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Fuel Cycle Technologies

Gap Analysis to Support Extended Storage of Used Nuclear Fuel

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Storage and Transportation

Presented to the
Nuclear Waste Technical Review Board
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Outline

- **Objectives**
- **Organization**
- **Technical Gap Analysis**
  - Methodology
  - Draft results
- **FY12 Pathforward**

UFD Storage and Transportation Objectives

The UFD S&T objectives can be rolled up to three focus points:

- **Develop the technical bases to support the continued safe and secure storage of UNF for extended periods**
- **Develop the technical bases for retrieval of UNF after extended storage**
- **Develop the technical bases for transport of high burnup fuel, as well as low and high burnup fuel after dry storage**

To develop these technical bases, the UFD S&T effort has been structured around six separate Work Packages: →

Theory + Experiments + Modeling = Science-based solutions

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UFD Storage and Transportation Organization

NE-53
Office of Used Nuclear Fuel Disposition Research & Development
Bill Boyle, Director

Used Fuel Disposition Campaign
Peter Swift (SNL), National Technical Director
Mark Nutt (ANL), Deputy

Used Fuel Disposition Campaign
Ned Larson, Federal Program Manager

Storage & Transportation
Ken Sorenson (SNL), Manager

Used Fuel Disposition Campaign
Ned Larson, Federal Program Manager

R&D Investigations	**T&E Capability Development**	**Security**	**Transportation**	**Engineering Analyses**	**Engineered Materials**
Brady Hanson (PNNL)	Ruth Weiner (SNL)	Felicia Duran (SNL)	Paul McConnell (SNL)	John Wagner (ORNL)	Ken Sorenson (SNL)
Sig Stockinger	Corinne Macaluso	J.C. De La Garza	John Orchard	Bob Clark	Jim George

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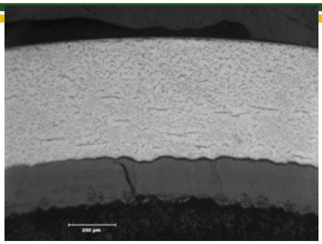
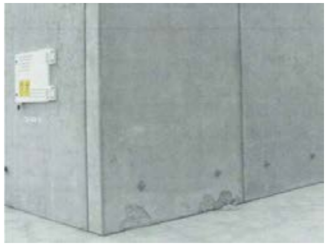
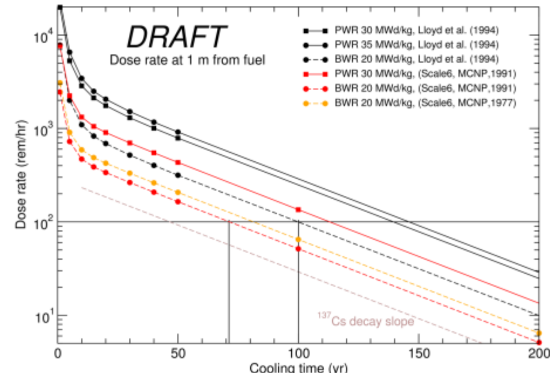
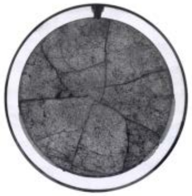
Work Package Structure

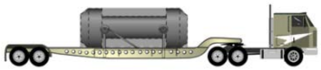




- **R&D Investigations**
  - Data gap analyses
  - Gap prioritization and closure plan
- **Security**
  - Identify issues for long-term storage and subsequent transportation
  - Evaluate methods for security assessment over long-term storage
- **Transportation**
  - High burnup fuels
  - Transportation of all fuels after storage
- **Test and Evaluation Capability Development**
  - Evaluate scenarios and facilities
  - Develop a systems framework for decision-making
- **Engineering Analysis**
  - Thermal and mechanical analyses
  - Burnup credit/moderator exclusion
- **Engineered Materials Experimental**
  - Near-term testing
    - Canister (corrosion; esp. closure systems)
    - Cladding








Current Technical Bases

- **Industry Experience: Technical issues addressed from past R&D program; [EPRI/DOE/NRC Dry Cask Storage Characterization (DCSC) Project at INL]**

Dry Cask Storage Characterization Project, EPRI 1002882, 2002.

- **Nuclear Waste Policy Act Section 218**
  - No cask functional degradation observed after 15 years
  - Assemblies look the same
    - *No sticking; no significant bowing upon removal*
    - *No visual signs of degradation*
  - No leaks during storage
  - No significant additional fission gas release to rod internals
  - No significant hydride reorientation
  - No creep during storage
  - “Creep life” remains
  - Most severe conditions during first 20 years???
  - Highest assembly-average burnup ~35.7 GWd/MTU

Regulatory Timeframes for Storage

- **Storage License Term**
  - 10CFR72.42(a) – "The license term for an ISFSI must not exceed 20 years", "Licenses may be renewed by the Commission at the expiration of the license term…"
  - Effective May 17, 2011, 10CFR72.42(a) updated to up to 40 year initial license and up to 40 year extensions.
  - Updated Waste Confidence Rule issued December 2010
    - *"Commission finds reasonable assurance that…spent fuel...can be stored safely…for at least 60 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor in a combination of storage in its spent fuel storage basin and either onsite or offsite independent spent fuel storage installations."*
      - Total storage period of 120 years (60 during reactor operations and 60 after)

For UFD, extended storage is defined as beyond the currently licensed periods

Safety Functional Areas

- **In order to meet the regulatory requirements of 10CFR72, NUREG-1567 (Section 4.4.3.1) gives the following guidance:**
  - "The applicant must identify design criteria and design bases for all SSCs determined to be important to safety. The basic design criteria for SSCs which are important to safety shall: maintain subcriticality, maintain confinement, ensure radiation rates and doses for workers and public do not exceed acceptable levels and remain as low as is reasonably achievable (ALARA), maintain retrievability, and provide for heat removal (as necessary to meet the above criteria).
  - Therefore, the key Safety Functional Areas for dry storage are:
    - *Subcriticality*
    - *Confinement*
    - *Radiation Protection*
    - *Retrievability*
    - *Thermal Performance*

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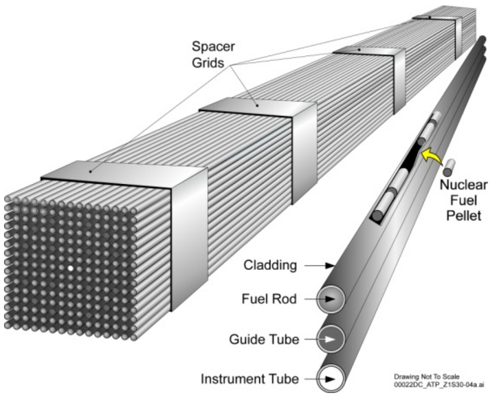
Storage Structures, Systems & Components (SSCs)

I. Fuel

- I. Fuel/Pellet
- II. Cladding
- III. Assembly hardware

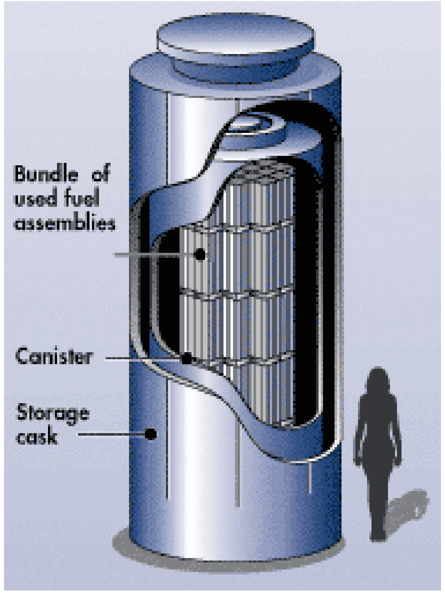


III. ISFSI

- I. Pad
- II. Rebar
- III. Physical Protection

II. Cask

- I. Internals (baskets, neutron poisons)
- II. Container (canister, welds, seals, bolts)
- III. Neutron shields
- IV. Overpack/Storage module

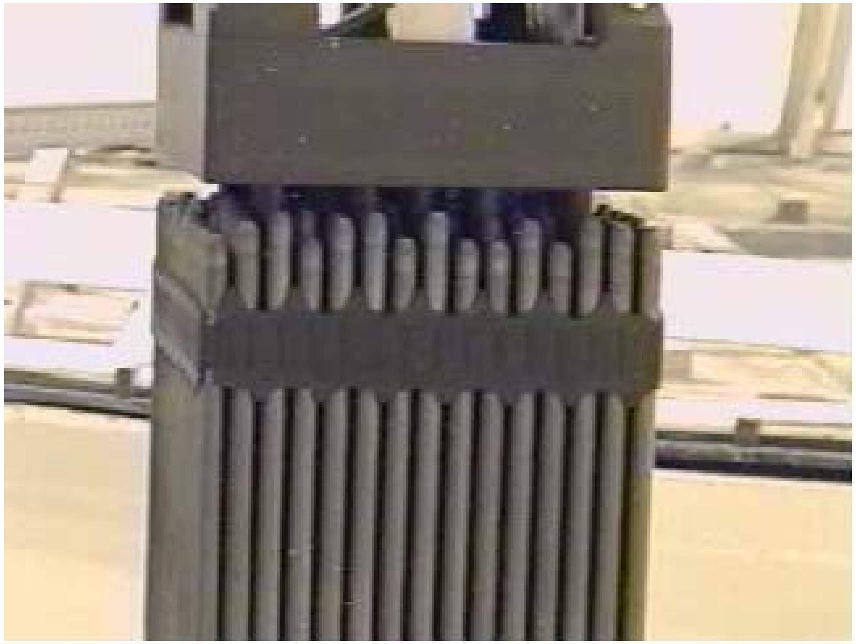


IV. Monitoring Systems

- I. Remote inspection
- II. In-package sensors
- III. Security

Examples of Stressors

- **Thermal Stressors**
  - Temperature during vacuum drying
  - Temperature changes due to decay
  - Ambient temperature fluctuations
- **Radiation Stressors**
  - Neutron radiation
- **Mechanical Stressors**
  - Pressure inside fuel pin
  - Vibration
  - Handling
- **Chemical Stressors**
  - Hydrogen effects
  - Water and oxygen presence
    - *Radiolysis*



Gap Identification and Prioritization

- **Extensive literature survey and Features, Events, and Processes (FEPs) identification**
- **Importance for further R&D under <u>normal conditions</u>**
  - **How important is the SSC to licensing? Importance to R&D cannot be higher than the importance to licensing.**
    - Is there sufficient data to evaluate the degradation mechanism and SSC performance?
    - What are the current regulatory requirements that can be addressed with additional data?
    - What is the likelihood of occurrence?
    - What are the consequences of the degradation mechanism?
    - Can the degradation be remediated or managed in an Aging Management Program?
    - Are there any design and operational difficulties that would have to be endured due to the degradation mechanism?
    - Would the degradation mechanism limit or complicate future waste management strategies?

Cross-Cutting or General Gaps

- **Temperature profiles (HIGH)**
  - Need actual, not conservative, axial and radial profiles
    - PNNL and industry (under ESCP) starting work on these models

- **Drying issues (HIGH)**
  - Determine how much water remains in cask after "normal" drying
  - Determine possible consequences of water
  - Determine need for mitigation and treatment of failed fuel

- **Monitoring (HIGH)**
  - Internal to package (temperature, gas composition, etc.)
  - External (dose, welds, etc.)
  - New instrumentation and monitoring task established in February

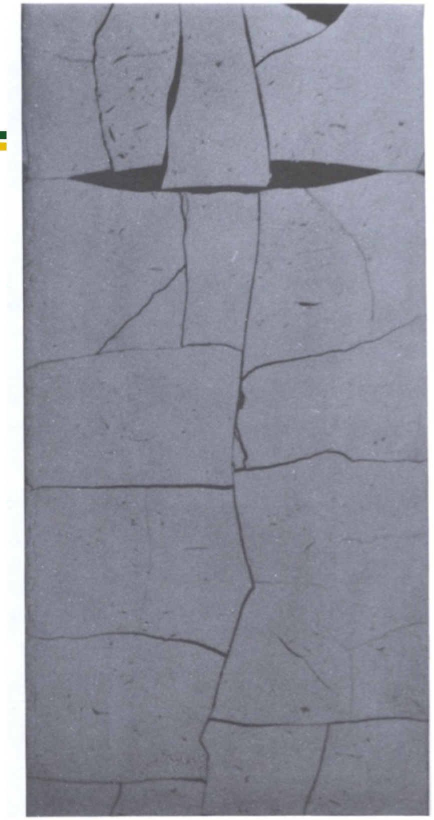
Cross-Cutting Gaps Continued

- **Re-examine INL Dry Cask Storage systems (HIGH)**
  - Additional 11+ years of storage in CASTOR V/21
  - Effect of confinement barrier failure
    - *REA 2023 had breach ~6 years ago when installing quick disconnect*
  - Instrument casks
  - Development of Test & Evaluation Complex

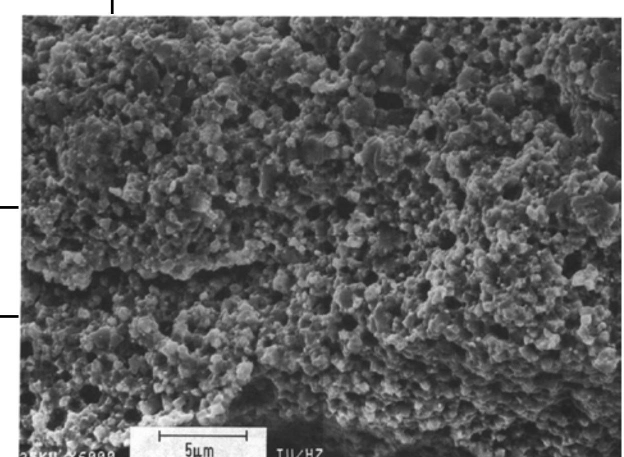
INL Dry Cask Storage Characterization (DCSC) Project

- **Subcriticality (High)**
  - Burnup Credit
  - Moderator exclusion
- **Fuel Transfer Options (HIGH)**
  - Effects of multiple drying, rewetting
  - Dry Transfer System

Data Gaps: Fuel

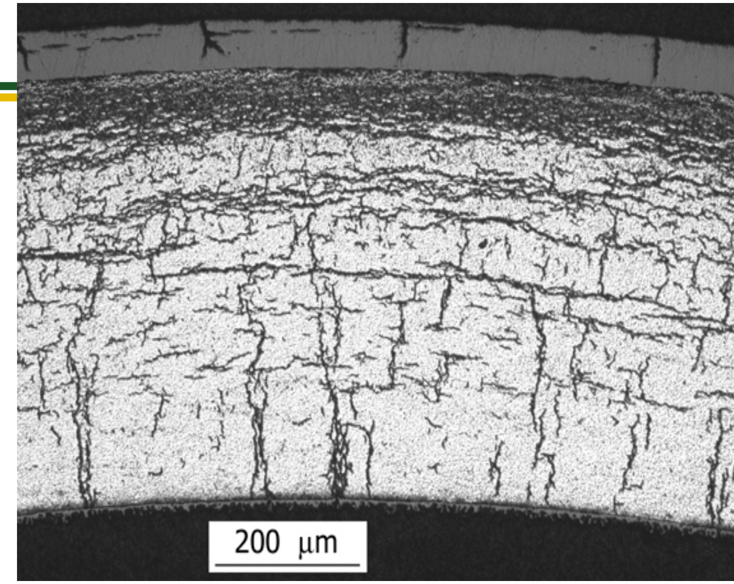


Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal and Mechanical	Fuel Fragmentation	Yes	Yes	Low
	Restructuring/ Swelling	Yes	Yes	Low
Chemical	Fission product attack on cladding	Yes	Yes	Low
	Fuel oxidation	Yes	Yes	Low

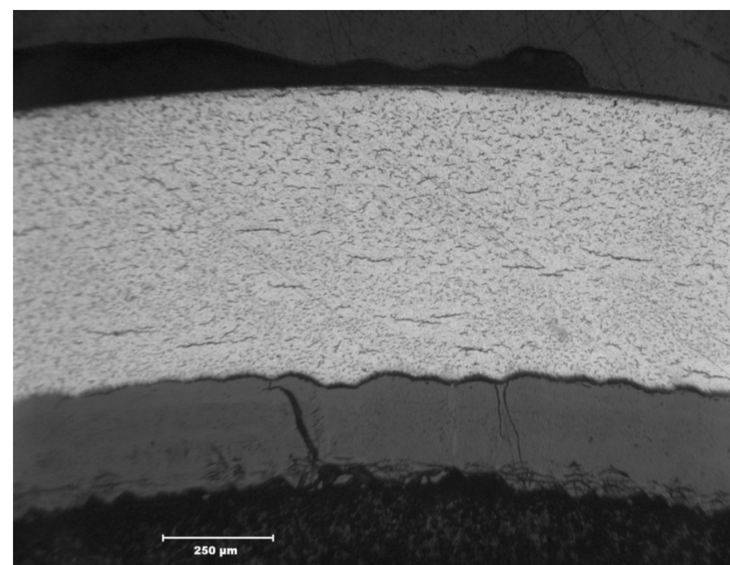


Data Gaps: Cladding

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal	Annealing of radiation damage	Yes	Yes	**Medium**
	Metal fatigue caused by temperature fluctuations	Yes	Yes	Low
	Phase change	No	Yes	Low
Chemical	Emissivity changes	No	Yes	Low
	H_2 effects: Embrittlement and reorientation	Yes	Yes	**High**
	H_2 effects: Delayed hydride cracking	Yes	Yes	**Medium**
	Oxidation	Yes	Yes	**Medium**
	Wet Corrosion:	No	Yes	Low
Mechanical	Creep	Yes	Yes	**Medium**



ANL Hydride and Oxidation Tests



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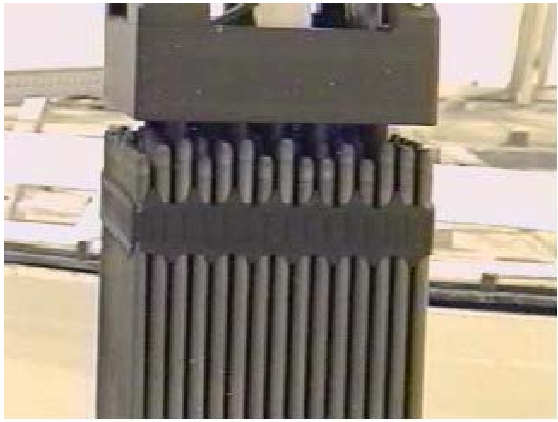
Data Gaps: Assembly Hardware & Fuel Baskets

Assembly Hardware

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal and Mechanical	Creep	Yes	Yes	Low
	Metal fatigue caused by temperature fluctuations	Yes	Yes	Low
Chemical	Corrosion and stress corrosion cracking	Yes	Yes	**Medium**
	Hydriding effects	Yes	Yes	Low



Upper grid spacer and differing fuel rod growth from INL test

Fuel Baskets

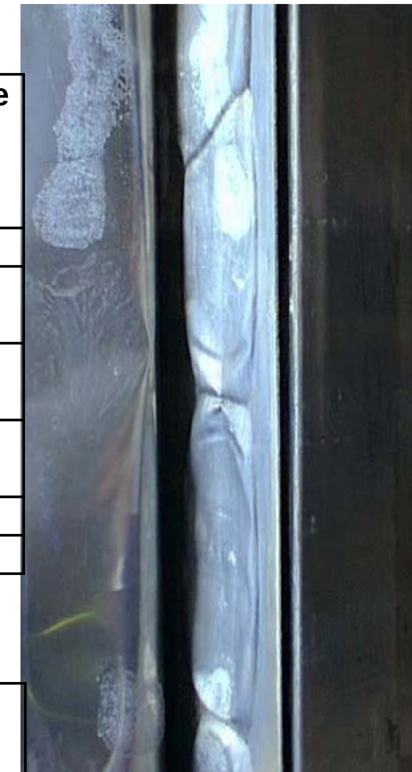
Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal and Mechanical	Creep	Yes	Yes	Low
	Metal fatigue caused by temperature fluctuations	Yes	Yes	Low
Chemical	Corrosion	Yes	Yes	Low

Top weld crack in fuel basket from 15-yr demo at INL

Data Gaps: Neutron Poisons and Shields

Neutron Poisons

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal	Thermal Aging effects	Yes	Yes	**Medium**
Thermal and Radiation	Embrittlement and cracking	Yes	Yes	**Medium**
Thermal and Mechanical	Creep	Yes	Yes	**Medium**
	Metal fatigue caused by temperature fluctuations	Yes	Yes	Low
Radiation	Poison burnup	Yes	Yes (analysis)	Low
Chemical	Corrosion (Blistering)	Yes	Yes	**Medium**



Example of BORAL blistering from EPRI

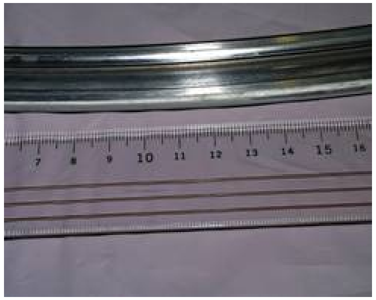
Neutron Shields

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal and Mechanical	Embrittlement, cracking, shrinkage, and decomposition	Yes	Yes	Low
Radiation	Radiation embrittlement	Yes	Yes	Low
	Poison burnup	Yes	Yes	Low
Chemical	Corrosion	Yes	Yes	Low

Data Gaps: Container (Canister/Cask-emphasis on closure systems)

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Welded Canister				
Chemical	Atmospheric Corrosion (Including Marine Environment)	Yes	Yes	**High**
	Aqueous Corrosion: general, localized (pitting, crevice), SCC, galvanic	Yes	Yes	**High**
Bolted Direct Load Casks				
Thermal and Mechanical	Embrittlement of elastomer seals	Yes	Yes	Low
	Thermo mechanical fatigue of seals and bolts	Yes	Yes	**Medium**
Radiation	Embrittlement of elastomer seals	Yes	Yes	Low
Chemical	Atmospheric Corrosion (Including Marine Environment)	Yes	Yes	**High**
	Aqueous corrosion: general, localized (pitting, crevice), SCC, galvanic	Yes	Yes	**High**

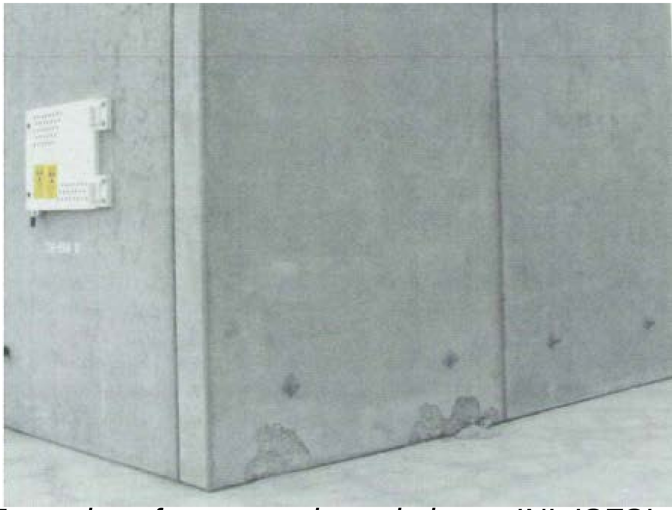
Cask bottom cover plate bolt corrosion observed in 15-yr demo at INL



White coloring on metal gasket from remaining water after 5 yr storage. Aida et al., IAEA 2010

Data Gaps: Overpack and Pad (Concrete)

Stressor	Degradation Mechanism	Influenced by Extended Storage or Higher Burnup	Additional Data Needed	Importance of R&D
Thermal	Dry Out	Yes	Yes	Low
	Fatigue	Yes	Yes	Low
	Freeze Thaw	Yes	Yes	**Medium**
Radiation	Aggregate Growth	Yes	Yes	Low
	Decomposition of Water	Yes	Yes	Low
Chemical	Aggregate Reaction	Yes	Yes	Low
	Calcium leaching	Yes	Yes	Low
	Chemical Attack	Yes	Yes	Low
	Corrosion of Embedded Steel	Yes	Yes	**Medium**
Mechanical	Blocked Air Flow	Yes	No	N/A
	Creep	Yes	No	N/A
	Shrinkage	No	No	N/A



Examples of concrete degradation at INL ISFSI

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FY11 Accomplishments & FY12 Pathforward

- ***Gap Analysis to Support Extended Storage of Used Nuclear Fuel* submitted to DOE on June 30, 2011**
  - Industry (NEI, EPRI, cask vendors, fuel vendors, utilities) review
  - Upon comment resolution, final report Rev. 0 will be issued
- **Rev 1 of Gap Analysis planned for July 31, 2012**
  - Incorporate Gap Analyses from Transportation; include design basis accidents
  - Compare against external gap analyses (NWTRB, NRC, EPRI ESCP International)
  - Compare against Requests for Additional Information from NRC
- ***Gap Prioritization and Closure Plan* Report planned for April 30, 2012**
  - Prioritize Medium and High Priority Gaps
  - Outline proposed testing and modeling means to close the gaps
  - Develop specific recommendations of facilities and equipment for conducting tests
- **Test & Evaluation Capability Development**
  - Initial Functions and Requirements document complete
  - Facility survey and tours conducted
  - Initial deliverable for Test and Validation Complex on track for completion September 22, 2011
  - Develop a 5- and 10-year plan for the TVC planned for June 30, 2012

Questions?