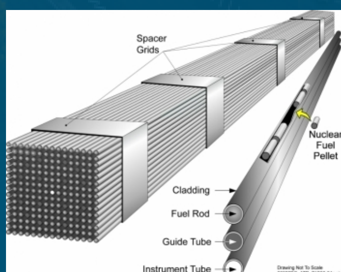
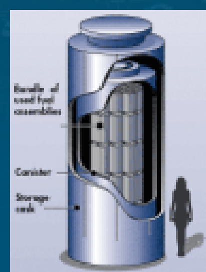
SAND2018-11924C

Sandia National Laboratories

U.S. DOE SPENT NUCLEAR FUEL STORAGE & TRANSPORTATION R&D ACTIVITIES





2018 FALL CONFERENCE

Korea Radioactive Waste Society

PRESENTED BY

Sylvia Saltzstein, Manager

SPENT NUCLEAR FUEL STORAGE, TRANSPORTATION, & SAFEGUARDS R&D

OCTOBER 2018

ENERGY NNSA

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U.S. DOE Spent Nuclear Fuel Storage & Transportation R&D Activities: *R&D Goal & Presentation Objective*

R&D Goal

Provide data and analysis to support decisions regarding storage and transportation of spent nuclear fuel

Presentation Objective

Provide a brief overview of some current R&D in DOE to show how our R&D points to a stronger fuel system and lower external loads than previously thought

Updated Gap Analysis Report

- Identifies priorities in research
- Last published in 2014 and being updated now.
- This is a key document to guide our current and future research efforts

PREDECISIONAL DRAFT

Gap Analysis to Support Extended Storage and Transportation of Spent Nuclear Fuel: Five-Year Delta

Spent Fuel and Waste Disposition

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology
Authors and Affiliations

September 29, 2017
SFWD-SFWST-2017-000005
National Laboratory Report No. XXXXXX

Rev. 11.29.16

Presentation Overview

I. Spent Fuel Integrity

- *Current tests and analyses indicate that spent fuel is robust.*
- *The DOE/EPRI High Burnup Confirmatory Data Project will obtain data > 10 years dry storage to confirm current test/analysis results.*
- *The NDE of the sister rods has been completed with no surprises. Destructive analysis has begun.*

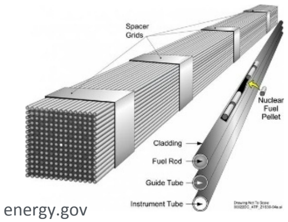
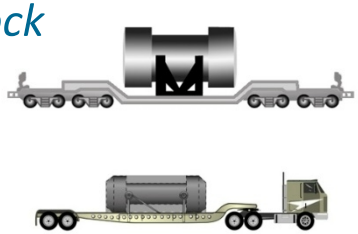


Photo: energy.gov

II. Spent Fuel Transportability Following Extended Storage

- *The realistic stresses cladding experiences due to vibration and shock during transportation are far below yield and fatigue limits.*
- *It appears as though there will be no problem storing and transporting fuel multiple times.*



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III. Storage System Integrity

- *Stress corrosion cracking of canisters may be a concern in some environments. Work is ongoing to understand incubation, pitting, transition from pit to crack, and then crack growth rate.*
- *Monitoring and Aging Management practices at storage sites will be important to confirm storage system performance during extended service.*

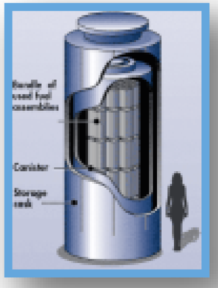
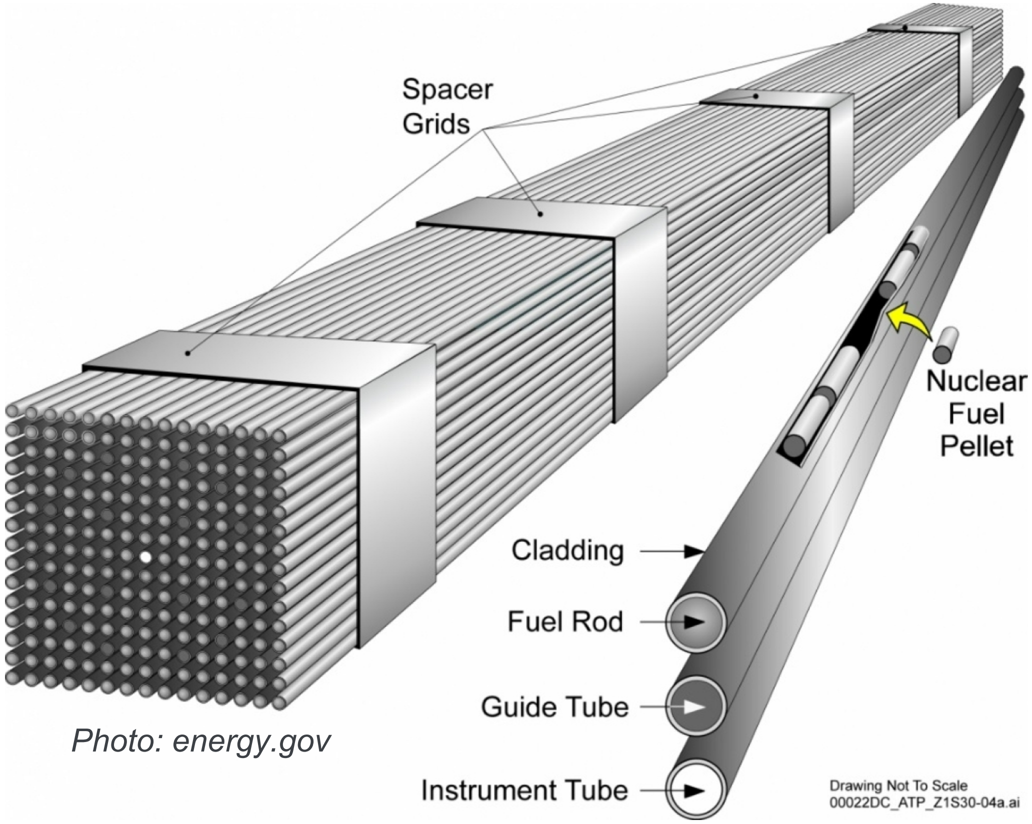


Photo: nrc.gov



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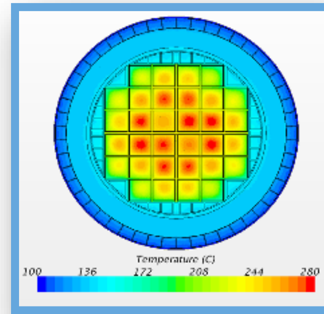
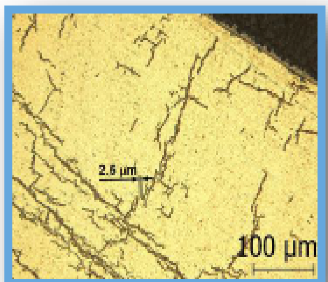
I. Spent Fuel Integrity

Understanding High Burn-up Cladding Performance: *Looked at Different Effects Separately*

- Thermal Analysis
  - More detailed modeling shows considerable margin between design basis loading and actual loading resulting in lower temperatures than previously thought

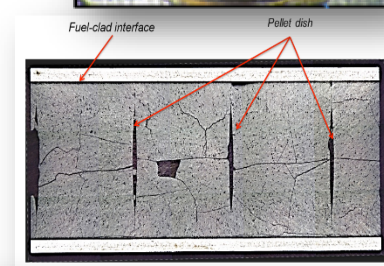


Maximum cladding surface temp. (°C) for each assembly in one type of licensed cask. (Fort, et al, 2016. PNNL)



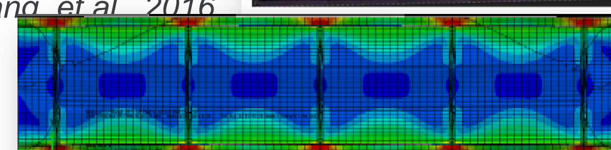
Circumferential and Radial hydrides in High Burn-up ZIRLO cladding subjected to peak temperatures of 350°C and 92 MPa hoop stress. (Billone, 2015. ANL)

- Ductile/Brittle Transition Temperatures
  - Lower temperatures and lower rod internal pressures than previously assumed results in fewer radial hydrides
  - Temperature where cladding loses significant ductility is thus lower than previously thought



Fuel rod segment before bend testing (Wang, et al., 2016)

- Strength and Fatigue
  - Cyclic bending tests of irradiated fuel segments identify increased strength due to pellet/clad and pellet/pellet bonding effects.



Stress distribution in fuel showing the fuel pellets supporting the clad due to cohesive bonding.(Wang, et al., 2014, ORNL)

Obtaining Data on High Burnup Cladding After 10 Years of Dry Storage: *Start Now with Baseline Pre-Storage Data to See Systemic Effects*

- DOE/EPRI High Burnup Confirmatory Data Project Goal:
  - To provide confirmatory data for models, future SNF dry storage cask design, to support license renewals and new licenses for ISFSIs

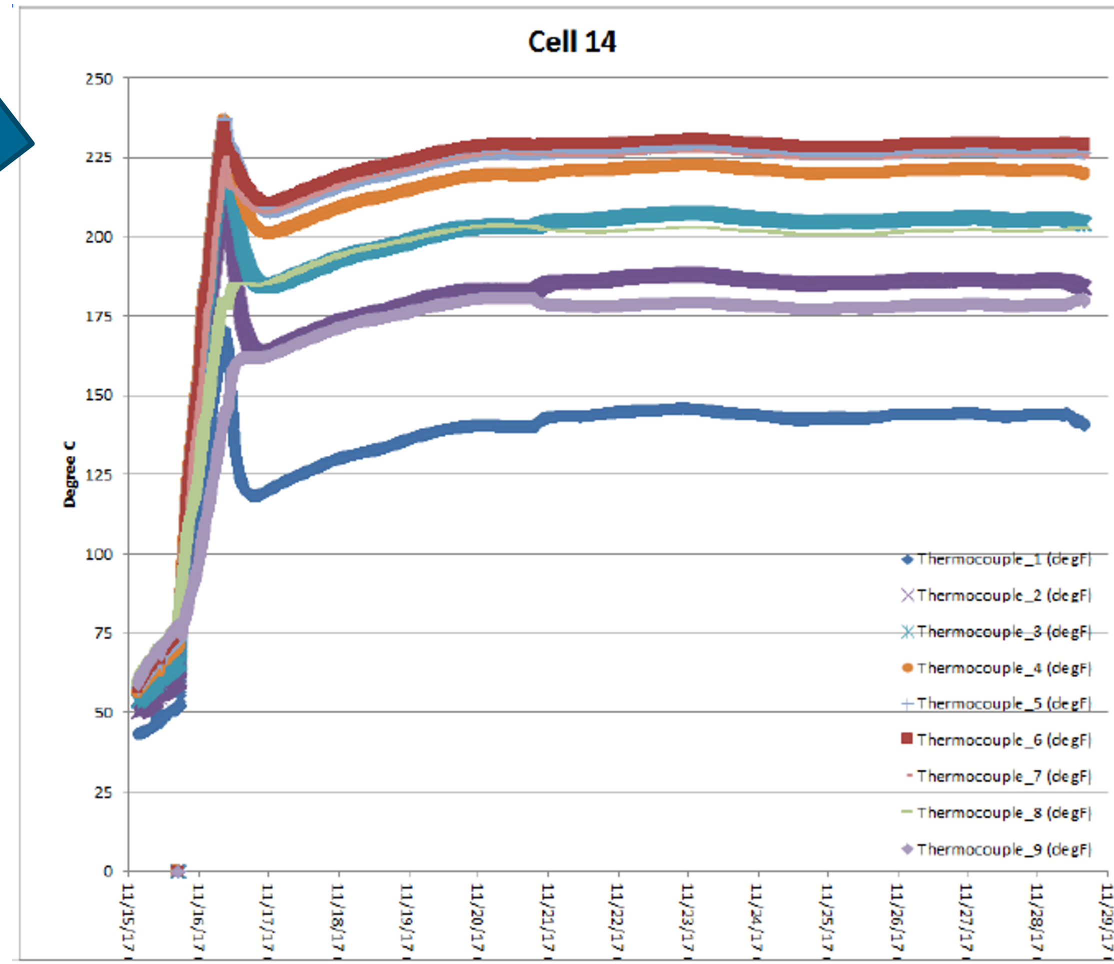
- Steps
  1) Loaded a commercially licensed TN-32B storage cask with high burn-up fuel in a utility storage pool (Nov 2017)
  2) Loaded well-characterized fuel of 4 common cladding alloys
  3) Instrumented cask outfitted with thermocouples
  4) Gas samples taken before going to pad and periodically during storage
  5) Dried using industry standard practices
  6) Storing at utility dry cask storage site – 10 years
  7) Transporting to lab to open
  8) Testing rods to understand mechanical properties

Loaded TN-32 and Data Logger at North Anna

Measured Cladding Temperatures in the Cask: *Lower than Expected (peak <250°C)*

Internal Cask Temperature vs. Time

(from drying to 2 weeks later)

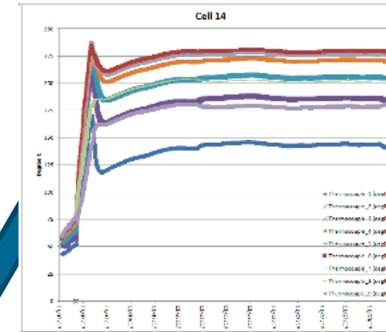


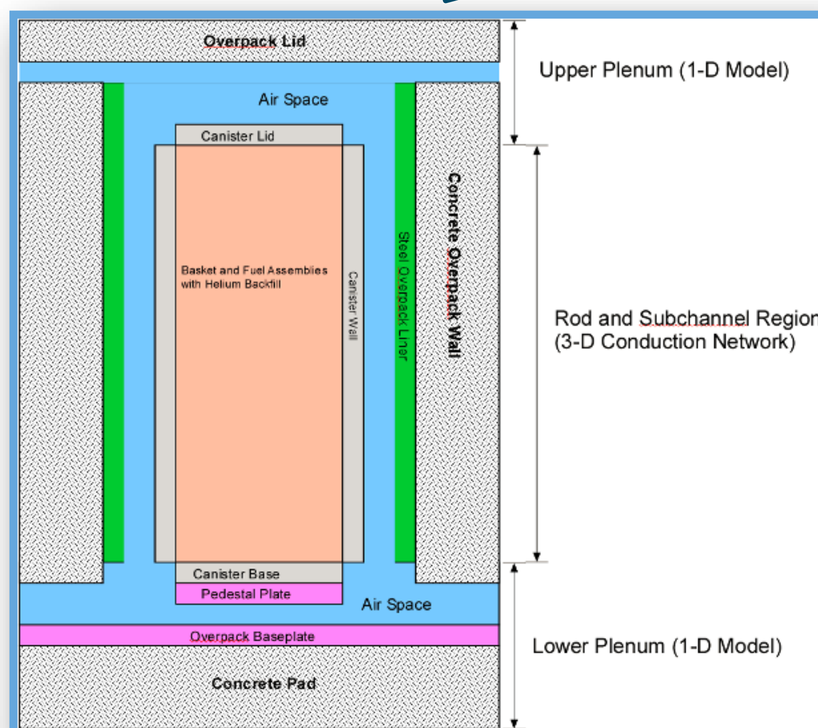
If temperatures are low, then internal pressures may be lower than needed for radial hydride formation.

Cask Thermal Data used to Improve Storage Thermal Modeling

Data is being used to identify and reduce uncertainties and conservatisms in the current thermal models for Spent Fuel Storage & Transportation Systems

- Peak clad temperatures
- Welded stainless steel canister temperatures and air flow
- Results:
  1) *Lower expected peak cladding temperatures: less likelihood of cladding embrittlement*
  2) *Canister surface temperatures may be low enough to support salt deliquescence sooner.*

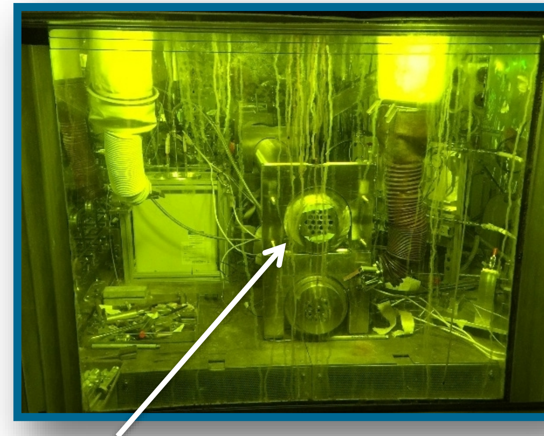




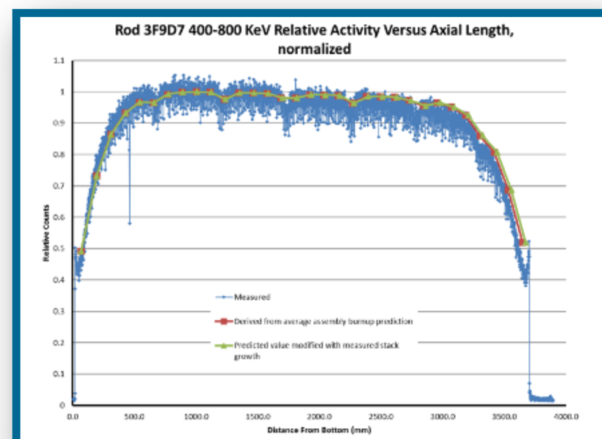
Source: DOE report FCRD-UFD-2016-000068

High Burnup Confirmatory Data Project: *Obtaining Baseline Data from Sister Rods*

- 25 rods with similar histories to those in the cask will be tested to document pre-storage properties
- "Sister Rod" Acquisition & Testing
  - *Areva and Westinghouse rods pulled in June and January 2015 from different assemblies*
    - 9 AREVA M5® rods
    - 12 Westinghouse Zirlo® rods
    - 4 Westinghouse Zircaloy-4
      - 2 Low-tin
      - 2 Standard
  - *All 25 sister rods underwent nondestructive analysis at Oak Ridge National Laboratory in 2017*
  - *Destructive tests began in FY18*
    - 14.5 rods at ORNL
    - 10 rod equivalents at PNNL
    - 0.5 rod equivalents at ANL

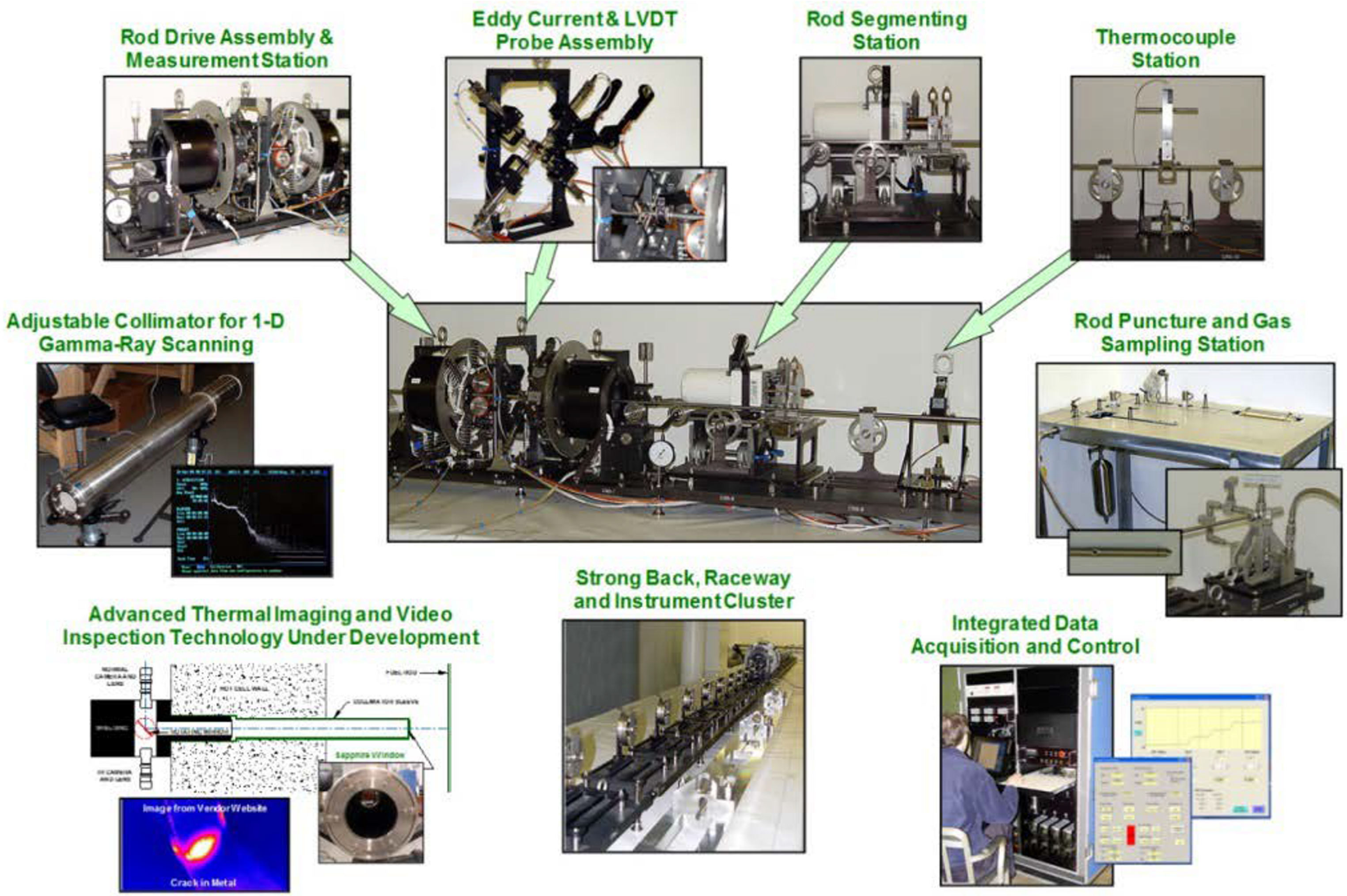


25 Sister Rods in ORNL Hot Cell
Photo: Saltzstein, SNL



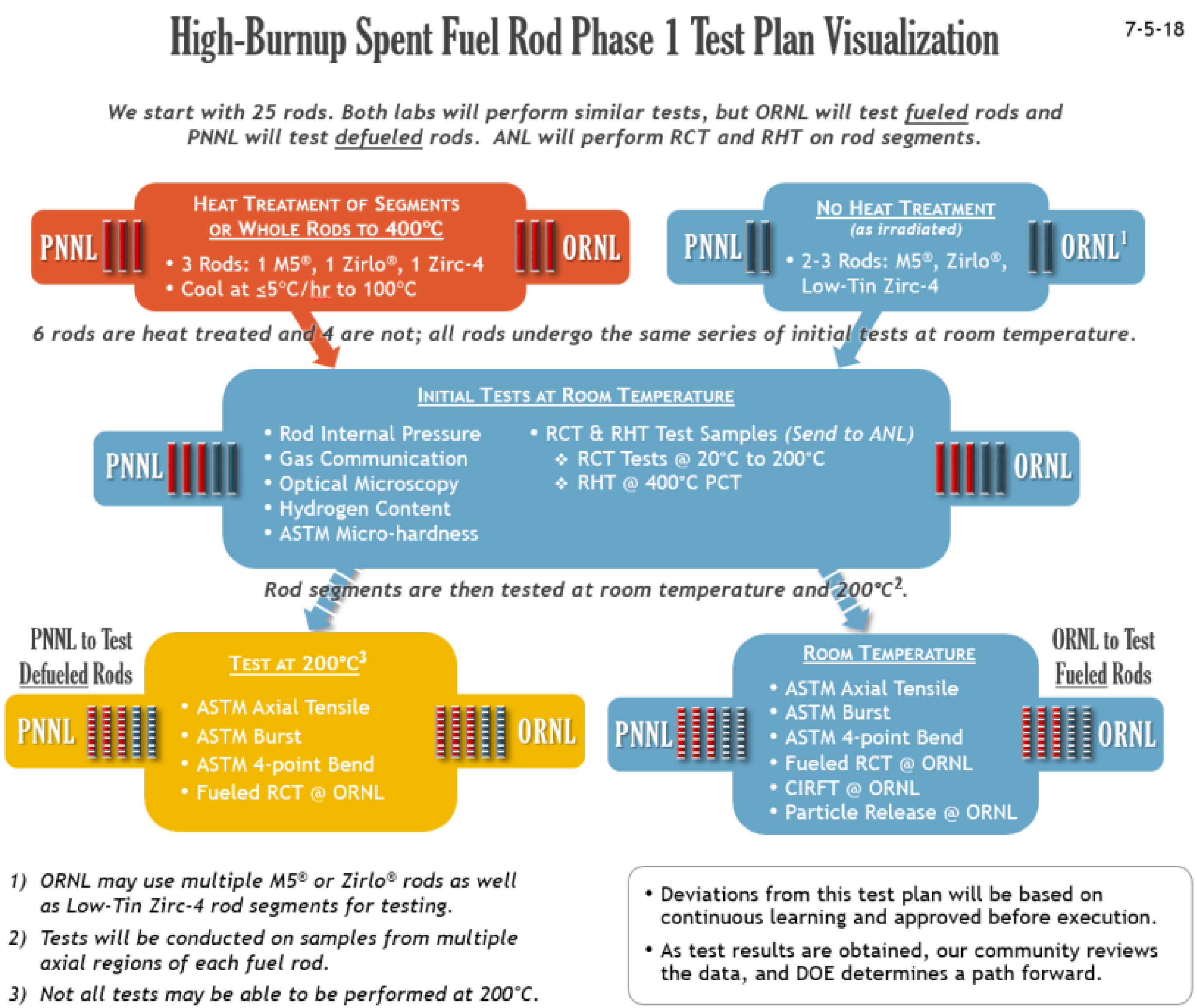
Sister Rod gamma scan results to determine the axial burnup profile and identify pellet locations (Montgomery R, 2016)

Sister Rod Nondestructive Examinations (NDEs): *Completed with no Surprises*



ORNL's Advanced Diagnostics & Evaluation Platform (ADEPT) provides rod handling and instrumentation for NDE of full-length commercial fuel rods.

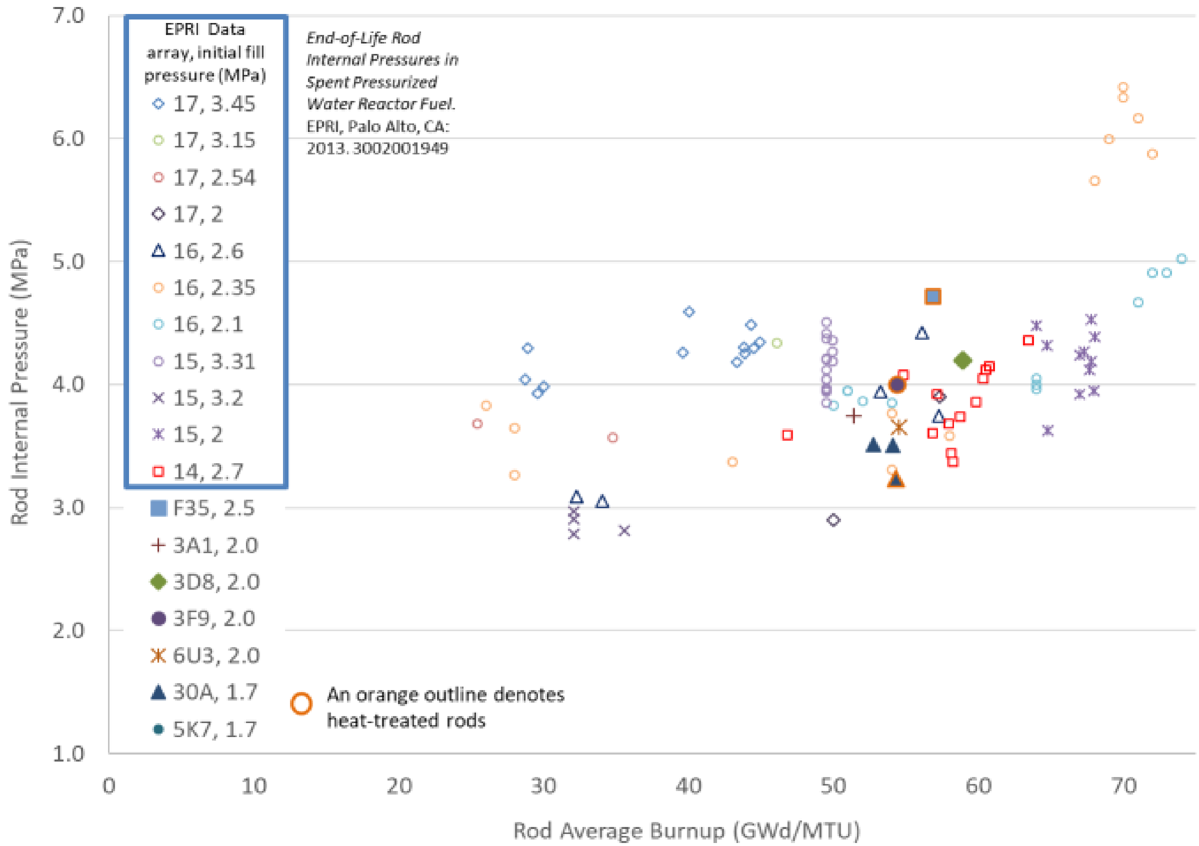
Sister Rod Test Plan Summary: *Results Starting Now and Ongoing for ~2 Years*



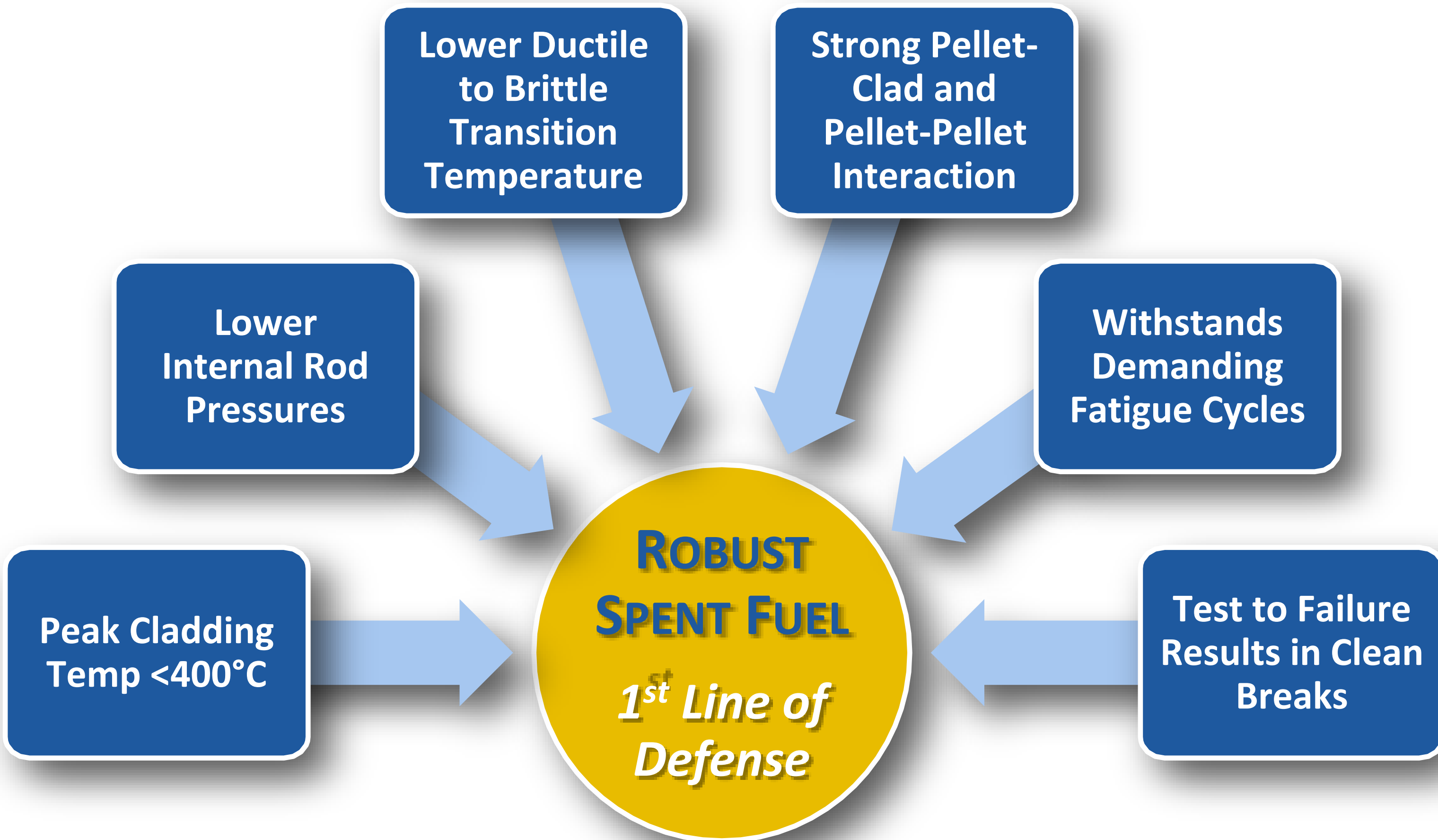
The rod internal pressure of eight sister rods was measured by ORNL and are between 3.2 and 4.7 MPa

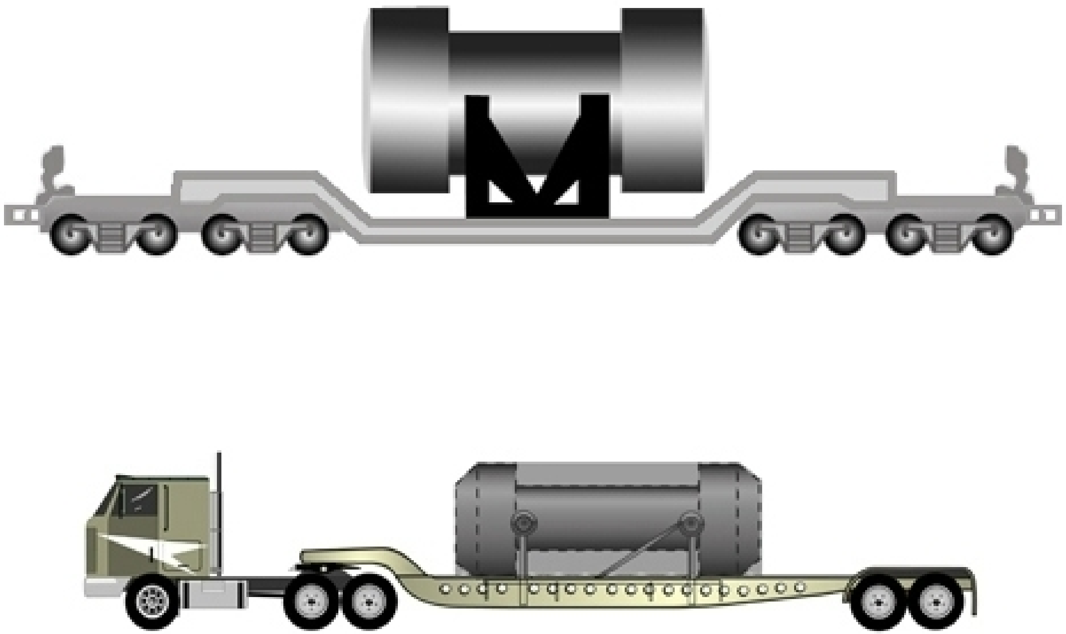
- Data includes Zirc-4, LT Zirc-4, M5, and ZIRLO
- All are within the envelope of past data
- No apparent affect of heat treatments

While the mechanical design of the sister rods is likely different from those presented in the EPRI report, the graph does provide some information about the sister rods relative to the pressure recorded for other commercial power pressurized water reactor rods.



Current Tests & Analyses Indicate Spent Fuel More Robust Than Previously Thought





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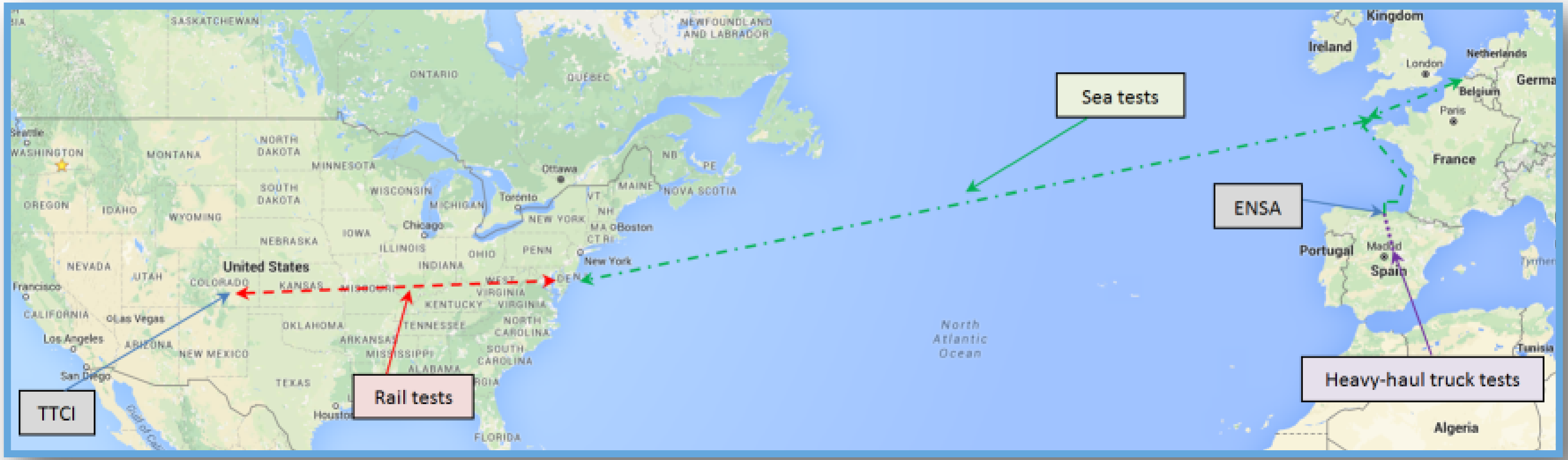
II. Spent Fuel Transportability Following Extended Storage

PLAY VIDEO HERE

Routing of Instrumented Cask & Assemblies *(Transportation Triathlon)*

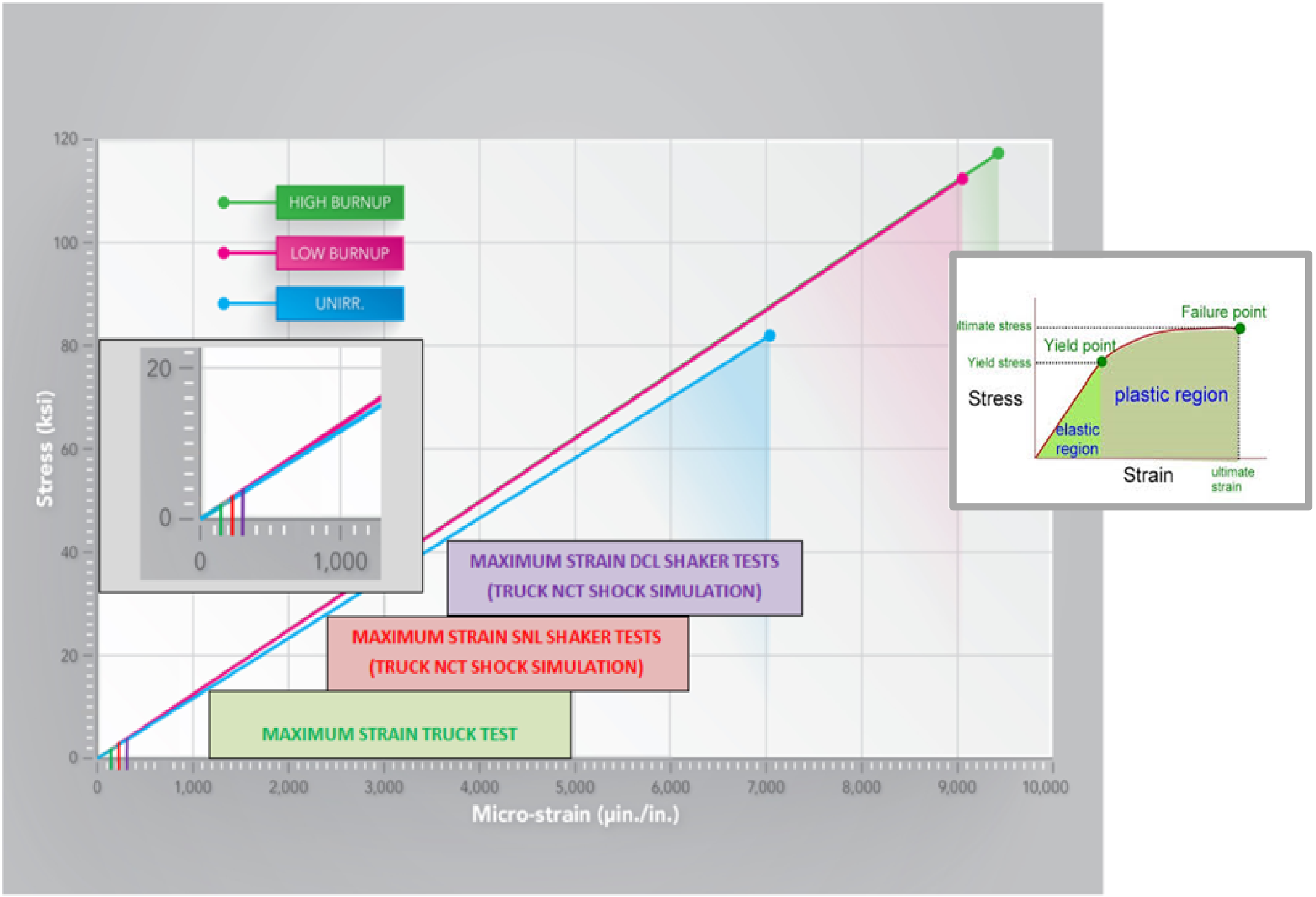


1) **Heavy-haul truck from within Spain** ~ June 14, 2017
2) **Coastal sea shipment from Santander to large northern European port** ~ June 27, 2017
3) **Ocean transport from Europe to Baltimore**
4) **Commercial rail shipment from Baltimore to Pueblo, Colorado** ~ Aug 3, 2017
5) **Testing completed at the Transportation Technology Center, Inc.**
6) **Return trip to ENSA, September 5, 2017**

Transportation Test Initial Results

- More than 7 terabytes of data collected
- Measured five different transportation modes:
  1) *Heavy haul Truck*
  2) *Barge*
  3) *Ocean-going ship across Atlantic*
  4) *Rail transportation using non-AAR S2043 standard equipment*
  5) *Different types/conditions for rail transport at TTCI*
- Cask transferred 9 times using different cranes/operators
- Results:
  1) *Cask weight of ~200 tons is an excellent damper no matter what is going on (no surprise)*
  2) *Even using a non-S2043 compliant rail car, measured deformations and resulting stresses are very low compared to what the cladding is expected be able to withstand.*

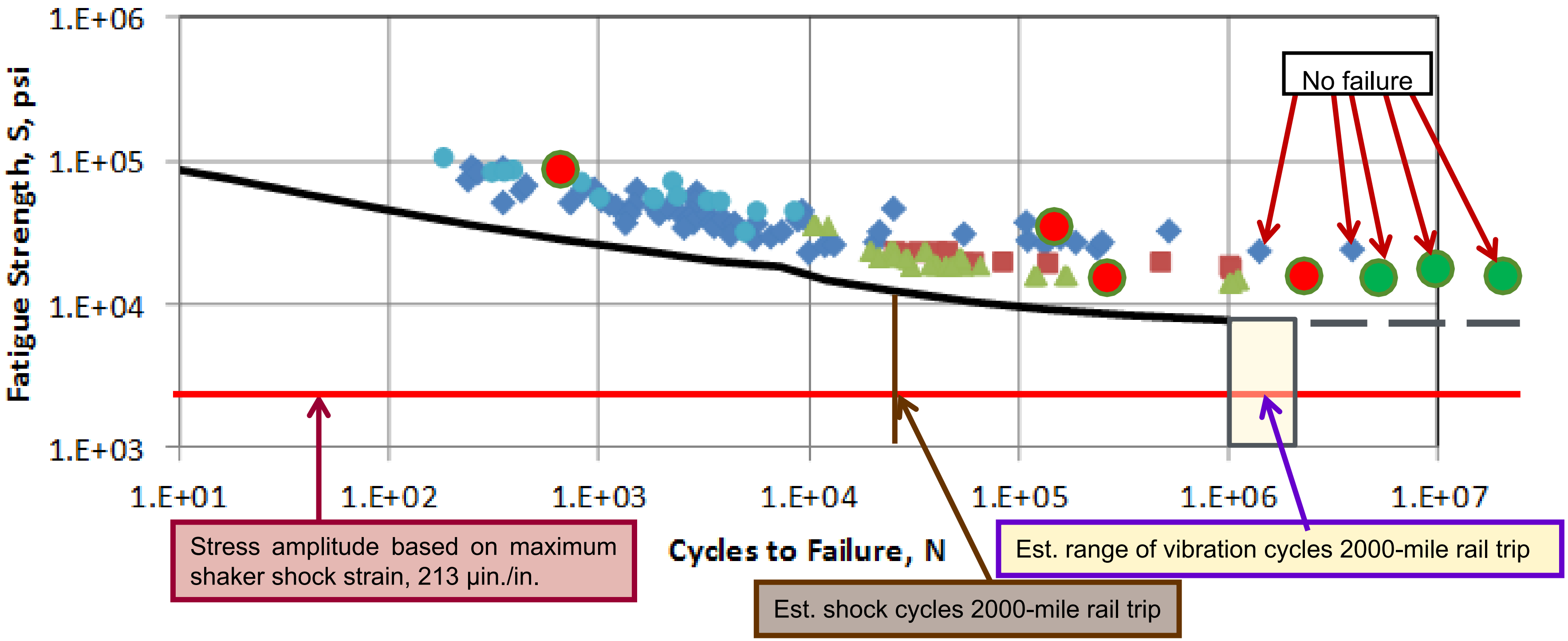
How Do Stresses on Fuel During Normal Conditions of Transport Compare to Failure Limits?



McConnell et al, 2016, SNL and PNNL

Could Vibrations or Shocks Result in Fatigue Failure?

Transporting Spent Nuclear Fuel



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

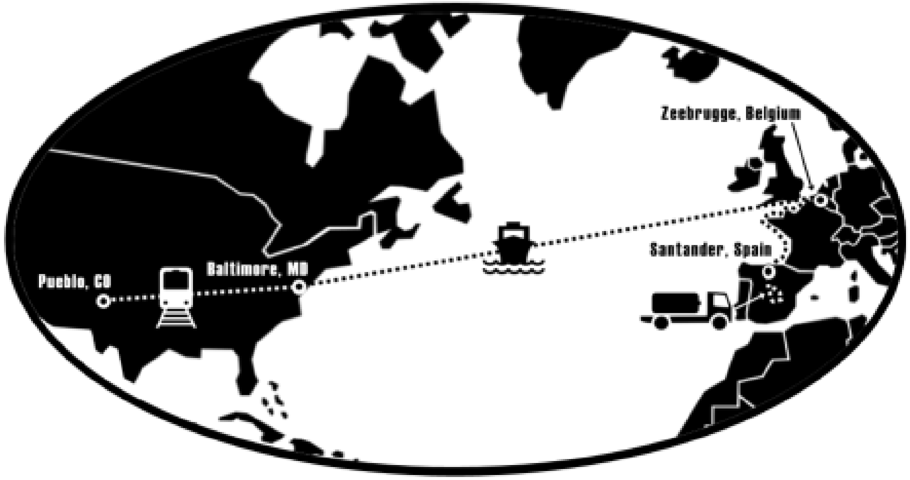
CONCLUSIONS

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

ENSA • PNNL • SNL

Truck • Ships • Rail

2017 RAIL CASK WORLD TOUR



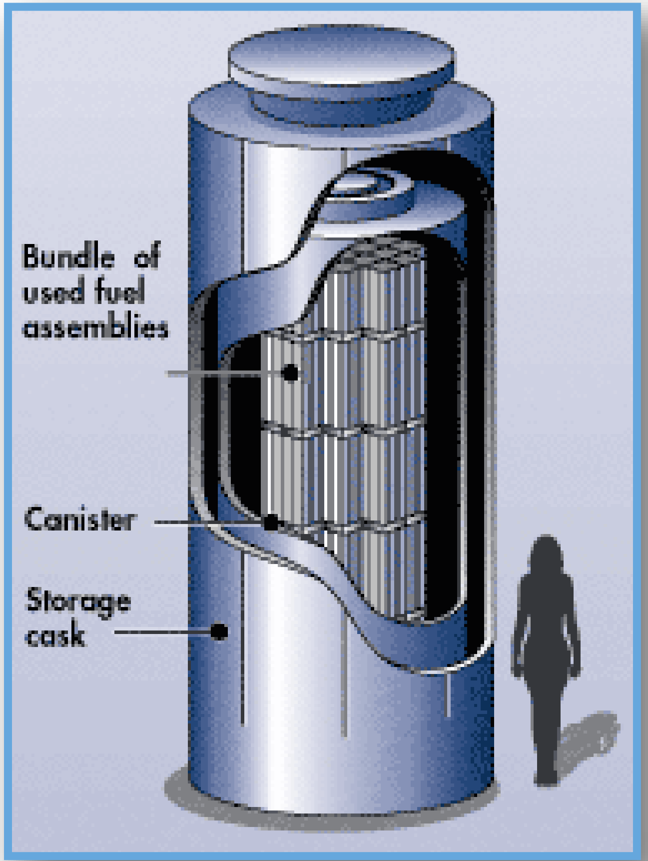
9458 Miles • 7 Countries • 12 States • 77 Accelerometers/Strain Gauges
54 Days of Data • 6 Terabytes of Data • 2 Miles of Cable

The Secretary of Energy Achievement Award

Presented to:

The International Multi-Modal Surrogate Spent Nuclear Fuel Transportation Test Team

August 2018



nrc.gov

III. Storage System Integrity

Primary Concern – Stress Corrosion Cracking (SCC) Requiring 3 Concurrent Conditions

Dust on canister surface at Calvert Cliffs (EPRI 2014)

Photo of dry canister weld. Photo: SNL

Mock-up Canister Photo: Enos, SNL

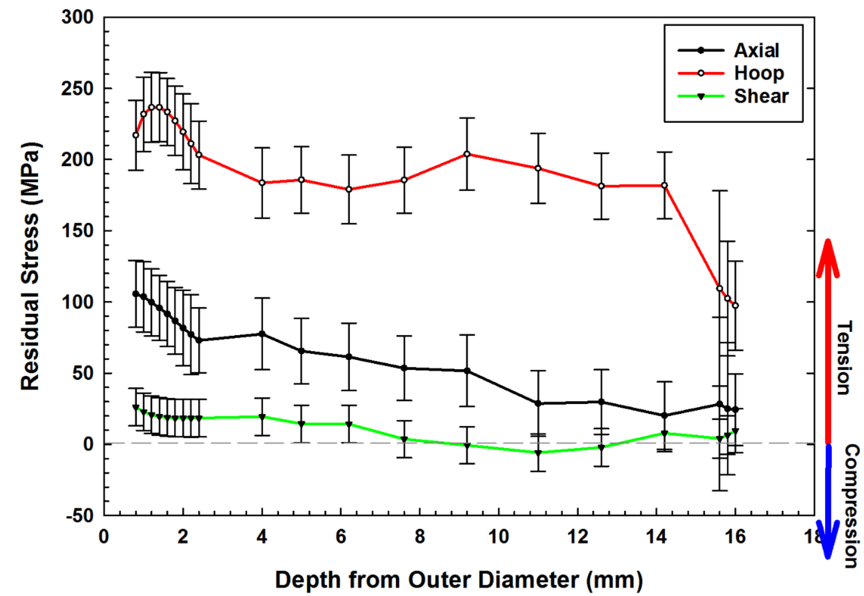
Is There Tensile Stress Through Canister Wall?

Canister Mockup WRS Measurement Results

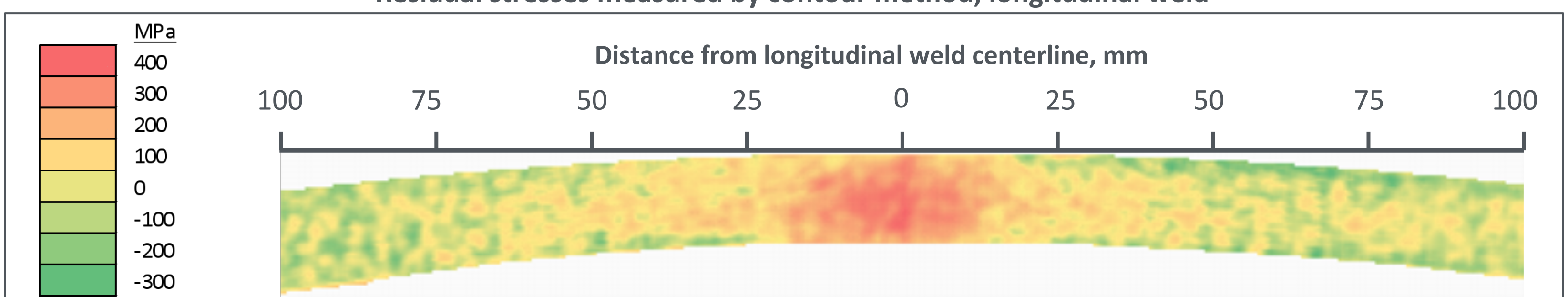
- DHD and contour mapping results are consistent.
- High *through-wall* tensile stresses measured in all weld types and in all HAZ. Highest tensile stresses are parallel to welds, but tensile stresses also occur perpendicular to welds.
- Highest tensile stresses (up to 600 MPa) measured at simulated weld repairs.

Enos D. and Bryan C., 2016. *Final Report: Characterization of Canister Mockup Weld Residual Stresses*, FCRD-UFD-2016-000064, U.S. DOE.

Residual stresses measured by deep-hole drilling (DHD) method, circumferential weld HAZ



Residual stresses measured by contour method, longitudinal weld



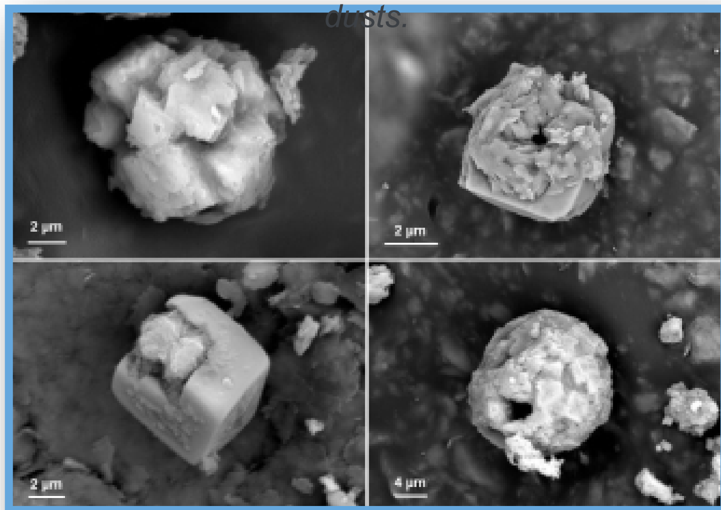
Can a Corrosive Environment Form?

- DOE/EPRI sampling efforts at Calvert Cliffs, Hope Creek, Diablo Canyon, and Maine Yankee
- Potentially corrosive chloride salts found in some areas. Need additional sampling to determine:
  1) *deposited salt compositions as a function of geographical location;*
  2) *salt loads and compositions as a function of canister surface location and surface temperatures.*

Dust Sampling at the Diablo Canyon ISFSI

Photos: Bryan, SNL

Sea-salt aerosols found in canister surface dusts.



Can a Corrosive Environment Form? *(cont.)*

Are deliquescent brines stable on the heated canister surface?

Previous Work

- Ammonium- and chloride-containing brines are not stable on heated surfaces, rapidly degassing until one or the other component is consumed. This makes presence of chloride-rich brines at inland sites with ammonium-rich continental salts unlikely.

Current Work

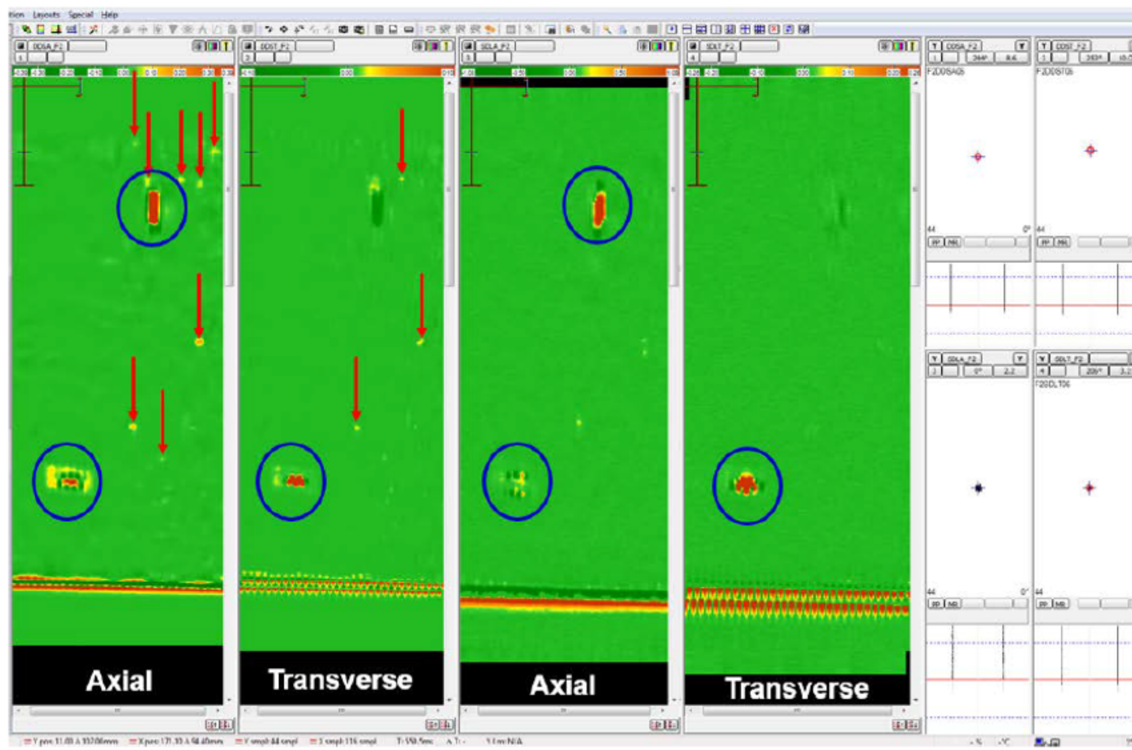
- Evaluating the stability of brines formed by sea-salt deliquescence at elevated temperatures.

Working with EPRI

Eddy Current Inspection – Cracks/Pitting

= Simulated Cracks

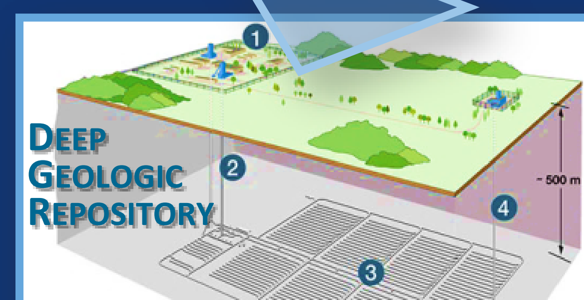
= Pitting ~1.0-2.5 mm pits



Working with Small Businesses

Robot in a Simulated DCSS Vent

THE BIG PICTURE



Observations from Current Storage & Transportation R&D

I. Spent Fuel Integrity

- *Current tests and analyses indicate that spent fuel is robust.*
- *The DOE/EPRI High Burnup Confirmatory Data Project will obtain data > 10 years dry storage to confirm current test/analysis results.*
- *The NDE of the sister rods has been completed with no surprises. Destructive analysis has begun.*

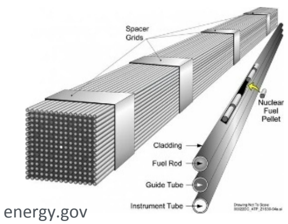
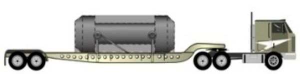


Photo: energy.gov

II. Spent Fuel Transportability Following Extended Storage

- *The realistic stresses cladding experiences due to vibration and shock during transportation are far below yield and fatigue limits.*
- *This data strengthens the technical basis that storing and transporting fuel multiple times will be safe.*



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III. Storage System Integrity

- *Stress corrosion cracking of canisters may be a concern in some environments. Work is ongoing to understand incubation, pitting, transition from pit to crack, and then crack growth rate.*
- *Tools are being developed to help with monitoring and aging management practices at storage sites.*

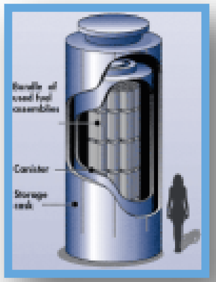

Photo: nrc.gov

QUESTIONS?