Critical Data to Obtain from a Demonstration

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Objective

- To facilitate a discussion of:
  - What data are necessary vs. what data would be nice to have
  - What means can be used to obtain these data
  - What impacts on data do non-prototypic scenarios have

to assist DOE in developing an integrated strategy for a high burnup used nuclear fuel demonstration program.

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Purposes of the Engineering-Scale Demonstration (High Burnup Fuel)

- **Confirm** the expected conditions after a substantial storage period
- Provide data to be used to benchmark and confirm predictive models (developed using data from single-effects tests, small scale tests, and modeling and simulation efforts)
- Identify any aging effects the could be missed through short-term accelerated studies and analyses
  - Integrated effects
  - Extended period (e.g., until disposition path identified)
- Provide public confidence
- Provide test platform for experimental work (e.g., remote monitoring capability)
- Focus is on fuel, cladding, and assembly hardware (basket, neutron absorbers, cask/canister interior)

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Technical Data Gaps Identified - 1

- Thermal profiles (UFDC, NRC) — Must have
- Stress profiles (UFDC) — Not from demo
- Fuel transfer options (UFDC) — Must have PRIOR
- Monitoring (UFDC, NRC) — Must have PRIOR
- Drying issues (UFDC, NRC) — Must have
- Fuel
  - Helium & fission gas release (NRC) — Must have
  - Fragmentation (NRC) — Must have
  - Restructuring/swelling (NRC) — Must have
- Cladding – H_2 effects
  - Hydride reorientation & embrittlement (UFDC) Must have
  - Delayed Hydride Cracking (UFDC, NRC) Must have

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Technical Data Gaps Identified - 2

- Cladding
  - Aqueous corrosion (NRC) Nice to have (water?)
  - Creep – low temperature (UFDC, NRC) Must have
  - Annealing of radiation damage (UFDC, NRC) Must have
  - Oxidation (UFDC) Not from demo (water/failed clad?)
  - Helium pressurization (NRC) Must have (very long term)
  - Propagation of existing flaws (NRC) Nice to have (existing?)
- Fuel assembly hardware
  - Corrosion including SCC (UFDC, NRC) Must have
  - Metal fatigue caused by temperature fluctuations (NRC) Nice to have (very long term)

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Technical Data Gaps Identified - 3

- Baskets
  - Metal fatigue caused by temperature fluctuations (NRC) Nice to have (very long term)
  - Weld embrittlement (NRC) Nice to have (very long term)
- Neutron poisons (minimal from demo, variable materials)
  - Corrosion & blistering (UFDC, NRC)
  - Embrittlement & cracking (UFDC)
  - Metal fatigue caused by temperature fluctuations (NRC)
  - Thermal aging effects (UFDC, NRC)

Review of Used Nuclear Fuel Storage and Transportation Technical Gap Analyses, Used Fuel Disposition Campaign, FCRD-USED-2012-000215, PNNL-21596, July 31, 2012.

Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel, Draft report for comment, NRC, May 2012

Used Nuclear Fuel Storage and Transportation Data Gap Prioritization, Used Fuel Disposition Campaign, FCRD-USED-2012-000109, PNNL-21360, Draft April 30, 2012.

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Thermal Profiles – Must Have

- Realistic, best estimate models need to be confirmed and codes validated for high burnup fuel and newer storage configurations
  - How accurate/precise does it need to be? (±X°C)
- Measure radial and axial thermal profiles during
  - Drying
  - Storage
- Cladding, but what other materials
  - Basket (welds), internal canister/cask wall, other
- How to obtain this data
  - Thermocouples (trees), resistance temperature detectors (RTDs), other?
- How many instruments are necessary (radial and axial)?
  - Redundancy for failures

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Thermal Profiles - 2

- Where to and how to locate instruments?
  - Can you get direct contact with material (cladding)?
  - Limited space
- How to assure long-term performance
  - How long must they last?
    - Drying
    - Until first examination (assumes they can be replaced for longer times)
  - Account for drift
  - Must withstand underwater, vacuum, high temperature, high pressure (when canister backfilled), radiation
- Impacts of non-prototypic scenarios (higher heat load, short loading, accelerated cooling, etc.)

Monitoring (Internal) - Must Have

- Frequency of reading
- How long must instruments last?
- Temperature (covered under Thermal Profiles)
- Lid or body penetrations for instrument leads vs. signal transmission through wall (to be discussed as part of regulatory concerns and logistics)
- Pressure (How? Where? Accuracy/precision? How many? Drift [environmental resistance]?)
- Gas (He, Xe, Kr, O_2, H_2O, H_2)
  - Monitoring vs. ability to take gas samples
  - How? Where? Accuracy/precision? How many? Drift?
- Liquid water (at bottom of cask)
- Corrosion/degradation

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Drying Issues - Must Have

- Verify/quantify residual water left in cask/canister
- Demo should be prototypic and not reopened, so only verification is possible- other tests/analyses should be performed to determine the quantity of residual water
- What instrumentation is necessary?
  - In-cask
  - Outside (vacuum lines)
- What are the impacts of non-prototypic scenarios (short loading, higher/lower heat load, etc…)

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Fuel - Must Have

- Most fuel issues (helium release and pressurization, fragmentation-other than from mechanical means, restructuring/swelling) will only occur over very long times (multiple decades to centuries).
  - Can be examined as part of the pre-characterization and post-characterization on rods, but not expected to have any validation at the first interim examination
- Release of fission gas or particulates resulting from mechanical impacts/vibrations are not part of the demo

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Cladding – Must Have

- The necessary data are:
  - Mechanical properties at various times (as impacted by the various mechanisms identified)
  - Do through wall failures occur during extended storage or normal transportation as a result of degraded mechanical properties
- Unlike low burnup cladding, initial tests have shown that high burnup cladding is susceptible to a ductile to brittle transition as it cools below a threshold temperature
  - That threshold temperature is not expected to occur for X decades
- Low temperature creep and long-term annealing will potentially take decades to occur
- Unlike low burnup cladding, an “early” data point can NOT be extrapolated to longer times???
  - Or does cooling upon removal simulate extended storage

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Cladding – What Cladding to Test

- BWR vs. PWR
- How many cladding types are necessary?
- Can some cladding be considered bounding?
- What is the minimum burnup/duty cycle for the HBU tests?
- Do we include lower burnup fuels?
- Do we include known failed fuels in the demonstration?

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Cladding – Sibling Rods

- Sibling rods necessary for pre-characterization
- What constitutes a sibling rod?
  - Same assembly or “sister” assembly?
  - Same burnup/duty cycle
  - How do you verify oxide and crud layers and hydrogen content are similar?
- Do you dry sibling rods (is t_0 prior to drying or after) and if so, how do you obtain a similar temperature profile?
  - When do you dry the sibling rods?
    - Does staying in the pool longer affect anything?
- Do you need any data from pre-characterization prior to the demonstration?

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Cladding – Non-Prototypic Scenarios

- How do you assure that the properties you measure during post-characterization are indeed those properties of the cladding in storage?
- What are the effects of re-wetting (relatively rapid temperature quench) vs. “slower” cool down when removing dry?
- What are the effects of redrying?
- Are there any impacts from short loading or “non-standard” loading patterns?

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Fuel Assembly Hardware

- Can you obtain this data, other than just observation over time, from a demonstration without taking apart an assembly?

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Conclusions

- Thermal profiles and cladding data are the most important gaps to be addressed from a demonstration
- Many mechanisms of concern, especially with the fuel, can only be obtained by very long-term tests such as the demonstration provides
- Can “short” term data points be extrapolated to longer times

- So when should the first examination occur?
- When should subsequent examinations occur?

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