SAND2014-19007C

U.S. Department of Energy R&D Program on Developing the Technical Basis for Spent Fuel Extended Storage and Subsequent Transportation

4th International Conference on Asian Nuclear Prospects (ANUP)

November 9 – 12, 2014
Jeju, Republic of Korea

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Sandia National Laboratories
Albuquerque, New Mexico
SAND2015-XXXXP

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Used Fuel Disposition R&D Campaign

The *DOE Office of Used Nuclear Fuel Disposition Research and Development and nine national laboratories participate in the DOE Office of Nuclear Energy's "Used Fuel Disposition Campaign"*

Campaign Mission:

to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles

Los Alamos NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

Sandia National Laboratories

BERKELEY LAB

SRNL SAVANNAH RIVER NATIONAL LABORATORY

INL Idaho National Laboratory

ornl OAK RIDGE NATIONAL LABORATORY

Science in the National Interest
Lawrence Livermore National Laboratory

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Contents

- **Overall Objectives**
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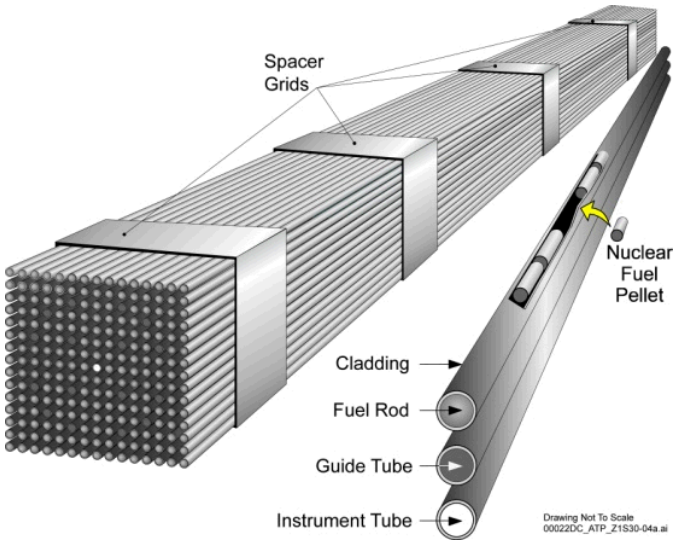
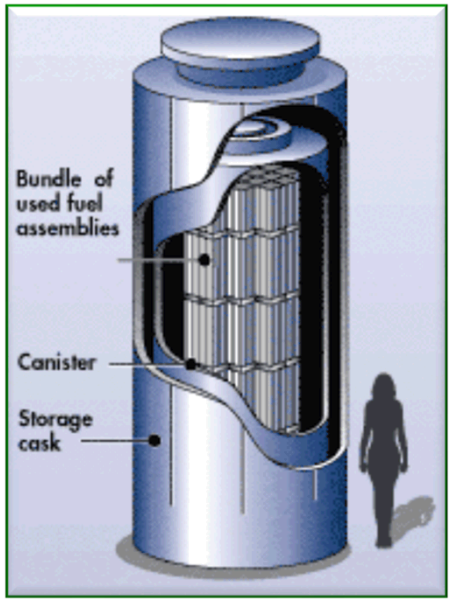


http://energy.gov/sites/prod/files/styles/



www.nrc.gov/waste/spent-fuel-storage/

www.connyankee.com/

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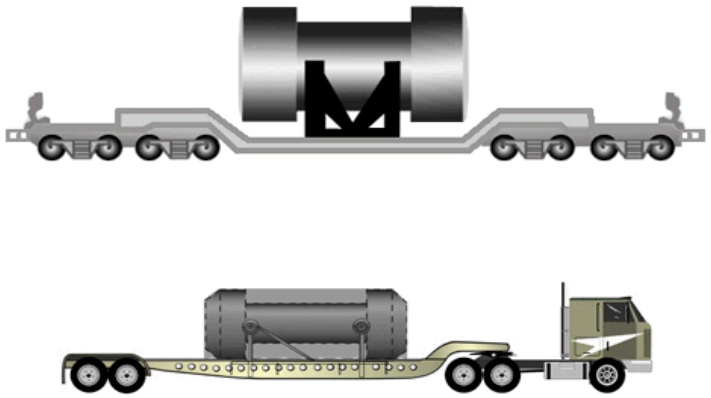
DOE's R&D Focus for Storage & Transportation

- **Prepare for extended storage and eventual transport of used nuclear fuel and high-level radioactive waste**

- **Develop the technical basis for**
  - **Extended storage of used nuclear fuel**
  - **Fuel retrievability and transportation after extended storage**
  - **Transportation of high-burnup used nuclear fuel**

www.connyankee.com/



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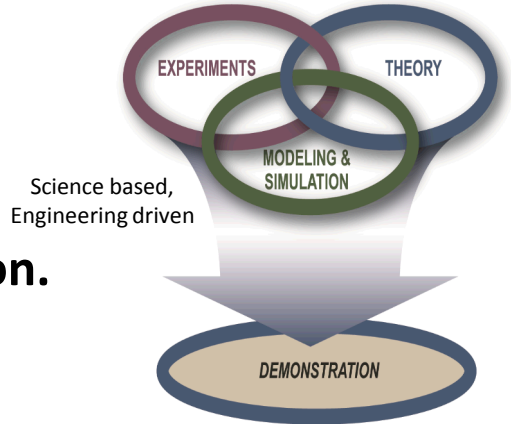
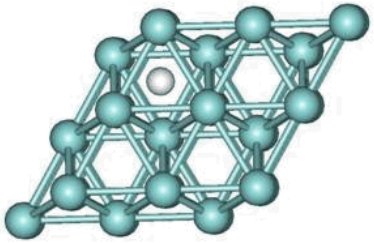
Storage & Transportation Scope

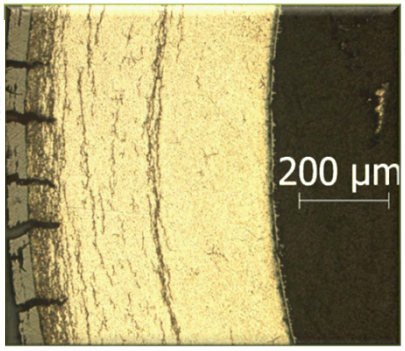
Science Based, Engineering Driven

- Combining theory, experiments and predictive models. Verifying with the large scale demonstration.
- From Å to meters, µg to tonnes



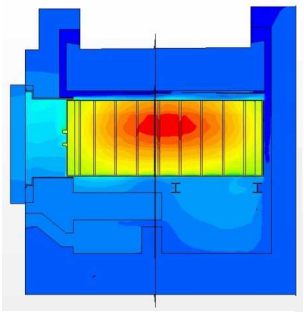


SAND2013-6809P, August 2013, Tikare, Weck



UFD Telecon, April 12, 2012
Billone, Liu; Argonne

UFD Telecon, April 12, 2012
Wagner, Adkins; ORNL



'Jones 2010.ppt',
Calvert Cliffs Dry Fuel Storage and Industry Lessons Learned

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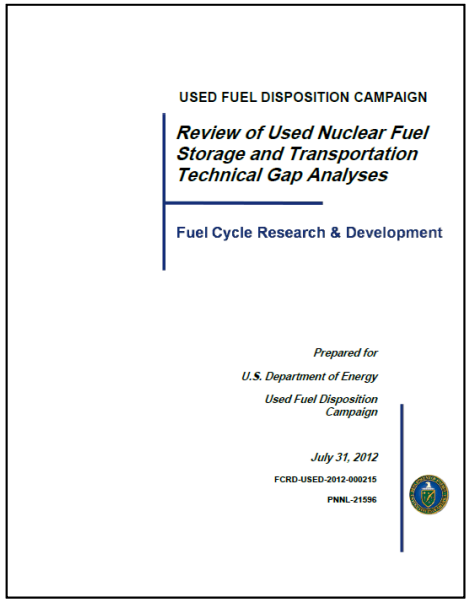
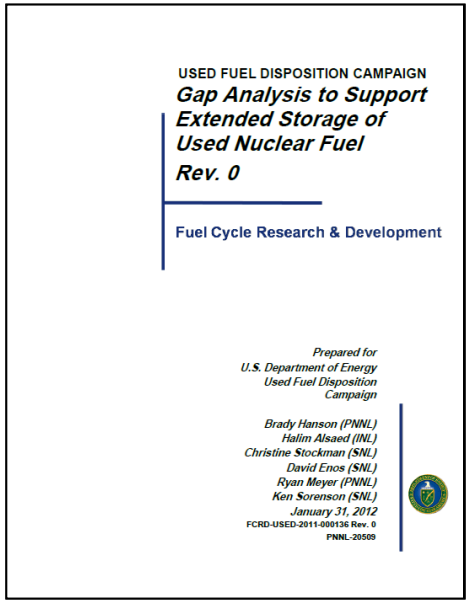
Storage & Transportation R&D

- **DOE's Storage and Transportation R&D activities are guided by:**
  - **Detailed analysis of gaps in the existing technical bases**
  - **Thorough review of comparable gap analyses by others**
    - *U.S. Nuclear Waste Technical Review Board*
    - *U.S. Nuclear Regulatory Commission*
    - *Electric Power Research Institute*
    - *International Atomic Energy Agency*



http://energy.gov/sites/prod/files/Gap%20Analysis%20Rev%200%20Final.pdf



http://energy.gov/sites/prod/files/Gap%20Comparison%20Rev%200.pdf

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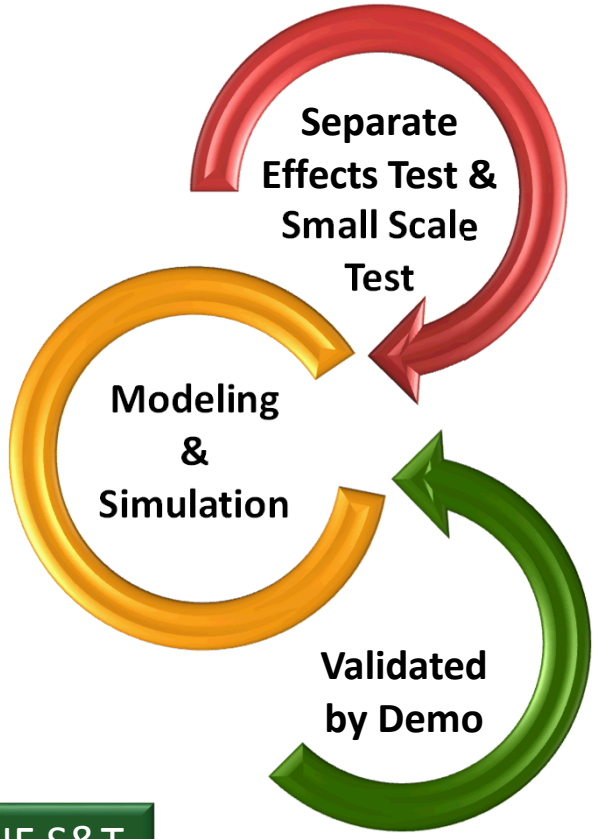
Storage & Transportation Control Accounts

- **Five Control Accounts are designed to define the work to address the objectives:**
  - Experiments
  - Engineering Analysis
  - Transportation
  - Field Demonstration
  - Security



All work is prioritized according to the 2012 UNF S&T Data Gap Prioritization. FCRD-USED-2012-000109.

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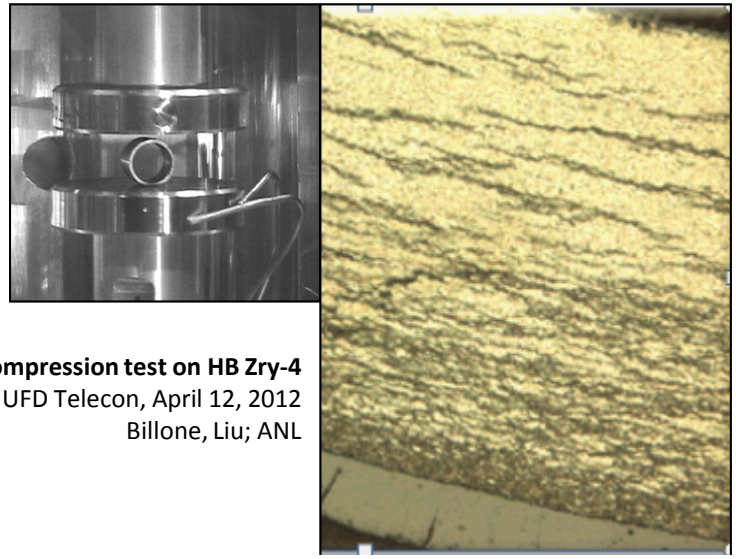
ST Experiments

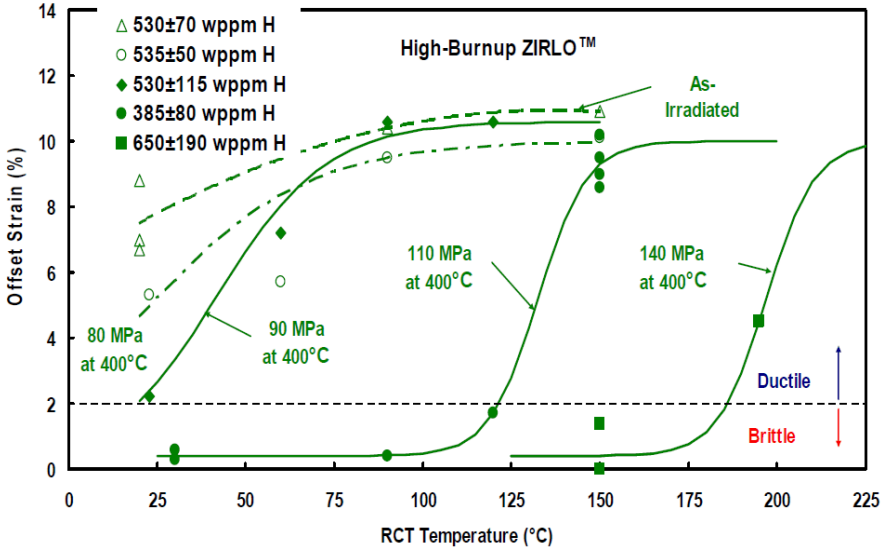
Obtain data to confirm understanding of material degradation effects on cladding and canister materials during long-term storage conditions.

Fuel Cladding

- **Conduct ring compression and DBTT tests on PWR high burnup spent fuel cladding**
  - **Cladding types have significant differences in mechanical performance**
  - **Hydride orientation effects ductility**
  - **Thermal loadings effect hydride orientation and thus, ductility**
  - **Plenum pressures effect ductility**



Ring compression test on HB Zry-4
UFD Telecon, April 12, 2012
Billone, Liu; ANL



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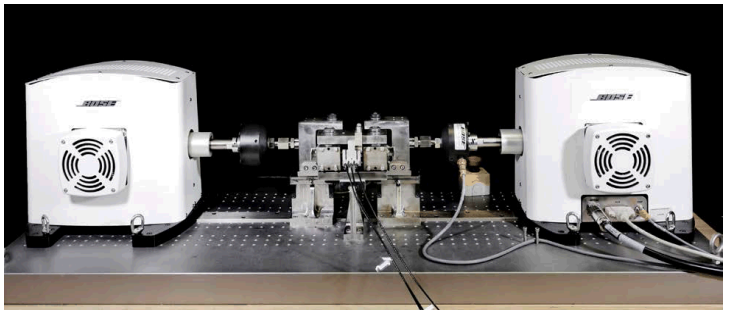
ST Experiments

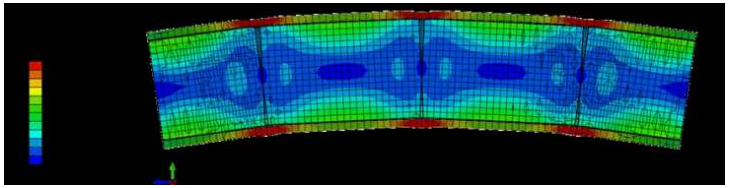
Obtain data to confirm understanding of material degradation effects on cladding and canister materials during long-term storage conditions.

Fuel Cladding

- **Conduct vibration/fatigue tests on high burnup spent fuel rodlets**
  - **Stiffness of rod highly dependent on pellet to pellet and pellet to cladding interaction (i.e., interface bonding)**
  - **Flexural rigidity is inferred through deflection measurements (i.e., rod curvature)**
  - **This interaction acts to strengthen the mechanical behaviour of the used fuel. This has positive implications for Normal Conditions of Transport**

Wang, Jy-An, CIRFT Test Framework and its Applications to SNF Vibration Reliability Investigation, 2014 ASTM C26 Committee Meeting, June 10-12, 2014





Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

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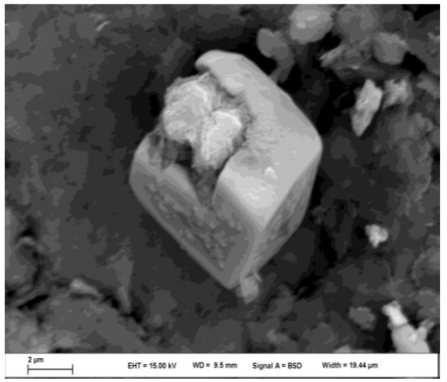
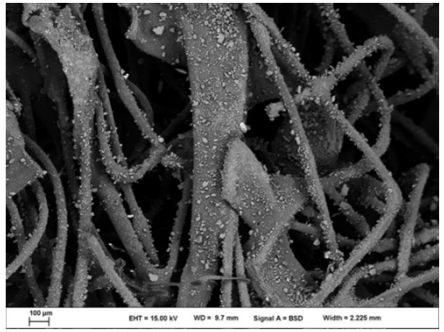
ST Experiments

Obtain data to confirm understanding of material degradation effects on cladding and canister materials during long-term storage conditions.

Canister Corrosion and Stress Corrosion Cracking (SCC)

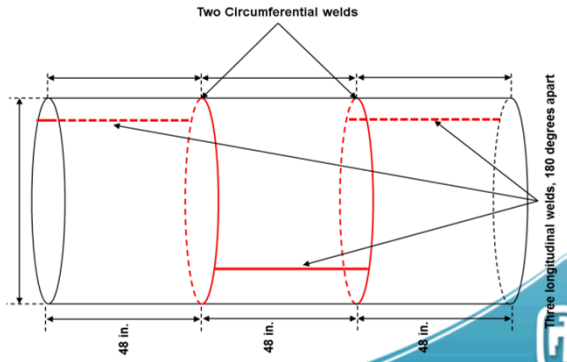
- Collect data to better understand initiating initiating conditions for corrosion and SSC
- Obtain site data to assess environmental conditions to compare with initiating conditions
- Procure a full-scale (diameter) welded SS canister to investigate residual stresses due to plate rolling and welding
  - Thermal profile analyses align with site canister measurements
  - Environmental data provides insight to site conditions
  - SS canister work to begin in FY15





Enos, et al., Data Report on Corrosion Testing of Stainless Steel SNL Storage Canisters, FCRD-UFD-2013-000324

Conceptual design for full-scale (diameter) SS welded canister



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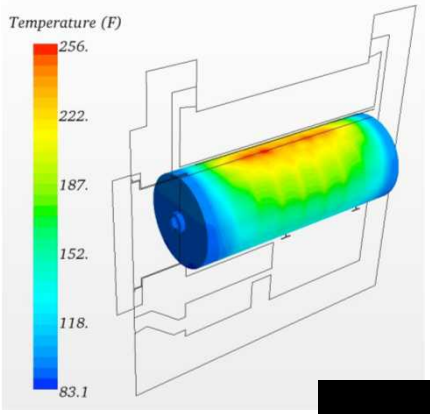
ST Analysis

Develop and benchmark models that will predict behavior during long-term storage and transportation conditions

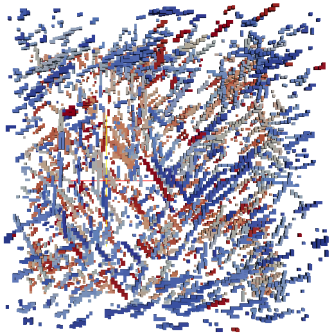
Predictive modeling

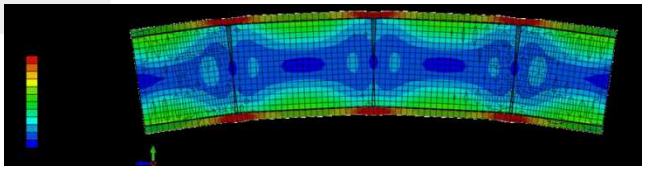
- Thermal Analysis to predict cool down, Ductile to Brittle Transition, deliquescence, etc.
  - HBU Demonstration fuel selection and cool down
  - Modern, high heat load, high capacity systems
  - In-service inspections validation data
- Hybrid hydride reorientation model
- Structural uncertainty analysis at assembly and canister level
- Finite element analysis validation with CIRFT and application to out-of-cell testing

CFD Thermal Analysis of Dry Storage Casks
Suffield, et al, PNNL-21788



Model for Simulation of Hydride Precipitation, Tikare et al, FCRD-UFD-2013-000251.

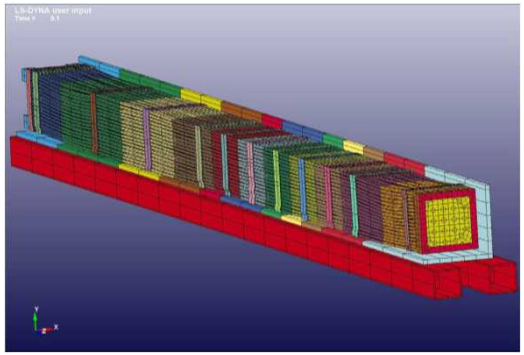




Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

Thermal profile analyses

- Detailed thermal analyses for licensed dry storage systems



FE Models of Assembly
Klymyshyn, et al, PNNL, FCRD-UFD-2013-000168

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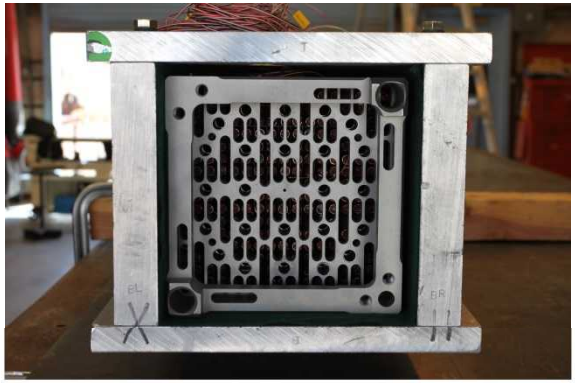
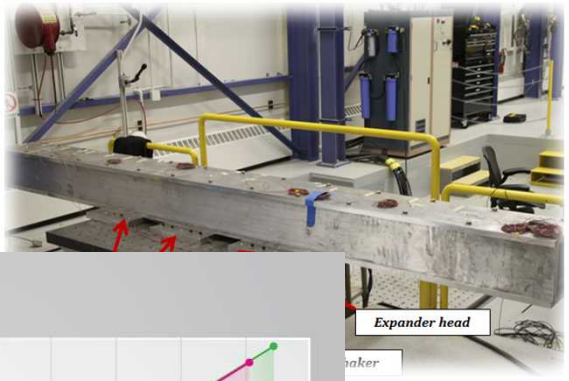
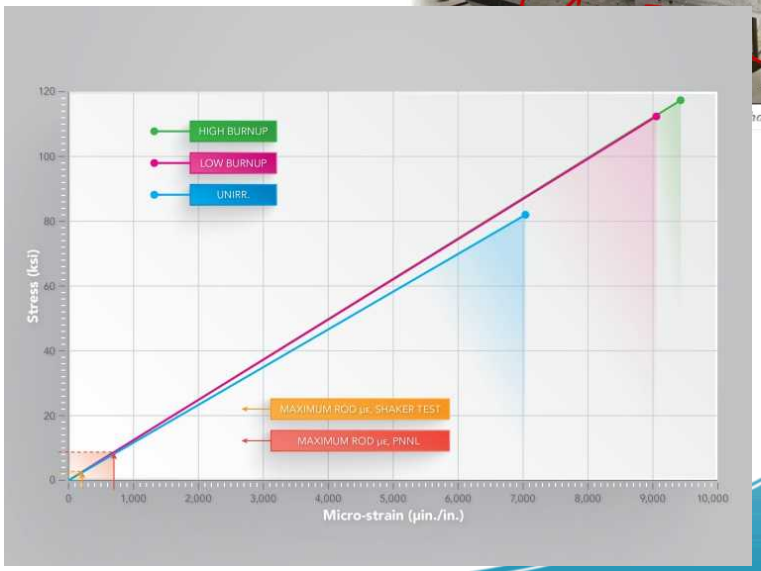
ST Transportation

Normal Conditions of Transport – Loading on fuel assemblies

- A surrogate assembly was subjected to truck data from a 700 mile trip on a shaker table and 50 miles on a real truck with representative weight.
  - Data results were >10 times below yield strength.
  - The strains measured in both were an order of magnitude lower than either an irradiated or unirradiated Zircaloy rod yield strength.







Data collection and analysis for NCT loads on a surrogate fuel assembly

- If high burnup fuel can maintain its integrity during transport, pressure will be taken off experimental R&D efforts associated with hydride effects on cladding strength and ductility.

Sorenson, K., Determination of Loadings on Spent Fuel Assemblies During Normal Conditions of Transport, SAND2014-2043P.

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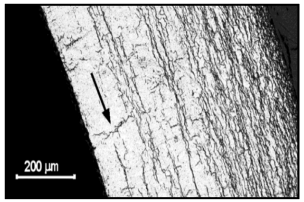
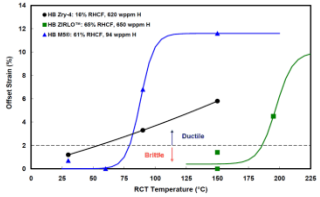
Making a Case for Transport of High Burnup Fuel

Experimental
Material properties
Benchmark data

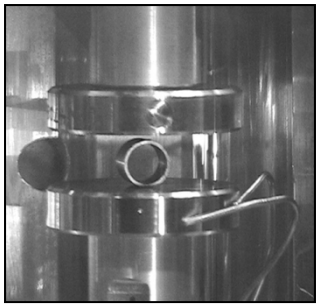




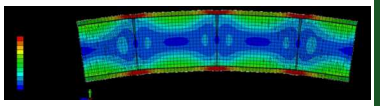
Clad morphology ⟷ **Clad properties**:

- Hydrogen
  - Concentration
  - Distribution
  - Orientation
- Oxidation
- Pellet/clad interaction

σ_{ys} = yield stress
σ_{ult} = ultimate stress
K_{Ic} = fracture toughness
E = elastic modulus
ϵ_{ult} = ultimate strain



Instron 8511 used for Ring Compression Tests



Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

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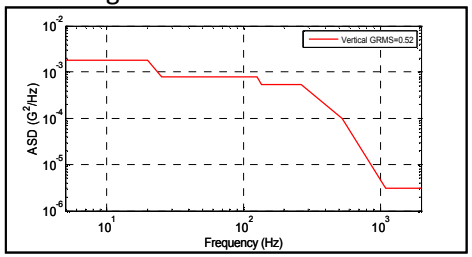
Field Tests

- Realistic configurations
- Realistic loads
- Regulatory alignment

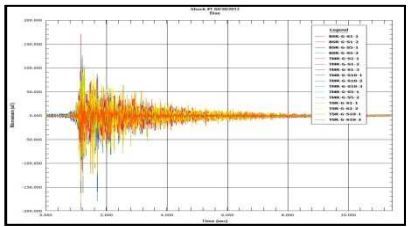
Loads:

- Shock/vibrations loads representing normal conditions of transport
- g = accelerations



Response:

- g and ϵ on individual rods



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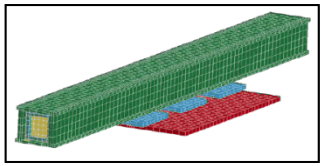
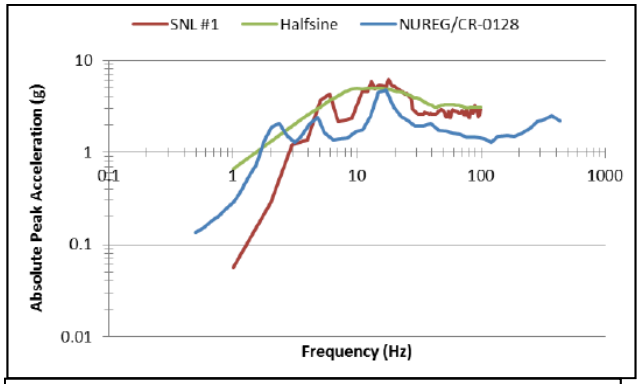
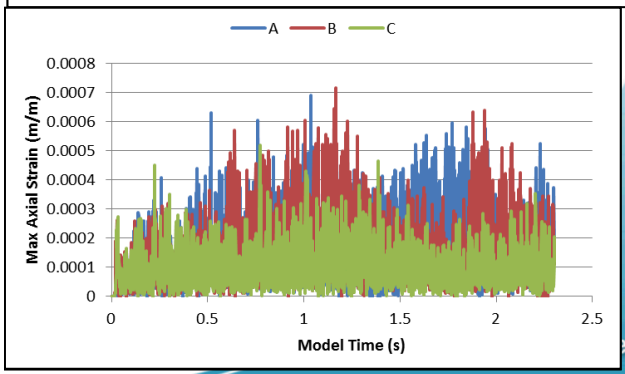
Analysis ➡ $\sigma < \sigma_{ys}$?

$K_I < K_{Ic}$?

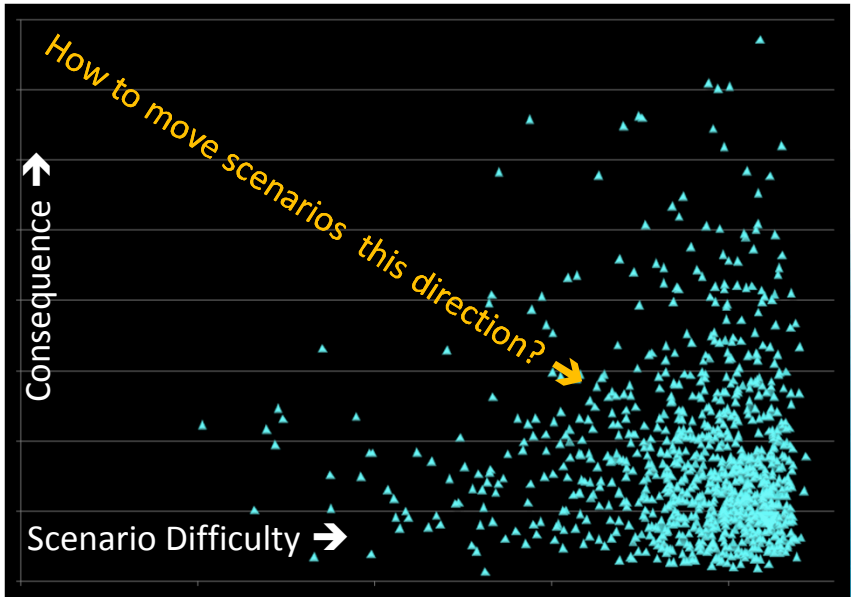






Security

- Assess current regulatory rule-making developments
- Assess security implications related to early shipments of used fuel
- Continue assessment of the regulatory rule-making process and changes being considered for UNF storage and transportation, especially as it relates to de-inventorying orphaned sites
- Conduct relative risk assessments to assess comparative risks given specific types of attack events



Collaborations

External collaborations are an important part of this program.

One important focus for external collaborations is through the Electric Power Research Institute Extended Storage Collaboration Program (EPRI/ESCP)

Vision: **Provide the technical bases to ensure safe, long-term used fuel storage and future transportability.**

Objectives:

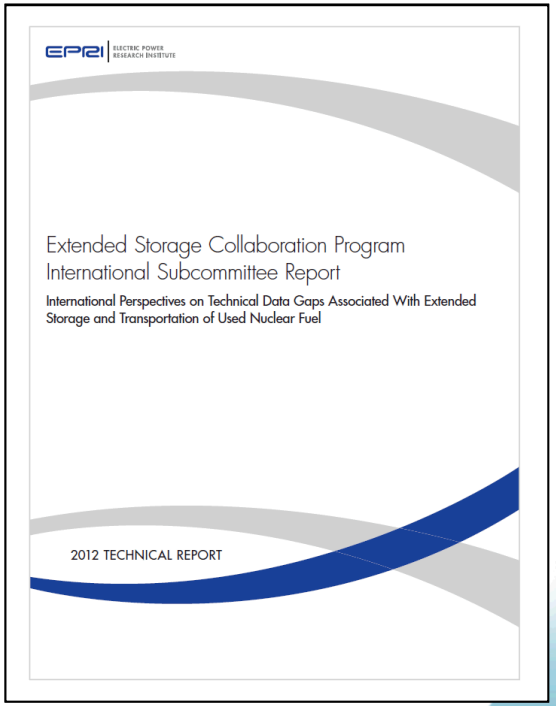
- **Identify what we already know**
- **Identify the open items for even longer storage (gap analysis)**
- **Suggestions for what needs to be done (and how, if possible)**
- **Form standing groups to continue pursuing additional, appropriate R&D**

Standing Subcommittees:

- Fuel/Internals
- Demonstration
- Marine Environments
- Concrete
- Nondestructive Examination
- International

Participants:

- Industry (EPRI/NEI/fuel & cask vendors/utilities)
- U.S. Nuclear Regulatory Commission
- U.S. Department of Energy (DOE)
- DOE laboratories
- Universities
- International organizations



Recent deliverable:
International Data Gap Report

http://my.epri.com/portal/server.pt?Product_id=000000000001026481

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