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Regulatory Approaches to Safe Storage and Transportation of Spent Nuclear Fuel

Jill Hruby
Sandia National Laboratories President, Emeritus

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Outline of Presentation

- Brief status of spent nuclear fuel storage in the US
- Regulatory review
- Technical efforts to prepare for future safe storage and transportation of spent nuclear fuel

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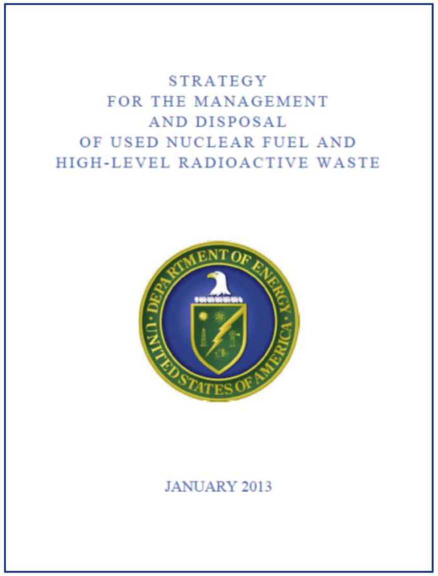
Status of Spent Nuclear Material Disposition in United States

- The Yucca Mountain Nuclear Waste Repository is designated in law (1987) as the first US deep geological repository for spent nuclear fuel
- During the Obama administration, the US halted work on Yucca Mountain and adopted a new consent-based approach to siting a geological repository for nuclear waste (but did not repeal the existing law)
- The Trump administration has supported the completion and opening of Yucca Mountain, however Congress has not allocated funds



STRATEGY
FOR THE MANAGEMENT
AND DISPOSAL
OF USED NUCLEAR FUEL AND
HIGH-LEVEL RADIOACTIVE WASTE

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

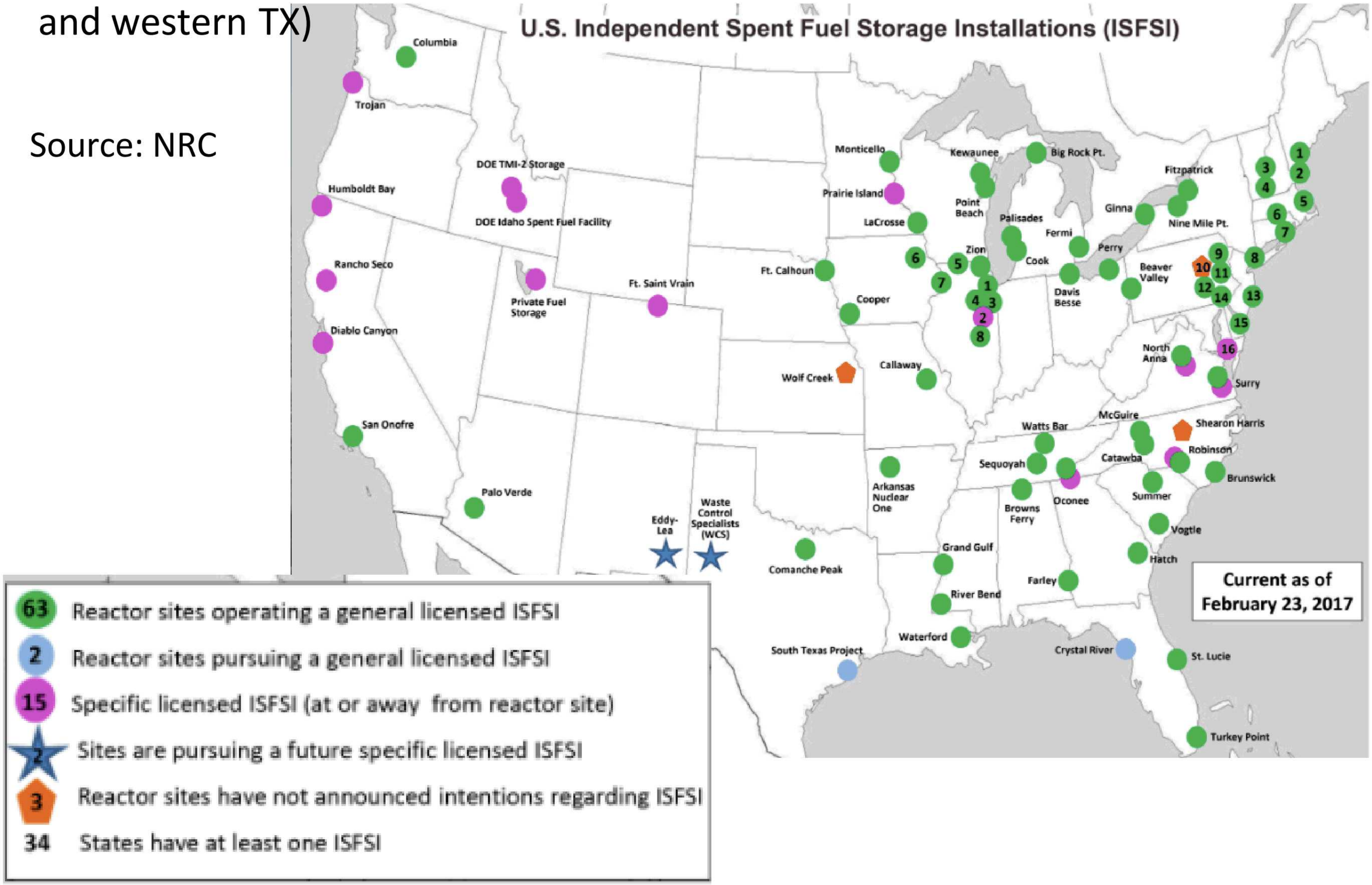
JANUARY 2013

Because no repository for commercial spent nuclear fuel exists, the need to develop safe ***transport*** of commercial spent nuclear fuel in the US has not been urgent.

Location of Commercial Spent Nuclear Fuel in US

- 78 sites have a licensed independent spent fuel storage installations
- Industry is working on licensing two consolidated storage sites (eastern NM and western TX)

Source: NRC



U.S. Independent Spent Fuel Storage Installations (ISFSI)

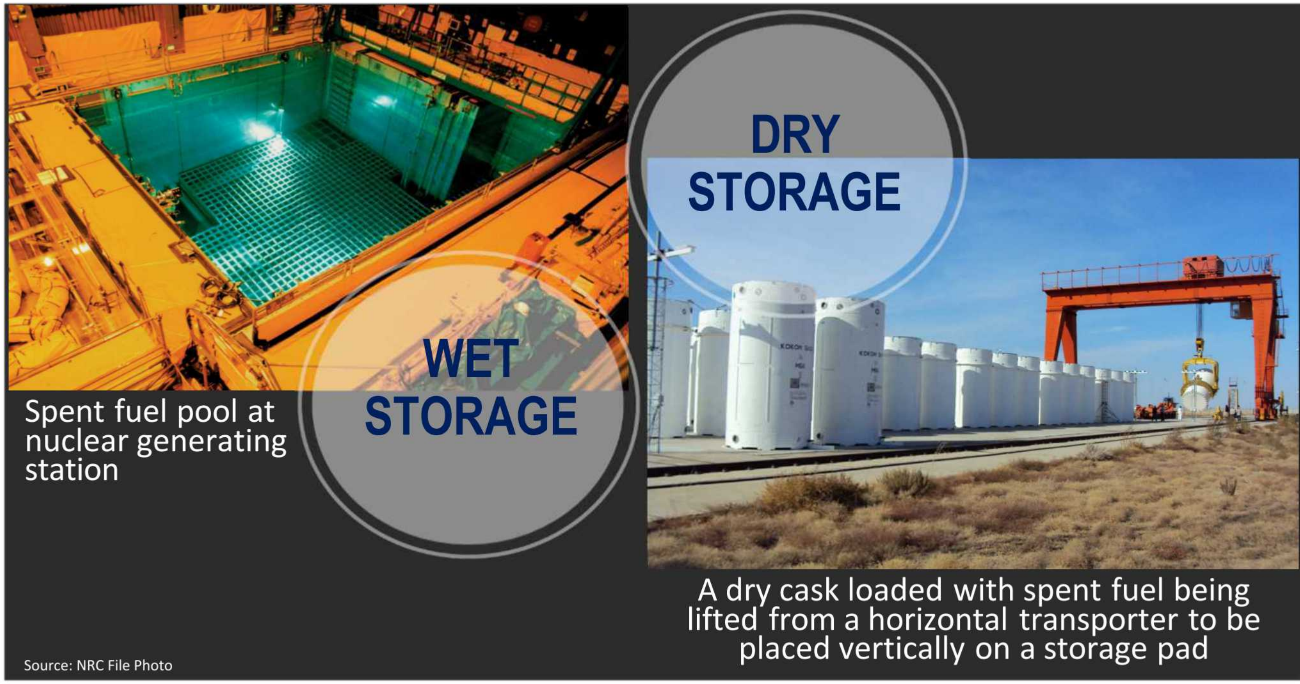
Current as of February 23, 2017

Independent Spent Fuel Storage Installation Configurations

- Spent fuel is stored in wet storage then moved to dry storage as needed, usually at the same site

- There are over 30 different types of containers in use for dry storage

- Transnuclear (Areva/Orano); Holtec; and NAC are the current vendors for dry storage containers in the US – each with many configurations



Spent fuel pool at nuclear generating station

A dry cask loaded with spent fuel being lifted from a horizontal transporter to be placed vertically on a storage pad

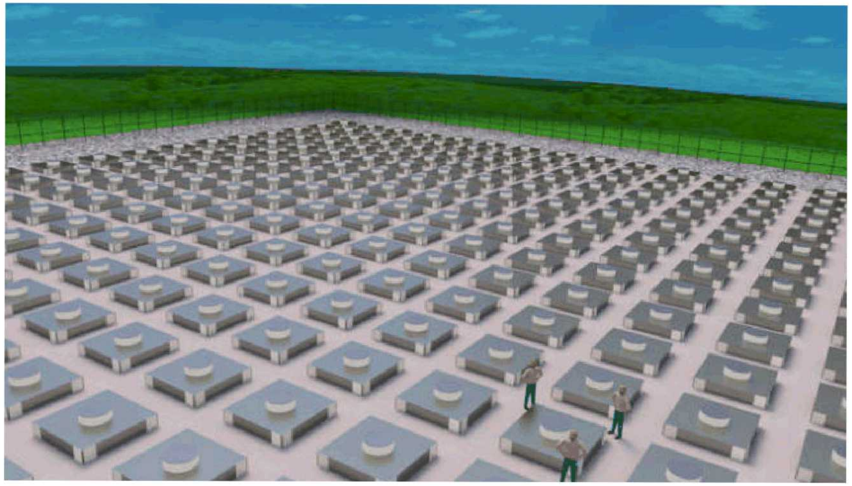
Source: NRC File Photo

Transnuclear TN-32

Holtec Hi-Storm 100

Proposed Consolidated Dry Storage Sites in Review by NRC

- Due to the lack of underground repository, DOE is in partial breach of contract with utilities
- A study by Oak Ridge National Laboratory showed a consolidated interim storage site could save the U.S. $3B by 2040, $7B 2050, and $12B by 2060
- NM (Holtec) and TX (WCS/Orano) storage sites have submitted applications to NRC
  - Reviews expected to take 3 yrs
- In addition to storage site design approval, transportation would also need to be approved

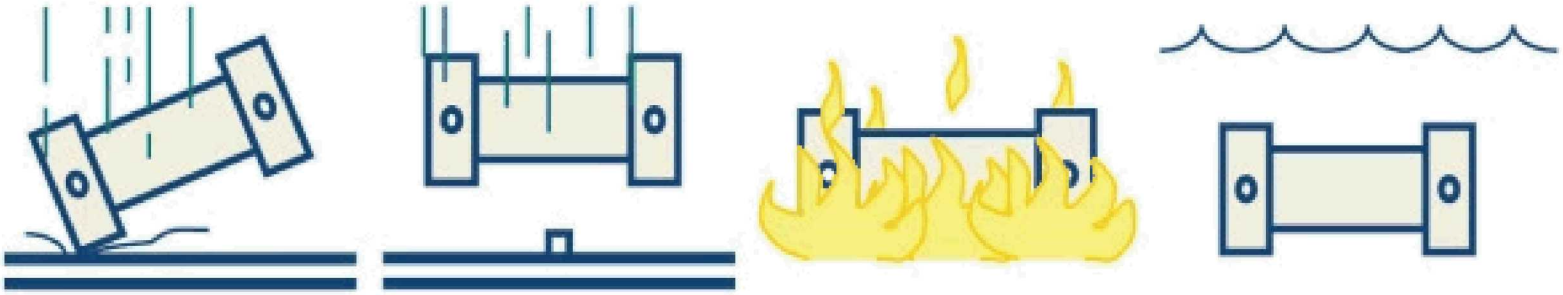


US Storage and Transportation Requirements Based on the Nuclear Waste Policy Act (NWPA)

- Section 141(b)(1)(C) of the NWPA requires a Department of Energy owned monitored retrievable storage (MRS) facility be designed "to provide for the ready retrieval of such spent fuel and waste for further processing or disposal"
- NRC has codified this requirement in regulations
  - 10 CFR 72.122(l) "Storage systems must be designed to allow ***ready retrieval of spent fuel*** or high-level radioactive waste and reactor-related Greater-Than-Class C (GTCC) waste for further processing or disposal."
  - 10 CFR 72.122(h)(1) "***The spent fuel cladding must be protected during storage*** against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate."
  - 10 CFR 71.55 (b) "A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under the normal conditions of transport … (2) ***The geometric form of the package contents would not be substantially altered***."
- When the NWPA was written, no spent fuel was in dry storage and planning for transportation options assumed handling would begin with bare fuel assemblies
- The Holtec and WCS/Orano facilites are not MRS facilities
- The NWPA is not optimal for integrated dry storage, transportation, and disposal

Transportation Regulatory Requirements

- US Department of Transportation relies on the Nuclear Regulatory Commission (NRC) to develop regulations for transportation of large quantities of nuclear materials
- The NRC package performance regulations have been essentially the same since the 1950s
  - 9 m drop onto a rigid target, 1 m drop on puncture spike, 30 minute fire, 200 m submersion test
  - Drops and fire tests are considered in sequence



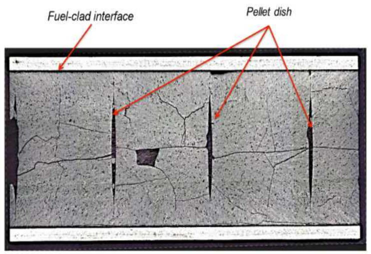
Technical Efforts to Evaluate Safe Storage and Subsequent Transportation of Spent Nuclear Fuel

- Spent fuel integrity
- Storage system integrity
- Spent fuel transportability

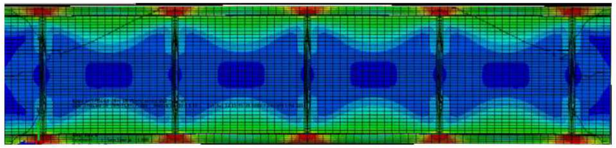
- Primary support provided by US DOE, Office of Nuclear Energy
- Collaboration among multiple national laboratories: ANL, INL, LANL, ORNL, PNNL, SRNL, SNL
- US NRC, Office of Nuclear Materials Safety and Safeguards
- Industry: fuel and storage systems vendors, site operators, Electric Power Research Institute (EPRI), and Nuclear Energy Institute (NEI)
- Universities: Penn State, U Illinois, U SC, U Florida, South Carolina Sate, Colorado School of Mines, NC State, U Miss, Oregon State, U of Houston, Pepperdine, U Utah, Utah State, MIT, Texas A&M, U Nevada at Reno, Northwestern, Michigan, UC Irvine
- International Collaborators; Germany, Japan, Spain, Korea, IAEA, Euratom

Spent Fuel Integrity

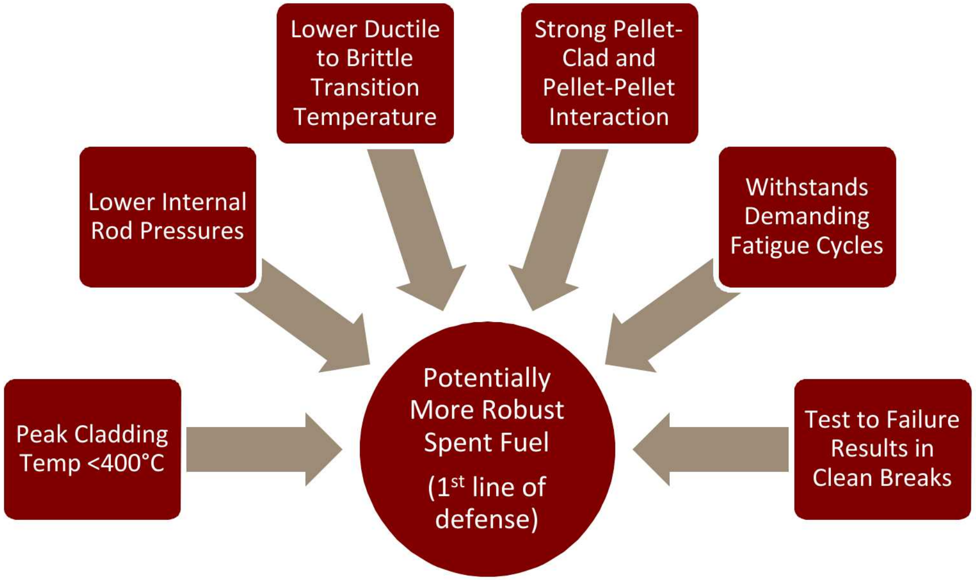
- Understanding high burn-up cladding performance
  - Tests and analysis to date indicate spent fuel rods are more robust than previously thought
- Obtaining baseline data from 25 high burn-up rods
  - AREVA M5, Westinghouse Zirlo, Westinghouse low-tin Zircaloy-4, Westinghouse standard Zircoloy-4
- DOE/EPRI high burn-up program will obtain additional data on high burn-up fuel rods after 10 years of storage
  - Loaded a TN-32B cask with high burn-up, well-characterized fuel rods
  - Placed in dry storage for 10 years
  - Transport to lab for testing and comparison to baseline data will occur



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



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



Lower Internal Rod Pressures

Lower Ductile to Brittle Transition Temperature

Strong Pellet-Clad and Pellet-Pellet Interaction

Withstands Demanding Fatigue Cycles

Peak Cladding Temp <400°C

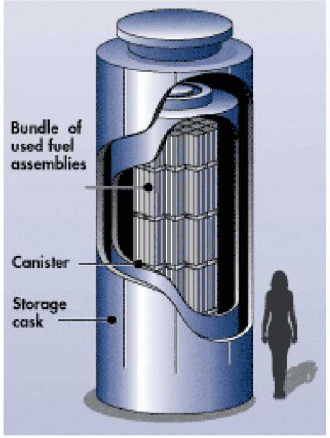
Test to Failure Results in Clean Breaks

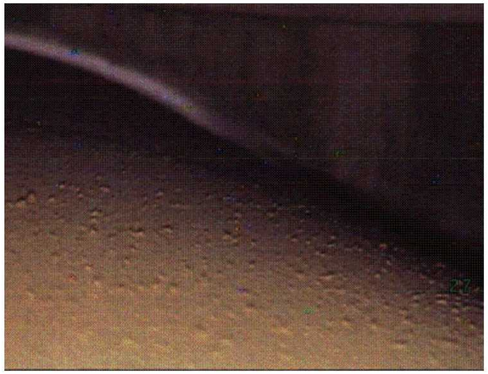
Potentially More Robust Spent Fuel

(1st line of defense)

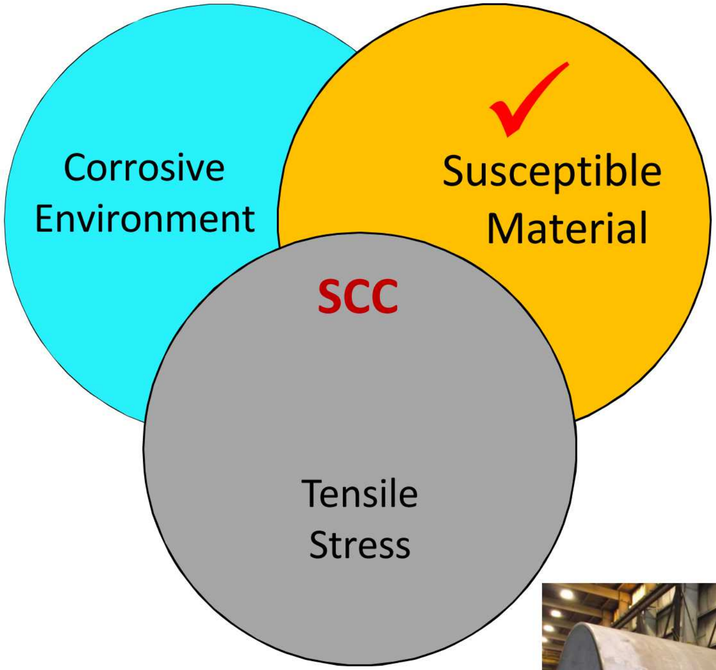
Storage System Integrity

- Understanding canister performance, especially stress corrosion cracking
- Dry storage is being relied on for longer time periods than originally envisioned and stress corrosion cracking needs to be better understood.





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



Corrosive Environment

✓ Susceptible Material

SCC

Tensile Stress

Weld zone, 304 SS plate.
Photo: Ranor

More studies needed because could have repackaging implications

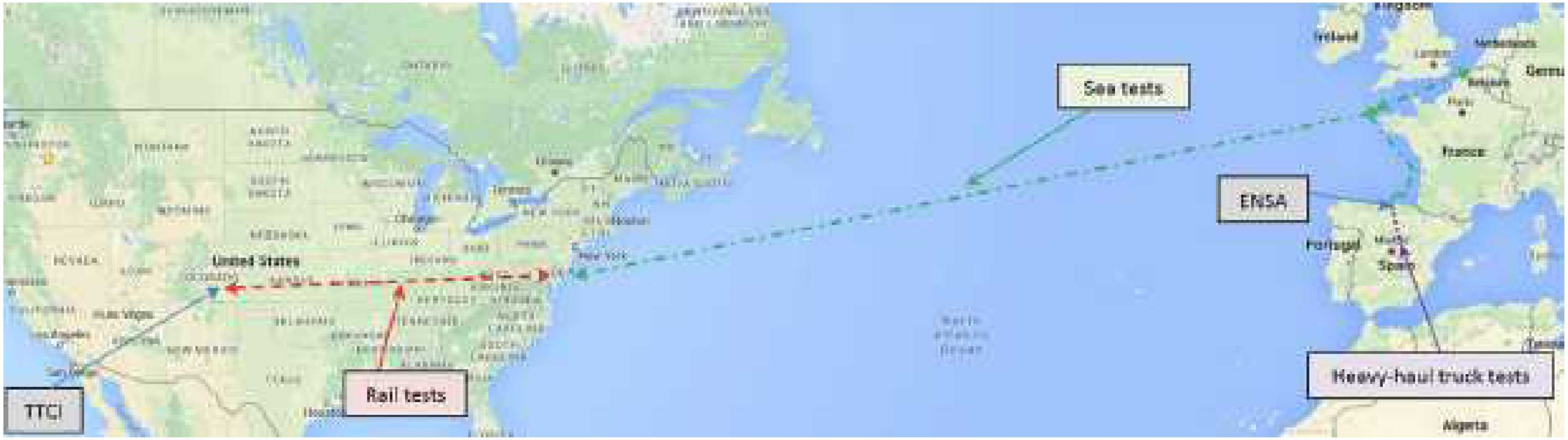
Mock-up Canister
Photo: Enos, SNL

Spent Nuclear Fuel Transportability

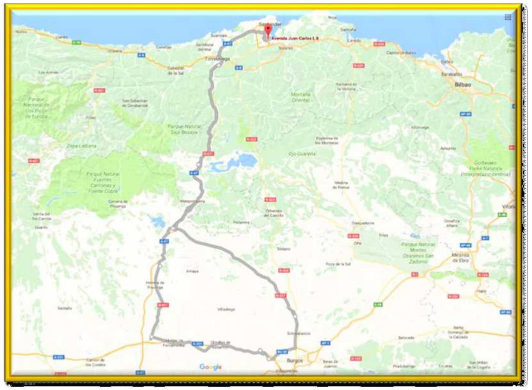
- Lab tests
  - Truck data on vertical acceleration shaker table
  - Truck and rail data on a commercial seismic shaker
- Road tests
- Multi-mode transportation tests
  - Joint Spanish (ENSA) and US (DOE) testing
  - Sandia National Laboratories, Equipos Nucleares S.A., Pacific Northwest National Laboratories, Korea Radioactive Waste Agency (KORAD) & KAERI

Multi-Modal Transportation Tests

- 54 days of data collection, 4 transport modes, 7 countries, 12 states
- ENSA ENUN 32P Cask with surrogate fuel rods (Sandia fuel assembly, ENSA fuel assembly, and Korean fuel assembly). Other slots were filled with concrete blocks which had the same mass as the surrogate assemblies so that all 32 slots were filled.
- 77 accelerometers and stain gauges



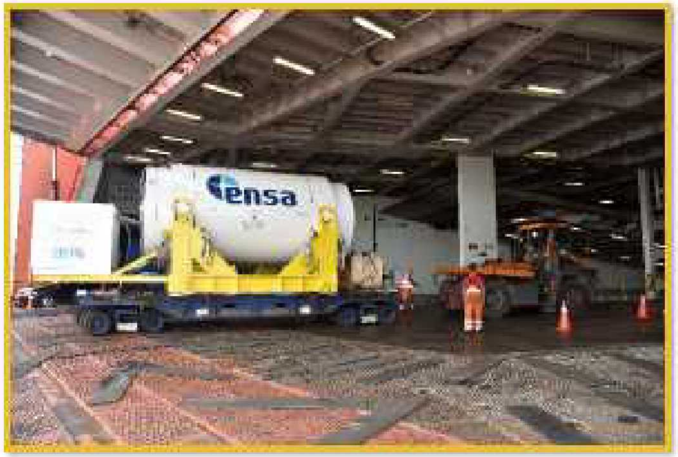
Heavy-haul Truck Route through Northern Spain



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

Intercoastal and Transoceanic Ship Transport

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



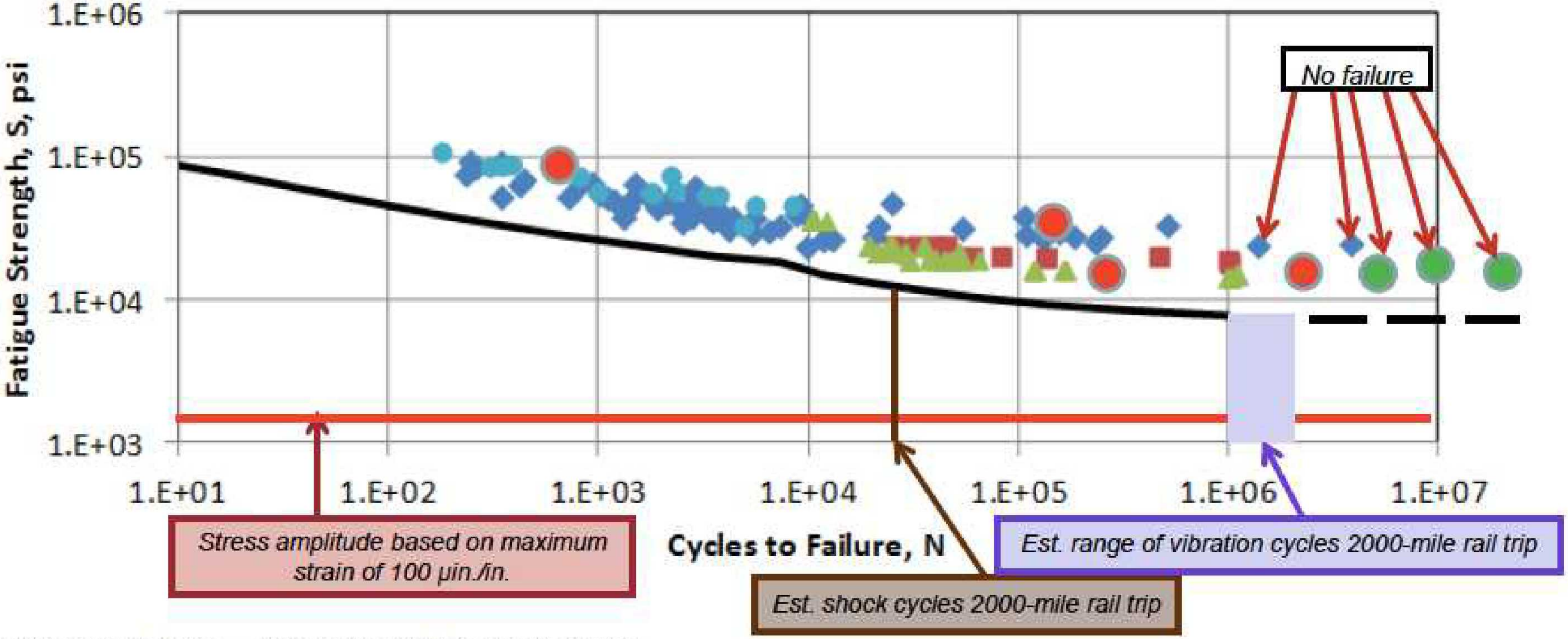
Maximum Assembly Strain, µm/m	Maximum Platform Acceleration, g	Maximum Cask Acceleration, g	Maximum Cradle Acceleration, g	Maximum Basket Acceleration, g	Maximum Assembly Acceleration, g
≤20	0.38	≤0.2	≤0.2	≤0.2	≤0.2

Rail shipment and rail tests

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.*

Multi-Mode Transportation Results to Date



Stress amplitude based on maximum strain of 100 μin./in.

Est. shock cycles 2000-mile rail trip

Est. range of vibration cycles 2000-mile rail trip

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.

Summary

- Storage and transportation have become interwoven issues in the US
- While little commercial spent nuclear fuel is being transported today, the US is studying transport of spent nuclear fuel after extended storage
- Tests are underway and planned over next 10+ years
- Data to date indicate that spent fuel rods are robust and not expected to fail under realistic storage and transportation environments
- International collaborations are essential for this work