EPRI's Long-Term Storage Projects

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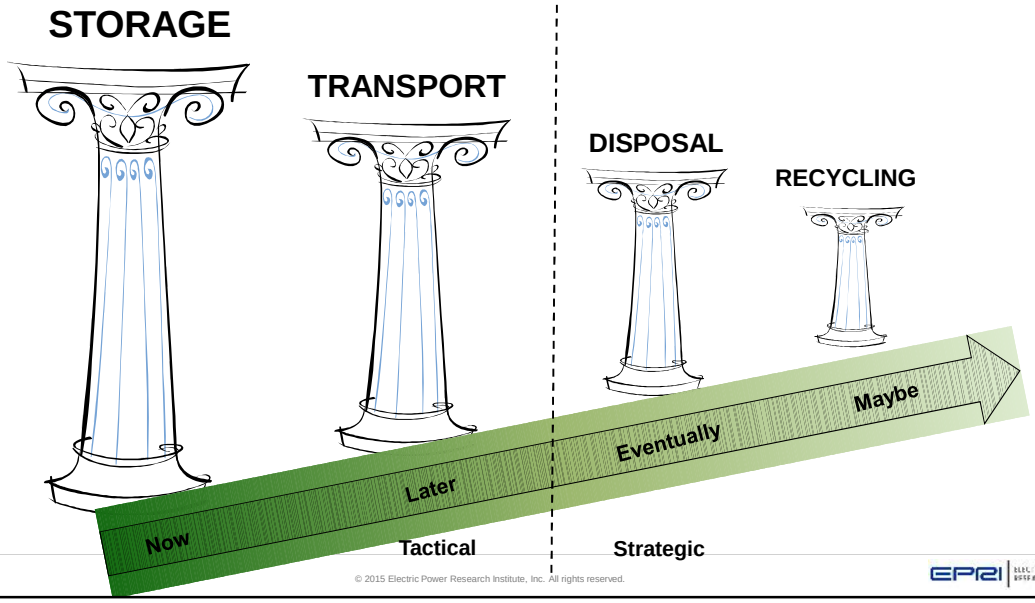
Overview

- EPRI's Used Fuel and HLW Management Program
- EPRI work related to long-term storage (followed by transportation)
  - Wet storage
    - Boral degradation
    - BADGER testing
  - Dry storage
    - High burnup, full-scale, confirmatory research project (the "Demo")
    - Welded stainless steel canister chloride-induced stress-corrosion cracking (CISCC)

EPRI's Used Fuel and HLW Management Program: Supporting Four Pillars of Integrated Used Fuel Management



3

Used Fuel Criticality During Wet Storage: Boral Degradation

- Historical: two decades of EPRI work on Boraflex degradation
- US industry: widespread replacement of Boraflex with Boral
- NRC concern about Boral degradation and measuring loss of neutron absorber
- Existing EPRI Boral projects:
  - Accelerated corrosion testing
  - Recent work at Zion
    - Benchmarking data for BADGER (in-pool "blackness" testing)
    - Collect Boral samples from Zion pool
  - MOU with NRC-Research

4

EPRI's Extended Dry Storage Projects

- **Primary goals:**
  - *Aging management of existing systems and high burnup fuel*
    - Inspections and advanced NDE techniques
    - Failure modes and effects
    - Susceptibility criteria
    - Identify mitigation options
- **Primary research components**
  - International collaboration
  - High burnup extended storage confirmatory demonstration
  - SS canister degradation: in situ inspection and atmospheric monitoring; modeling; advanced NDE; aging management guidance

5

Extended Storage Collaboration Program (ESCP)

- Purpose: "Provide the technical bases to ensure continued safe, long-term used fuel storage and future transportability"

- Phased approach
  - ✓ Phase 1: Review current technical bases and conduct gap analysis for storage systems
  - ➢ **Phase 2: Conduct experiments, field studies, and additional analyses to address gaps**
  - ➢ **Phase 3: Confirm long-term dry storage performance**
    - **Use a full-scale dry storage system loaded with high burnup fuel (>45 GWd/MTU)**

6

ESCP Subcommittees

- Fuel/Internals
- **"Marine environments"**
  (chloride-induced stress-corrosion cracking, CISCC)
- **Non-destructive evaluation (NDE)**
- Concrete Systems
- **High burnup confirmatory demonstration**
- "International"
  - International gap analysis:

  http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001026481

  International gap analysis being updated (late 2015 publication)

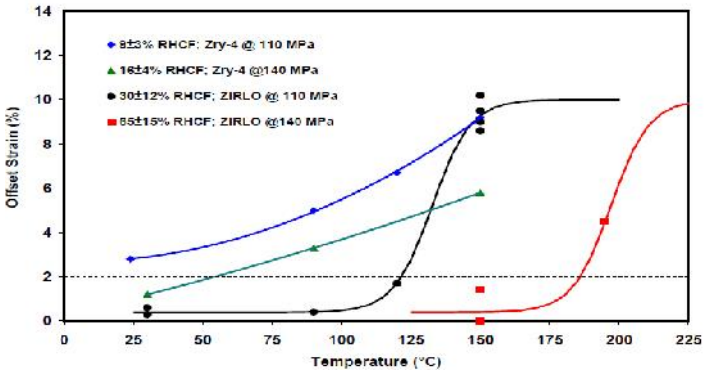
EPRI Work Related to Extended (long-term) Storage – Followed by Transportation

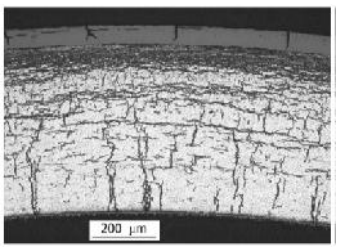
Extended Storage Gap Analyses (US and International): Highest Priority Items

- **High burnup cladding: hydride effects (reorientation, embrittlement)**
- **Welded SS canisters CISCC**
- Bolted casks:
  - Corrosion of bolts
  - Embrittlement and mechanical degradation of bolts
- Fuel pellet swelling

NRC Concern: *High* BU Cladding Loss of Ductility During Extended Storage

(followed by transportation)





Used fuel cladding cross-section showing hydride embrittlement

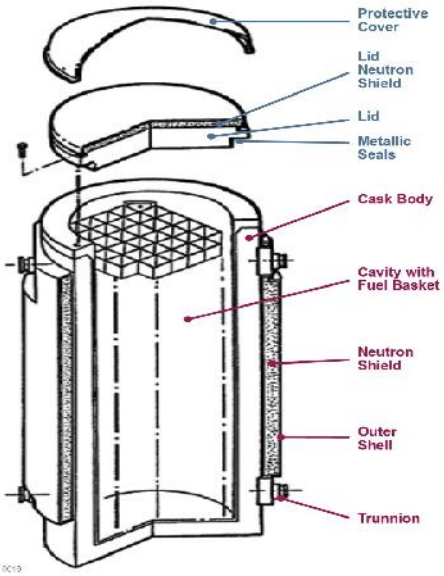
Gap: Full Scale *High* Burnup Demonstration

- Repeat earlier low BU demo (1986-2000) using high BU fuel
- Will high BU cladding become so brittle it cannot be moved?
- DOE desire for *assembly* retrievability for repacking purposes

- Need for data for high BU license extensions:
  - ***Now: Prairie Island; Calvert Cliffs*** *(in process)*
  - ***Imminent: TN CoC 1004*** *(affects multiple sites)*
  - Mid to late 2020's: several more in the US, international
  - NRC wants "industry commitment" to high BU R&D

EPRI-led Team to Conduct Demonstration

- Awarded DOE contract April 2013
  - 80/20 DOE/EPRI cost split
- Willing host: North Anna
  - Multiple, high burnup fuel types already on site
  - Site-specific license
- TN-32 cask already available
  - Dominion Virginia Power uses them already



EPRI Project Team

- AREVA Federal Services
  - Transnuclear (AREVA TN): cask designer and current cask owner
  - Dominion: host utility, licensing and operational lead
  - AREVA NP: design and supply thermocouple lances
  - AREVA Fuels: pull AREVA fuel sister rods
- Westinghouse Fuels: pull Westinghouse sister rods
- Sister rods shipper to national lab: NAC

AREVA

Federal Services

Transnuclear

Fuels

NP

Dominion

NAC INTERNATIONAL

Westinghouse

High Burnup Demo Schedule: 2014 – 2016

2014:

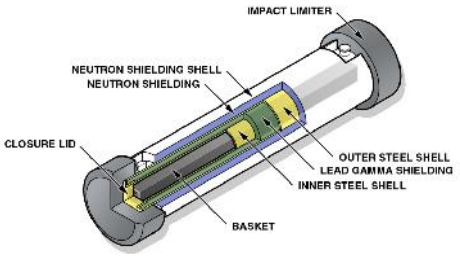
- Complete the design of the modified cask bolted lid that includes:
  - Thermocouples
  - Gas sampling

2015:

- Extract the sister rods from some of the high burnup assemblies
- Begin modifications to the cask lid; perform fit-ups
- Submit storage license application to NRC

2016:

- Ship the extracted sister rods to Idaho National Lab for evaluation
- Ship the modified TN-32 cask and lid to North Anna



High Burnup Demo Schedule: 2017 through 2018+

2017:

•Obtain storage license from NRC (tentative, pending NRC review)

•Perform dry runs

•Load the Demonstration Cask and begin temperature and gas data collection during the drying process

2018 to the end of the storage period:

•Continue taking periodic temperature measurements

•Submit and obtain transportation Certificate of Compliance (CoC) from NRC (tentative, pending NRC review)

End of the Storage Period

- Ship the cask to a Fuel Examination Facility (to be provided by DOE)
- Open the cask and visually examine the fuel
  - Extract high burnup rods for subsequent examination
  - Conduct non-destructive and destructive examinations of the rods at the national lab(s)
    - Same exams as “t=0” exams
    - Compare end-of-storage and “t=0” fuel properties
- Option: re-close Demo cask and continue storage; re-open again later

Figure E-4
Fuel rod being pulled from fuel assembly T-11.

Figure F-5
Fuel rod pulled into inspection tray.

Welded Stainless Steel Dry Storage Canisters:

Chloride-Induced Stress-Corrosion Cracking (CISCC)

All Pieces of the SS Corrosion "Story" Need to be Available for an Aging Management Plan

1. Amount of salt deposited on the SS canister surfaces
   - Canister surface sampling
   - Atmospheric monitoring
2. Canister surface temperature
3. Humidity at the canister surface
4. Amount of time in the "right" conditions
   - Crack initiation time
   - Crack growth time
5. Susceptibility assessment
6. Capability of finding part-wall cracks
7. Aging management guidance

EPRI is working on all of the above

SS Canister Inspection #1: Calvert Cliffs

Chesapeake Bay

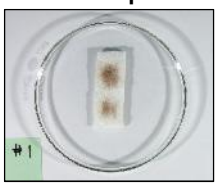
Independent Spent Fuel Storage Installation (ISFSI)

Calvert Cliffs – Visual Inspections

- No gross degradation
- Light surface corrosion
- Top covered in dust

Calvert Cliffs Inspection Summary

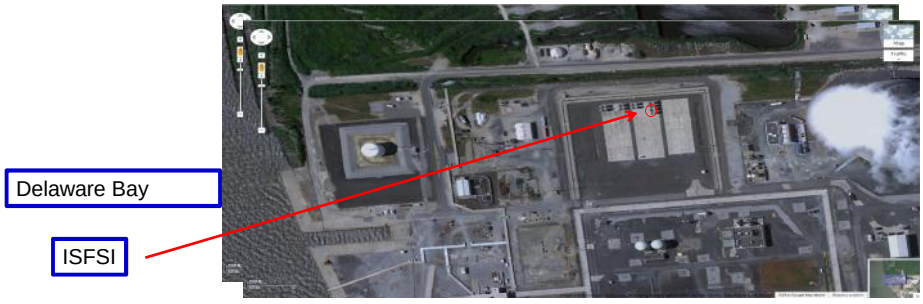
- Surface sample results confirm key observation, very little Cl present in samples
  - Brown stain on filter consists mostly of pollen



- Reports documenting Calvert Cliffs inspection:
  - "Thermal Modeling of NUHOMS HSM-15 and HSM-1 Storage Modules at Calvert Cliffs Nuclear Power Station ISFSI," PNNL-21788
  - Evans Analytical results available in NRC ADAMS system: ML13119A242, ML13119A243 and ML13119A244
  - "Data Report on Corrosion Testing of Stainless Steel SNF Storage Canisters," FCRD-UFD-2013-000324
  - Comprehensive EPRI report: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025209

21

Inspection #2: Hope Creek Canisters



- Inspected two canisters, completed 11/22/13
- Results
  - **Not much chloride**
  - **Composition looks like "inland" rainwater rather than "seawater"**
- Comprehensive EPRI report will be published mid 2015

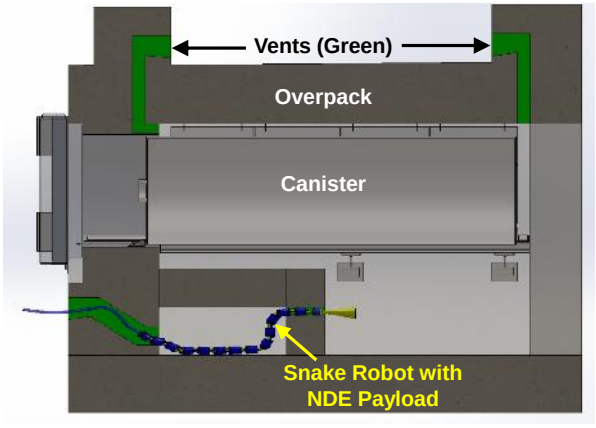
22

Inspection #3: Diablo Canyon Canisters

- Inspected two canisters January 2014
- Follow similar process as Hope Creek
- Surface deposits look more like sea salt
- Comprehensive EPRI report will be published mid 2015

EPRI Project on Improved DCSS Inspection Techniques

- EPRI is focusing on 4 main areas
  - Collaborations
  - Mockups
  - NDE Technologies
  - Delivery Systems
- End goal is to demonstrated NDE techniques with a functional delivery system
  - **Reliably detect part-wall cracks**



Potential inspection option for a DCSS

EPRI NDE Workshop, Sept.-Oct. 2014

- Goal was to clearly define the problem, and create opportunities for collaboration
  - EPRI's role was to play matchmaker
- Attendees from
  - EPRI
  - NRC
  - DOE / National Labs
  - Cask vendors
  - Inspection vendors
  - Universities
  - Robotic Manufacturers

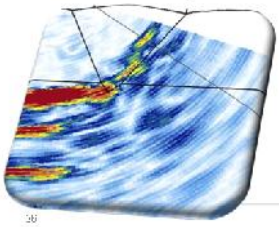
- Key Takeaways
  - Significant collaboration between NRC, DOE, EPRI, utilities, and vendors
  - NRC desires inspections ready in <5 years (2019) in a 3 phase approach

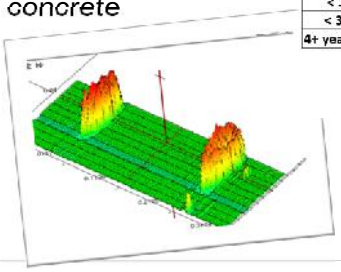
NDE for DCSS

- DCSS environments create inspection challenges
  - Radiation dose from 1-10,000 R/hr
  - Temperatures from ~70-250+°F (~21-120+°C)
  - Challenging access
    - Small vent ports for access
    - Narrow annulus between canisters and concrete overpack

NDE Technique	Temperature Resistant	Radiation Resistant	Small Form Factor	Sensitive to ODSCC	Compatibility for DCSS Inspection	Time to Delivery
Visual (VT)						
Eddy Current Testing (ECT)						
Ultrasonic Testing (UT)						
EMAT/Guided Waves (GW)						
Acoustic Emission (AE)						
X-ray (RT)						
Penetrant Testing (PT)						N/A
Thermography						
Muon Imaging						

Now	Not Applicable
< 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

NDE Techniques Under Development at EPRI

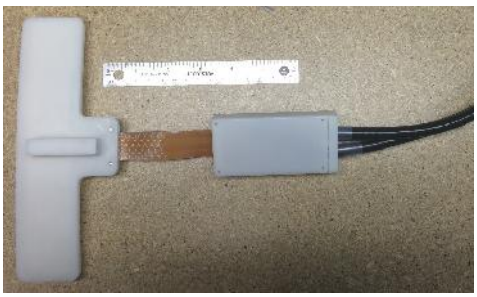
EPRI Projects

- Eddy Current
  - Eddy current array probe to be completed by Dec. 2014
- Guided Waves
  - High frequency guided waves using EMATS with Structural Integrity (inspection)
  - EPRI project using lower frequency guided wave inspection (monitoring)
- Acoustic Emission
  - 2015 project with USC

- Supplement above inspections using visual imaging (not VT)

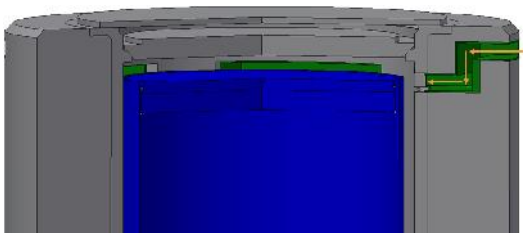
Vendor Development Needs

- Visual Techniques
  - VT-1 and VT-3 techniques
- UT Techniques
  - For crack length and depth sizing



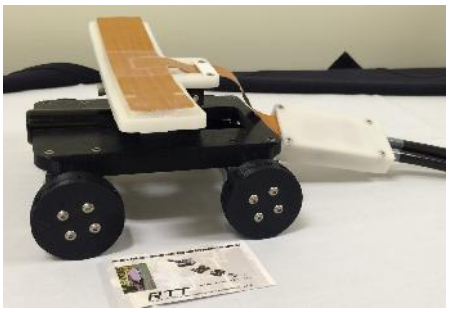
NDE Delivery

- The NDE inspection options are well understood
  - NDE should not be the primary challenge
- Delivering an NDE payload into a confined space environment under high temperature and high radiation is quite challenging
  - No techniques are available for inspection delivery today



NDE Delivery

- Working on robotic delivery concepts
  - Two envisioned concepts are below



EPRI Next Steps

- Continue supporting ESCP
- SS canister CISCC
  - Failure Modes and Effects Analysis: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000003002000815
  - Flaw growth and tolerance report http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000003002002785
  - Susceptibility assessment (late 2015)
  - Aging management guidance (late 2016)
  - Improved NDE instrumentation and delivery systems (2014 – 2017)
- Continue preparations for 2017 high burnup “demo”

Together…Shaping the Future of Electricity