Recent Advancements in Used Fuel R&D Activities

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Program Manager

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Overview of Current R&D Projects

- High Burnup Fuel Demonstration
- Nuclear Fuel Thermal Modeling
- HBU Fuel Cladding Properties
- Aging Management
- Dry Storage NDE, Mitigation, and Repair

Collaborative R&D Projects Spanning the Back End of the Fuel Cycle
Industry Collaboration via ESCP

- The Extended Storage Collaboration Program (ESCP) is a collaborative working group organized to identify and address issues related to use fuel storage and transportation.

- ESCP is made up of utilities, vendors, regulators, national labs, universities, EPRI, and other organizations.

- These organizations work together to solve global issues.

- Many/most of the organizations present today are involved in ESCP.
ESCP Overview and Structure

2010-2018
Regular May and December meetings, in US
14 International SC meetings
6 subcommittees

2019
~650 members from 22 countries
>180 participants, from 11 countries attended ESCP
6 → 4 subcommittees

2009
1st ESCP meeting
1 country,
39 participants
2 subcommittees

2019 Highlights
- Workshop on back end effects of ATF
- Fuel, Thermal, and Decay Heat PIRTs discussed
- SONGS work on in situ cold spray repair
- Merged 3 subcommittees (CISCC, NDE, and Mitigation & Repair) into 1 subcommittee (Canister Integrity)
Recent Collaborations Generated by ESCP

Thermal Modeling

High Burnup Demo

Sister Rod Testing

Transportation Triathlon

NDE Inspection & Repair

Image credit: Sandia National Laboratories
HBU Demo provided valuable information to the industry

- Identified as the #1 priority in the 1st ESCP Meeting
- DOE and EPRI co-funded the project and EPRI served as the project lead
- HBU Demo gathered various important data
  - Temperatures
    - Identified significant biases in thermal models
  - Gas composition
    - Verified no fission gas released
    - Identified ~70 cc of water present
- DOE funded Sister Rod testing at the National Laboratories to gather key information

Peak Cladding Temperature (Cell 14) = 237°C
Current Status of HBU Demo

High Burnup Demo
- Cask is loaded and collecting data
- Data will support storage license renewal aging management plans

Extracting More Value than Planned
- Data for thermal modeling benchmarks
- Rod internal pressure measurements (DOE)
- Hydride Reorientation Issue Resolution

Next Steps
- Prepare to ship and open cask in 10 years
- Support technical basis for long-term storage of HBU fuel

HBU Demo data available at:
The High Burnup (HBU) Demo Offered a Unique Opportunity

The HBU demo cask was loaded in Nov. 2017

EPRI Identified an opportunity to perform a blind benchmark of thermal models

EPRI established a thermal modeling subcommittee under the EPRI Extended Storage Collaboration Program (ESCP)

ESCP brought in multiple thermal models for a best-estimate comparison to actual data

Using HBU Demo data for international thermal modeling round robin studies
**ESCP Thermal Modeling Progression**

**ESCP Steering Committee**
Chair: Hatice Akkurt (EPRI)

**Canister Integrity/Aging Management Subcommittee**
Chair: Jeremy Renshaw (EPRI)

**Fuel Assembly Subcommittee**
Chair: Mike Billone (ANL) / Vice-Chair: Sven Bader (Areva)

**Thermal Modeling Subcommittee**
Chair: Al Csontos (EPRI) / Vice-Chair: Sam Durbin (SNL)

**International Subcommittee**
David Hambley (NNL) / Maik Stuke (GRS), Woo-seok Choi (KAERI), Brady Hanson (PNNL)

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**Phase I**
- BWR DCS Simulator
- EPRI Lead

**Phase IIa**
- HBU Demo Round Robin
- EPRI Lead

**Phase IIb**
- Sensitivity and Transient Analyses
- DOE Lead

**Phase IIc**
- Phenomena Identification Ranking Table (PIRT) Gap Analysis
- EPRI Lead

**Phase IId**
- Int’l HBU Demo Round Robin
- EPRI Lead
Blind benchmarking temperatures were all biased on the high side.

Cell 14 (Hottest Cell)

- S1
- S2
- S3
- S4
- Measured

Elevation (m)

Temperature (°C)

~90°C Bias/Margin

DLB

17-20% Decay Heat Penalty

Max Ambient Temperature Assumption

Large Biases in Thermal Models

Conservative Gap Sizes

Added Uncertainties & Regulatory Margin

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Benefits of Improved Thermal Models

- **Occupational dose benefits:**
  - Temporary shielding restrictions (blankets)
  - Time limits to keep mating device door open
- **Dry storage operational benefits:**
  - Storing hotter fuel sooner
  - More flexible SNF loadouts
  - Drying time limits and time to boil
  - Supplemental cooling requirements
  - Vent surveillance requirements
  - Fuel and canister degradation mechanisms
  - Risk informing aging management
- **Reactor operations/safety benefits:**
  - Reduced SFP temperatures/time-to-boil
- **Accelerate decommissioning:**
  - Pool to pad sooner (active to passive cooling)
- **Informs repository loading footprint**
Thermal Affects the Entire Back End of the Fuel Cycle

Lower Temperatures
• ↓ Rod internal pressure
• ↓ Stress
• ↓ Creep
• ↓ Hydride reorientation
• ↓ Oxidation

Storage/Transportation
• ↓ Fuel degradation
• ↑ Understanding of CISCC
• ↓ Dose to workers/public
• ↑ Transportability

Decommissioning & Disposal
• ↓ Decommissioning costs
• ↓ Repository footprint
• ↓ Repository costs
• ↑ Safety
Stress relaxation occurs due to creep - most beneficial at higher temperatures

400°C case starts at highest stress, but quickly reduces to the lowest stress in all cases
Cladding Hoop Stress Modeling

- Initial peak hoop stress greater than unbonded fuel
- Stress relaxation occurs in days
- Peak hoop stress reduces to ~half of initial value

Effect of reduced hoop stress on radial hydride concentration

Reduced hoop stress ➞ Reduced radial hydrides
Effects on Cladding

- Highly Robust Cladding
- Oxidation rate ↓
- Temperatures ↓
- Rod Internal Pressure ↓
- Cladding Stress ↓
- Cladding reorientation
- Hydride reorientation
- Cladding ductility ↑
- Fuel-clad bonding effects
- Stress relief from creep
- Ductility from annealing
- Electrostatic adherence of small UO₂ particles
- Fuel-clad bonding effects
- Stress relief from creep
- Ductility from annealing
- Electrostatic adherence of small UO₂ particles
Inspection, Mitigation, and Repair Developments
Aging Management - Maintaining Safety from the Reactor to the Repository

- Dry storage systems are needed for longer periods of time than originally anticipated.
- Aging management will be required to verify continued safe operation.
- ASME Code Case N-860 initiated to identify inspection and evaluation criteria.
  - Code Case approaching final acceptance.
- Adopts EPRI Susceptibility Criteria for evaluating CISCC Susceptibility.
  - Defines inspection and evaluation criteria.
  - Sets inspection frequency.
    - Inspection frequency adopts a risk-informed approach (frequency increases or decreases based on inspection results).
  - Provides a flowchart for process implementation.
# Qualitative Overview of NDE Technologies

<table>
<thead>
<tr>
<th>NDE Technique</th>
<th>Temperature Resistant</th>
<th>Radiation Resistant</th>
<th>Small Form Factor</th>
<th>Sensitive to ODSCC</th>
<th>Compatibility for DCSS Inspection</th>
<th>Time to Delivery</th>
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<tbody>
<tr>
<td>Visual (VT)</td>
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<td>Eddy Current Testing (ECT)</td>
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<td>Now, if needed</td>
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<td>EMAT/Guided Waves (GW)</td>
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<td>&lt;1 Year</td>
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<td>X-ray (RT)</td>
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<td>Penetrant Testing (PT)</td>
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<td>Muon Imaging</td>
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### Technical Capability

- **Not Applicable**
- **Now or < 1 year**: Good Performance / Yes
- **< 3 years**: Fair Performance / Maybe
- **4+ years or N/A**: Poor Performance / Not Well Suited

**Desire is to have qualified NDE techniques, such as UT or EC**
## Robotic Development

**Goal:** Develop and Deploy Robots Capable of Performing Required Dry Storage System Inspections

### Upgrade/Retrofit
- VT, UT, and eddy current devices
- Temp. & Dose Measurements
- Surface Cleaning
- Robot Upgrades

### Field Trials
- Work with utilities and vendors to deploy and upgrade developed systems

### Implementation
- Work with Vendors to deploy developed technologies

### Table: Robot Development and Deployment

<table>
<thead>
<tr>
<th>Item</th>
<th>NAC Robot</th>
<th>Holtec Robot</th>
<th>TN Dual Robot</th>
<th>TN Top Vent Robot</th>
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<tbody>
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<td>VT Inspection</td>
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<td>Dose Measurement</td>
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<td>RTD Measurement</td>
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<td>Surface Cleaning Capability</td>
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<tr>
<td>Field Trial(s)</td>
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<tr>
<td>Surface Cleaning Test</td>
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<td>Done</td>
<td>Done</td>
<td>Done</td>
</tr>
</tbody>
</table>
Improving Safety and Reducing Dose for ISFSI Operations
Using Drones with AI for Automated Inspection & Analysis to Reduce Worker Dose
Conclusion: A LOT HAS CHANGED IN 5 YEARS

Collaboration
- Collaborating with many organizations via ESCP
- Leverages resources of many organizations (DOE, IAEA, utilities, vendors, nat. labs., etc.)

High Burnup Demonstration
- Providing key data to support license renewals
- Results published and data are available at www.epri.com

Thermal Modeling
- Utilized opportunity provided by HBU Demo – identified significant biases in thermal models
- Phase II results published and international round robin studies will begin in 2020

Cladding Properties
- Temperatures, pressures, and stresses are all much lower than originally modeled
- Fuel clad bonding, creep, and composite fuel behavior lead to more robust cladding than previously believed

Aging Management: Inspection and Repair Activities Underway
- VT, UT, Eddy current, guided waves, and acoustic emission techniques developed
- Thirteen field trials have been completed inspecting 13 loaded systems

Results available in: 3002015075, 3002015076, 3002013124, 3002008234, 3002010617, 3002010621, & 3002016034
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