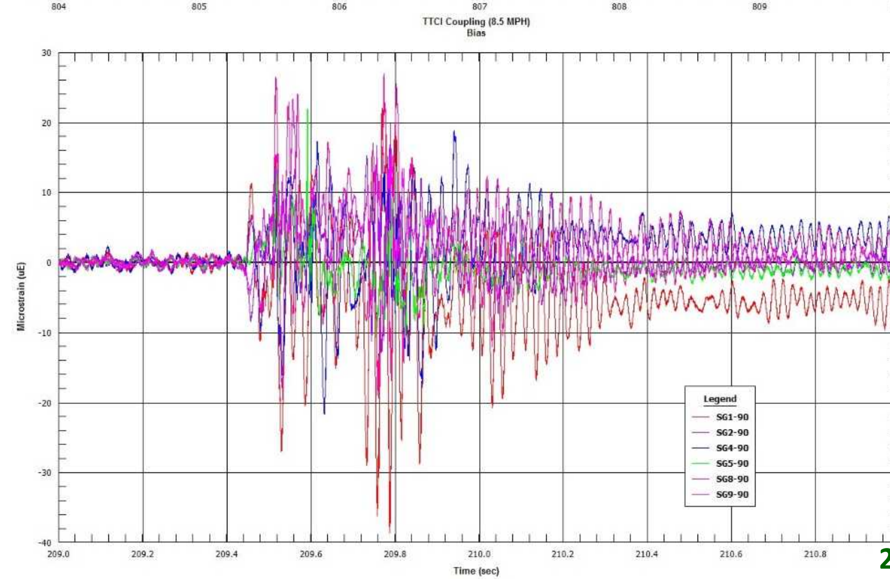
Preliminary Railcar Coupling at 7.0, 8.2, 8.5 mph

SNL Assembly Strain Gauge Data

Maximum Assembly Strains = 39, 92, 77 µm/m

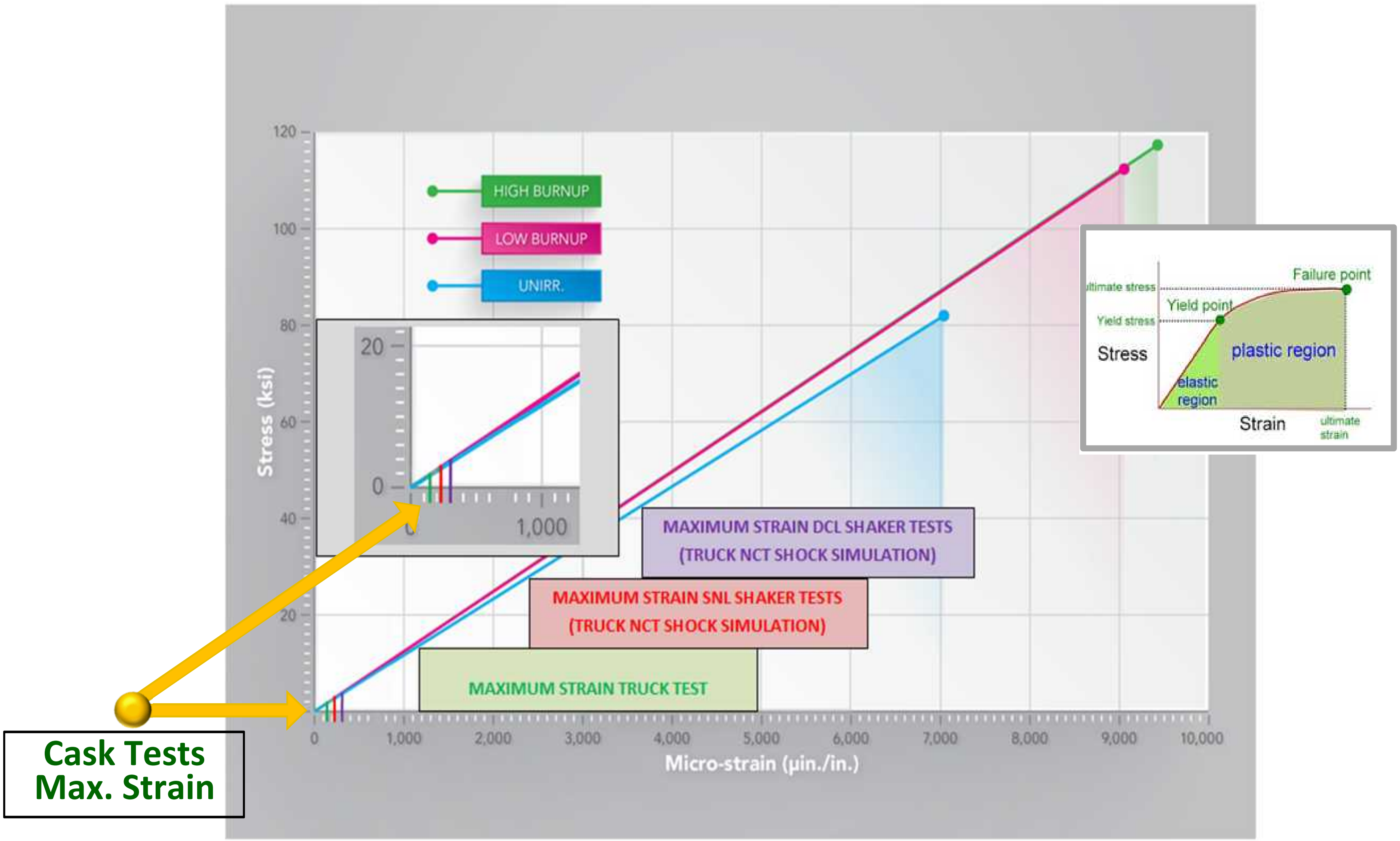




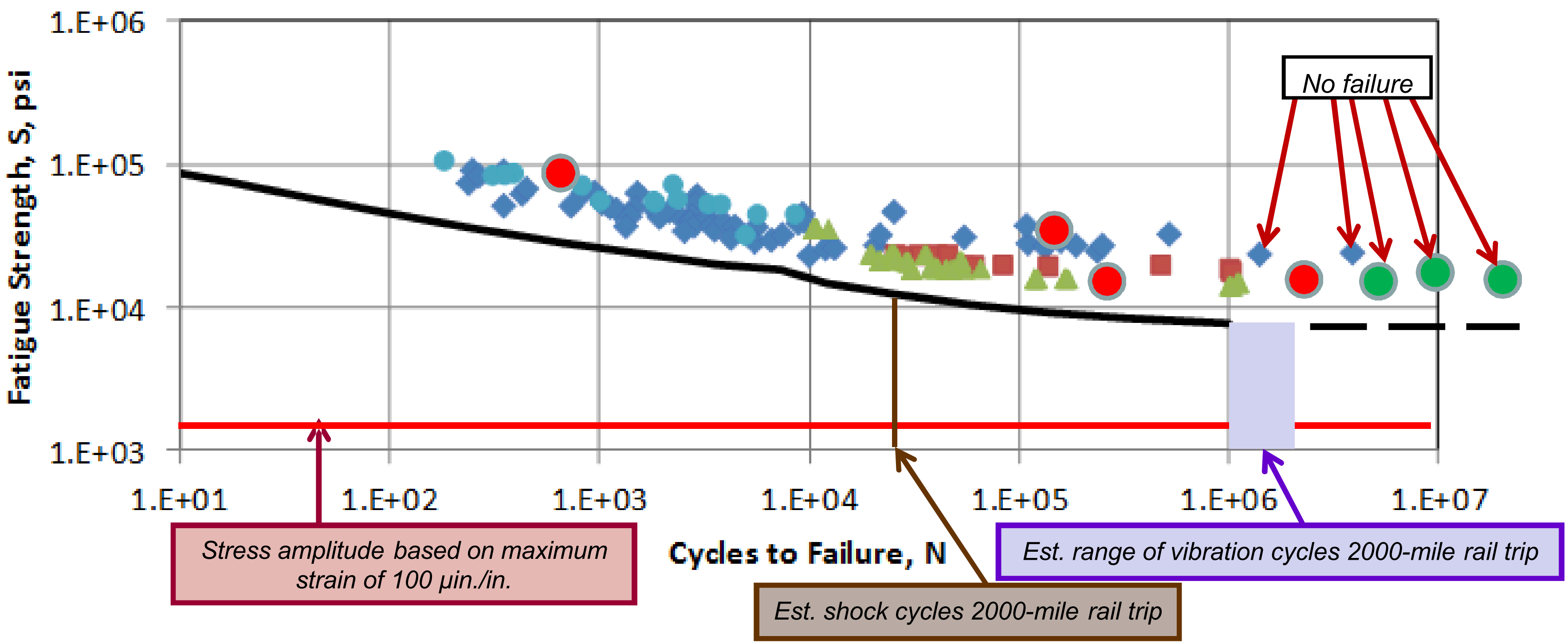


Assembly Strains in Rail-Cask Tests

Demo Sister Rod Tests will confirm post-drying high burnup cladding yield points.



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

Realistic stresses fuel rods experience due to vibration and shock during normal transportation below yield and fatigue limits for cladding.

FY18 will examine frequency transmission, instantaneous v. gross loading, system behavior, and refine our modeling to allow us to relate these results to other casks/transportation systems and other fuel mechanical properties.

QUESTIONS?