

# Overview of the U.S. Department of Energy Research and Development Efforts Associated with the Storage and Transportation of Used Nuclear Fuel

The 4<sup>th</sup> East Asia Forum on Radwaste Management  
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**Albuquerque, New Mexico**  
**SAND2013-XXXXP**

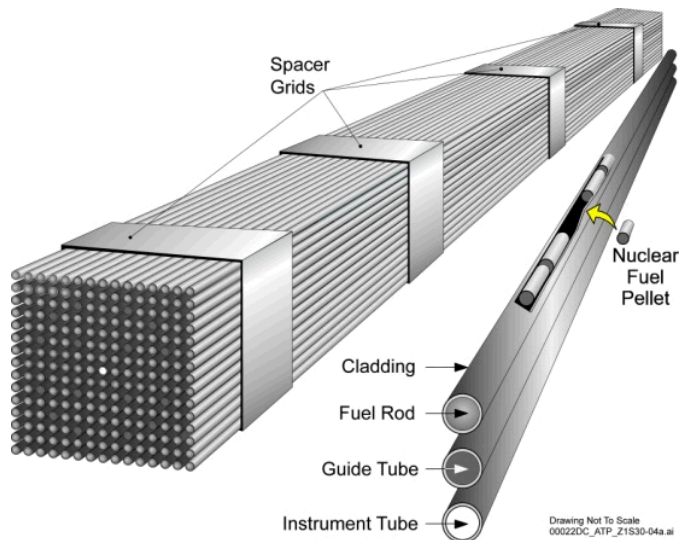


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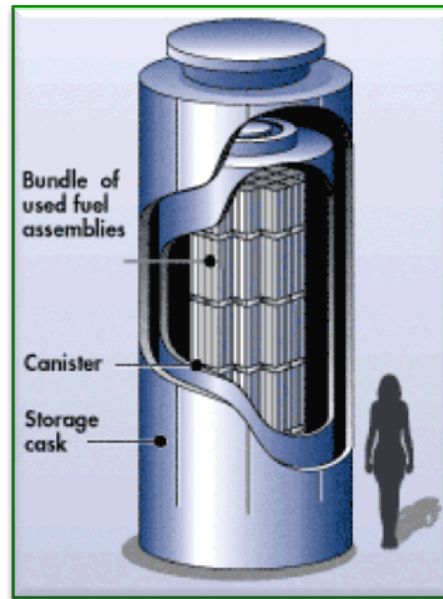


# Contents

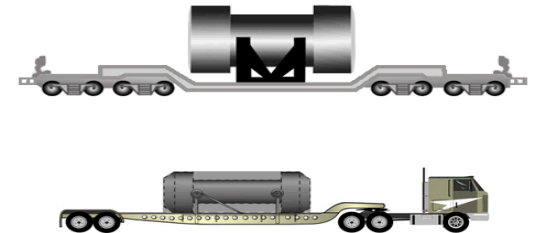
- Overall Objectives
- Major Activities
- Collaborations



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



[www.nrc.gov/waste/spent-fuel-storage/](http://www.nrc.gov/waste/spent-fuel-storage/)



[www.connyankee.com/](http://www.connyankee.com/)

# 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



Science in the National Interest

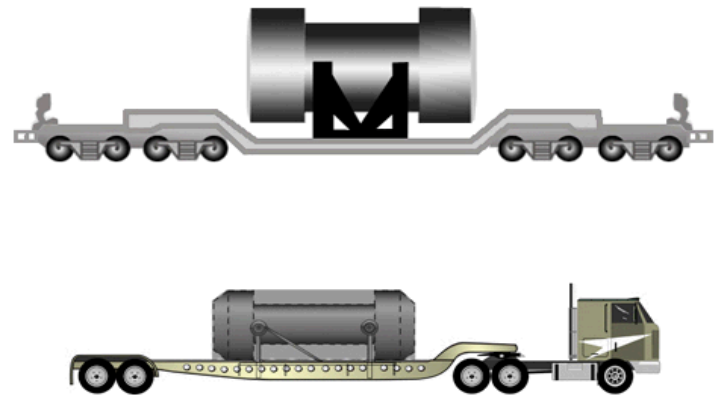


# DOE's R&D Focus for Storage & Transportation

- 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/](http://www.connyankee.com/)

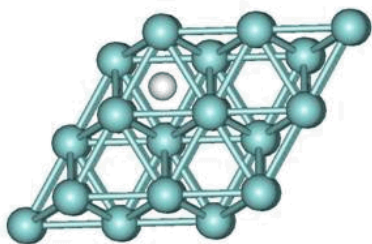
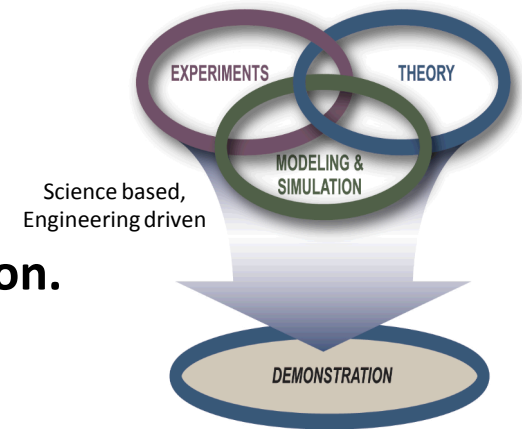




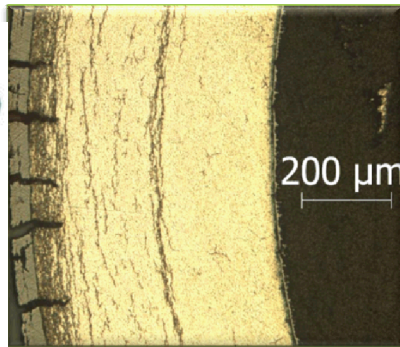
# Storage & Transportation Scope

## Science Based, Engineering Driven

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



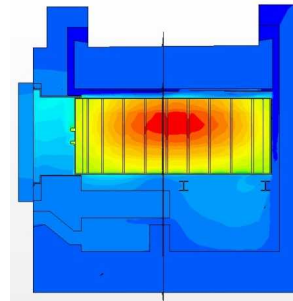
SAND2013-6809P, August 2013, Tikare, Weck



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



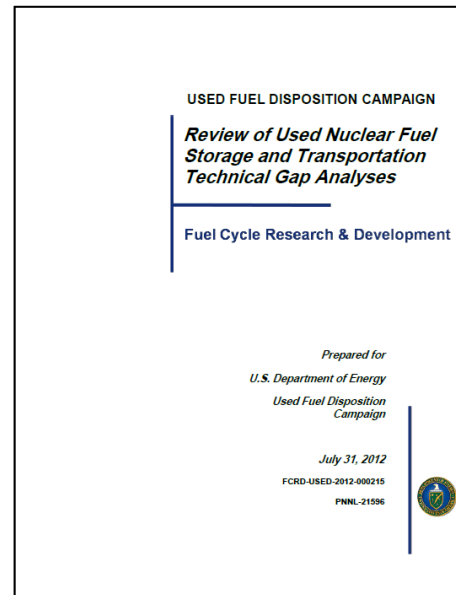
UFD Telecon, April 12, 2012  
Wagner, Adkins; ORNL



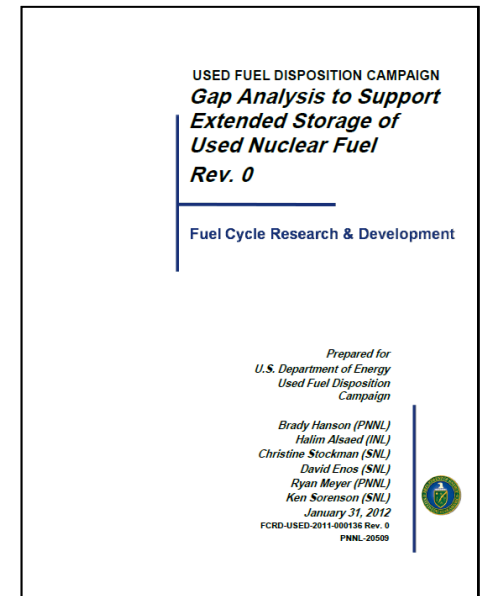
'Jones 2010.ppt',  
Calvert Cliffs Dry Fuel Storage  
and Industry Lessons Learned

# 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>

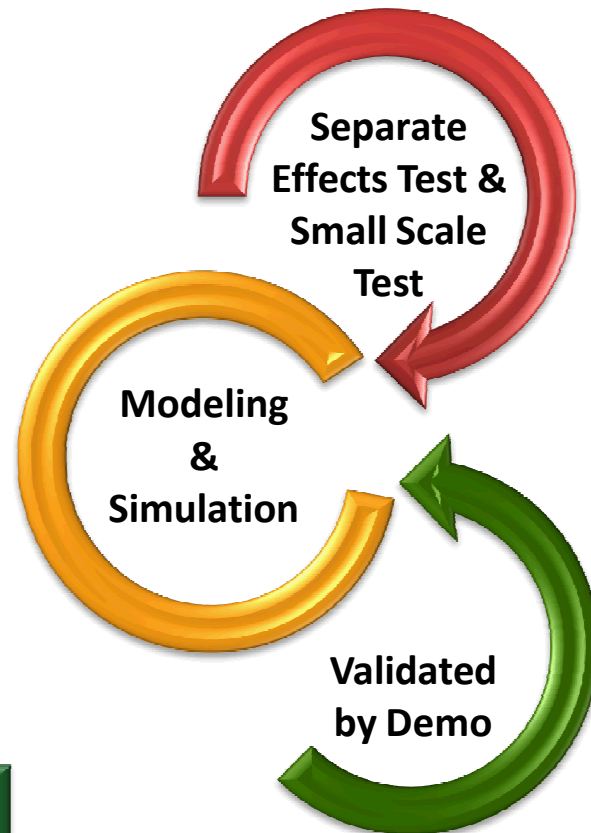


<http://energy.gov/sites/prod/files/Gap%20Comparison%20Rev%200.pdf>

# 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-

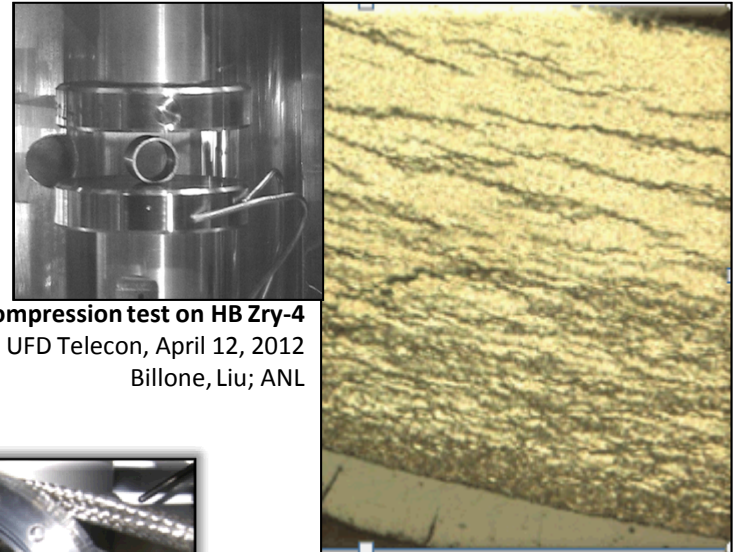
2012-000109

# ST Experiments

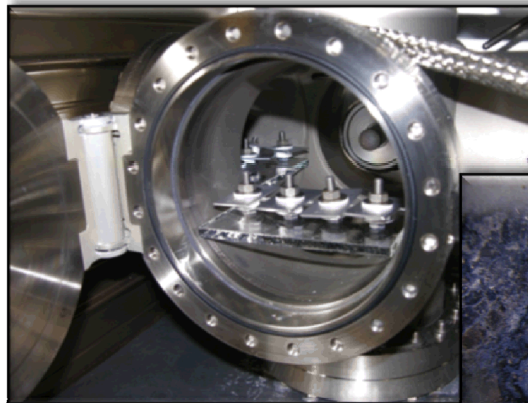
Obtain data to better understand material degradation effects on cladding and canister materials during long-term storage conditions.

## CURRENT WORK

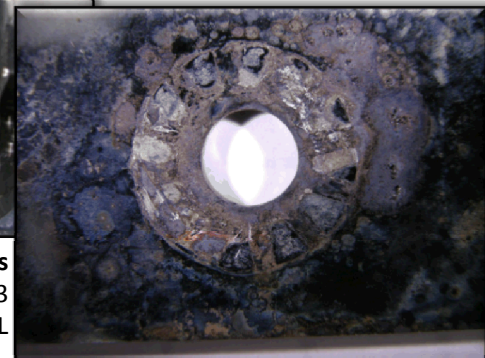
- Conduct ring compression and DBTT tests on PWR high burnup cladding
- Conduct hydrogen doping and irradiation in HFIR
- Conduct hydrogen doping/distribution tests with thermal gradients across cladding
- Conduct SS canister corrosion testing



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



SS Corrosion tests  
IHLWM Conference 4/2013  
Enos, Bryan; SNL





# ST Experiments

Obtain data to better understand material degradation effects on cladding and canister materials during long-term storage conditions.

## FY14

### ■ Materials properties of cladding

- Hydride effects
- Radiation damage annealing
- Effects of numerous wetting and drying cycles

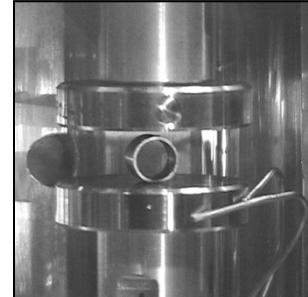
### ■ Corrosion and SSC of SS canisters

### ■ On-site environmental sampling

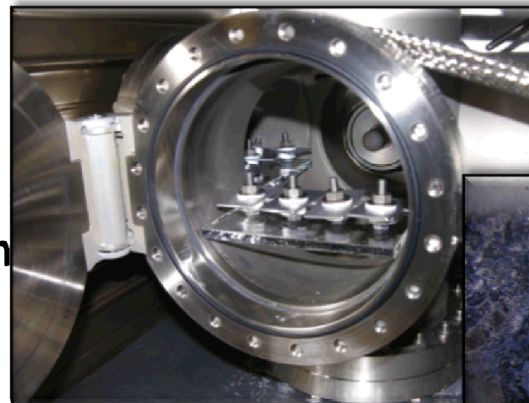
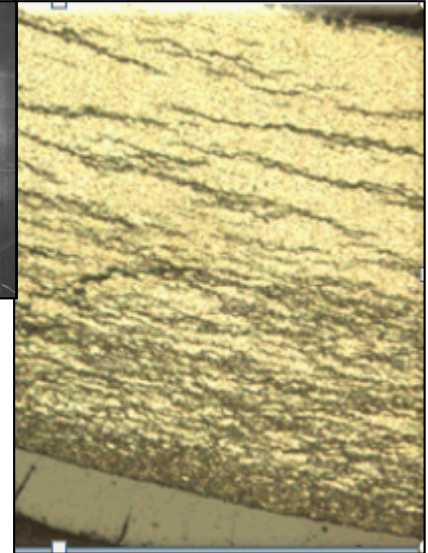
### ■ Monitoring and Instrumentation

### ■ Aging management plans

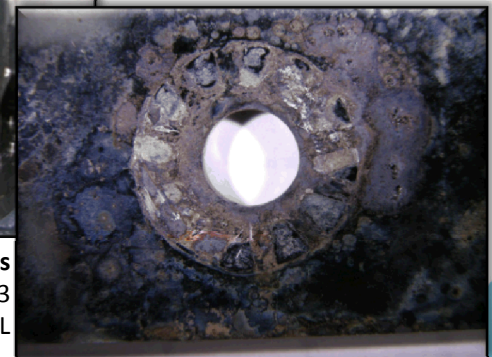
### ■ BWR and PWR Ring Compression Test



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



SS Corrosion tests  
IHLWM Conference 4/2013  
Enos, Bryan; SNL

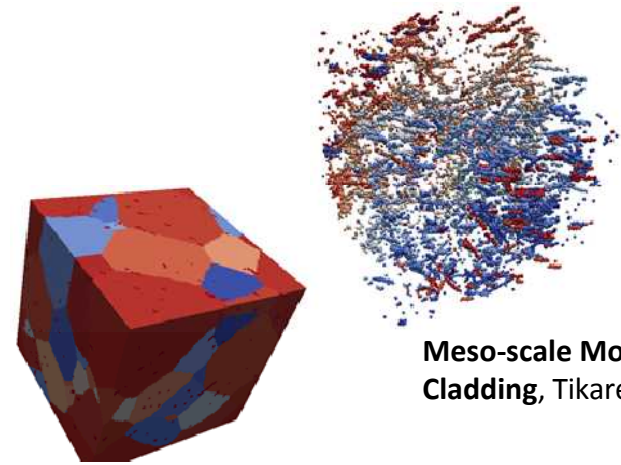


# Engineering Analysis

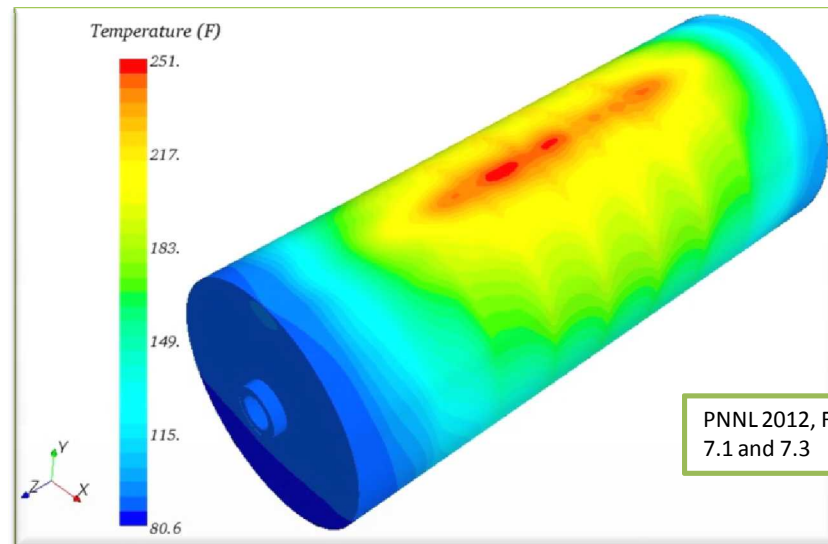
Develop models that will predict behavior during long-term storage and transportation conditions.

## CURRENT WORK

- Develop methodology to estimate used fuel cladding hydride re-orientation during long term dry storage
- Understand strains on fuel rods during normal truck transport.
- Conduct thermal profile analyses on dry storage canister systems



Meso-scale Modeling of Cladding, Tikare



PNNL 2012, Figures 7.1 and 7.3

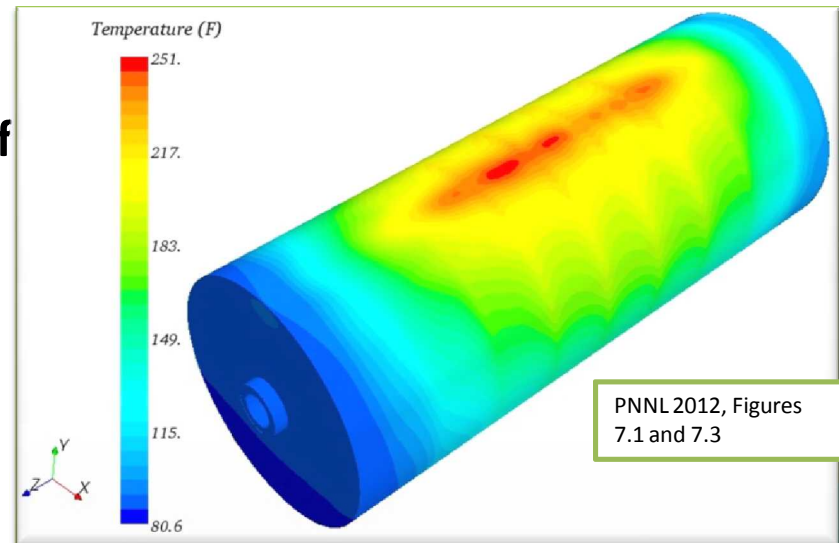
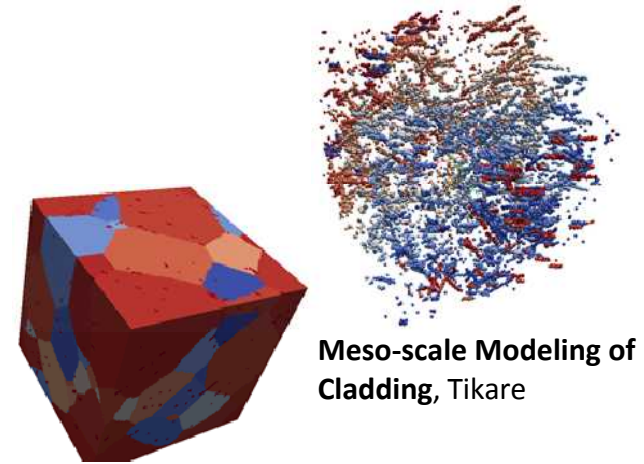
Thermal Profile of Storage Canister

# Engineering Analysis

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

## FY14

- Benchmark basic mechanical-microstructure hydride model on Zircaloy-4 to ANL ring compression test data and incorporate into Moose-Bison Model.
- Understand strains on fuel rods during normal truck and rail transport.
- Continue thermal profile modeling of storage systems.
- Initiate Uncertainty Quantification (UQ) methodology development to focus testing and prioritize high and medium ranked gaps.



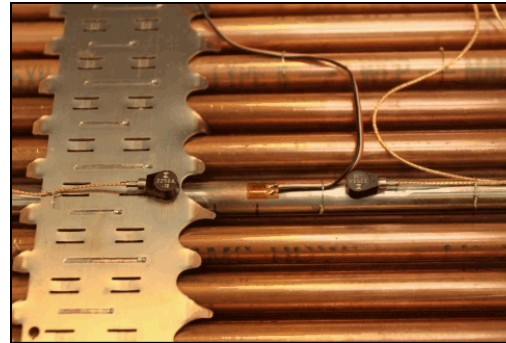
Thermal Profile of Storage Canister

# Transportation

Demonstrate the transportability of high burn up used fuel.

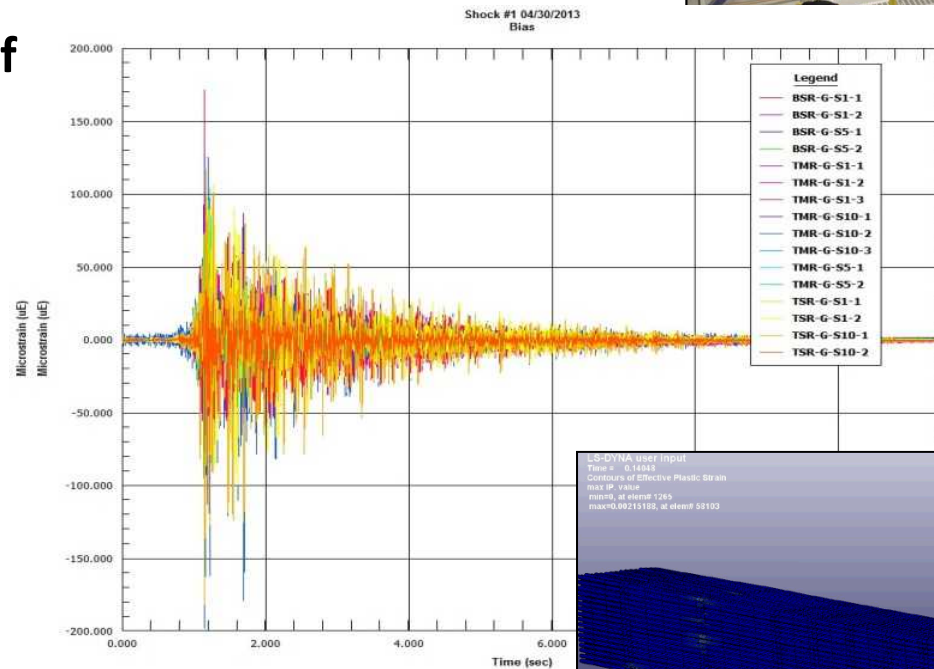
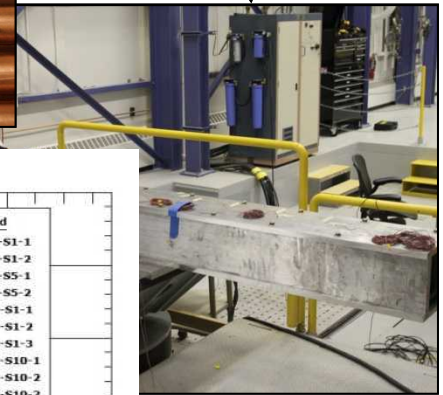
## CURRENT WORK

- Conduct shock/vibration tests on a surrogate PWR assembly for truck normal conditions of transport
- Analyze fuel rod response to accelerometer and strain gauge data



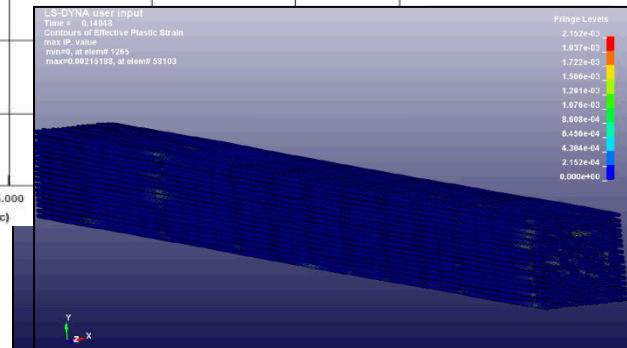
Instrumentation

Test



Data Acquisition

Analysis



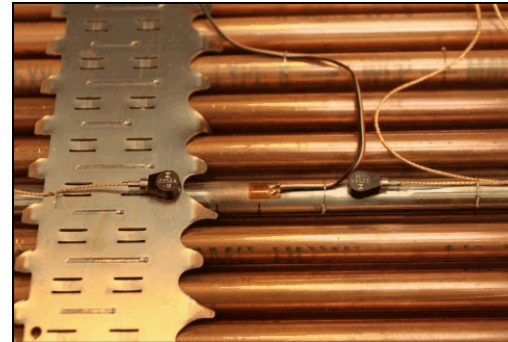


# Transportation

Demonstrate the transportability of high burn up used fuel.

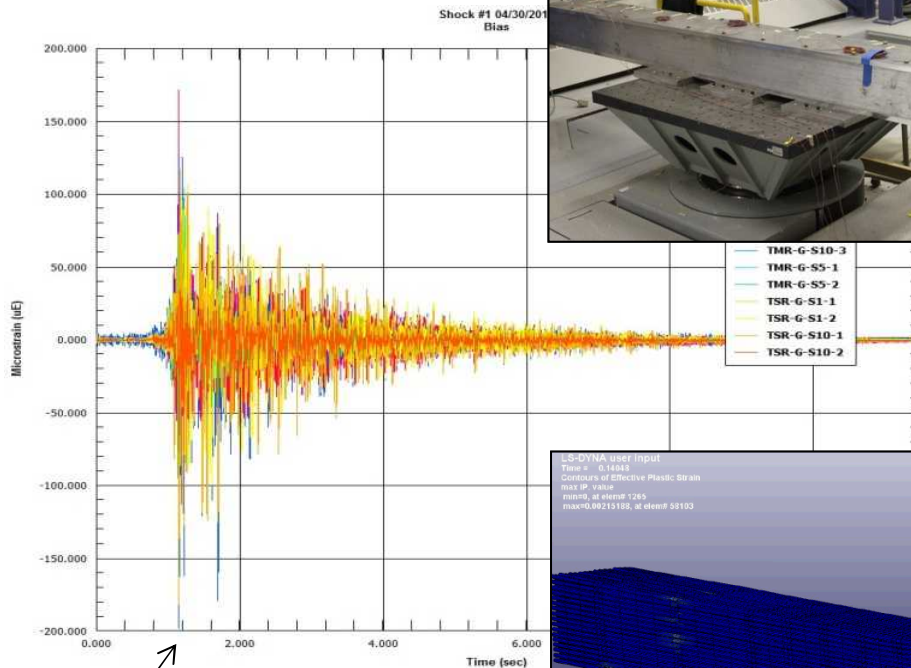
## FY14

- Complete analyses of truck shock/vibration data
- Duplicate shock/vibration test for rail data.
- Collaborate with industry to ship an instrumented surrogate “dummy” PWR assembly to SNL to conduct a shock/vibration test using the vibration/shock response spectra obtained from the transport.



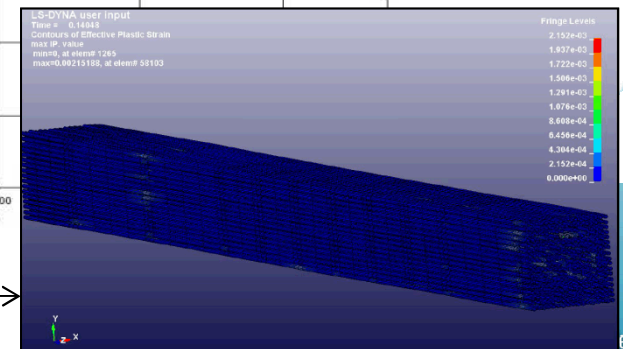
Instrumentation

Test



Data Acquisition

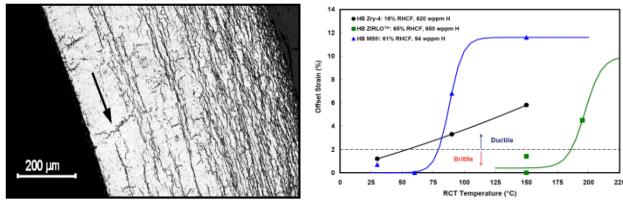
Analysis



# Making a Case for Transport of High Burnup Fuel

## Experimental

Material properties  
Benchmark data

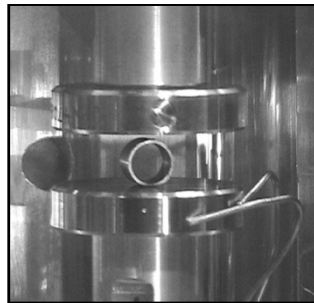


## Clad morphology

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

## Clad properties:

$\sigma_{ys}$  = yield stress  
 $\sigma_{ult}$  = ultimate stress  
 $K_{Ic}$  = fracture toughness  
 $E$  = elastic modulus  
 $\epsilon_{ult}$  = ultimate strain



Instron 8511 used for  
Ring Compression Tests

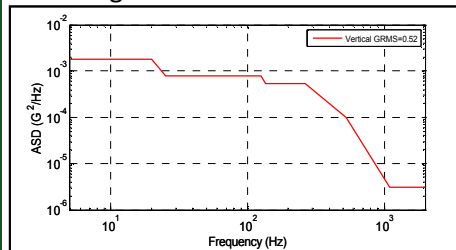
## Transportation

- Realistic configurations
- Realistic loads
- Regulatory alignment



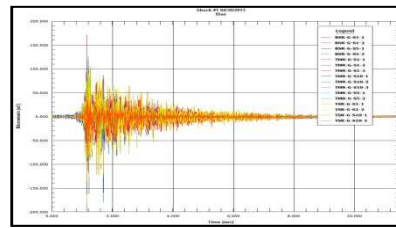
## Loads:

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



## Response:

- $g$  and  $\epsilon$  on individual rods

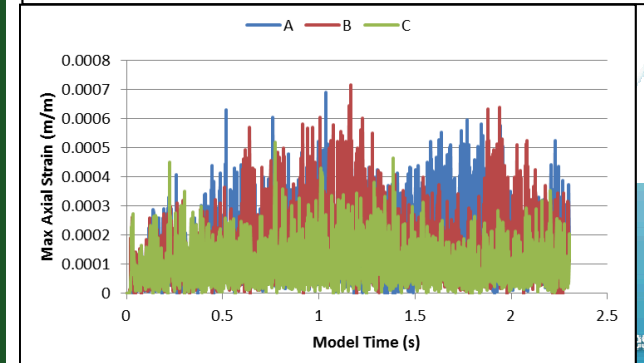
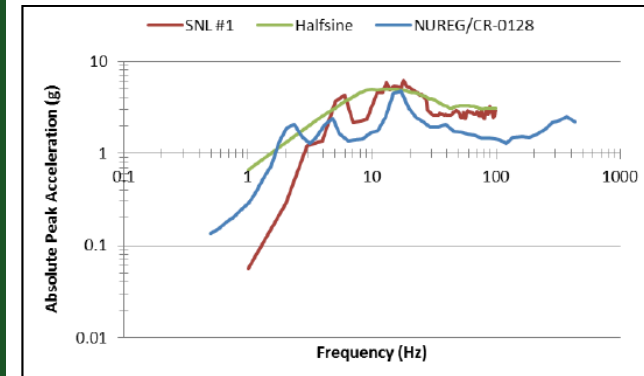
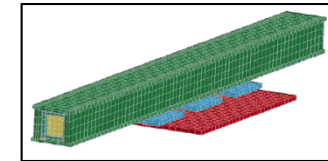


## Analysis



$$\sigma < \sigma_{ys} ?$$

$$K_I < K_{Ic} ?$$



# Security

## CURRENT WORK

- Assess current regulatory rule-making developments
- Assess security implications related to early shipments of used fuel

## FY14

- 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



# 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)

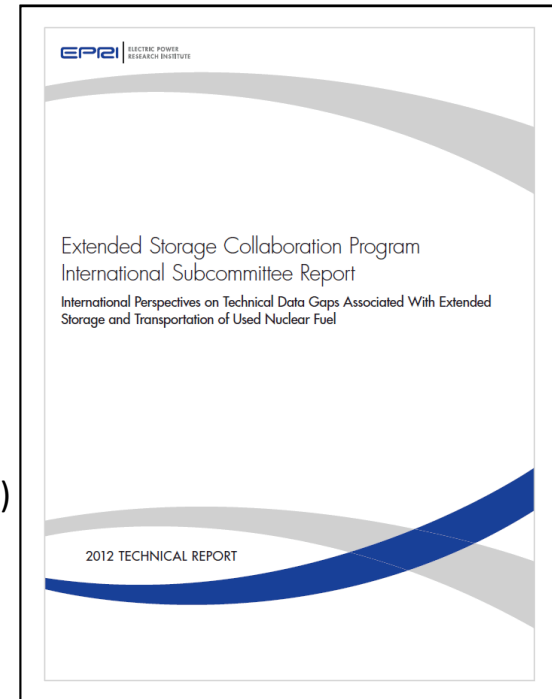
**Vision:** Provide the technical bases to ensure safe, long-term used fuel storage and future transportability.

**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:**    **Participants:**

- |  |  |
|--|--|
| <ul style="list-style-type: none"><li>• Fuel/Internals</li><li>• Demonstration</li><li>• Marine Environments</li><li>• Concrete</li><li>• Nondestructive Examination</li><li>• International</li></ul> | <ul style="list-style-type: none"><li>• Industry (EPRI/NEI/fuel &amp; cask vendors/utilities)</li><li>• U.S. Nuclear Regulatory Commission</li><li>• U.S. Department of Energy (DOE)</li><li>• DOE laboratories</li><li>• Universities</li><li>• International organizations</li></ul> |
|--|--|



Recent deliverable:  
International Data Gap Report

[http://my.epri.com/portal/server.pt?Product\\_id=000000000001026481](http://my.epri.com/portal/server.pt?Product_id=000000000001026481)