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FY14 DOE R&D in Support of the High Burnup Dry Storage Cask R&D Project

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U.S. Department of Energy

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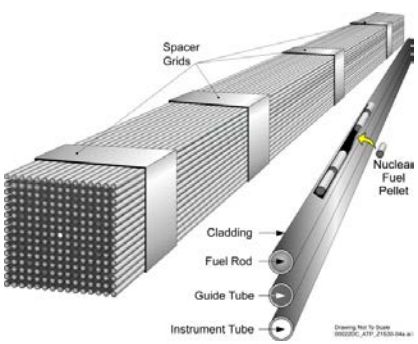
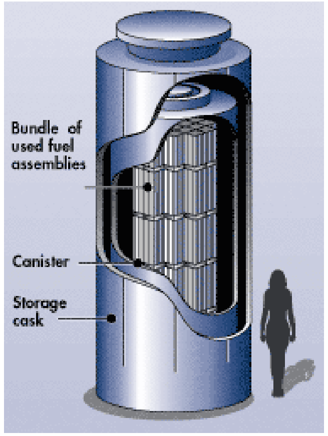


http://energy.gov/sites/prod/files/styles/



www.nrc.gov/waste/spent-fuel-storage/

www.connyankee.com/

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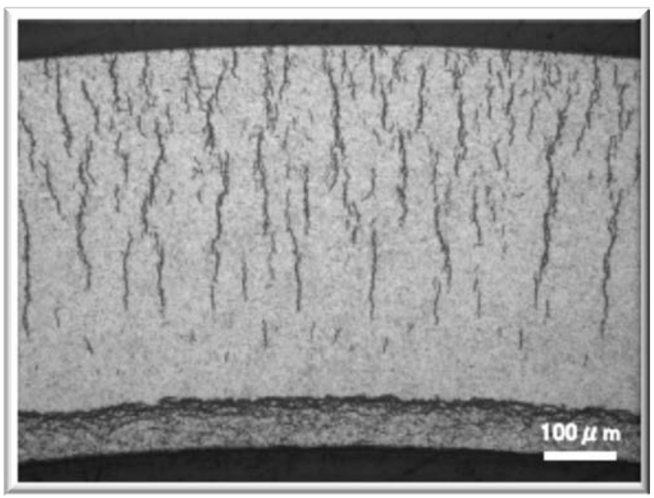
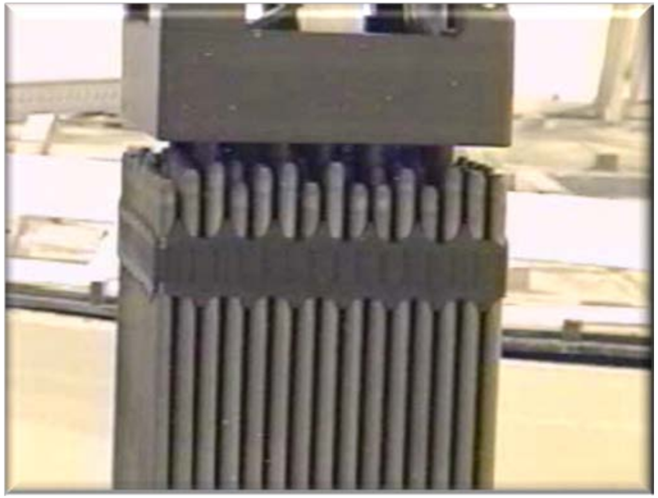
Storage and Transportation R&D Objectives

Overall Objectives:

- Develop the technical bases to demonstrate high burn-up used fuel integrity for extended storage periods.
- Develop technical bases for fuel retrievability and transportation after long term storage.
- Develop the technical basis for transportation of high burnup fuel.





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

Source: Gap Analysis to Support Extended Storage of Used Nuclear Fuel, January 2012

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 for fuel*** — ***High***
- ***Drying issues*** — ***High***
- ***Monitoring*** — ***High***
- ***Subcriticality*** — ***High***
- ***Fuel transfer options*** — ***High***
- ***Re-examine INL dry cask storage*** — ***High***

Identification of these data gaps are used to inform new initiatives for FY15

Source: Gap Analysis to Support Extended Storage of Used Nuclear Fuel, January 2012

Storage and Transportation Issues Associated with High Burn-up Fuels (HBF) Burnup > 45 GWd/MTU

- **Increased burnup may increase the degree of zirconium alloy material corrosion because higher burnup also means longer residence time in the reactor.**
- **Increased corrosion results in more corrosion-produced hydrogen that will be picked up by the zirconium alloy and form zirconium hydrides and may embrittle the cladding**
  - Increased fraction of hydrides may reduce ductility and fracture toughness.
  - Embrittlement effect of the hydrides is temperature dependent
  - Nonuniform distribution of hydrides may reduce ductility and fracture toughness more than uniformly distributed hydrides
- **HBF is hotter radioactively and thermally, requiring additional data to confirm fuel behavior characteristics during storage and transportation.**
- **HBF requires a higher degree of thermal management due to the higher heat loads and higher radioactivity.**
- **There is limited non-proprietary data on HBF cladding characteristics under storage or transportation conditions.**

High Burn-up Confirmatory Data Project: Dry Storage R&D Project

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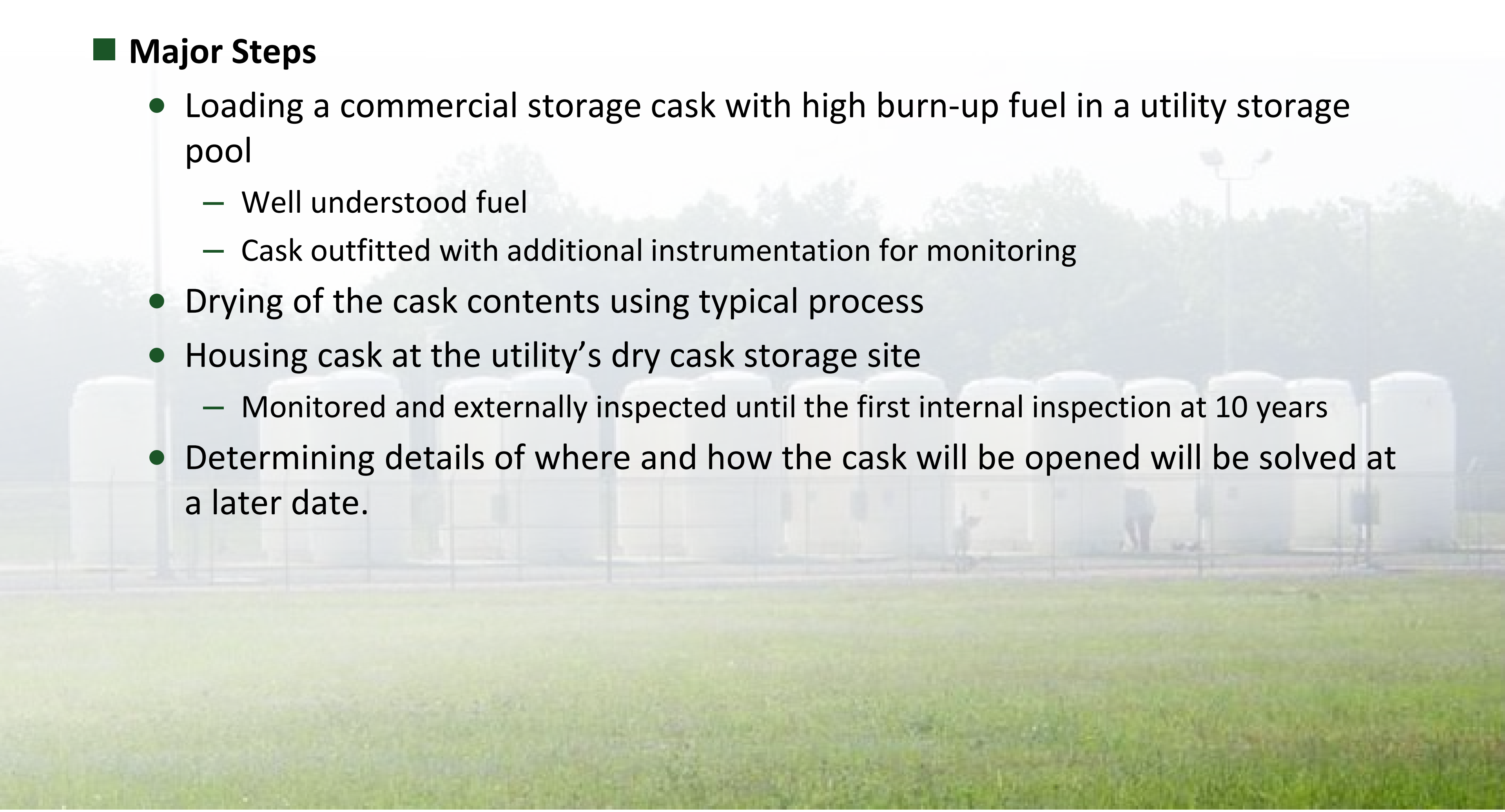
- **Major Steps**
  - Loading a commercial storage cask with high burn-up fuel in a utility storage pool
    - Well understood fuel
    - Cask outfitted with additional instrumentation for monitoring
  - Drying of the cask contents using typical process
  - Housing cask at the utility’s dry cask storage site
    - Monitored and externally inspected until the first internal inspection at 10 years
  - Determining details of where and how the cask will be opened will be solved at a later date.

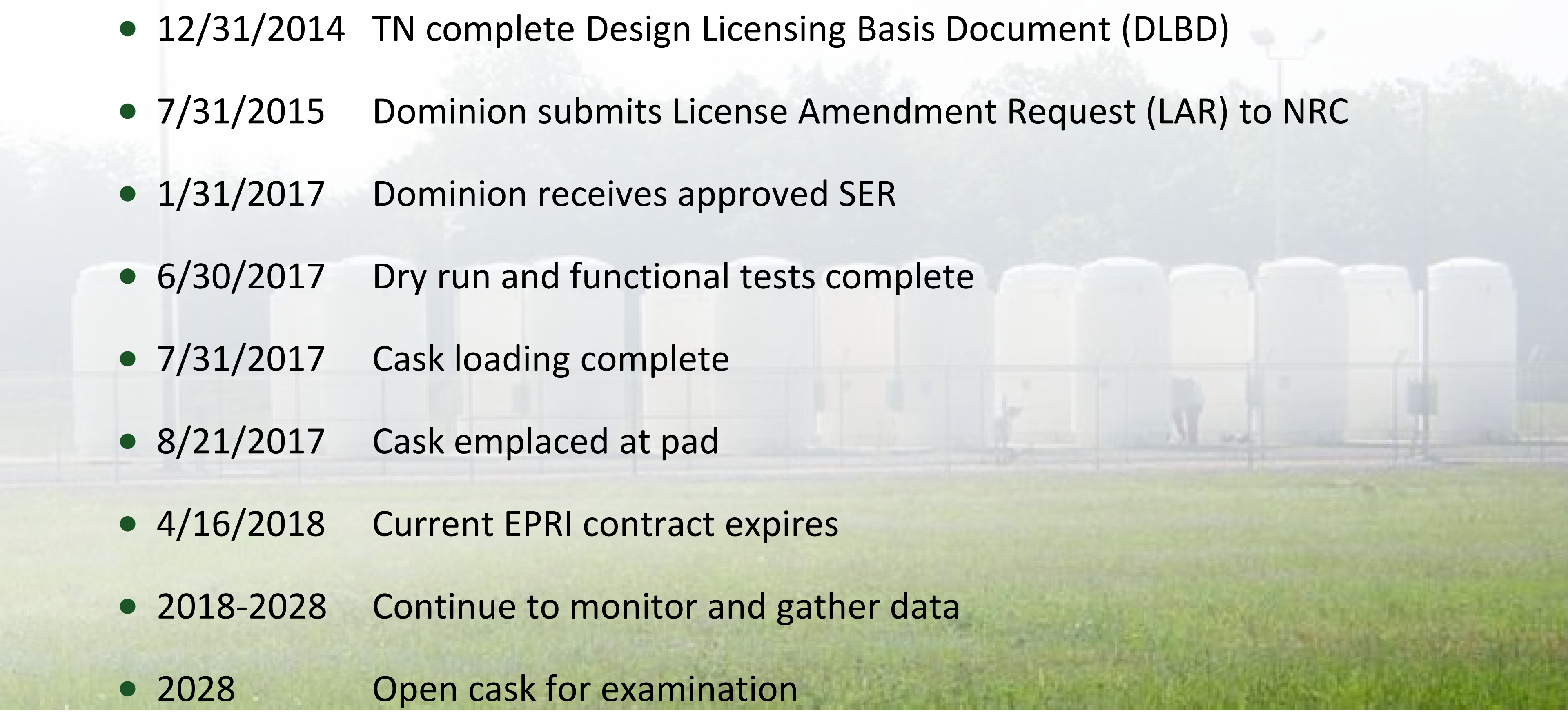


Picture from North Anna ISFSI

High Burn-up Confirmatory Data Project: Current 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



Picture from North Anna ISFSI

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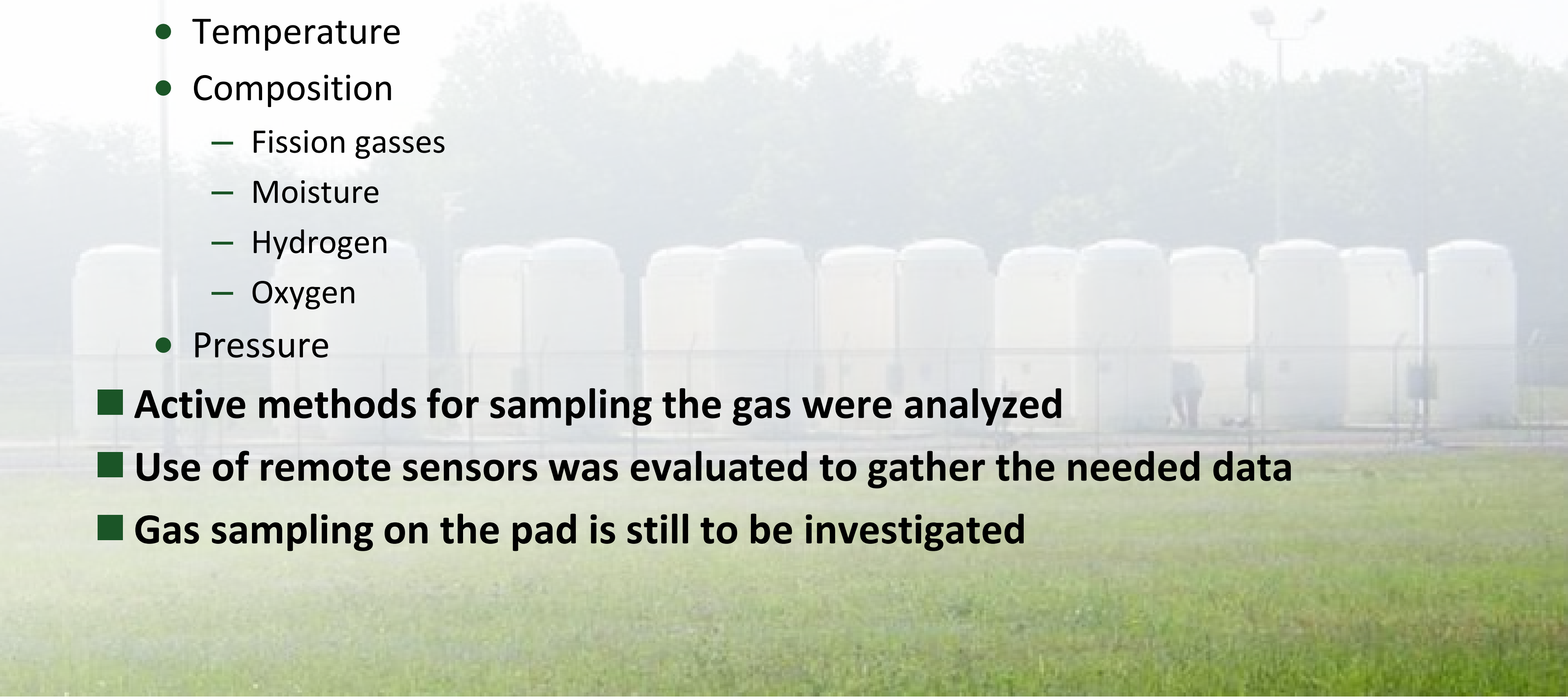
High Burn-up Confirmatory Data Project: Data to be Monitored

- **Fuel cladding temperature (indirect via thermocouple lances)**
- **Cavity gas monitoring is being evaluated**
  - Temperature
  - Composition
    - Fission gasses
    - Moisture
    - Hydrogen
    - Oxygen
  - Pressure
- **Active methods for sampling the gas were analyzed**
- **Use of remote sensors was evaluated to gather the needed data**
- **Gas sampling on the pad is still to be investigated**



Picture from North Anna ISFSI

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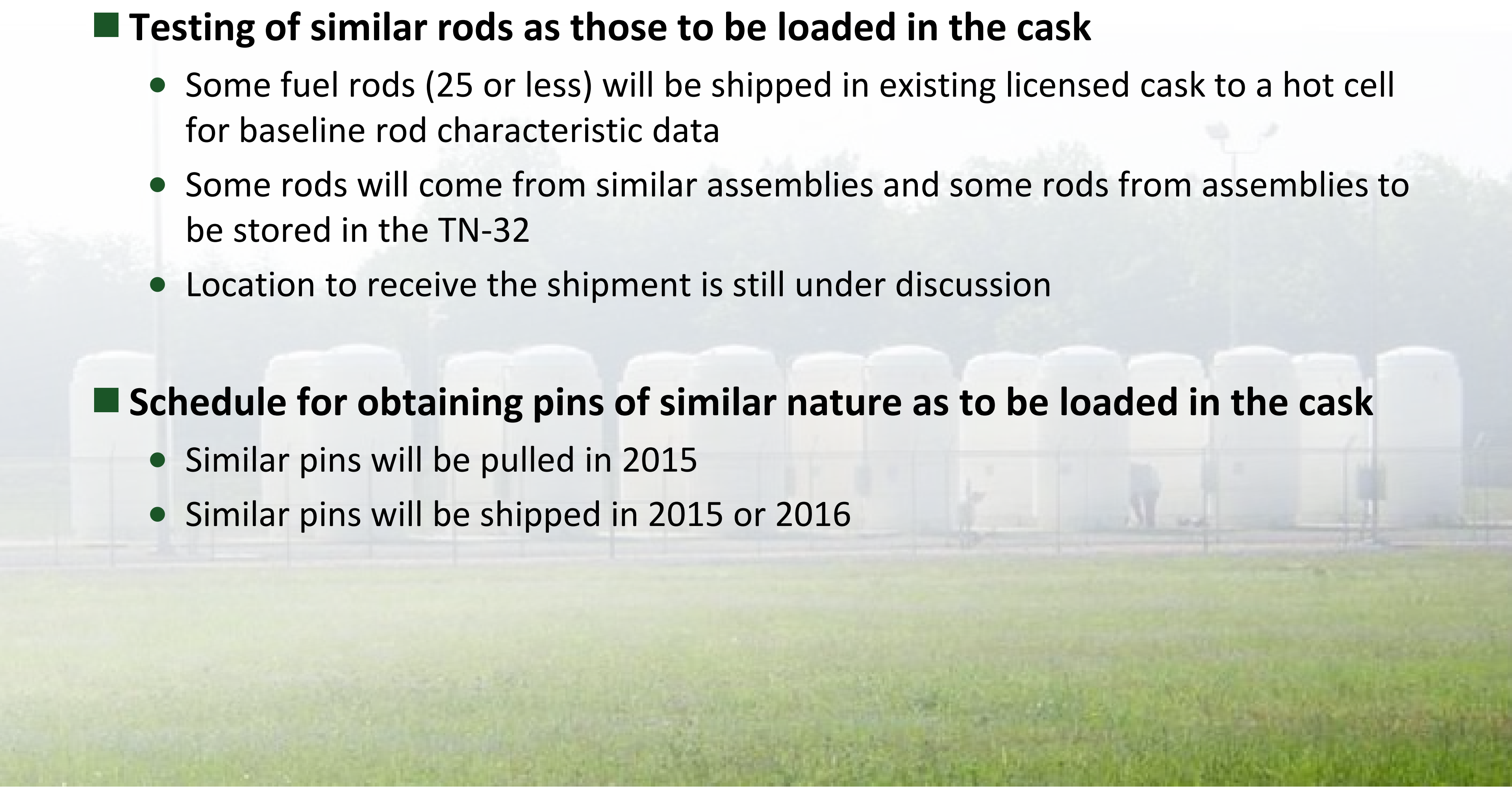
High Burn-up Confirmatory Data Project: Rod Testing to Establish the Baseline



- **Testing of similar rods as those to be loaded in the cask**
  - Some fuel rods (25 or less) will be shipped in existing licensed cask to a hot cell for baseline rod characteristic data
  - Some rods will come from similar assemblies and some rods from assemblies to be stored in the TN-32
  - Location to receive the shipment is still under discussion
- **Schedule for obtaining pins of similar nature as to be loaded in the cask**
  - Similar pins will be pulled in 2015
  - Similar pins will be shipped in 2015 or 2016

Picture from North Anna ISFSI

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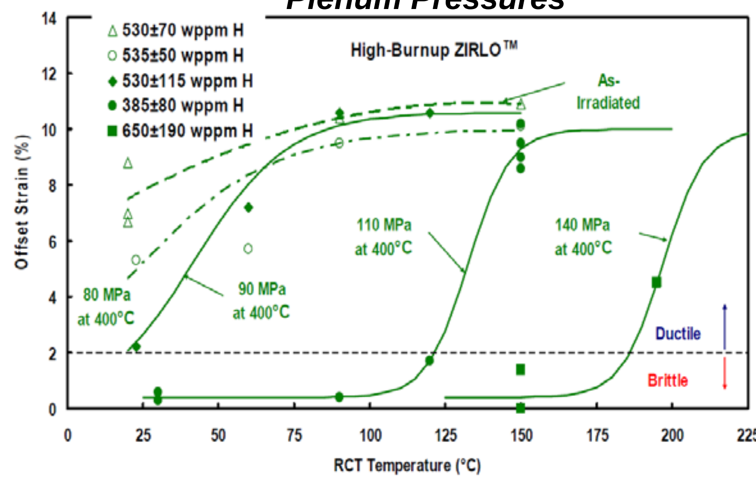
Experiments:

High Burnup Fuel Cladding Material Properties

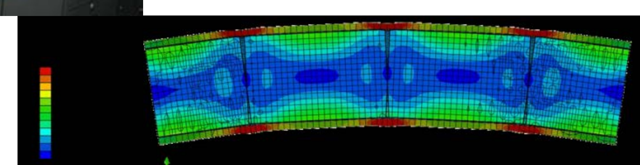
- **Separate effects tests to determine effects of hydrides, hydride reorientation, radiation damage, thermal annealing, and clad thinning on materials properties and performance.**
- **Hydrides and reorientation**
  - Ring Compression Tests and determination of Ductile-Brittle Transition Temperature (ANL)
  - Cladding bend test and effects of fuel/clad bonding and pellet/pellet interfaces (ORNL)
  - Creation of a hydride rim in unirradiated cladding and burst, tube tensile, and tube compression testing (PNNL)
- **Radiation damage and thermal annealing**
  - Irradiate cladding in HFIR reactor at ORNL without all other effects.

DBTT data for Zirlo clad with Varying Internal Plenum Pressures



Billone, Argonne National Laboratory, EPRI ESCP Meeting, Dec. 2013

Used fuel rod stiffness Experiments (in hot cell and out) and analyses of stress distribution



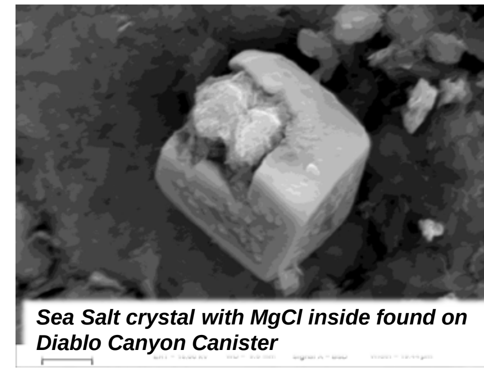
Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

Experiments:
Stainless Steel Canister Corrosion

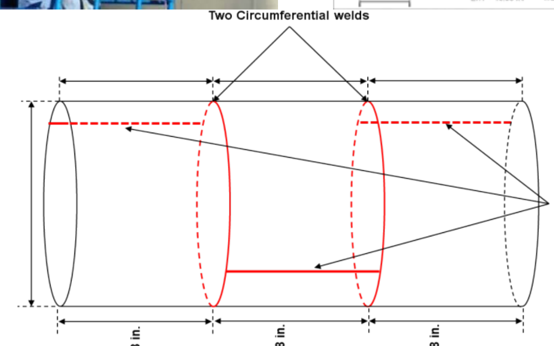
Purpose: Better understand canister degradation, support Aging Management Plans, and license extensions.

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

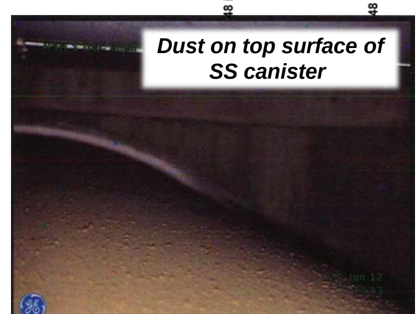
Collecting dust samples at Diablo Canyon



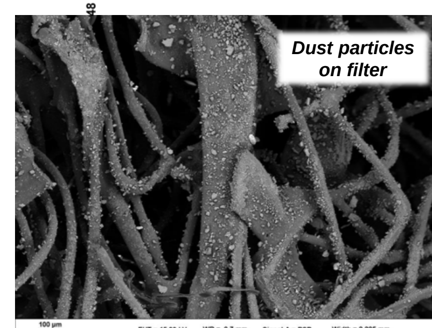
Sea Salt crystal with MgCl inside found on Diablo Canyon Canister



Conceptual design for full-scale (diameter) SS welded canister



Dust on top surface of SS canister



Dust particles on filter

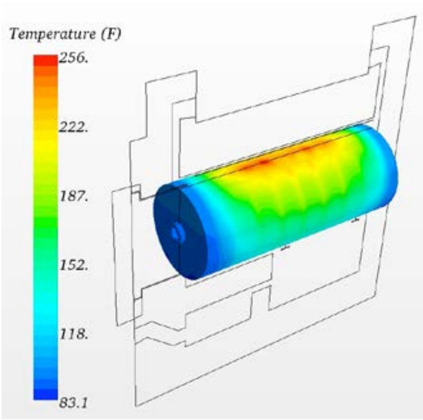
Enos, et al., Data Report on Corrosion Testing of Stainless Steel SNL Storage Canisters, FCRD-UFD-2013-000324

Analysis

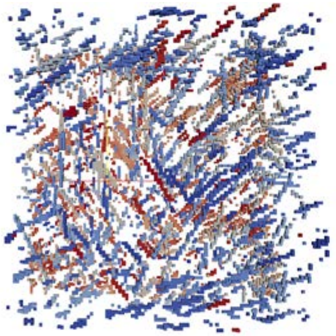
Develop predictive models of material behavior to establish the technical bases for extended storage and transportation

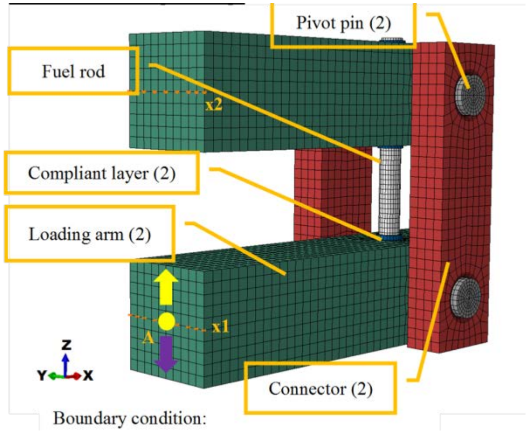
- **Predictive modeling**
  - Thermal Analysis (PNNL) to predict cool down, Ductile to Brittle Transition, deliquescence, etc.
    - HBU Demonstration fuel selection and cool down
    - Modern, high heat load, high capacity systems
    - In-service inspections validation data
  - Hydride reorientation 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 2-3 licensed dry storage systems (PNNL FY15)

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

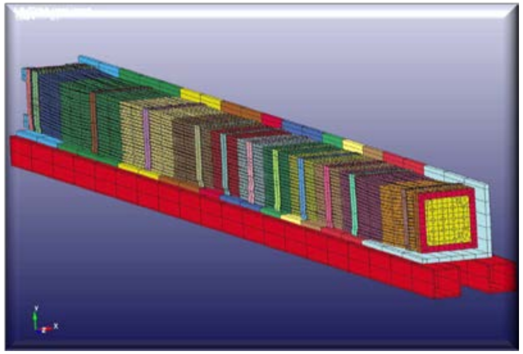


Model for Simulation of Hydride Precipitation, Tikare et al, FCRD-UFD-2013-000251.





FE Model of Rod Bend Tests
Jy-An Wang et al, ORNL



FE Models of Assembly
Klymyshyn, et al, PNNL, FCRD-UFD-2013-000168

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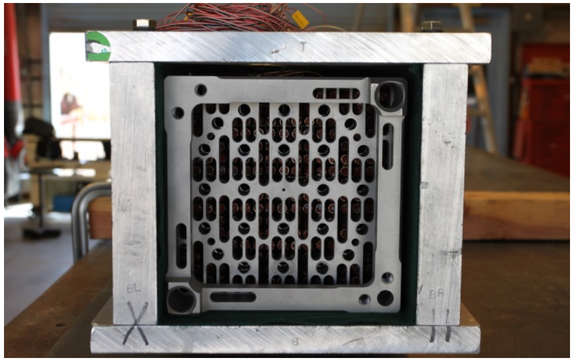
Transportation:

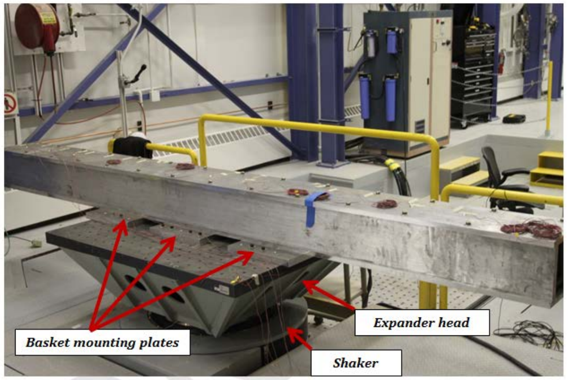
Normal Conditions of Transport – Loading on fuel assemblies

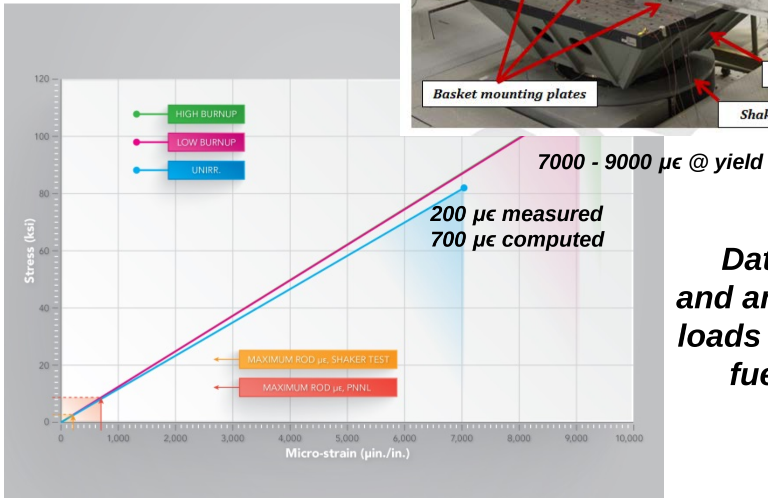
- **A surrogate assembly was subjected to truck data from a 700 mile trip on a shaker table and 50 miles on a real truck with representative weight.**
  - Data results were >10 times below yield strength.
  - The strains measured in both were an order of magnitude lower than either an irradiated or unirradiated Zircaloy rod yield strength.

- **If high burnup fuel can maintain its integrity during transport, pressure will be taken off experimental R&D efforts associated with hydride effects on cladding strength and ductility.**

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







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

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Field Demonstration:
Sensor Technology Development

- **Assess 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
- **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)**

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FY 14 Major Reports (M2 Milestones)

Control Account	Lab	Title
ST Field Demonstration	INL	Strategy for fuel pin receipt, characterization, sample allocation for the demonstration sister pins
ST Field Demonstration	SNL	Develop a UFD ST Program Plan
Experiments	ANL	Results of Fuel Clad Testing
Experiments	ORNL	Results of Bend Tests
Experiments	PNNL	Results of Fuel Transfer Options
Experiments	SNL	Results of Stainless Steel canister corrosion studies and environmental sample investigations
Analysis	SNL	Documentation of Hybrid Hydride Model for Incorporation into Moose-Bison and Validation Strategy
Analysis	PNNL	Thermal profile analyses of in-situ industry storage systems identified for inspection
Transportation	SNL	Results of shock/vibration testing on shaker table
Transportation	SNL	Over-the-road truck test with surrogate assembly

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UFD NEUP Projects

Projects Funded
2011
(11-3117) Life Prediction of Spent Fuel Storage Canister Material - MIT
(11-3180) Quantification of cat ion sorption to engineered barrier materials under extreme conditions - CU
(11-2987) Anisotropic azimuthal temperature distribution on fuel rod: impact on hydride distribution - PSU
(11-3278) Fuel Aging in Storage and Transportation (FAST) of Used Nuclear Fuel - TAMU
2012
(12-3756) Seismic Performance of Dry Casks Storage for Long-Term Exposure - UU
(12-3528) Radiation and Thermal Effects on Used Nuclear Fuel and Nuclear Waste Forms - UTK
(12-3298) Optimization of Deep Borehole Systems for HLW Disposal - MIT
(12-3736) Nonlinear Ultrasonic Diagnosis and Prognosis of ASR Damage in Dry Cask Storage - NU
(12-3361) Coupling nuclear waste corrosion and radionuclide transport in repository sediments - WSU
(12-3545) Concrete Materials For Extended Nuclear Fuel Storage Systems - UH
(12-3660) Simulations to Predict Used Nuclear Fuel Cladding Temperatures - UNR
(12-3374) Validation Experiments for Spent-Fuel Dry-Cask In-Basket Convection - USU
(12-3730) Probabilistic Multi-Hazard Assessment of Dry Cask Structures - UH