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Used Nuclear Fuel Overview

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NEET ASI Review Meeting
October 28, 2015

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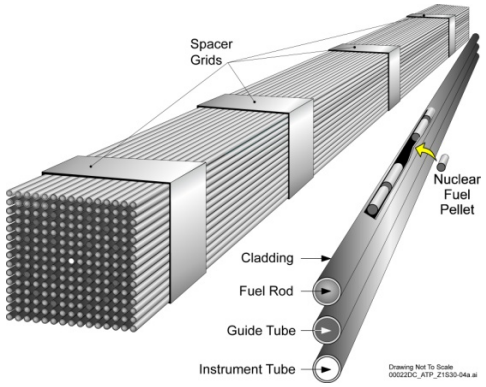
Today's Discussion

- **R&D Objectives**
- **What Guides S&T Work**
- **FY15-16 Workscope**
  - Full-Scale High Burn-Up Demo
  - Experiments
  - Transportation
  - Analysis



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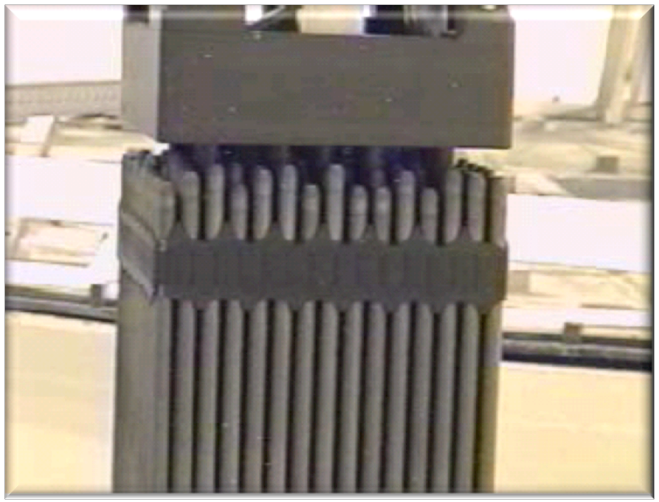
Storage and Transportation R&D Objectives

Overall Objectives

- Develop the technical bases to demonstrate the continued safe and secure storage of used nuclear fuel for extended periods.
- Develop technical bases for fuel retrievability and transportation after long term storage.
- Develop the technical basis for transportation of high burnup fuel.



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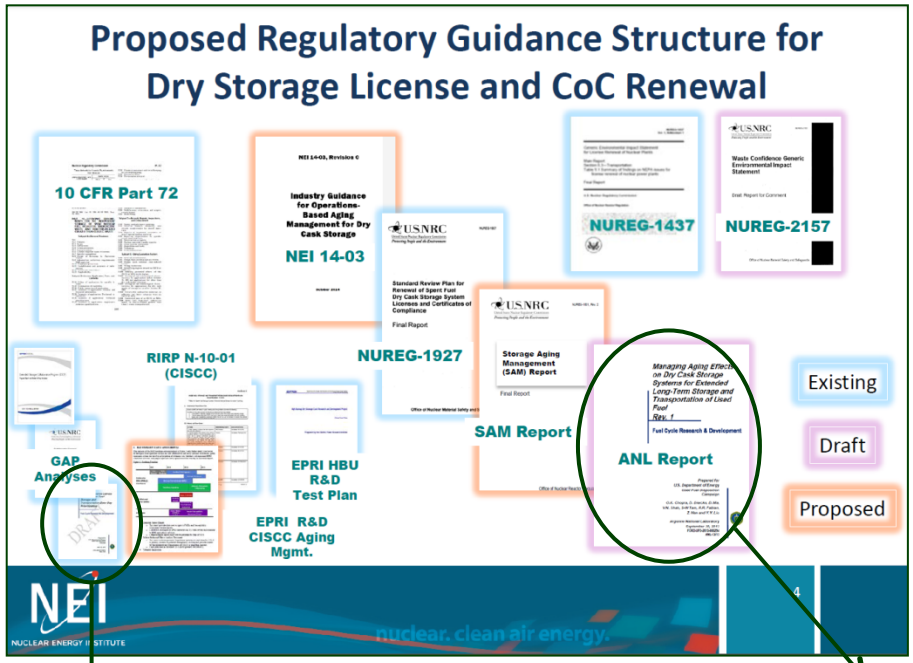
Storage and Transportation Objectives

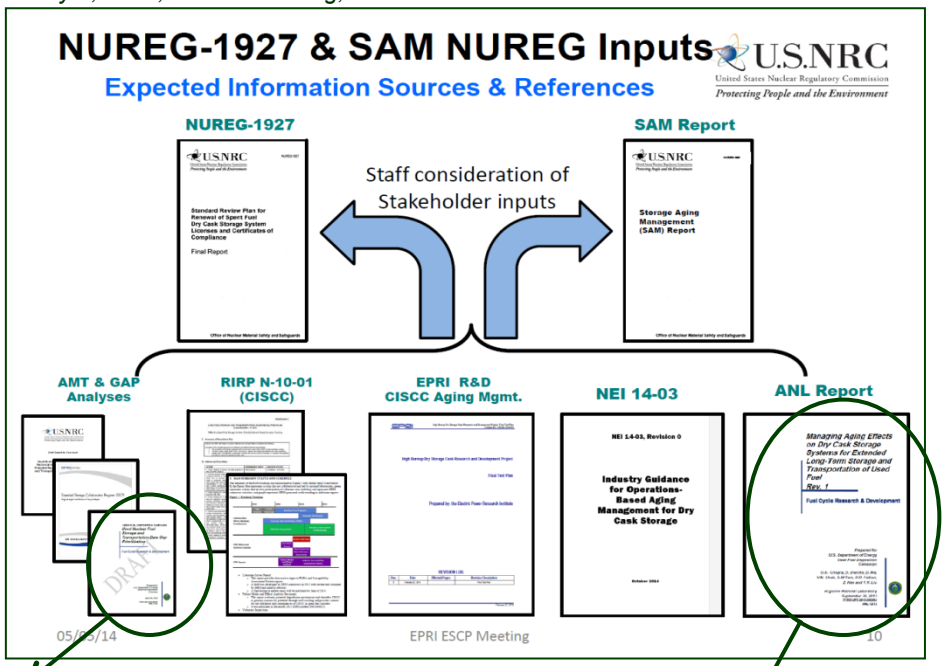
What does developing the technical basis for extended storage and transport of high burnup used fuel look like?

Brian Guntherman, NEI, EPRI/ESCP mtg,
May 5, 2014, St. Petersburg, FL



Hanson, Brady, et al.; Gap Analysis to Support Extended Storage of Used Nuclear Fuel, Rev. 0, FCRD-USED-2011-000136, PNNL-20509, Jan 31, 2012.

Al Csontos, NRC, EPRI/ESCP mtg,
May 5, 2014, St. Petersburg, FL



Chopra, O.K., et al.; Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel, Rev. 1, FCRD-UFD-2013-000294, ANL-13/15, Sept 13, 2013.

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Storage and Transportation R&D is Guided by a Comprehensive Gap Analysis

Storage system component "High" and "Medium" priorities

System Component	Issue	Importance of R&D
Cladding	Annealing of Radiation Effects	Medium
	Oxidation	Medium
	H_2 effects: Embrittlement	High
	H_2 effects: Delayed Hydride Cracking	High
	Creep	Medium
Assembly Hardware	Stress corrosion cracking	Medium
Neutron Poisons	Thermal aging effects	Medium
	Embrittlement and cracking	Medium
	Creep	Medium
	Corrosion (blistering)	Medium
Canister	Atmospheric corrosion (marine environment)	High
	Aqueous corrosion	High

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Storage and Transportation R&D is Guided by a Comprehensive Gap Analysis

Storage system component "High" and "Medium" priorities

System Component	Issue	Importance of R&D
Bolted Direct Load Casks	Thermo-mechanical fatigue of bolts/seals	Medium
	Atmospheric corrosion (marine environment)	High
	Aqueous corrosion	High
Overpack and Pad (Concrete)	Freeze/Thaw	Medium
	Corrosion of steel rebar	Medium

Cross-cutting or General Gaps

- ***Temperature profiles*** ***High***
- ***Stress profiles*** ***High***
- ***Drying issues*** ***High***
- ***Monitoring*** ***High***
- ***Subcriticality*** ***High***
- ***Fuel transfer options*** ***High***
- ***Re-examine INL dry cask storage*** ***High***

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Storage and Transportation R&D Observations

Observations

- A major shift in programmatic direction has resulted from fuel performance testing
  - *Irradiated high burnup fuel actually has reasonable vibration properties (millions of cycles to failure).*
  - *Thermal model improvements suggest peak cladding temperatures are not anywhere near 400°C (around 300°C). Models have been tested and validated.*
  - *Fuel/clad bonding in high burnup fuel is sufficient to keep the majority of fuel inside the clad even if fully fractured.*

Impact

- The program has deemphasized
  - *Internal cask/canister thermal conditions*
  - *Fuel rod failure/fission gas release*
  - *Radiation dose rates*

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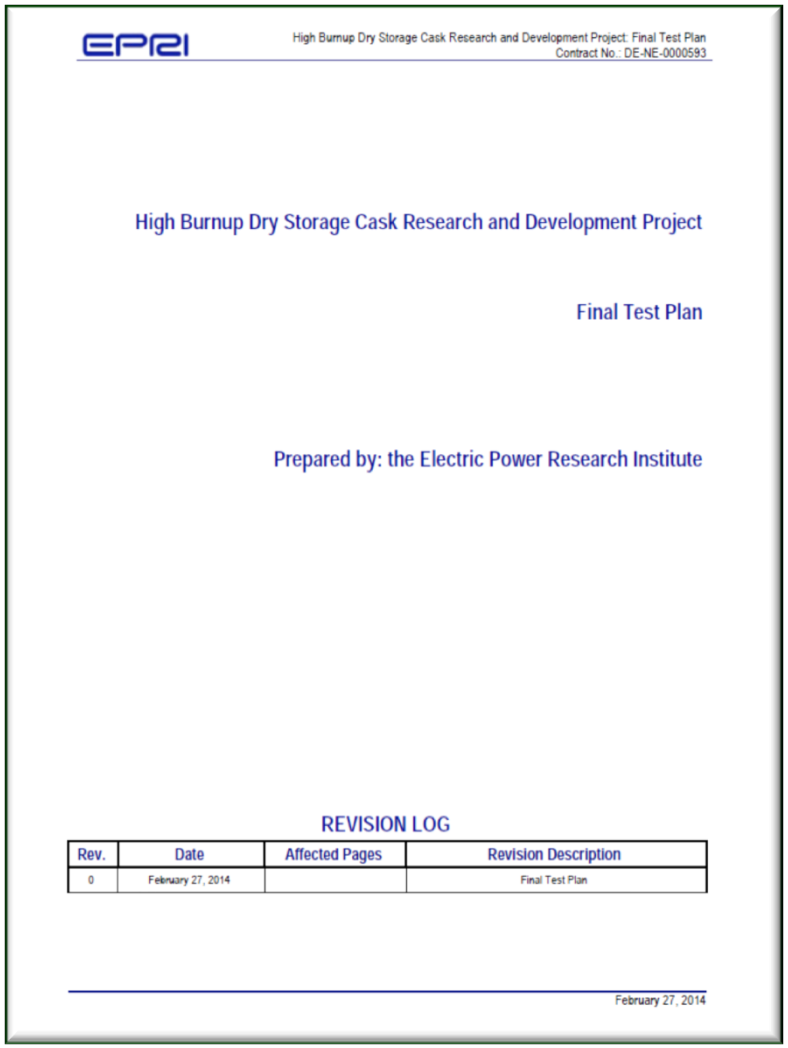
HBU Dry Storage R&D Project: Support of DOE/EPRI Confirmatory Demonstration Program

- **Objectives:**
  - Support the design and implementation of a full-scale dry storage demonstration using high burnup used fuel
  - Load and store high burnup used fuel in a TN-32B at the Dominion North Anna ISFSI

- **Impact:**
  - This demonstration will provide valuable confirmatory data to compare against the data that is gathered during the R&D



EPRI

High Burnup Dry Storage Cask Research and Development Project: Final Test Plan
Contract No.: DE-NE-0000593

High Burnup Dry Storage Cask Research and Development Project

Final Test Plan

Prepared by: the Electric Power Research Institute

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	February 27, 2014		Final Test Plan

February 27, 2014

DOE/EPRI Storage Demonstration Project: Final Test Plan, February 27, 2014

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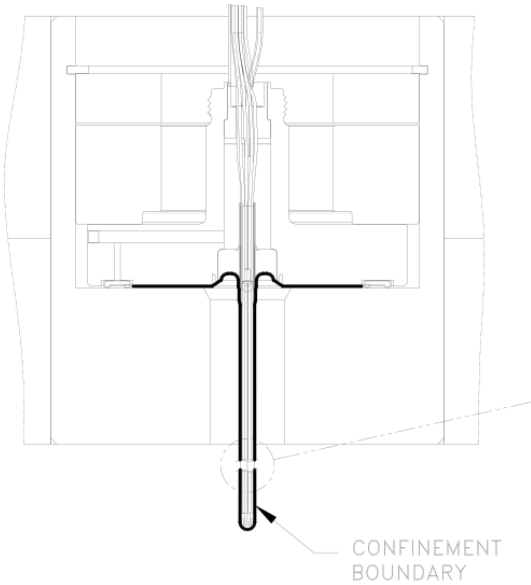
High Burn-up Confirmatory Data Project

- **Cask will be loaded with high-burnup used nuclear fuel in 2017.**
- **Sister rods were selected and pulled from assemblies during the summer of 2015. Will be sent to ORNL in February 2016 for characterization and testing.**
- **Instrumentation needs were very limited.**
  - AREVA selected their own thermocouple lance design for temperature measurements.
  - Gas sampling should be sufficient to understand integrity of fuel in the cask.
  - TRL of other potential methods/devices too low to pursue



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HBU Dry Storage R&D Project: Sensor Technology Development

Current Sampling Plan

- **First two weeks:** Gas samples collected and analyzed 2-3 times per week while the cask is still on the fuel floor. Additional Samples can be collected if moisture, fission gas, etc. are detected.
- **Next ten years:** Current gas sampling plan is to collect samples from the vent port 3 times (1 and 3 years after placement on pad, then just before cask is moved for transport).
- **63 Thermocouples:** Cask lid will have penetrations to accommodate 7 thermocouple lances with 9 thermocouples per lance to record internal temperatures.

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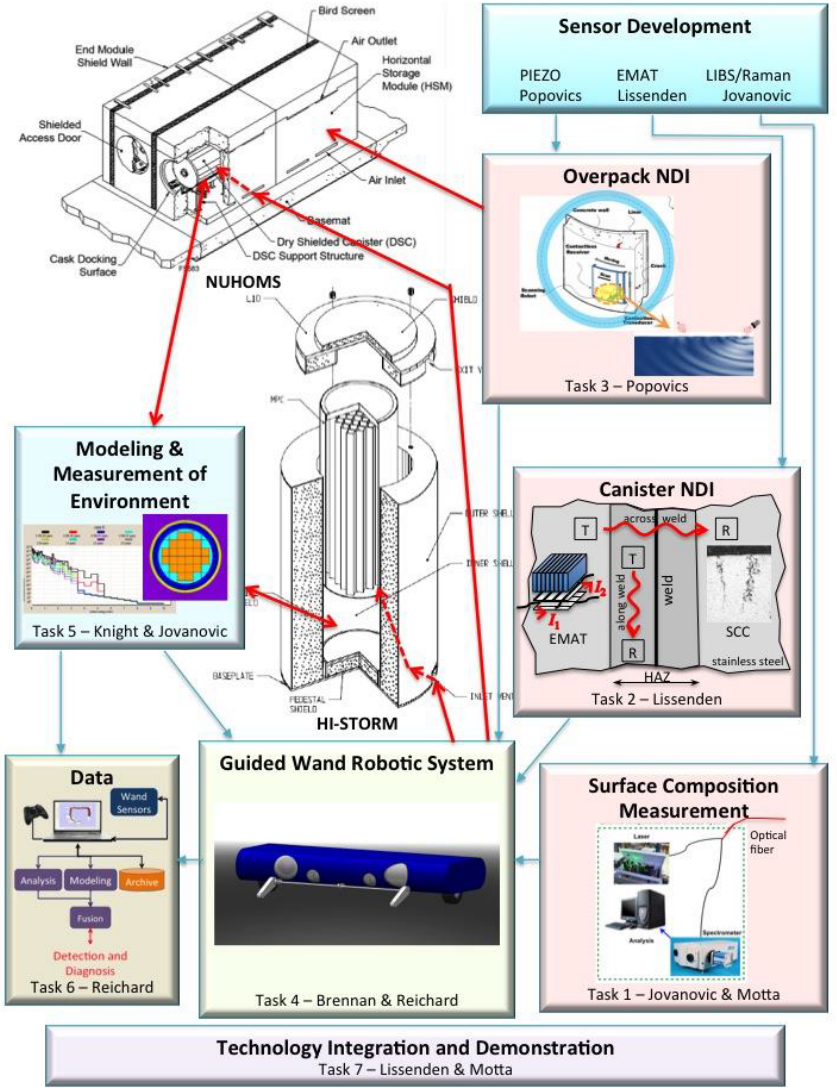
Multi-Sensor Inspection And Robotic Systems For Dry Storage Casks

- **Monitor across the degradation spectrum:**
  - Conducive environment
  - Changes in microstructure
  - Macroscale degradation

PENNSTATE 1855

UNIVERSITY OF SOUTH CAROLINA 1801

UNIVERSITY OF ILLINOIS LEARNING & LABOR CHARTERED 1867



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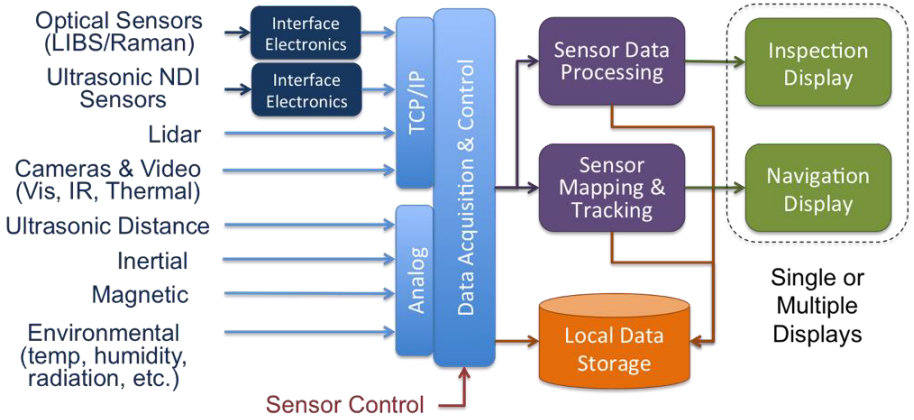
Multi-Sensor Inspection And Robotic Systems For Dry Storage Casks

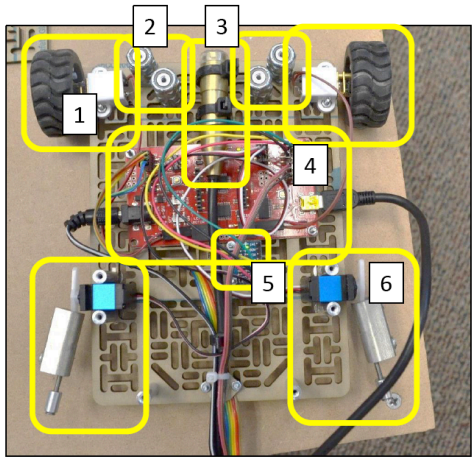
Sensors to be delivered through ventilation system:

- LIBS, RS
- EMAT, MST
- Thermocouples
- Hygrometer
- IR thermography
- Video
- Geiger-Mueller counter, Dosimeter
- UT, LIDAR
- Vacuum sampling



Environment inside ventilation system is harsh:

- high temperature and gamma radiation



1. Front wheels and motors
2. Front supports and ballast
3. USB borescope camera and LED light
4. Microcontroller/motor driver
5. Gyroscope
6. Lever arms and servos

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Experiments

- **The objective of the Experimental CA is to develop the data necessary to further our understanding of fundamental materials degradation issues associated with the safety components (including the fuel) of long term storage systems and subsequent transportation of used nuclear fuel. This data also serves as an important benchmarking function for the validation and verification of predictive models.**

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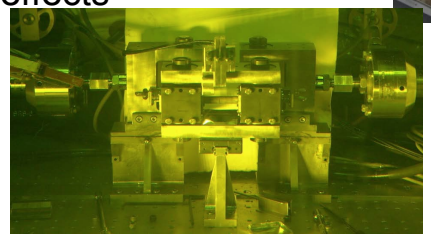
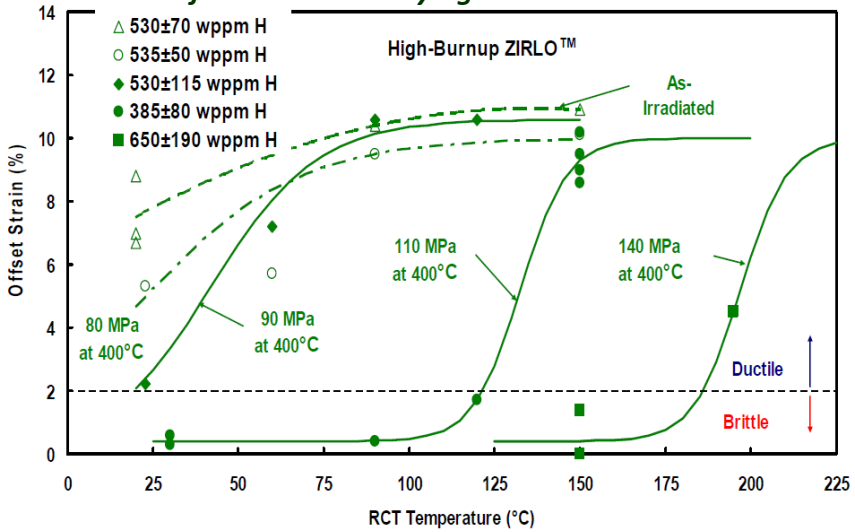
Experiments:
High Burnup Fuel Cladding

Separate effects tests to determine effects of hydrides, hydride reorientation, radiation damage and thermal annealing, and clad thinning (due to hydride rim, oxidation, etc.) on materials properties and performance

- **Hydrides and reorientation**
  - Ring Compression Tests and determination of Ductile-Brittle Transition Temperature (ANL)
  - Cladding bend tests and effects of fuel/clad bonding and pellet/pellet interfaces (ORNL)
  - Creation of hydride rim in unirradiated cladding and burst, tube tensile, and tube compression testing (PNNL)
- **Radiation damage and thermal annealing**
  - Irradiate H-doped cladding in HFIR reactor at ORNL without all other effects

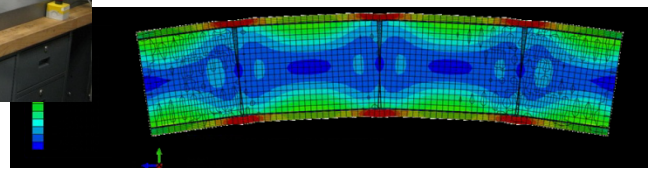


DBTT Data for Zirlo with Varying Internal Plenum Pressures



Billone, Argonne National Laboratory, EPRI ESCP Meeting, Dec. 2013

Used fuel rod stiffness experiments and analyses



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

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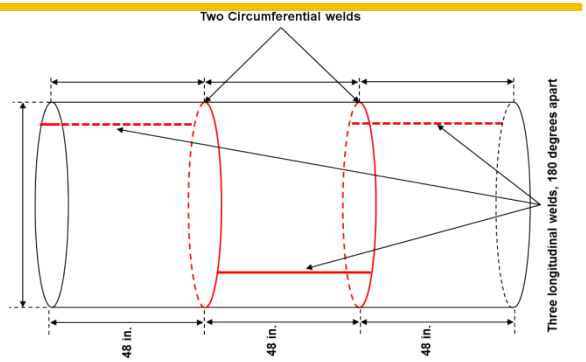
Experiments:
Stainless Steel Canister Corrosion

Impact:

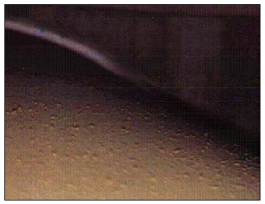
- This work will strengthen our understanding of canister degradation over time and will support site Aging Management Plans and license extensions to ensure canister integrity.
- Environmental sampling may help inform inspection frequencies.



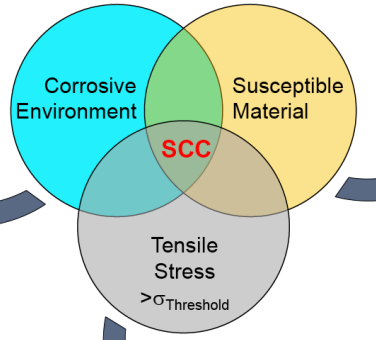
Mockup for SSC experiments

Objectives:

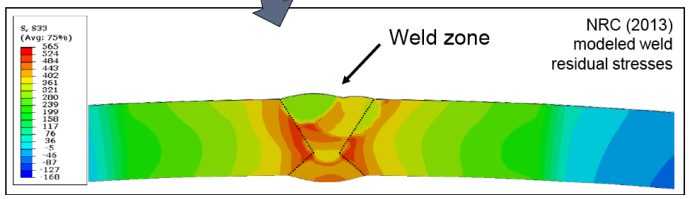
- Develop data to understand initiating conditions for corrosion of stainless steel canisters used for dry storage.
- Develop data to understand initiating conditions and progression of SCC-induced crack growth.
- Obtain site data to assess atmospheric conditions and compare with initiating conditions.
- Test a full-scale (diameter) welded SS canister to investigate residual stresses due to plate rolling and welding.



Dust on canister surface at Calvert Cliffs (EPRI 2014)



Weld zone, Ranor 304 SS plate



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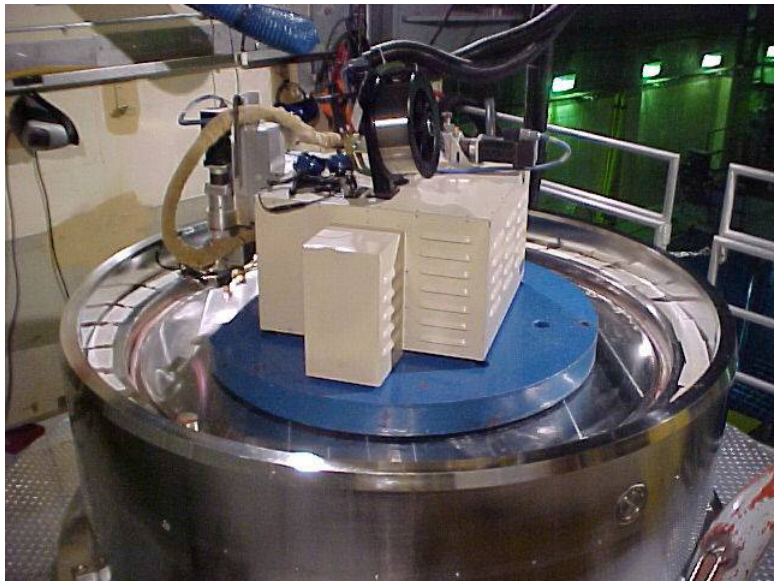
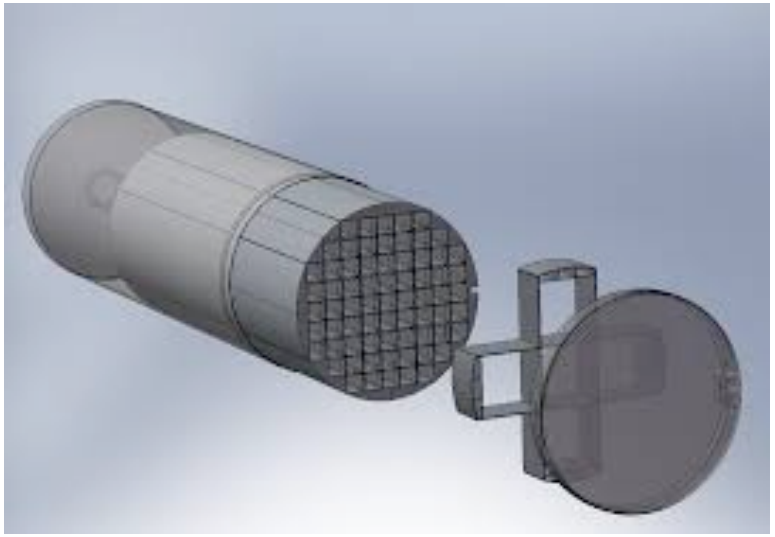
Experimental Determination and Modeling of Used Fuel Drying by Vacuum and Gas Circulation for Dry Cask Storage

- **A three year investigation has been awarded to investigate drying of used fuel canisters for dry storage.**
- **Objectives:**
  - This investigation will address questions surrounding the amount, form, and location of water remaining in dry casks/canisters.





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UF UNIVERSITY of FLORIDA

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Analysis

- Provide thermal and mechanical computations of operational conditions related to long term storage and subsequent transportation of used nuclear fuel. In addition, separate phenomenological models are being developed to predict behavior of specific high priority gap technical issues (e.g., hydride re-orientation) that can be integrated into existing larger platform models. The experimental data obtained will provide an important benchmarking basis for justifying the predictive value of the models and analyses.

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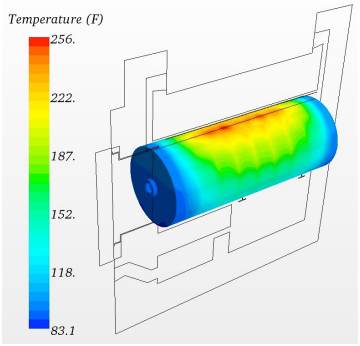
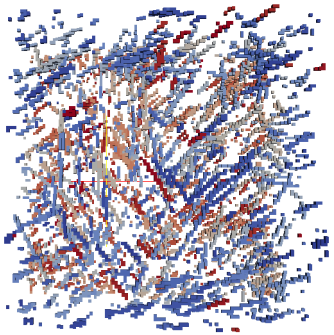
Analysis:
Thermal Profiles

Conduct thermal profile analyses on specific storage/transport applications and develop predictive models of material behavior to establish the technical bases for extended storage and transportation

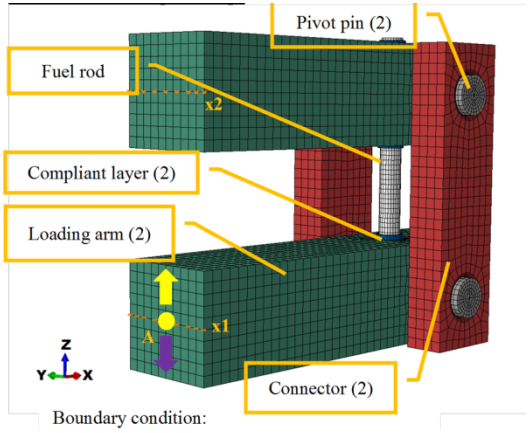
- **Predictive modeling**
  - Thermal Analysis (PNNL) to predict cool down, Ductile to Brittle Transition, deliquescence, etc.
    - *HBU Demonstration fuel selection and cool down*
    - *Modern, high heat load, high capacity systems*
    - *In-service inspections validation data*
  - Structural uncertainty analysis at assembly and canister level (PNNL)
  - Finite element analysis validation with CIRFT and application to out-of-cell testing (ORNL)
- **Thermal profile analyses**
  - Detailed thermal analyses for three licensed dry storage systems



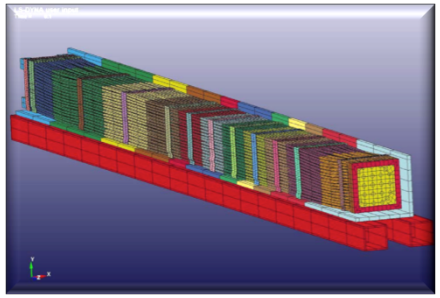
CFD Thermal Analysis of Dry Storage Casks
Suffield, et al, PNNL-21788



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



FE Model of Rod Bend Tests
Jy-An Wang et al, ORNL



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

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Transportation

- **Assess the retrieveablity of used fuel after long term storage and to ascertain the ability to transport high burnup fuel.**

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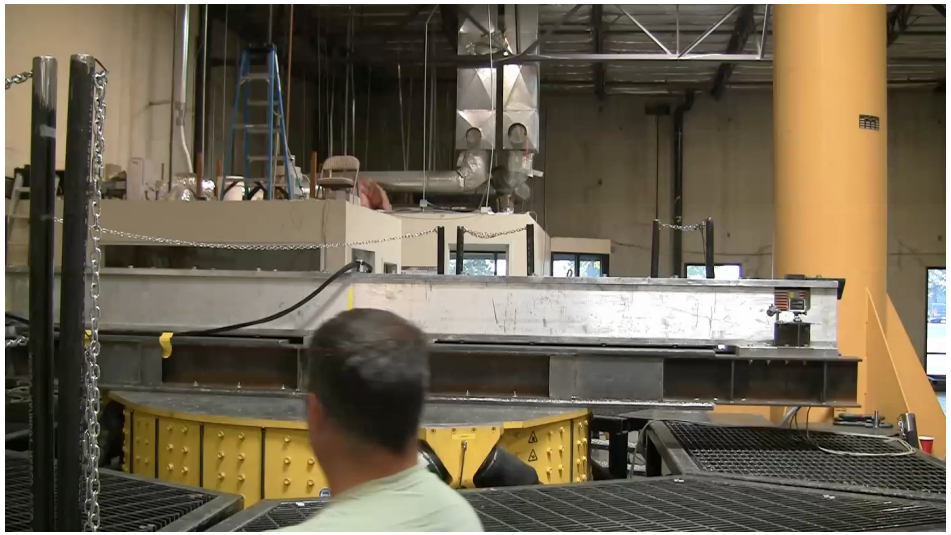
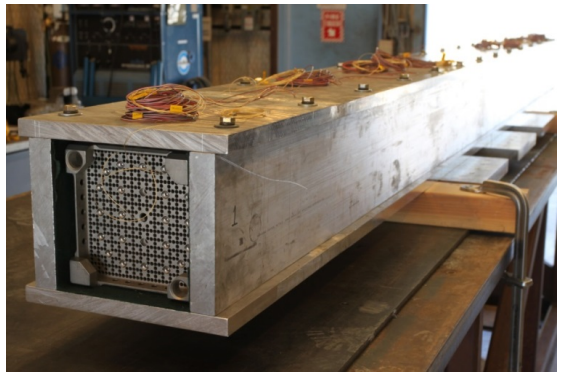
Transportation:

Normal Conditions of Transport – Loading on fuel assemblies

- **Three series of tests conducted using a surrogate PWR assembly**
  - Tests on a SNL shaker
    - *Vertical accelerations only*
    - *Truck NCT simulations*
  - Over-the-road truck test
  - Test on commercial seismic shaker
    - *6-degrees of motion*
    - *Rail and truck NCT simulations*
  - Inputs to the shakers simulated both Normal Conditions of Transport (vibrations and shocks) and some NOT normal conditions.

- **Results**
  - Based upon the test results, which simulated normal vibration and shock conditions of truck and rail transport, failure of fuel rods during normal transport seems unlikely.
  - Fatigue during transport does not appear to be an issue.





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Summary

- **Analysis of conditions on the surface of Stainless Steel UNF canisters is important to understand the risk of environmentally assisted Stress Corrosion Cracking. Instruments being worked on:**
  - Surface chemistry
  - Surface temperature
  - Detection of cracks/pits
  - **Open for other ideas**
- **Cask/canister internal measurements are deemphasized**
  - Data gathered to date tells us storage and transportation will not challenge UNF properties as severely as originally postulated (very good news).
  - Still working on drying studies to determine IF there is any residual water following vacuum drying. The High Burnup Confirmatory Data Project is expected to yield useful information along with the University of South Carolina IRP.