Used Nuclear Fuel Storage and Transportation Overview

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NEET ASI Review Meeting
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Today’s Discussion

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


### Storage system component “High” and “Medium” priorities

<table>
<thead>
<tr>
<th>System Component</th>
<th>Issue</th>
<th>Importance of R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cladding</strong></td>
<td><strong>Annealing of Radiation Effects</strong></td>
<td>Medium</td>
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<tr>
<td></td>
<td>Oxidation</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td><strong>H\textsubscript{2} effects: Embrittlement</strong></td>
<td>High</td>
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<tr>
<td></td>
<td><strong>H\textsubscript{2} effects: Delayed Hydride Cracking</strong></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Creep</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Assembly Hardware</strong></td>
<td>Stress corrosion cracking</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Neutron Poisons</strong></td>
<td>Thermal aging effects</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Embrittlement and cracking</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Creep</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Corrosion (blistering)</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Canister</strong></td>
<td>Atmospheric corrosion (marine environment)</td>
<td>High</td>
</tr>
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<td></td>
<td>Aqueous corrosion</td>
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Storage and Transportation R&D is Guided by a Comprehensive Gap Analysis

**Storage system component “High” and “Medium” priorities**

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<td><strong>Bolted Direct Load Casks</strong></td>
<td>Thermo-mechanical fatigue of bolts/seals</td>
<td>Medium</td>
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<tr>
<td></td>
<td>Atmospheric corrosion (marine environment)</td>
<td>High</td>
</tr>
<tr>
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<td>High</td>
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<tr>
<td><strong>Overpack and Pad (Concrete)</strong></td>
<td>Freeze/Thaw</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Corrosion of steel rebar</td>
<td>Medium</td>
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**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
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
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.

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
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)
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.*
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
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.
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.
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)
June 30, 2014: Fuel Selection was finalized based on the following priorities:

1. Get temperatures as close to 400°C as possible.
2. Keep the total cask heat load below the temperature limit on the neutron resin material (149°C)
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.

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

### NS resin long-term temperature limit:
149°C

<table>
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<tr>
<th>Case description (storage conditions, helium)</th>
<th>Average NS Resin Temperature (°C) at peak axial location</th>
<th>Peak NS Resin Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINAL loading (at 38.146 kW)</td>
<td>COBRA-SFS model: 87</td>
<td>Star-CCM+ model: 144 (side); 153 (top)</td>
</tr>
<tr>
<td>10 years later (at 25.89 kW)</td>
<td>72</td>
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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.
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
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


Calvert Cliffs site environmental assessment
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.
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
The objective of this CA is to assess the retrievability of used fuel after long term storage and to ascertain the ability to transport high burnup fuel.
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.