Used Nuclear Fuel Storage and Transportation Overview

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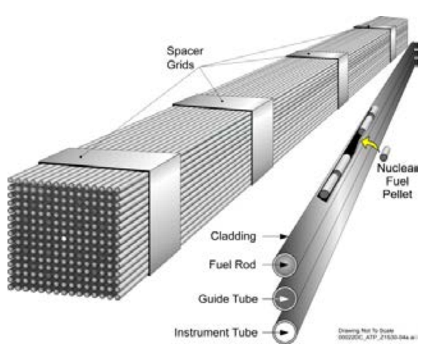
NEET ASI Review Meeting
September 17, 2014

Today's Discussion

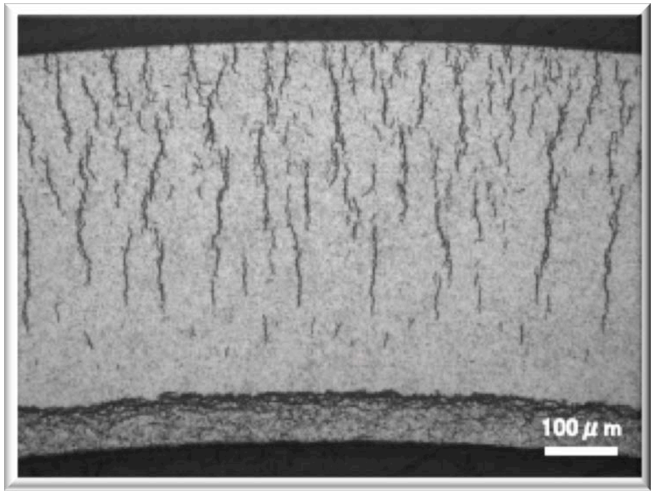
- **Our R&D Objectives**
- **What Guides Our Work**
- **FY14 and FY15 Work**
  - Full-Scale High Burn-Up Demo
  - Experiments
  - Transportation
  - Analysis

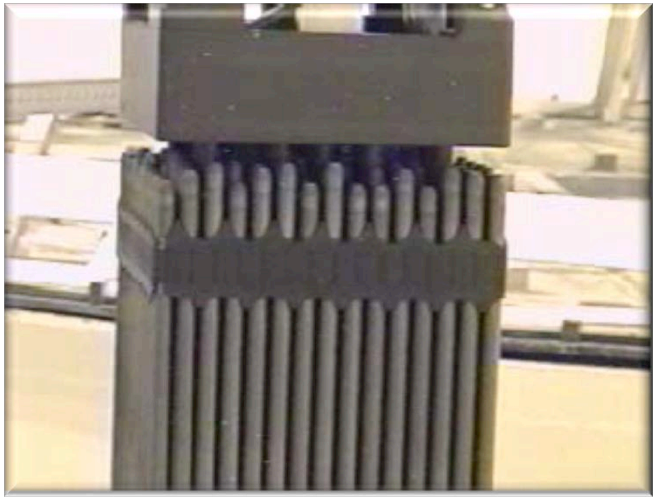


Storage and Transportation R&D Objectives

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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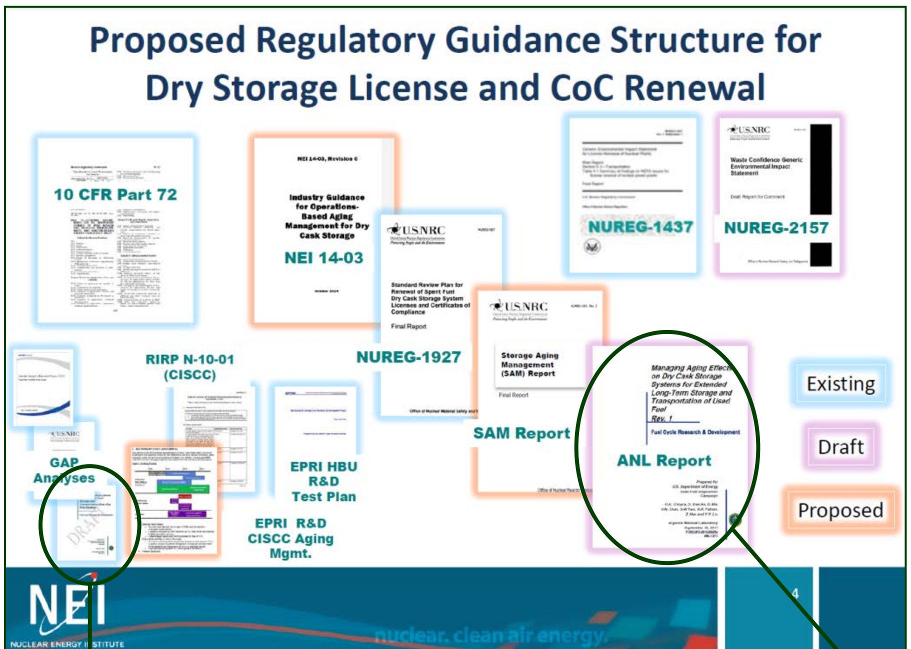
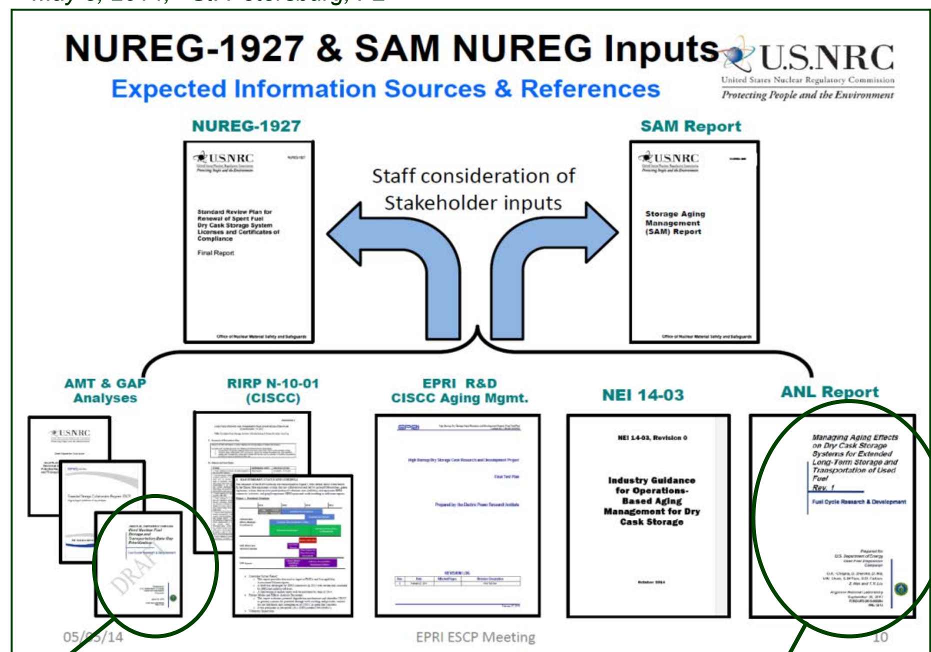
Storage and Transportation Objectives

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



Al Csontos, NRC, 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.

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*

Today's Discussion

- **Our R&D Objectives**
- **What Guides Our Work**
- **Workscope**
  - Full-Scale Dry Storage R&D Development Project
    1. *Background, Work To Date And Sensor Technology Development*
    2. *Final Fuel Selection and plans for sister rod analysis*
  - Experiments
  - Transportation
  - Analysis
- **Summary of Feedback**

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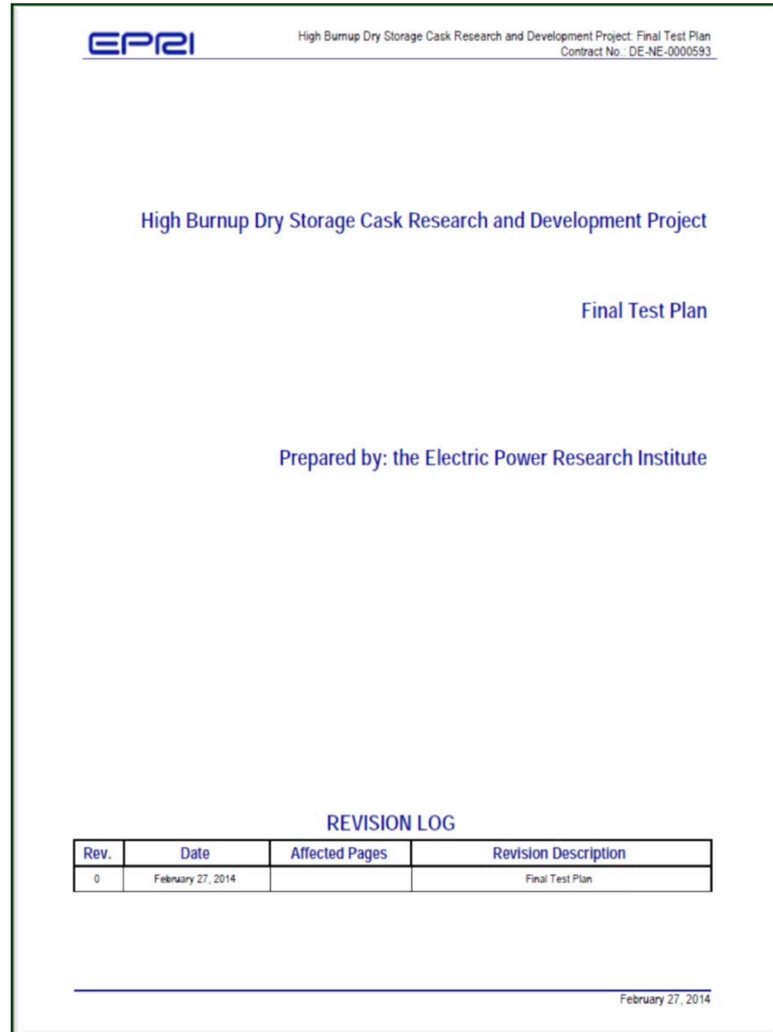
HBU Dry Storage R&D Project: Support of DOE/EPRI Confirmatory Demonstration Program

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
- Develop sensor technologies to interrogate cask internal gasses during storage

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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NRC and Industry Link to the Confirmatory Data Project

U.S.NRC

Protecting People and the Environment

AMP Element 10: Operating Experience

NUREG-1927: Include past corrective actions; provide objective evidence to support a determination that the effects of aging will be adequately managed so that the SSC intended functions will be maintained during the period of extended operation

- Surrogate surveillance demonstration programs with storage conditions and fuel types similar to those in the dry storage system that satisfies the ISG-24 acceptance criteria is a viable method to obtain operating experience
- Licensee intends to rely on the information from the Department of Energy (DOE) High Burnup Fuel Cask Research and Development program with similar types of HBU fuel as provided in the response to RAI 3-2
- DOE Dry Cask Storage Demonstration Project is viable as a surrogate surveillance program for the industry
- Additional data/research to assess fuel performance

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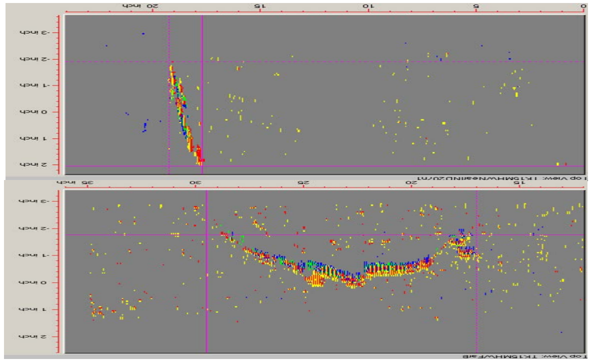
From materials presented by Robert Einziger at an NRC public meeting on the Prairie Island ISFSI license renewal meeting on June 16, 2014.

High Burn-up Confirmatory Data Project:
Schedule

- **High Level Milestones**
  - 12/31/2014 TN complete Design Licensing Basis Document (DLBD)
  - 7/31/2015 Dominion submits License Amendment Request (LAR) to NRC
  - 1/31/2017 Dominion receives approved SER
  - 6/30/2017 Dry run and functional tests complete
  - 7/31/2017 Cask loading complete
  - 8/21/2017 Cask emplaced at pad
  - 4/16/2018 Current EPRI contract expires
  - 2018-2028 Continue to monitor and gather data
  - 2028 Open cask for examination

Field Demonstration:
Sensor Technology Development

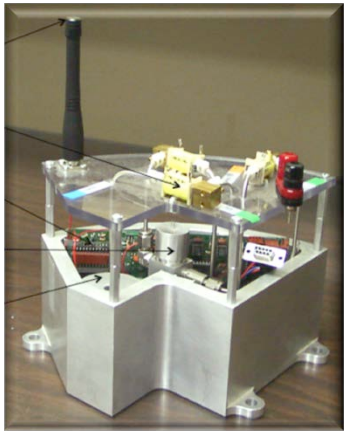
- **Objectives**
  - Assess instrumentation and sensor technologies to interrogate dry storage canister systems for:
    - *thermal conditions*
    - *humidity conditions*
    - *fission gas release*
    - *crack characteristics associated with stress corrosion cracking*
  - Assess both internal and external sensor technologies
  - Collaborate with industry to align sensor technologies with operational constraints



- **Impact**
  - Support dry storage license extension certification efforts
  - Support confidence in licensee's ability to detect cracks, assess crack growth rate, and determine inspection intervals that support site Aging Management Plans (AMPs)

Field Demonstration:
Sensor Technology Development

December 6, 2013: Brainstormed possible methods and determined requirements.



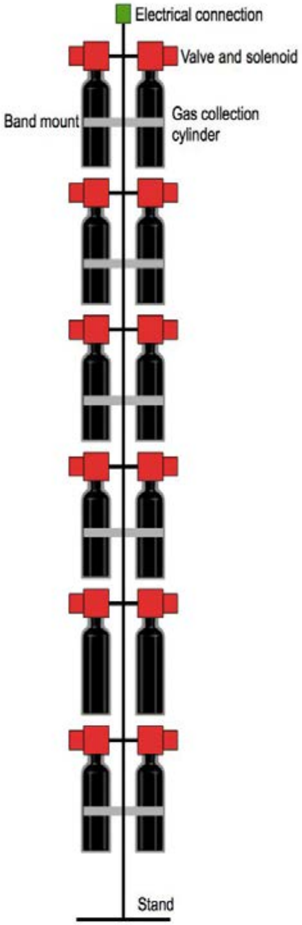
- **Operational Requirements**
  - No unmonitored release at the ISFSI
    - *Taking samples from the cask causes concern*
  - No impact to the safety envelope or personnel rad exposure
    - *Anything going inside the cask must be analyzed by AREVA TN*

- **Sampling and Monitoring Requirements:**
  - Shall be proven/tested technology
  - Have been previously used in commercial nuclear power applications
  - Have a temperature range, accuracy, and physical dimensions compatible with the fuel and cask design
  - Have an operational lifespan of months to years.
    - *Realistic temperatures, pressures, radiation doses, and other environmental conditions must be considered*
  - Little impact on the cask lid design.
    - *Space is limited on the lid due to the thermocouple “lances” and overpressurization system that is on top of the lid.*

HBU Dry Storage R&D Project:
Sensor Technology Development

January 2014: More than 14 ideas evaluated

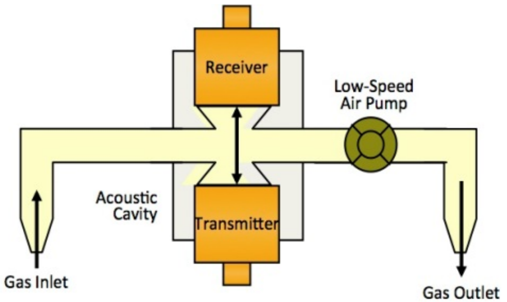
- **Gas Analysis**
  - LIBS (laser induced breakdown spectroscopy) technology
  - Acoustic speed of sound technology
  - Under-lid gas chamber
  - Beta Detector for beta emitters
  - Pinch-welded tube gas sampling
  - View-port-through-lid application of acoustic measurements
  - Millimeter wave technologies
  - Gas counting chamber under lid
  - Canberra Kr-85 analyzer
  - Coupons to sorb specific gases
  - RH calibration salts
  - Gas collection vessels opened by remote valve in the cask cavity
- **Water Detection**
  - Sensor for free water at cask bottom
  - Utilizing thermocouple lances for additional sensor application

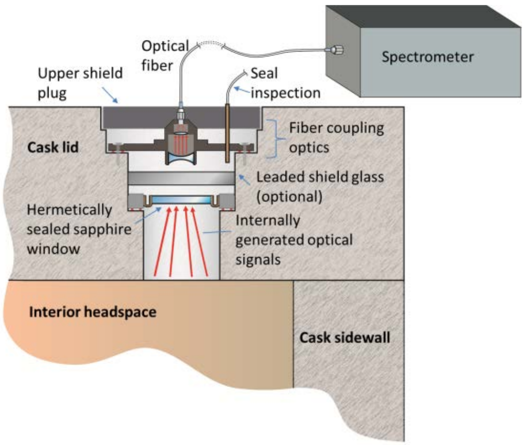


HBU Dry Storage R&D Project:
Sensor Technology Development

March 6, 2014: NRC Public Meeting to discuss "licensability" of the top ideas, resulting in the following conclusions:

- Better to keep any device/method contained within the cask's confinement boundary.
- Changes to the defined cask confinement boundary is a concern.
- Measurement devices that are housed within the existing confinement boundary are a concern.
- The methods characterized as "active, internal to cask" require the most technical development.
- Methods external to the cask pose no problem and evaluating the potential to use ultrasonic detection methods for the detection of free water was encouraged.
- The potential to put other instruments/sensors in a thermocouple lance configuration was also considered viable.
- The other methods presented were not strongly supported.





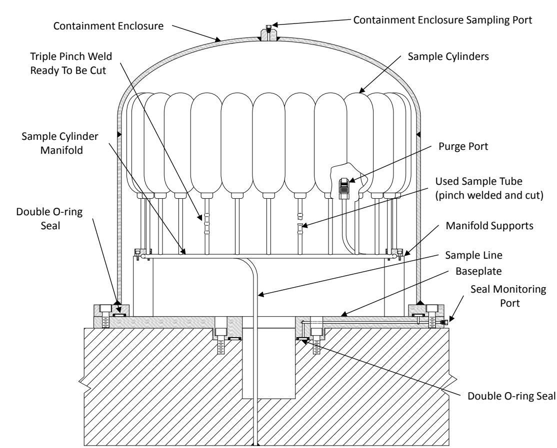
HBU Dry Storage R&D Project:
Sensor Technology Development

March 19, 2014: Labs and EPRI Follow-on Teleconference

– AREVA-TN needed a *fully-designed, tested, and qualified plan* in place by June 1, 2014, in order to meet their licensing submittal schedule.

There were no measurement technologies that could meet that date, therefore no additional instrumentation or sensors for taking samples or measurements from the interior of the cask will be pursued.

– Measurement methods that are completely external to the cask may be pursued
– Input has been gained that can steer future efforts
– The effort was also useful to inform the community on the complexity of developing additional measurement methods.



HBU Dry Storage R&D Project: Sensor Technology Development

July 2014: 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.
- DOE will continue to evaluate monitoring technologies that may be able to assess internal canister parameters (e.g., water)

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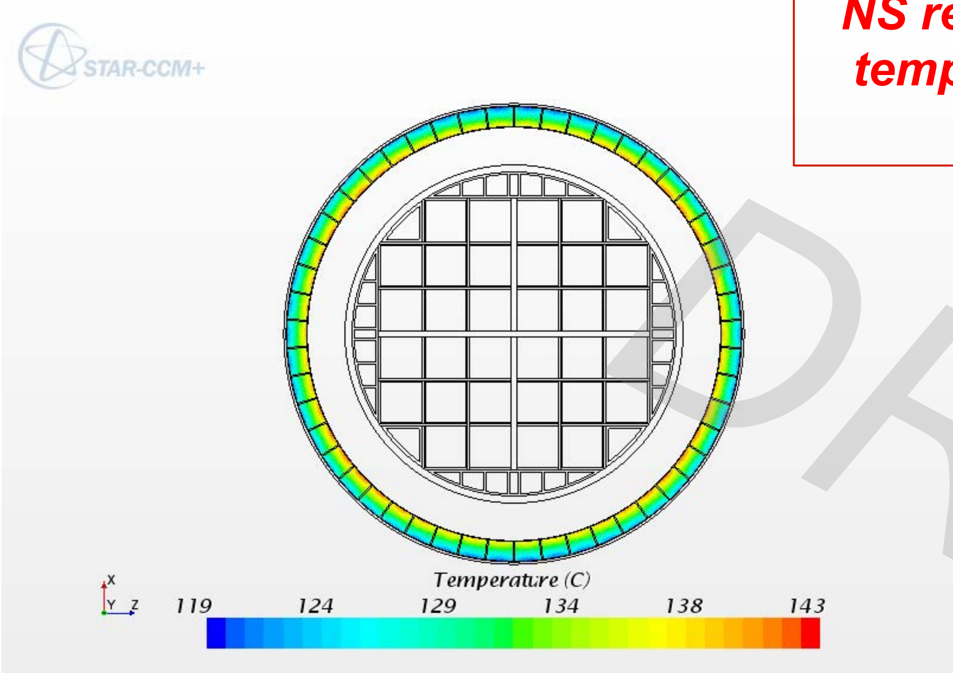
HBU Dry Storage R&D Project: Final Fuel Selection Priorities

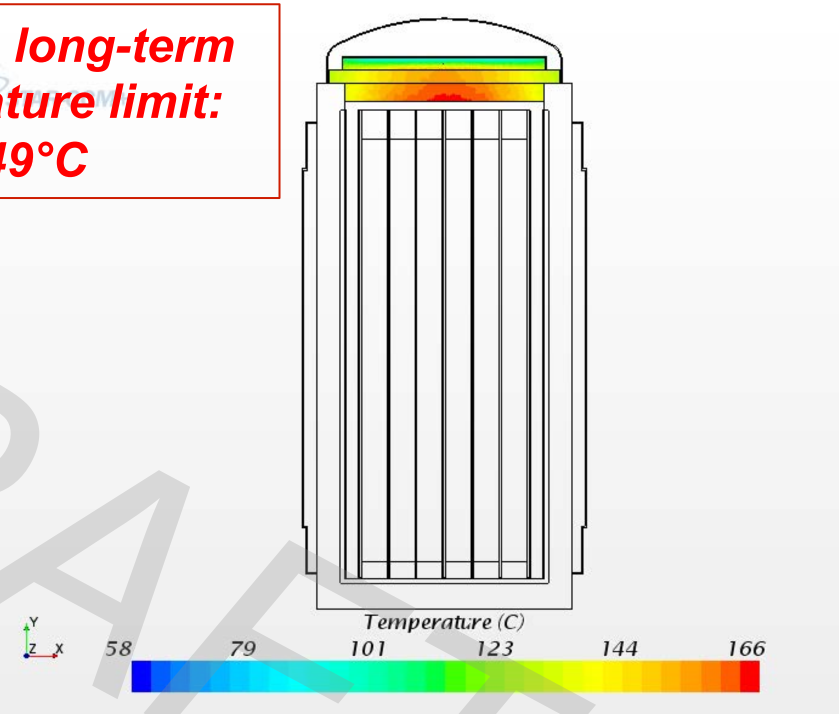
- **June 30, 2014: Fuel Selection was finalized based on the following priorities:**
  1. Get temperatures as close to 400C as possible.
  2. Keep the total cask heat load below the temperature limit on the neutron resin material (149C)
  3. Put one of each of the four kinds of PWR cladding in the center four slots
  4. Surround 4 HBU assemblies in center with lower burnup, fresher fuel to drive up heat.
  5. Put one higher BU, shorter cooling time M5 in a middle corner to try to get a wide variation in storage temperature over the prolonged storage period.
  6. Thermocouple lance positions: 4 in middle; 3 in periphery; keep some area clear on the lid for the helium overpressure tank et al.

	1 6T0 Zirlo, 54.2 GWd 4.25%, 3cy, 11yr 1013/819W	2 (TC Lance) 3K7 M5, 53.4 GWd 4.55%, 3cy, 8yr 1167/838W	3 3T6 Zirlo, 54.3 GWd 4.25%, 3cy, 11yr 1015/821W	4 6F2 Zirlo, 51.9 GWd 4.25%, 3cy, 13yr 909/757W	DRAIN PORT
5 3F6 Zirlo, 52.1 GWd 4.25%, 3cy, 13yr 914/762W	6 (TC Lance) 30A M5, 52.0 GWd 4.55%, 3cy, 6yr 1276/832W	7 22B M5, 51.2 GWd 4.55%, 3cy, 5 yr 1637/841W	8 20B M5, 50.5 GWd 4.55%, 3cy, 5 yr 1608/827W	9 5K6 M5, 53.3 GWd 4.55%, 3cy, 8yr 1163/834W	10 5D5 Zirlo, 55.5 GWd 4.2%, 3cy, 17yr 906/797W
11 Vent Port 5D9 Zirlo, 54.6 GWd 4.2%, 3cy, 17yr 885/779W	12 28B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1629/837W	13 F52 Zirc-4, 58.1 GWd 3.59%, 4cy, 28yr 858/805W	14 (TC Lance) 57A M5, 52.2 GWd 4.55%, 3cy, 6yr 1281/835W	15 30B M5, 50.6 GWd 4.55%, 3cy, 5 yr 1614/830W	16 3K4 M5, 51.8 GWd 4.55%, 3cy, 8 yr 1162/803W
17 5K7 M5, 53.3 GWd 4.55%, 3cy, 8yr 1165/836W	18 50B M5, 50.9 GWd 4.55%, 3cy, 5 yr 1625/835W	19 (TC Lance) 3U9 Zirlo, 53.1 GWd 4.45%, 3cy, 10yr 1037/806	20 0A4* Low-Sn Zy-4, 50 GWd 4.0%, 2cy, 22yr 725/665W	21 15B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1629/837W	22 6K4 M5, 51.9 GWd 4.55%, 3cy, 8 yr 1162/803W
23 3T2 Zirlo, 55.1 GWd 4.25%, 3cy, 11yr 1036/838W	24 (TC Lance) 3U4 Zirlo, 52.9 GWd 4.45%, 3cy, 10yr 1031/802W	25 56B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1628/837W	26 54B M5, 51.3 GWd 4.55%, 3cy, 5 yr 1645/846W	27 6V0 M5, 53.5 GWd 4.4%, 3cy, 8yrs 1178/844W	28 (TC Lance) 3U6 Zirlo, 53.0 GWd 4.45%, 3cy, 10yr 1035/804W
	29 4V4 M5, 51.2 GWd 4.40%, 3cy, 8yr 1109/787W	30 5K1 M5, 53.0 GWd 4.55%, 3cy, 8yr 1155/829W	31 (TC Lance) 5T9 Zirlo, 54.9 GWd 4.25%, 3cy, 11yr 1031/833W	32 4F1 Zirlo, 52.3 GWd 4.25%, 3cy, 13yr 918/765W	High Priority Assys

Summary of Peak Resin Temperatures from COBRA-SFS and STAR-CCM+ models



NS resin long-term temperature limit: 149°C



Case description (storage conditions, helium)	Average NS Resin Temperature (°C) at peak axial location	Peak NS Resin Temperature (°C)
	COBRA-SFS model	Star-CCM+ model
FINAL loading (at 38.146 kW)	87	144 (side); 153 (top)
10 years later (at 25.89 kW)	72	

Experiments

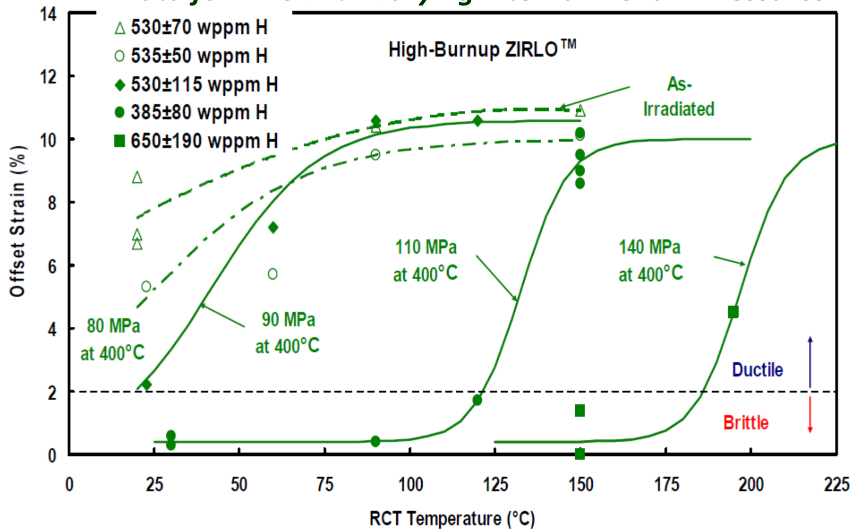
- **The objective of the Experimental CA is to develop the data necessary to further our understanding of fundamental materials degradation issues associated with the safety components (including the fuel) of long term storage systems and subsequent transportation of used nuclear fuel. This data also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

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

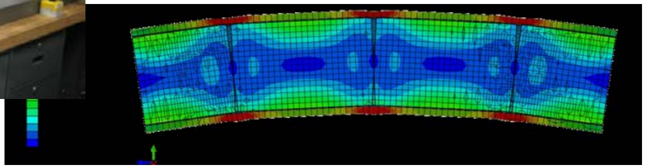
- **Hydrides and reorientation**
  - Ring Compression Tests and determination of Ductile-Brittle Transition Temperature (ANL)
  - Cladding bend tests and effects of fuel/clad bonding and pellet/pellet interfaces (ORNL)
  - Creation of hydride rim in unirradiated cladding and burst, tube tensile, and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

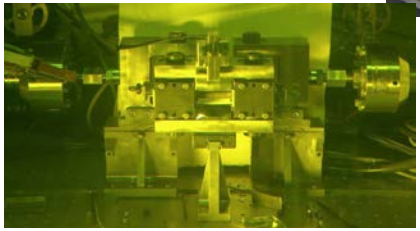
DBTT Data for Zirlo with Varying Internal Plenum Pressures



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

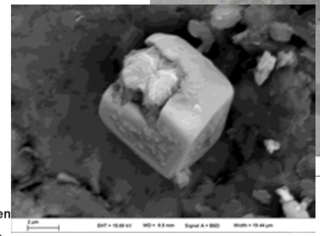
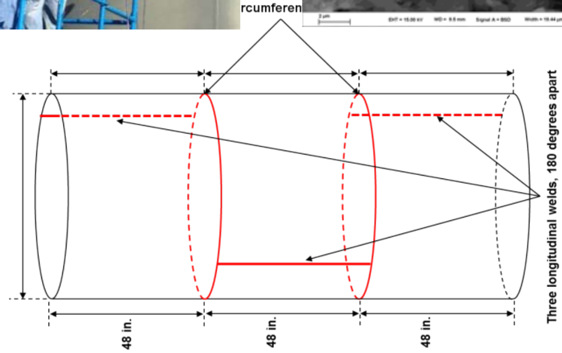
Experiments:
Stainless Steel Canister Corrosion

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 for AMPs.

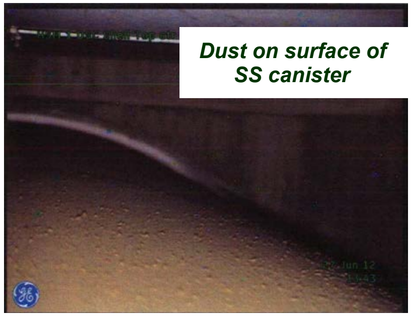
Objectives:

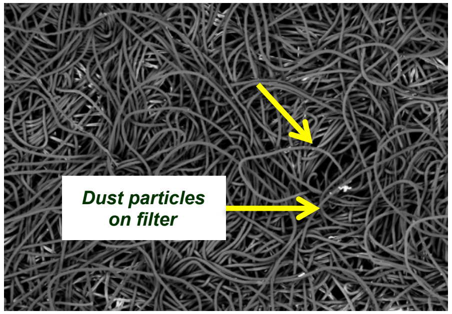
- Develop data to understand initiating conditions for corrosion of stainless steel canisters used for dry storage
- Develop data to understand initiating conditions and progression of SCC-induced crack growth
- Obtain site data to assess atmospheric conditions and compare with initiating conditions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

Mockup for SSC experiments

Conceptual design for full-scale SS welded canister





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

Calvert Cliffs site environmental assessment

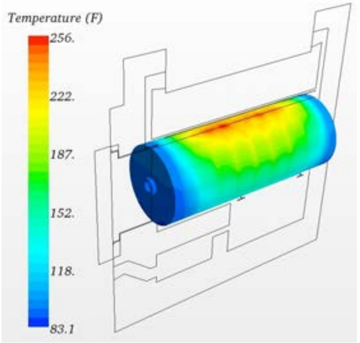
Analysis

- **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.**

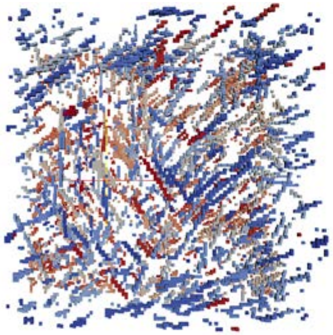
Analysis:
Thermal Profiles

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

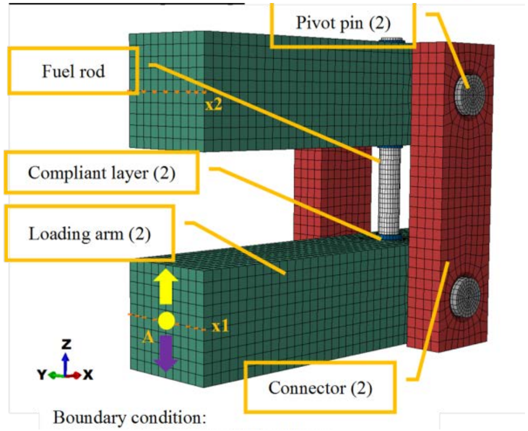
- **Predictive modeling**
  - Thermal Analysis (PNNL) to predict cool down, Ductile to Brittle Transition, deliquescence, etc.
    - *HBU Demonstration fuel selection and cool down*
    - *Modern, high heat load, high capacity systems*
    - *In-service inspections validation data*
  - Hybrid hydride reorientation model (SNL)
  - 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



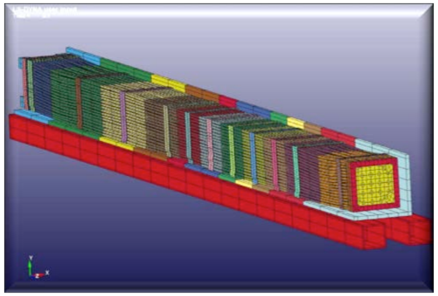
CFD Thermal Analysis of Dry Storage Casks
Suffield, et al, PNNL-21788



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

Transportation

- **The objective of this CA is to assess the retriveablity of used fuel after long term storage and to ascertain the ability to transport high burnup fuel.**

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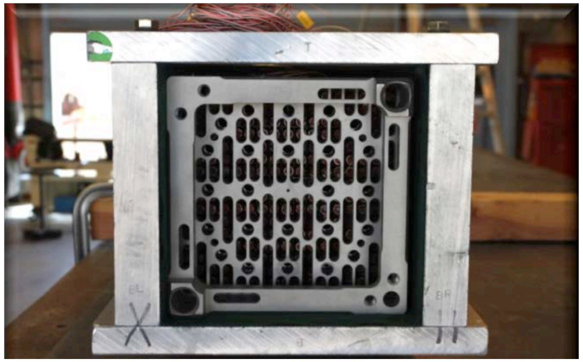
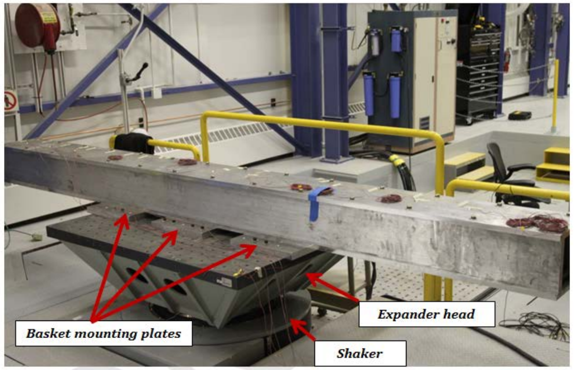
Transportation:
Normal Conditions of Transport – Loading on fuel assemblies

- **Test:**
  - Surrogate assembly was subjected to truck data from a 700 mile trip on a shaker table and the test was repeated on a real truck transport through Albuquerque.
  - Data results were >10 times below yield strength.
  - The strains measured in both the shaker and the truck test were over an order of magnitude lower than either an irradiated or unirradiated Zircaloy rod strain yield limits.
  - Future: over-the-rail test to confirm that strains are bounded by truck, to further validate models, and provide real rail data for public confidence.

- **Impact:**
  - This work will provide insight into the ability of high burnup fuel to maintain its structural integrity during NCT.
  - If high burnup fuel can maintain its integrity during transport, it will take a lot of pressure off experimental R&D efforts associated with hydride effects on cladding strength and ductility.
  - Work includes investigating fatigue behavior.

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





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