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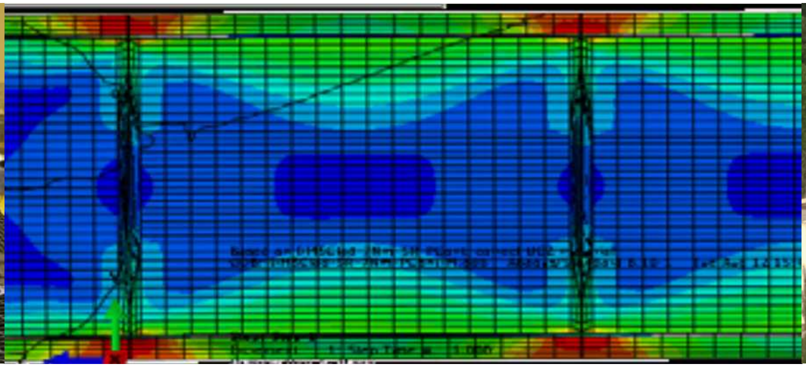

Overview of R&D for Extended Storage and Subsequent Transportation of Spent Nuclear Fuel

Presented to Meeting 4 of the "Reset of the U.S. Nuclear Waste Strategy and Policy"
George Washington University, Washington D.C.

Sylvia J. Saltzstein and Ken B. Sorenson
Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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R&D Goal and Presentation Objective

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Goal of the R&D:
To support development of the technical basis to inform future management and licensing decisions regarding storage and transportation of spent nuclear fuel.

Objective of this Presentation:
To provide a brief overview of some of the current R&D used to ensure the safe storage and transport of spent nuclear fuel.

Table of Contents

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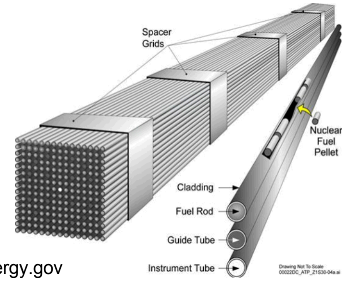
1. Spent fuel integrity



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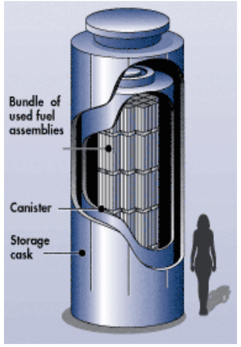
2. Storage system integrity



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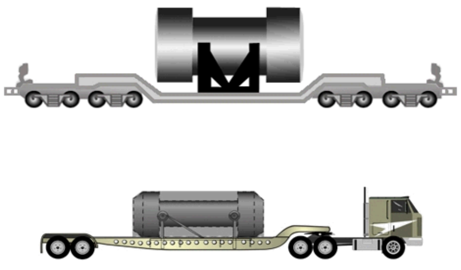
3. Spent fuel transportability following extended storage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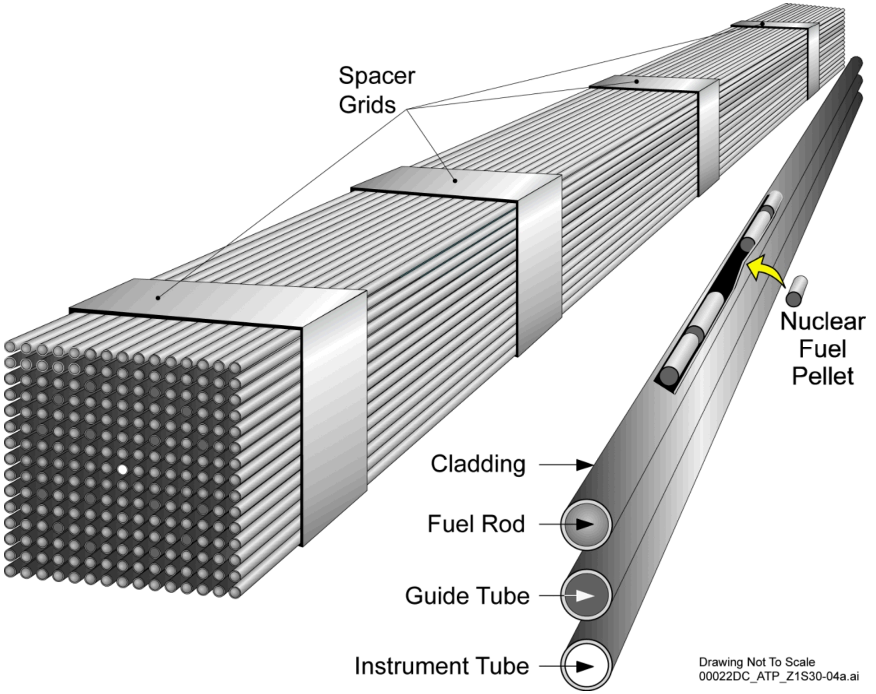
4. Observations and Discussion

Collaboration Leverages Research Dollars and Enables a Diversity of Perspectives, Skills, and Ideas.

- *US DOE (funding is primarily from DOE)*
  - Office of Nuclear Energy, Used Fuel Disposition
  - Multiple national laboratories (ANL, INL, LANL, ORNL, PNNL, SRNL, SNL)
- *US NRC*
  - Office of Nuclear Materials Safety and Safeguards
- *Industry*
  - Fuel and storage system vendors
  - Site Operators
  - Electric Power Research Institute (EPRI)
  - Nuclear Energy Institute (NEI)
- *Universities* (primarily through DOE-NE University Programs) including:
  - Penn State, University of Illinois, University of South Carolina, University of Florida, South Carolina State University, Colorado School of Mines, North Carolina State, University of Mississippi, Oregon State University, University of Houston, Pepperdine, University of Utah, Utah State, Massachusetts Institute of Technology, Texas A&M University, University of Nevada at Reno, Northwestern, University of Michigan, University of California at Irvine
- *International collaborations*
  - Germany, Japan, Spain, Korea, IAEA, Euratom



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1. SPENT FUEL INTEGRITY

Understanding High Burn-up Cladding Performance

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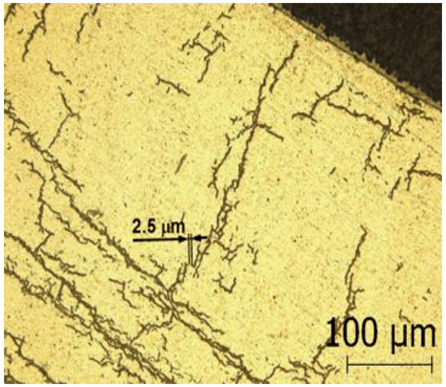
- *Ductile/Brittle Transition Temperatures:* Tests indicate that cladding is more ductile at cooler temperatures than previously thought. Lower rod internal pressure results in fewer radial hydrides.

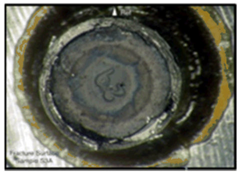


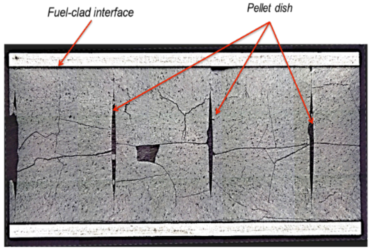
Circumferential and Radial hydrides in High Burn-up ZIRLO cladding subjected to peak temperatures of 350°C and 92 MPa hoop stress. (Billone, 2015. ANL)

- *Thermal analysis:* More realistic modeling indicates that peak clad temperatures may be lower than previously thought. This reduces the risk of forming radial hydrides.

	238	247	244	234	
234	257	269	268	256	235
241	268	255	271	269	246
247	268	268	260	269	247
238	255	269	269	257	238
	239	248	246	235	

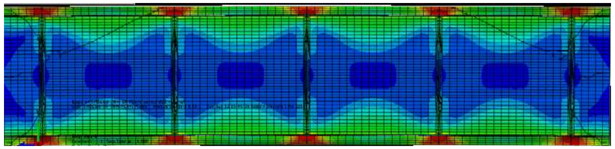
Maximum cladding surface temperature (°C) for each assembly in *one* type of licensed cask. (Hanson, et al, 2016. PNNL)





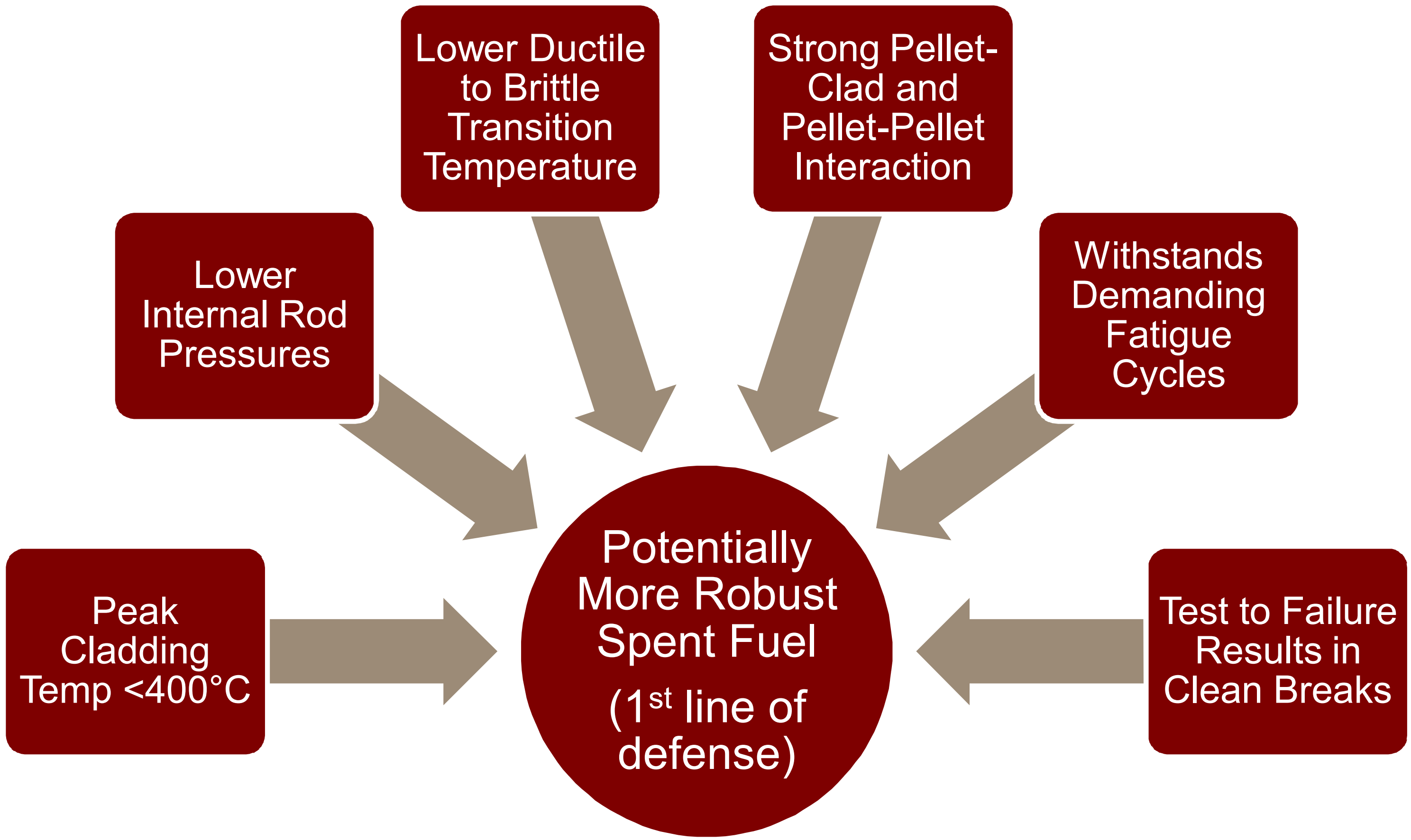
Fuel rod segment before bend testing (Wang, et al., 2016. ORNL)

- *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)

Current Tests and Analyses Indicate that Spent Fuel is ***More*** Robust than was Previously Thought:



Obtaining Data on High Burnup Cladding After 10 Years of Storage

The DOE/EPRI High Burnup Confirmatory Data Project Goal: To obtain data on physical properties of High Burnup Spent Fuel after 10 years of dry storage.

- Steps:
  1. *Loading* a commercially licensed TN-32B storage cask with high burn-up fuel in a utility storage pool (planned for 2017)
     1. Loading well characterized fuel of four common cladding alloys
     2. Instrumenting cask outfitted with thermocouples. Gas samples taken before going to the pad and periodically during storage.
  2. *Drying* using industry standard practices
  3. *Storing* at the utility's dry cask storage site for 10 years
  4. *Transporting* to a laboratory for opening
  5. *Testing* the rods to understand their mechanical properties.
- License Amendment request submitted to the NRC by Dominion in August, 2015, for lid design and additional heat load
- Draft Safety Evaluation Report anticipated from the NRC in summer of 2016

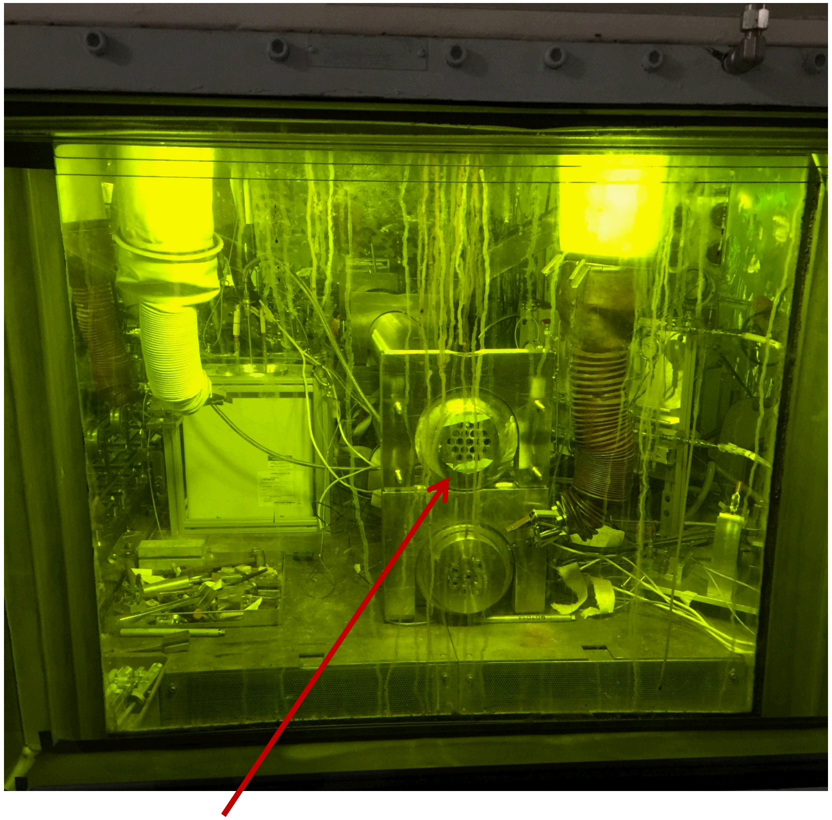
Prairie Island Dry Storage

High Burnup Confirmatory Data Project – Obtaining ***Baseline*** Data

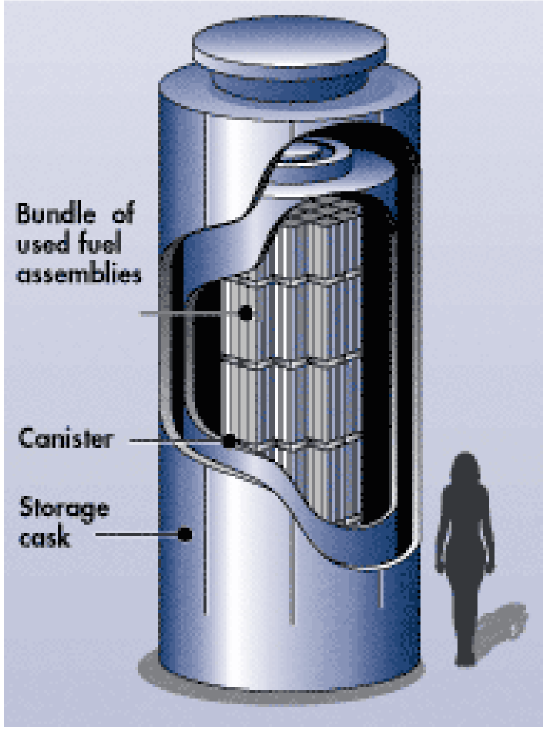
25 fuel rods with similar histories will be tested now to document properties before 10 years of storage.

“Sister Rod” Acquisition and Testing

- Areva and Westinghouse rods pulled in June and January 2015 from different assemblies
  - AREVA M5™ rods
  - Westinghouse Zirlo™ rods
  - Westinghouse low-tin Zircaloy-4 rods
  - Westinghouse standard Zircaloy-4 rods
- All 25 sister rods currently at Oak Ridge National Laboratory
- Draft Sister Rod Test Plan in peer review
  - Cladding mechanical properties
  - Hydride distribution
  - Pellet cladding bonding



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



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2. STORAGE SYSTEM INTEGRITY

Understanding Canister Performance:

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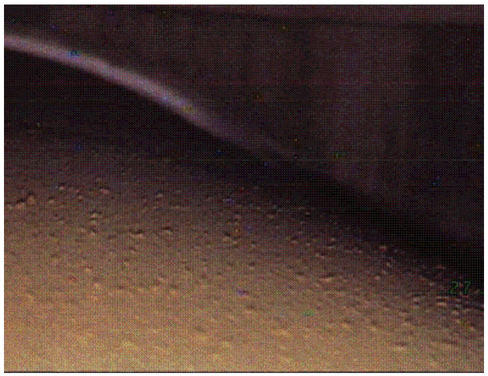
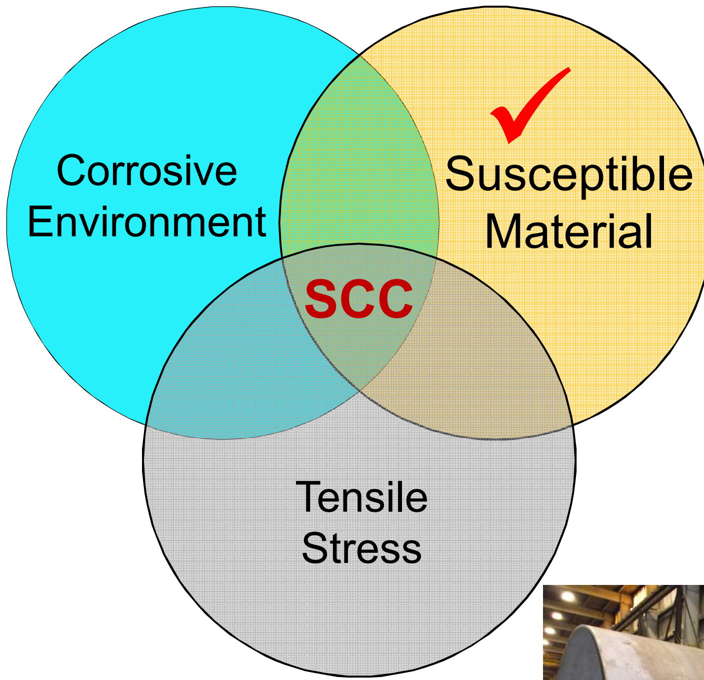
Primary Concern is Stress Corrosion Cracking (SCC), which requires three concurrent conditions:



Dust on canister surface at Calvert Cliffs (EPRI, 2014)



Weld zone, 304 SS plate.
Photo: Ranor

Mock-up Canister
Photo: Enos, SNL

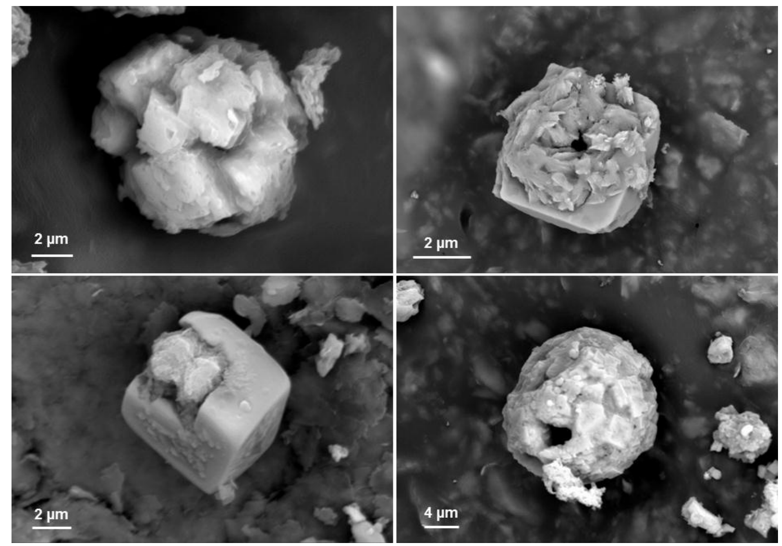
Understanding Canister Performance:

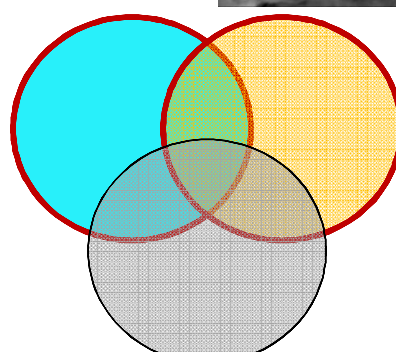
Do We Have a Corrosive Environment?

DOE and EPRI collected limited dust samples at Calvert Cliffs, Hope Creek, and Diablo Canyon. Chloride was found in some areas which could provide the chemistry needed for crack initiation and growth. Need more sampling to determine which areas of the country are at greater risk.

Photos: Enos, SNL

Examples of sea-salt aerosols found on canisters. Photo: Bryan, SNL





Conclusion: Need to determine higher risk areas both environmentally and on the canister.

Understanding Canister Performance:

Is there Tensile Stress Through the Canister Wall?

Full-diameter canister mockup undergoing residual stress testing. Preliminary results indicate through-wall tensile residual stresses along welds and exacerbated at weld repairs that could allow for cracks to grow through the canister wall.

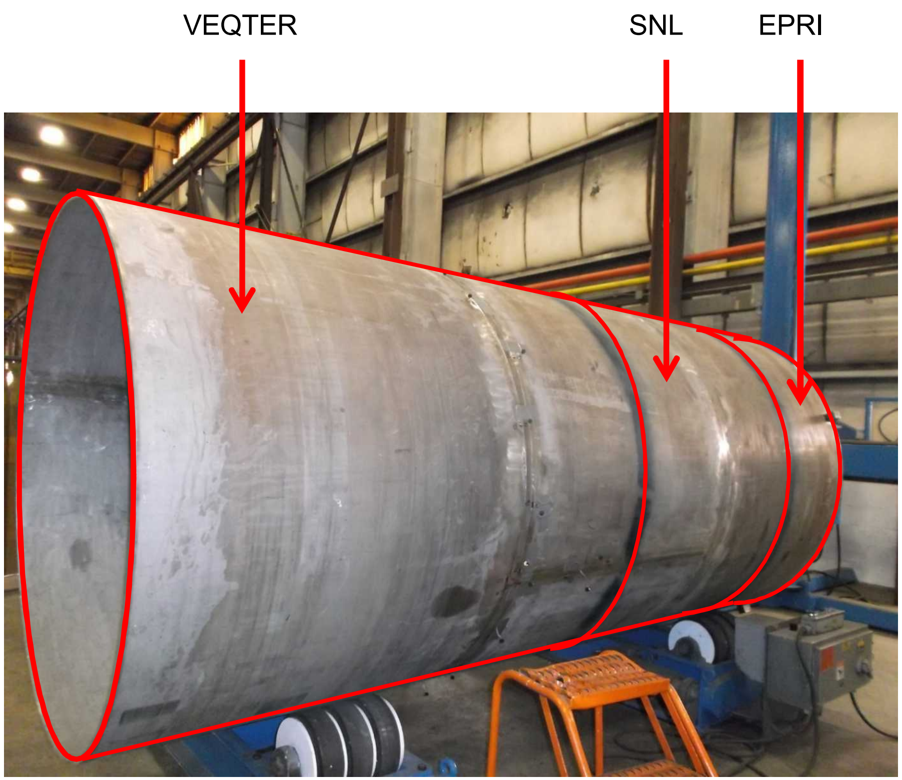
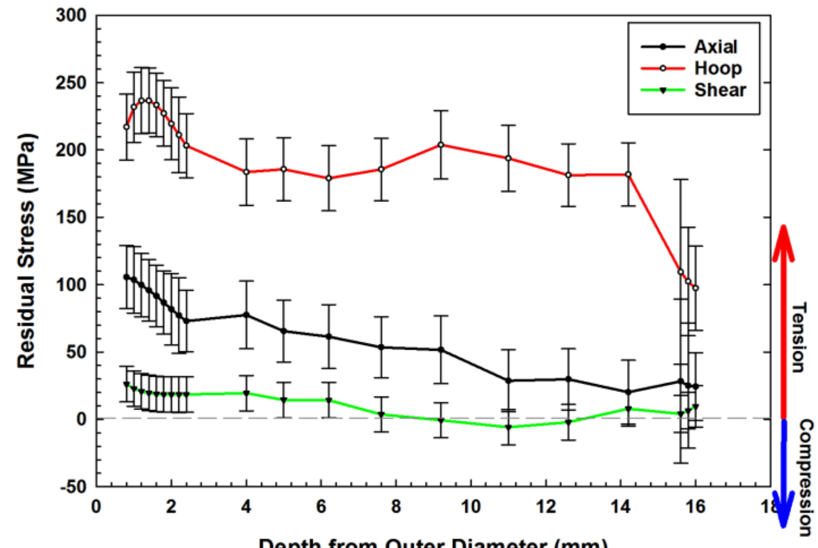
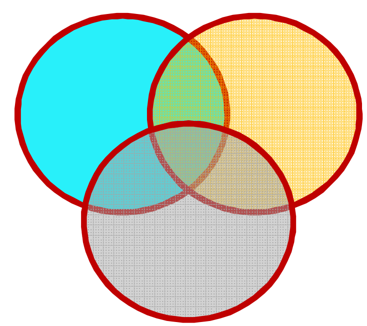
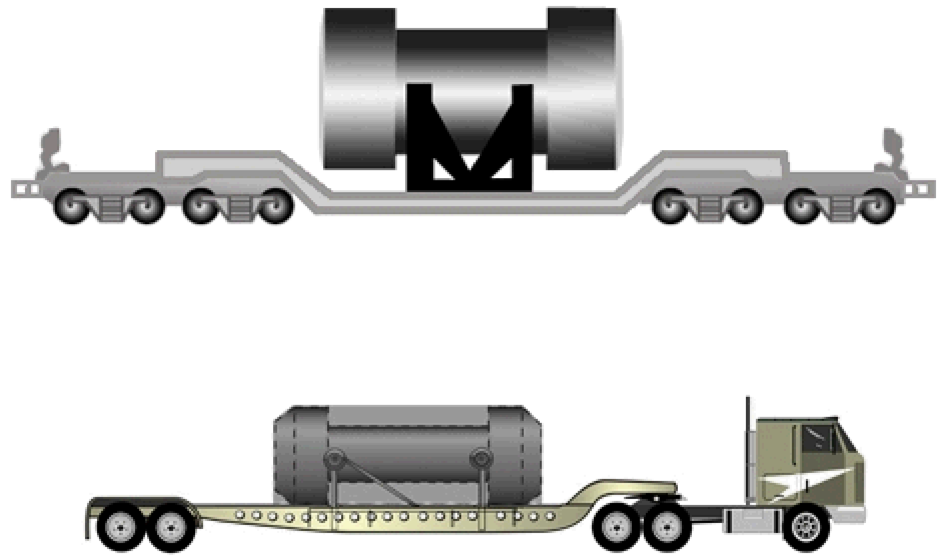


Photo: Enos, SNL



Measured Stresses, Circumferential weld HAZ, Sandia Canister Mockup. Enos, SNL





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3. SPENT FUEL TRANSPORTABILITY FOLLOWING EXTENDED STORAGE

Transporting Spent Nuclear Fuel:

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

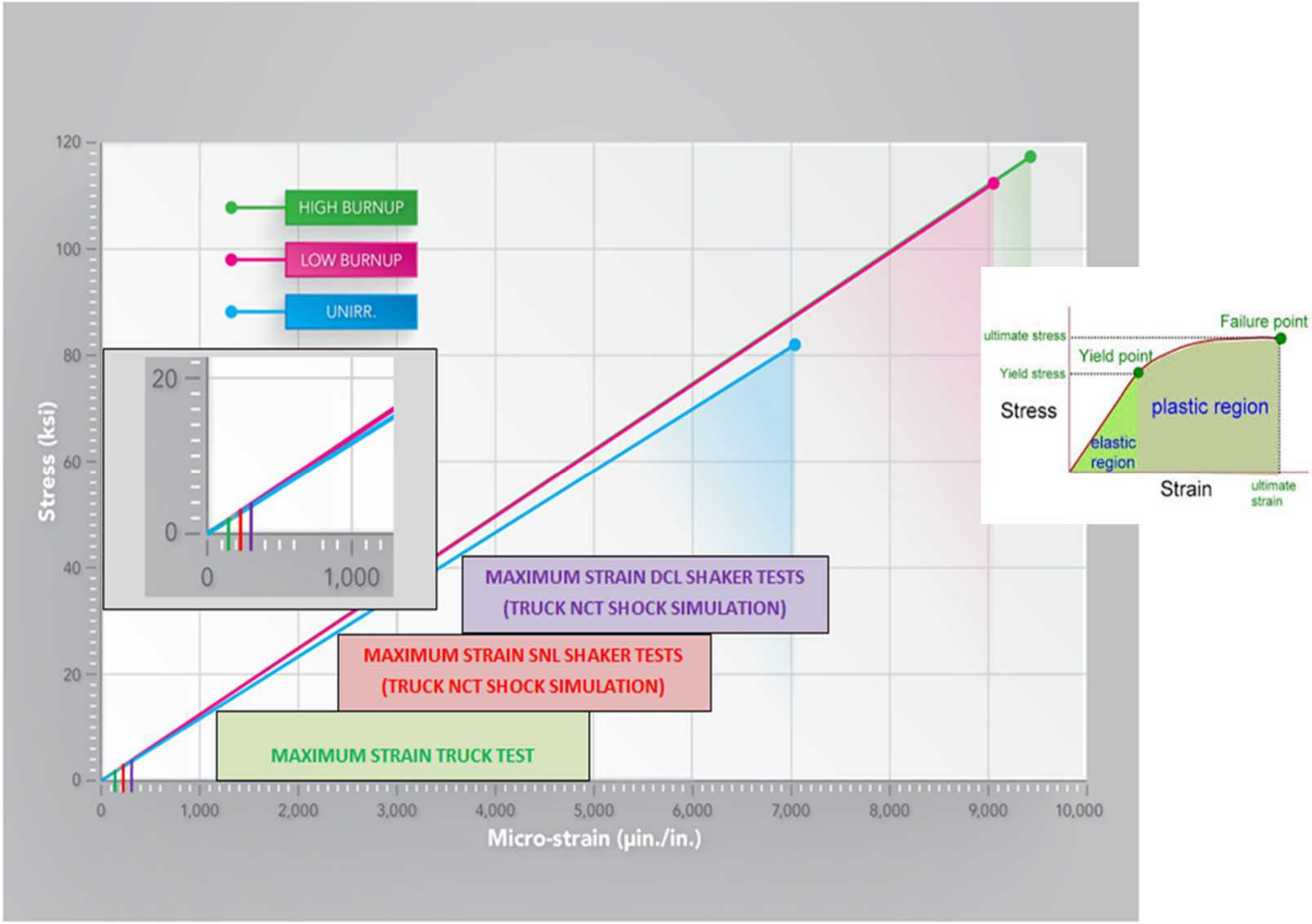
Three series of tests using a surrogate PWR assembly

1. Truck data on a vertical acceleration shaker table
2. Over-the-road truck test
3. Truck and rail data on a commercial seismic shaker with six degrees of motion

McConnell et al, 2016, SNL and PNNL

Transporting Spent Nuclear Fuel:

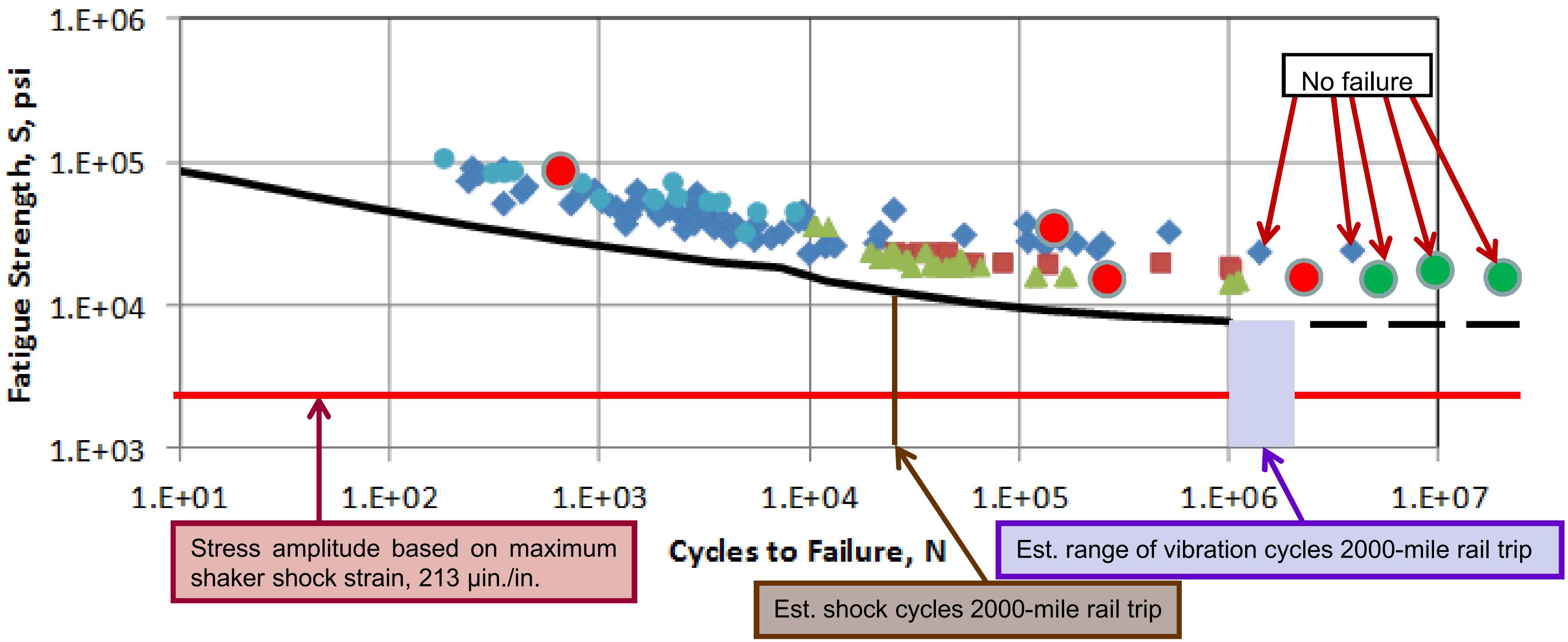
How do Stresses on Fuel During Normal Conditions of Transport Compare to Failure Limits?



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.

Observations from Current Storage and Transportation R&D

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1. Spent fuel integrity

- Current tests and analyses indicate that spent fuel is ***more*** robust than was previously thought.
- The *DOE/EPRI High Burnup Confirmatory Data Project* will obtain data after 10 years of dry storage to confirm current test and analysis results.

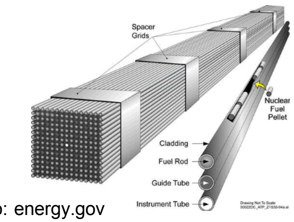


Photo: energy.gov

2. Storage system integrity

- *Stress corrosion cracking of canisters may be a concern in some environments. More work is needed in analysis and detection. This has repackaging implications.*
- *Monitoring and Aging Management practices at storage sites will be important to confirm storage system performance during extended service.*

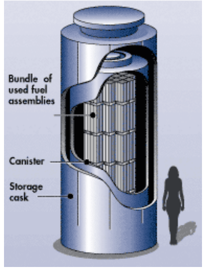
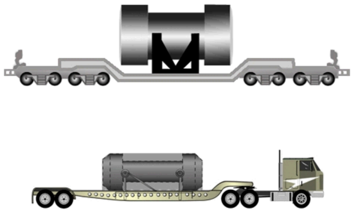


Photo: nrc.gov

3. Spent fuel transportability following extended storage

- *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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Discussion

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Placing spent fuel in dry storage in dual purpose canisters (DPCs) commits the US to some combination of three options

1) Repackaging spent fuel in the future
2) Constructing one or more repositories that can accommodate DPCs
3) Storing spent fuel at surface facilities indefinitely, repackaging as needed

Each option is technically feasible, but none is what was originally planned

- Questions for consideration over the next two days
  - How does the current understanding of the technical basis for extended storage and transportation impact policy choices?
  - What future R&D will best inform policy decisions regarding extended storage and transportation?

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