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Protecting People and the Environment

Dry Storage and Transportation of High Burnup Fuel

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Webinar to State Liaison Officers & Indian Tribes

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Outline

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- Background
  - Spent Fuel Assemblies
  - Wet Storage, Dry Storage, Transportation
  - Safety Requirements
- Burnup
  - What is it? Why is it important?
  - What is high burnup?
  - Technical Concerns - How does NRC address these?
  - Licensing Considerations (continued storage, transportation)
- Conclusions

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U.S. Licensed Reactors

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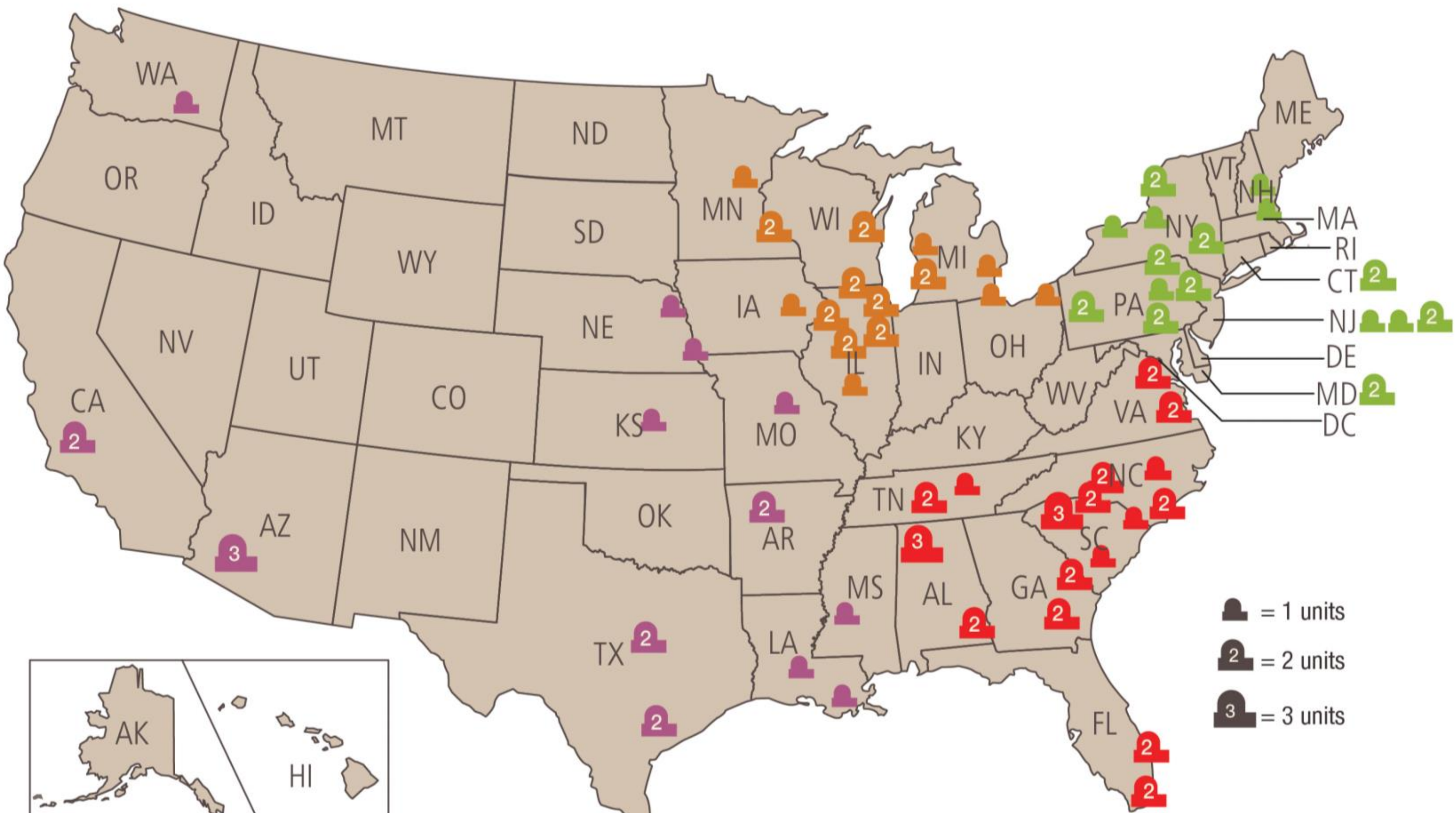
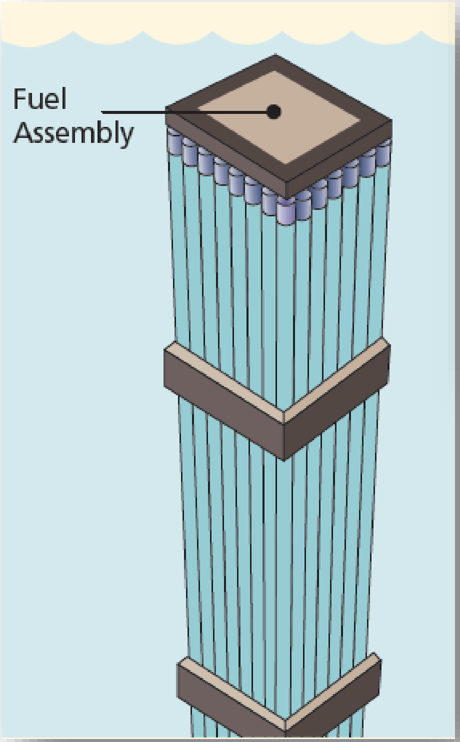
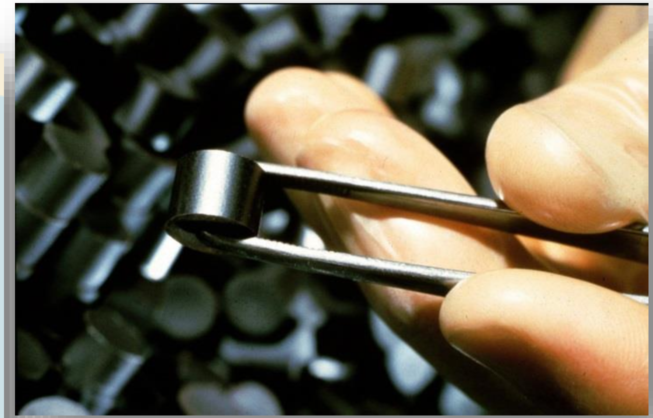


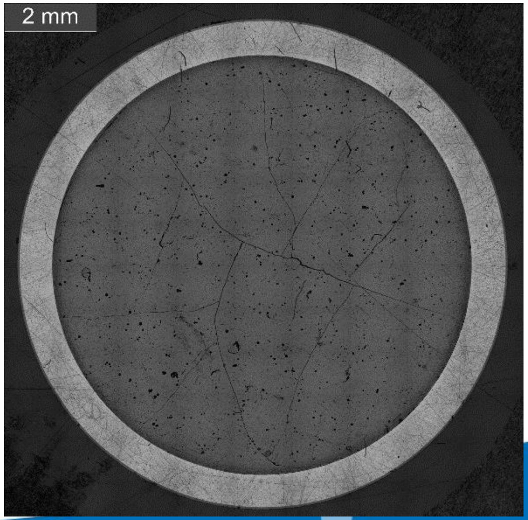
Licensed to Operate (100)

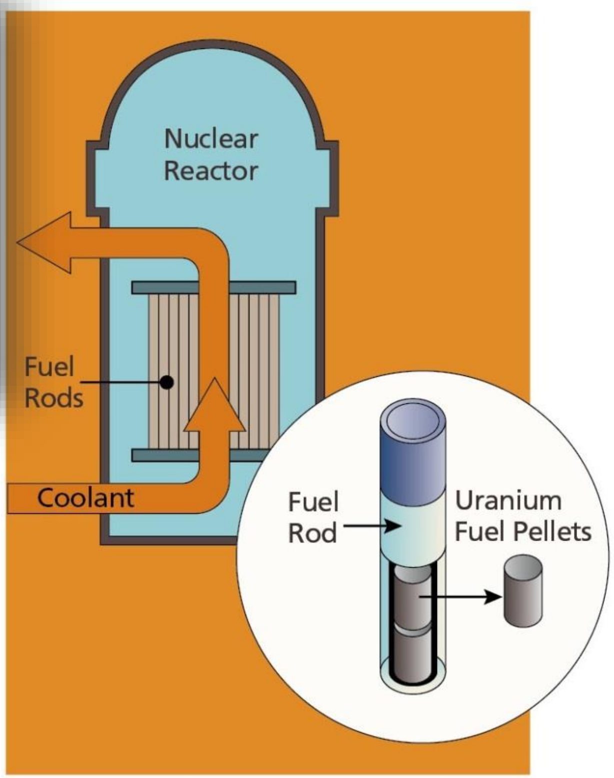
http://www.nrc.gov/reactors/operating/list-power-reactor-units.html

What are fuel rods made of?



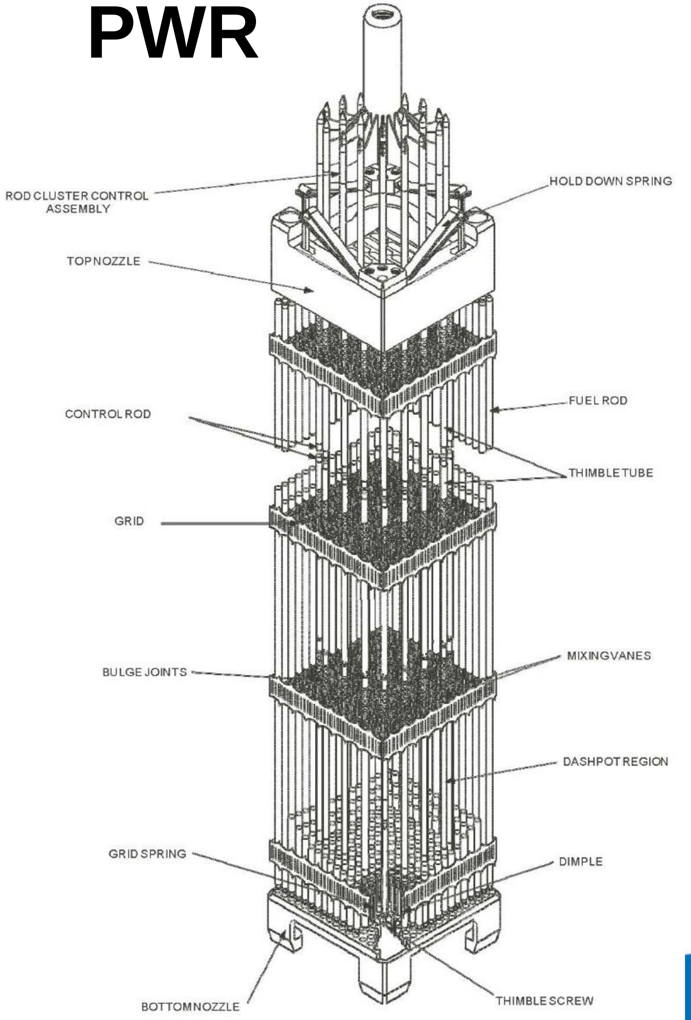




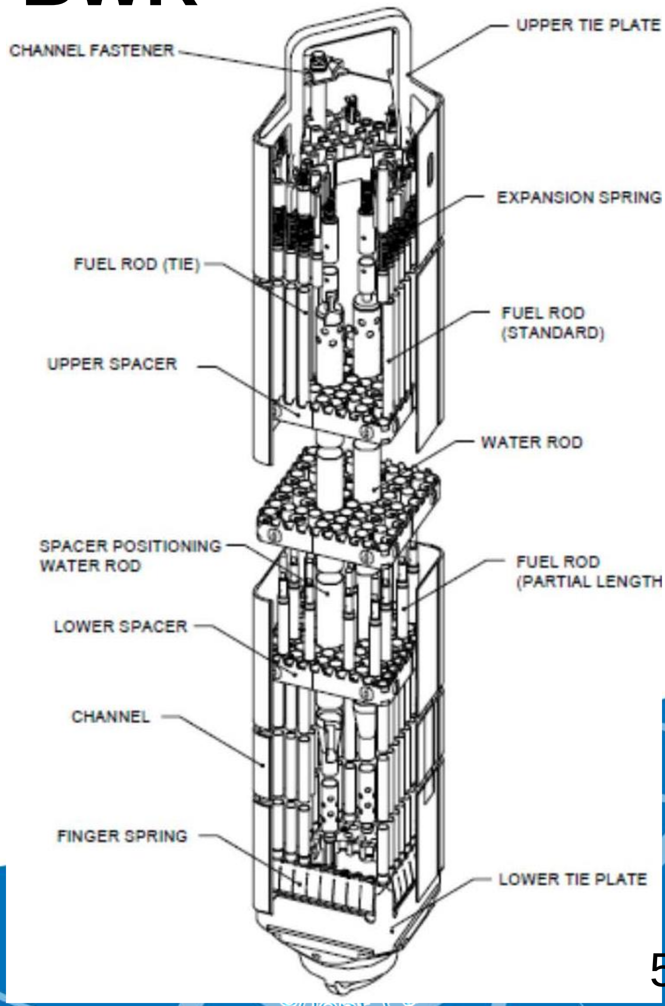


How do assemblies look like?

PWR



BWR



What happens after discharge? Wet Storage

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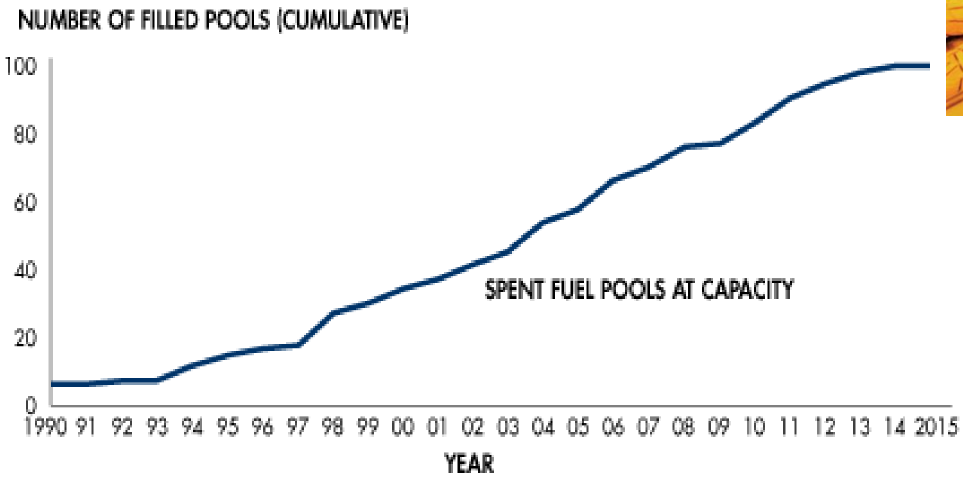
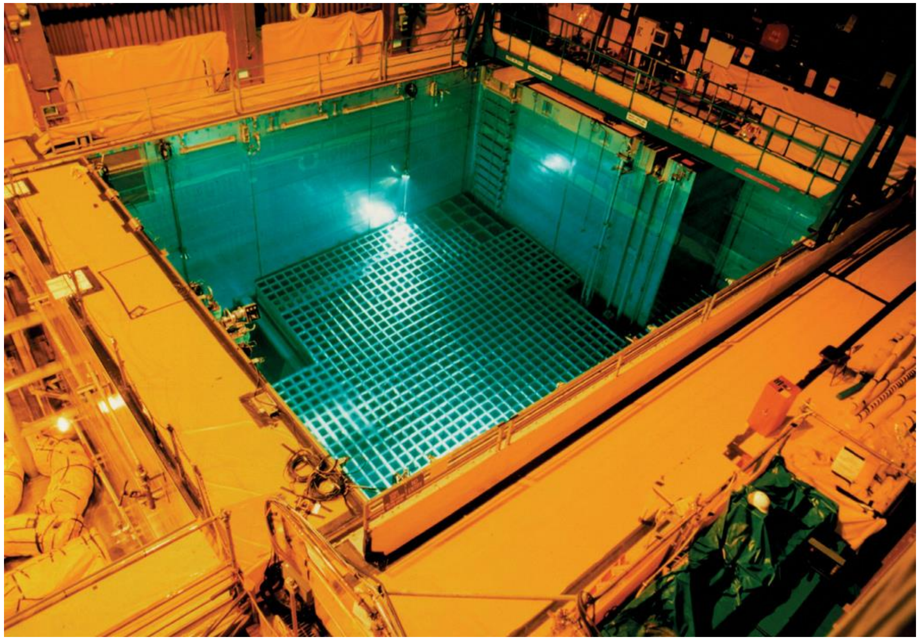
- After about 5-6 years in the reactor, fuel is no longer economically useful and is removed (~ 1/3 of fuel is removed every 18-24 months)
- More than 170,000 spent fuel assemblies (~ ⅔ of total) are stored in spent fuel pools





San Onofre Nuclear Generating Station

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What happens after discharge? Dry Storage

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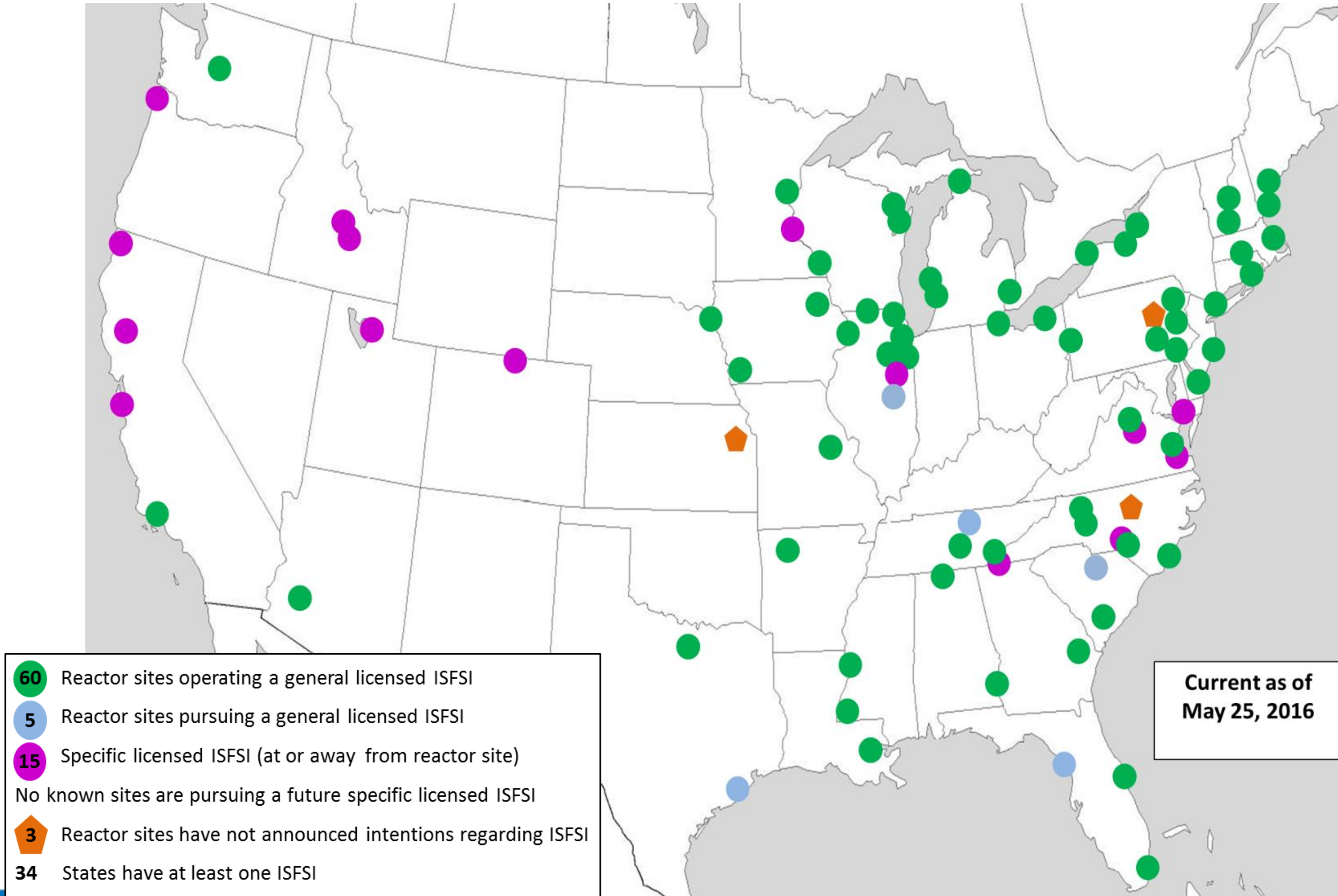
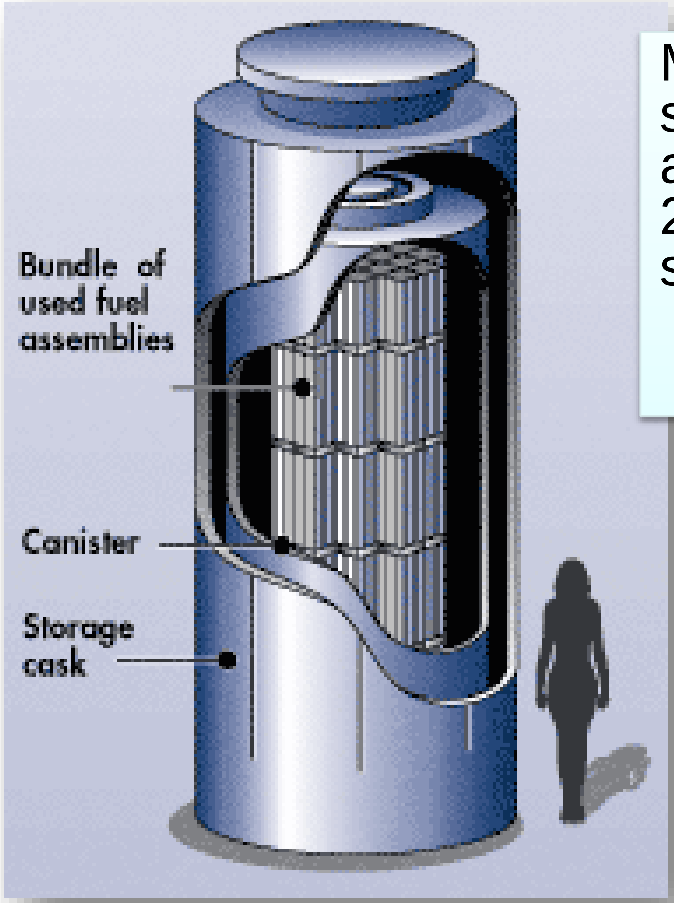
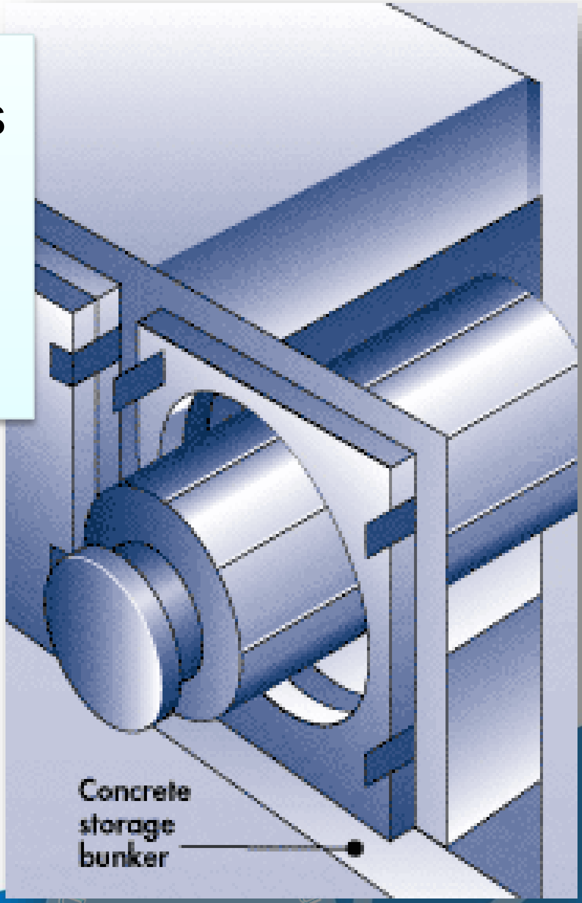


How do dry storage systems look like?

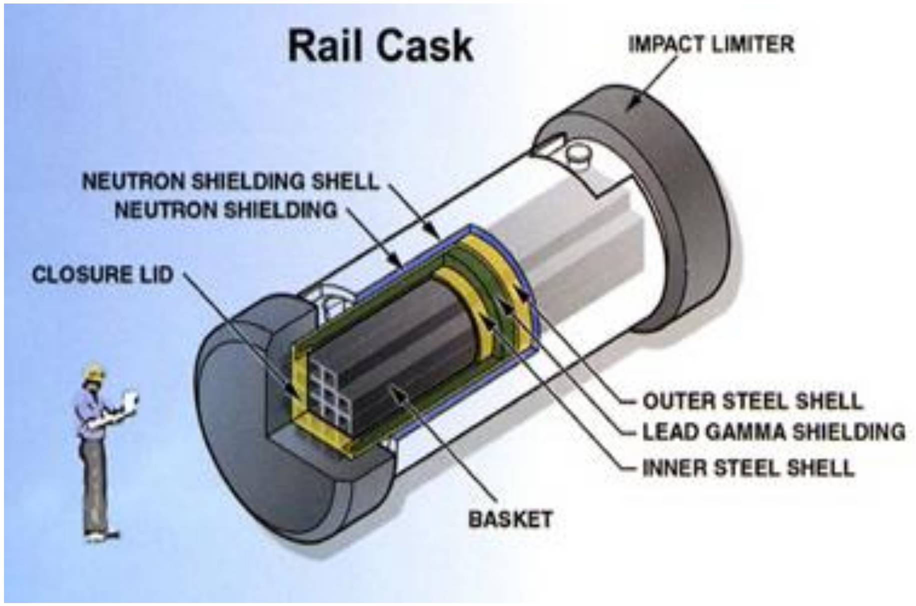


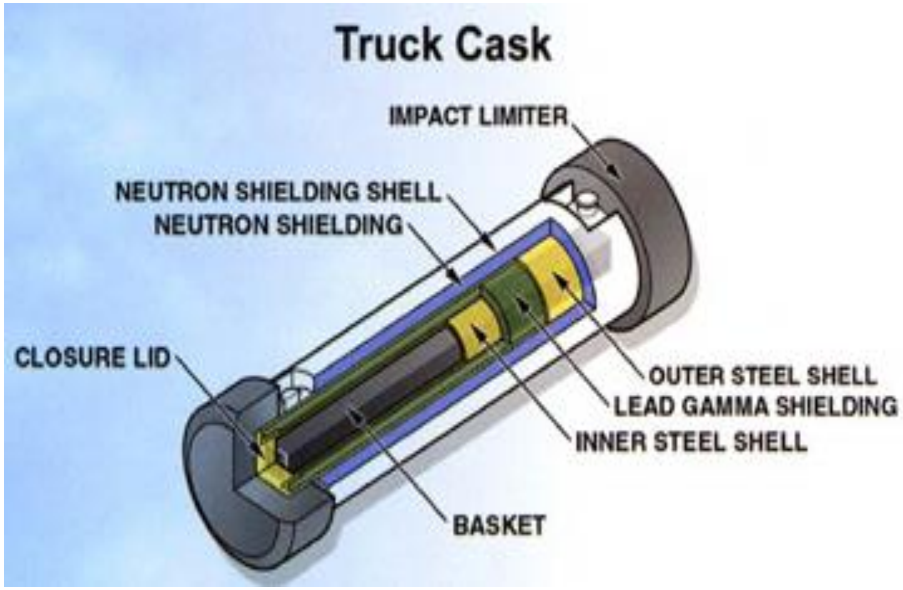
More than 87,000 spent fuel assemblies are stored in over 2300 dry storage systems

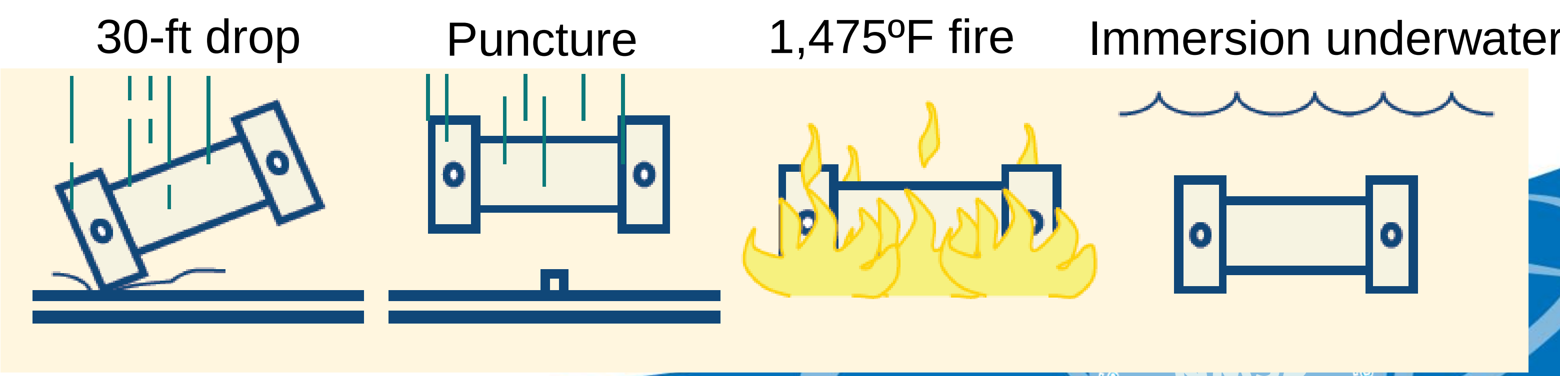
UxC SpentFUEL, vol.18, no.216, 2016



How do transportation packages look like?







How do users assure safety during SNF handling?

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- Maintain fuel in a sub-critical state – *fuel remains unreactive*
- Confinement / Containment – *no release of radioactive material*
- Radiation shielding – comply with *on-site worker and public dose limits*
- Thermal performance - *heat removal, controlled fuel temperature*
- Structural performance – *maintain analyzed configuration*

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How is the fuel loaded?

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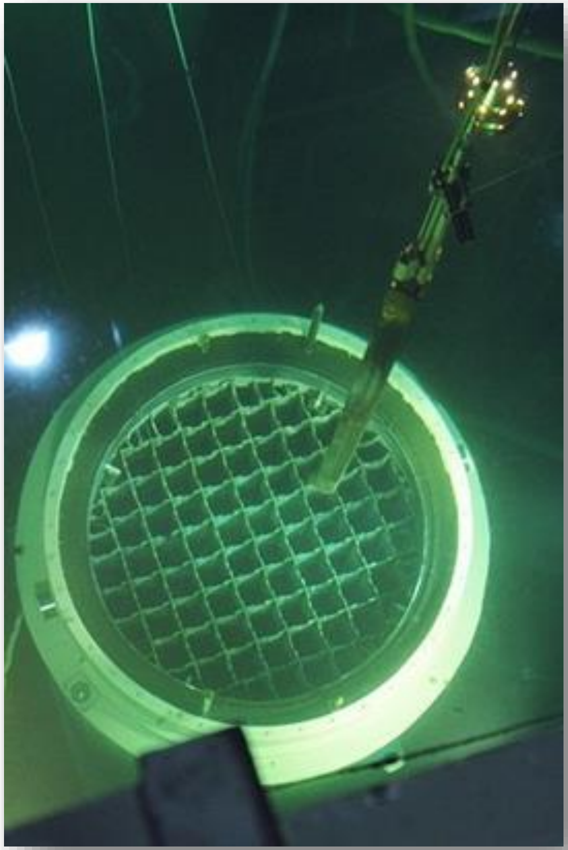
- Load fuel into the canister/cask from wet storage
- Drain
- Dry
- Backfill with helium
- Close (weld or bolt)
- Transfer to storage pad (with shielding overpack, as necessary)
- Install impact limiters for transport



*See Areva NUHOMS® used fuel storage video at us.areva.com

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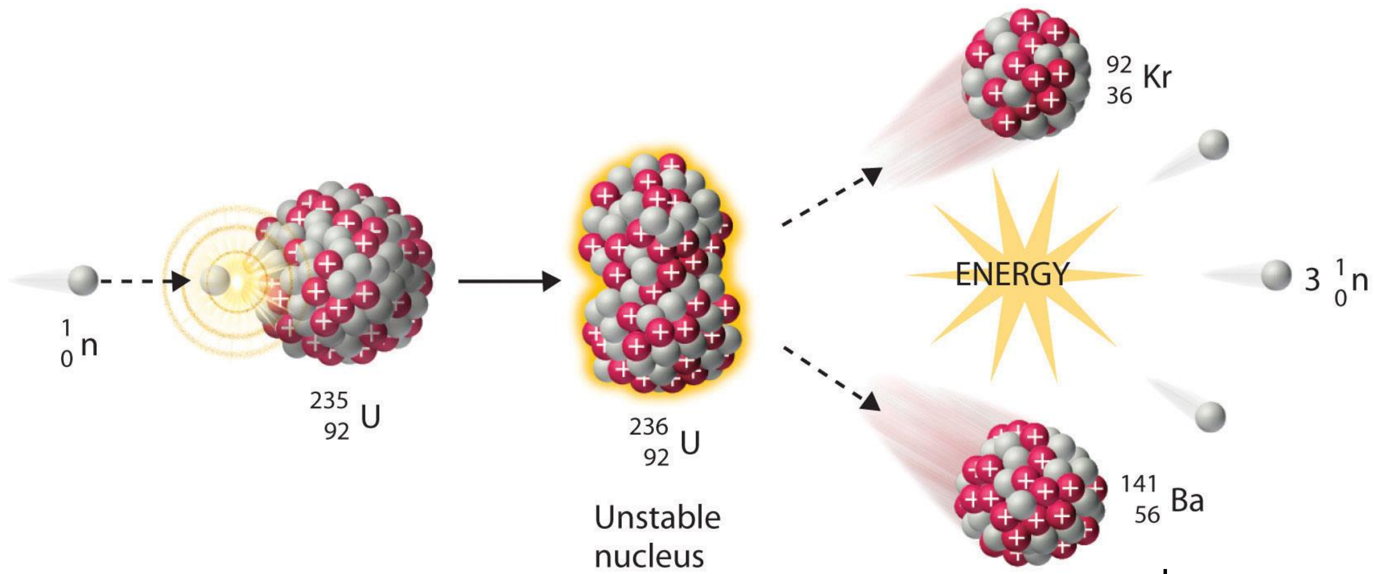
What is fuel burnup?

- Burnup refers to the amount of thermal energy produced over a given time frame divided by the initial mass of the fuel
- Units: gigawatt-days/metric ton of uranium (GWd/MTU)



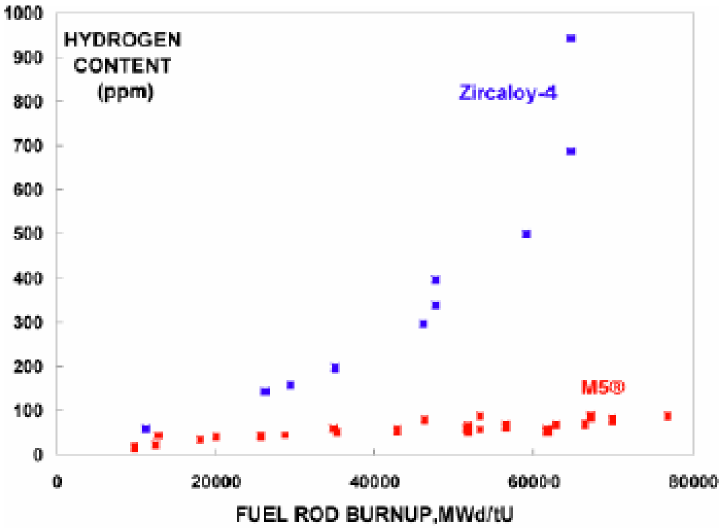
www.nuclear-power.net

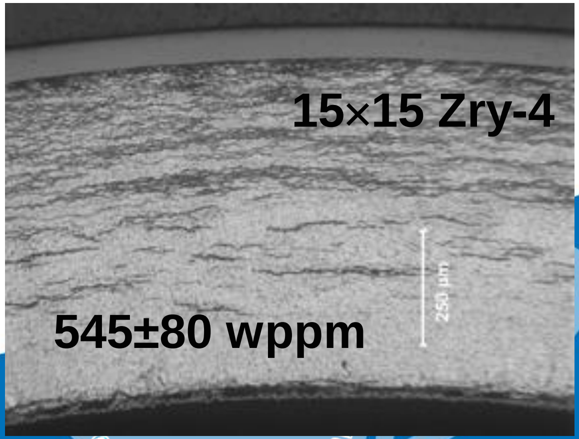
Why does fuel burnup matter?

- Burnup level affects the temperature, radioactivity and physical makeup of the spent fuel
- Increasing burnup affects:
  - Radionuclide inventory and distribution
  - Heat load
  - Crud thickness (deposits)
  - Cladding oxide thickness and hydride content
  - Fuel grain size and morphology (shape)
  - Fission gas release to the plenum (end-of-life rod internal pressures)

What is high burnup?

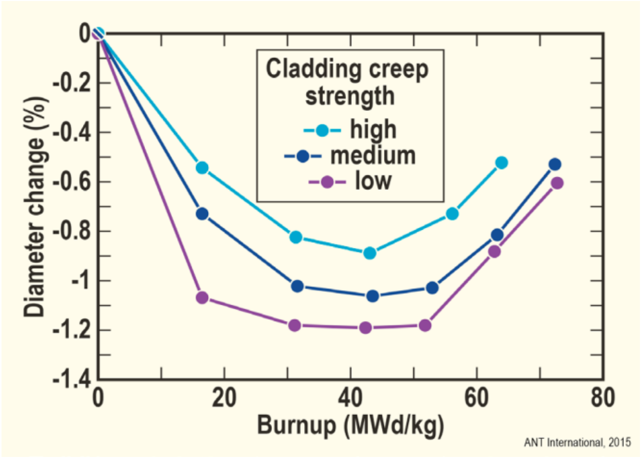
- Generally, as the fuel reaches burnups of 45 GWd/MTU
  - Cladding oxidation and hydrogen pickup accelerate
  - Fuel pellet swelling increases
  - Increased end-of-life rod internal pressures
  - Changes to mechanical properties
- NRC considers:
  - Low Burnup ≤ 45 GWd/MTU
  - High Burnup > 45 GWd/MTU



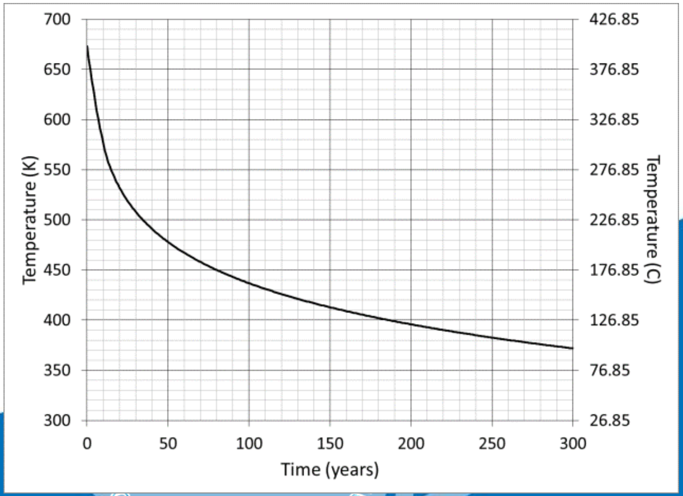


Technical Issue
Cladding Creep

- What is it?
  - Time-dependent deformation due to rod internal stresses
  - Self-limiting
- Why is it an issue?
  - Potential for cladding thinning
  - Susceptibility to hairline cracks or ruptures
- How has NRC addressed it?
  - Staff-issued guidance (ISG-11, Rev. 3)
  - Separate-effects testing and modeling



ANT International, 2016



Staff-Issued Guidance (ISG-11) Accelerated Short-Term Testing

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- Maximum calculated fuel cladding temperature should not exceed 400 °C (752 °F)
  - Applicable to normal conditions of storage and transport, and short-term loading operations (e.g., drying, backfilling with inert gas, and transfer of the cask to the storage pad)
- Cladding stress calculations use an effective cladding thickness reduced by oxide later
- References cited in ISG-11, Rev. 3 provide experimental evidence that cladding failures are not expected for creep strains below 2 percent

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HBU Fuel Monitoring and Assessment Program (AMP)

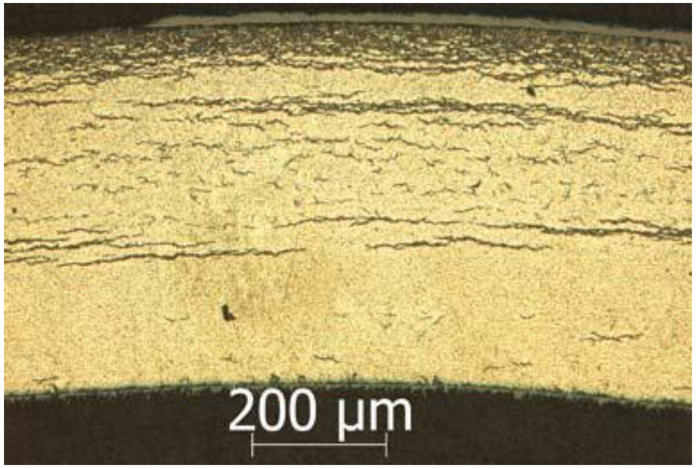
- Surrogate surveillance program to confirm condition of HBU fuel in dry storage to ISG-11 expectations
- Confirmation that analyzed fuel configuration has been maintained, as expected, during the period of extended operation
- AMP expectation for HBU fuel demonstration program:
  - DOE/EPRI Research Cask Program
  - Or an alternative program meeting ISG-24 "Use of a Demonstration Program as Confirmation of Integrity for Continued Storage of HBU Fuel Beyond 20 Years" (Appendix D, NUREG-1927, Rev. 1)

DOE/EPRI Research Cask Program

- Intact HBU fuel stored in AREVA TN-32 bolted lid cask at North Anna ISFSI (Dominion VA Power)
- Nominal burnups between 53-58 GWd/MTU
- Fuel assemblies include four cladding types
  - Zircaloy-4, low-tin Zircaloy-4, Zirlo™, and M5®
- Surveillance cask to be licensed to the ISG-11 temperature limits and loaded such that the fuel cladding temperature is as close to the limit as practicable

Technical Issue
Hydride Reorientation

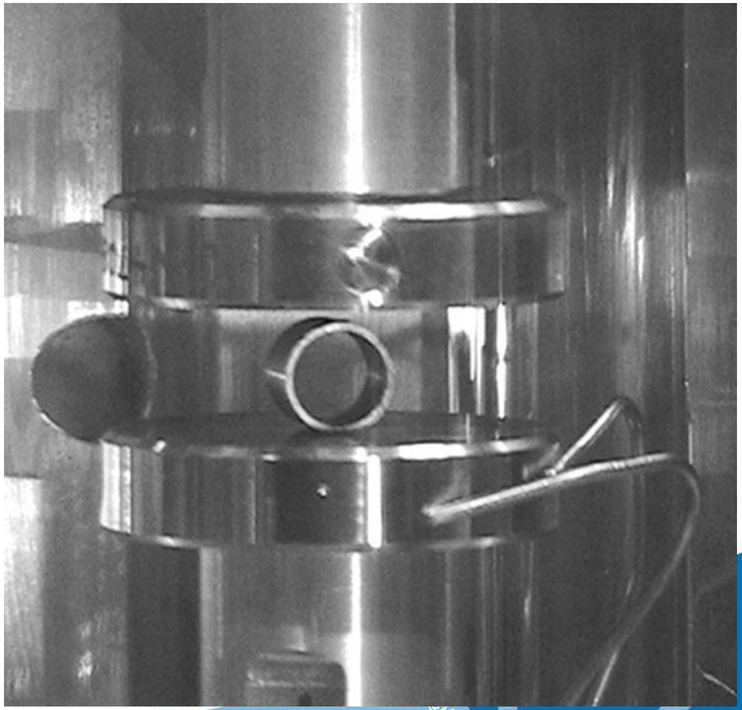
- What is it?
  - Hydrogen in the cladding dissolves during short-term loading operations
  - As the fuel cools down, it re-precipitates in a different orientation
- Why is it an issue?
  - Variation of mechanical properties over time
  - Pinch-loads during transportation
- How has NRC addressed it?
  - Separate-effects testing
  - Regulatory Information Summary



Hydride Reorientation: Ring Compression Testing

- NRC and DOE-sponsored testing at Argonne National Laboratory
  - Estimate temperatures at which the cladding may loose ductility
  - Subjected cladding specimens to bounding conditions for dry storage and transportation (temperature, hoop stresses)
  - Provided a method for the NRC to conservatively review licensing actions until fatigue/bending data was obtained

Controlled displacement rates
5 mm/s typical
1.7-mm maximum displacement



Controlled temperature

Hydride Reorientation: Regulatory Information Summary

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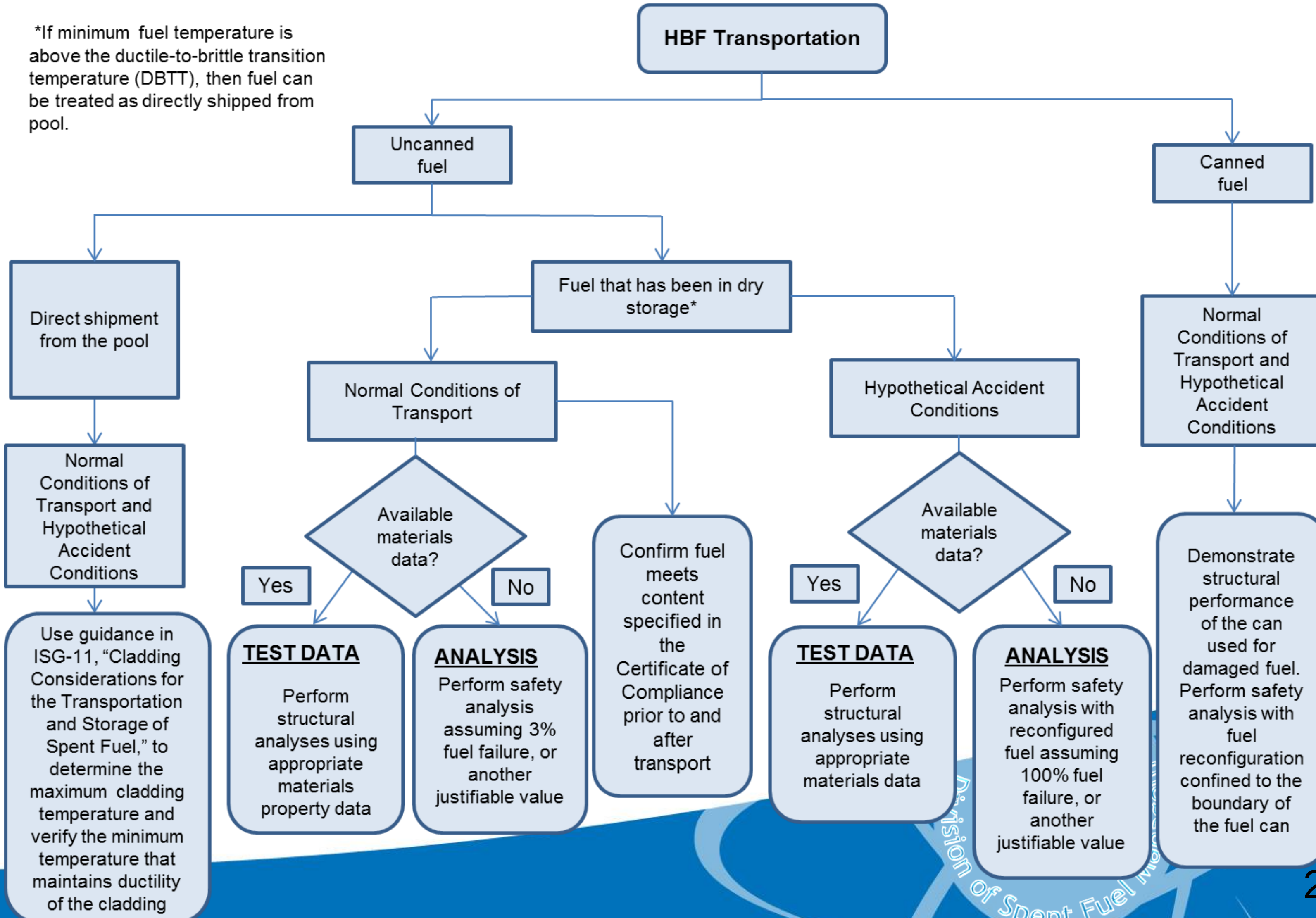
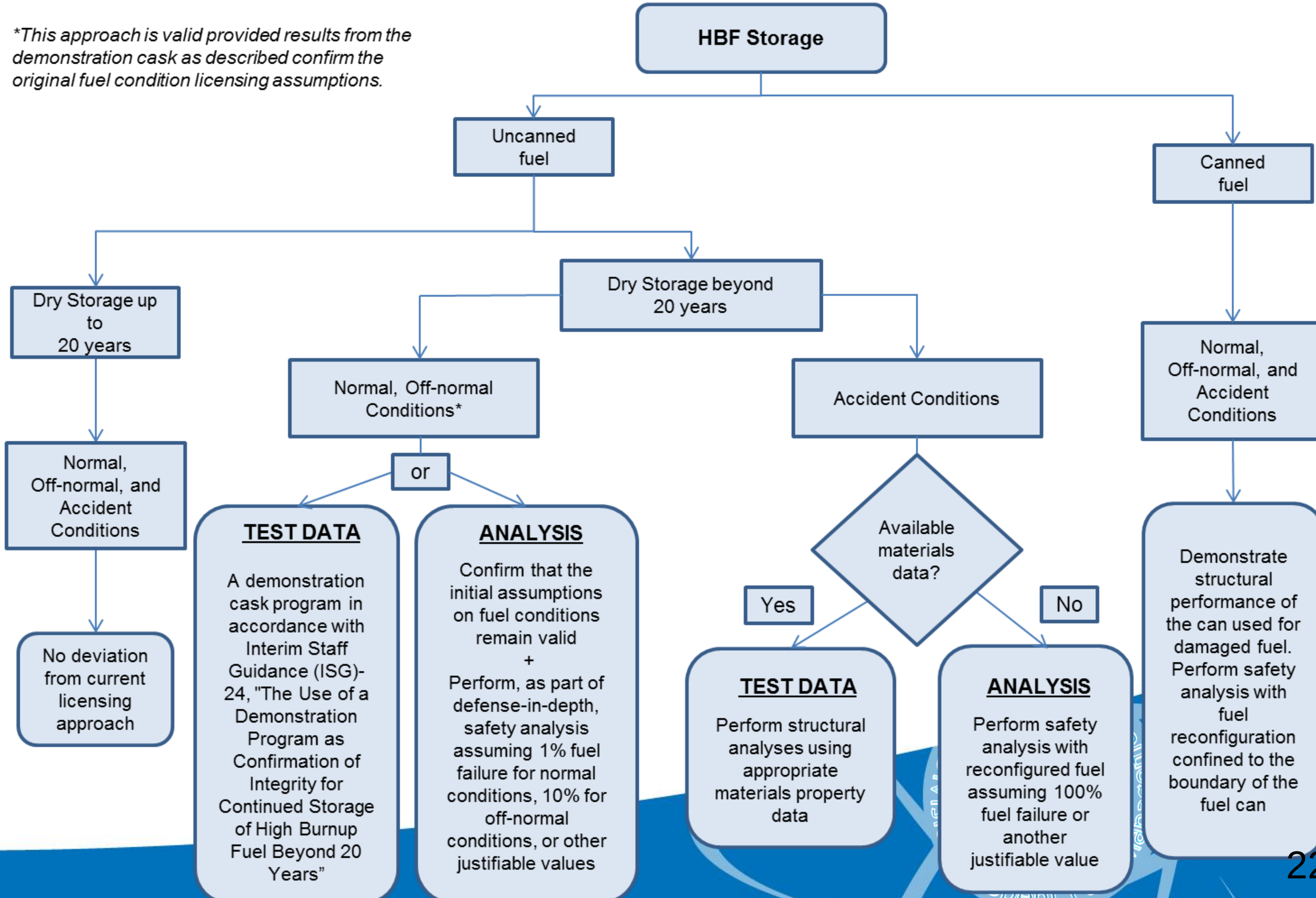


Hydride Reorientation: Regulatory Information Summary



Hydride Reorientation: Bending and Fatigue Testing

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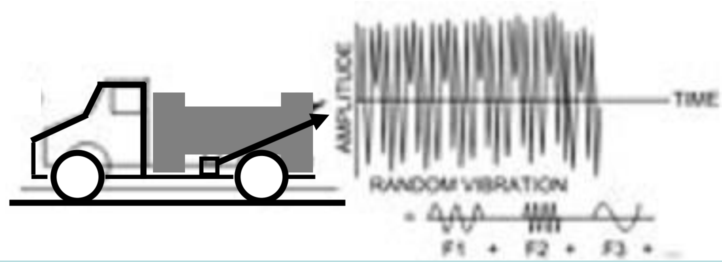
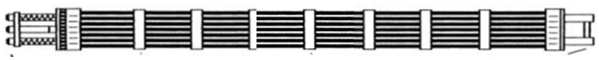
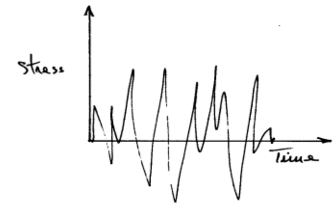
A transportation cask will experience some level of oscillation due to normal conditions of transport.



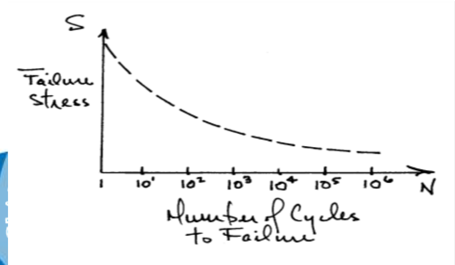
That oscillation will be transmitted in some way to the contents of the cask, the fuel elements.



The oscillation transmitted to the fuel elements will result in local stresses

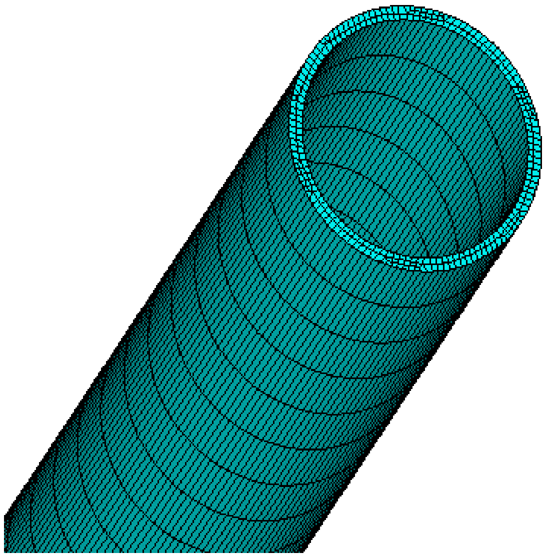


The fuel cladding has the potential for fatigue failure if a large number of cycles are seen during transport, even if the maximum stresses seen by the cladding are far below the yield stress of the material.

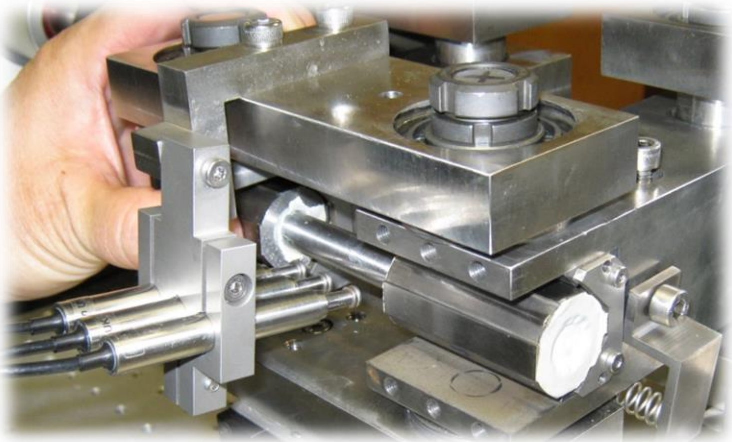


Hydride Reorientation: Bending and Fatigue Testing

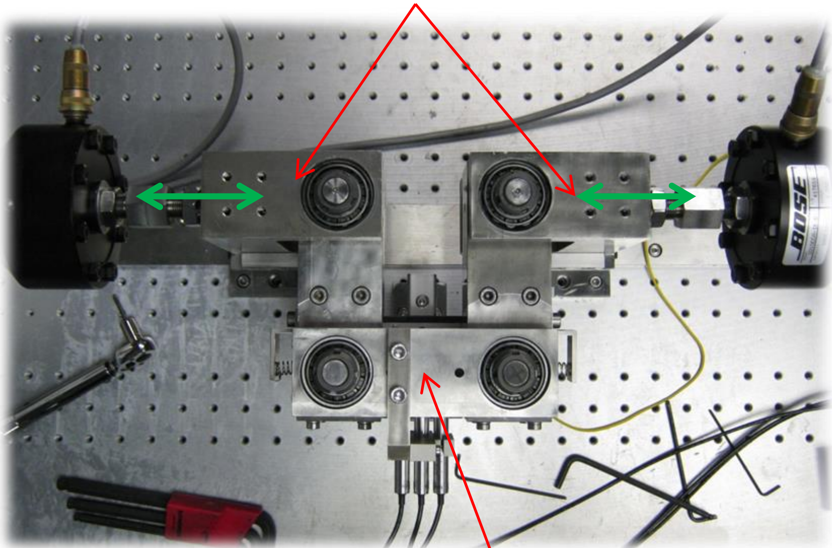
- NRC and DOE-sponsored testing at Oak Ridge National Laboratory
  - Determine if the presence of fuel pellet increases the flexural rigidity (bending stiffness) of the fuel rod
  - Determine if the presence of fuel pellet increases the failure strain of the cladding (storage and transport accident)
  - Determine the number of cycles to failure for high burnup fuel rods at a range of elastic strain levels. (normal transportation)



Hydride Reorientation: Bending and Fatigue Testing

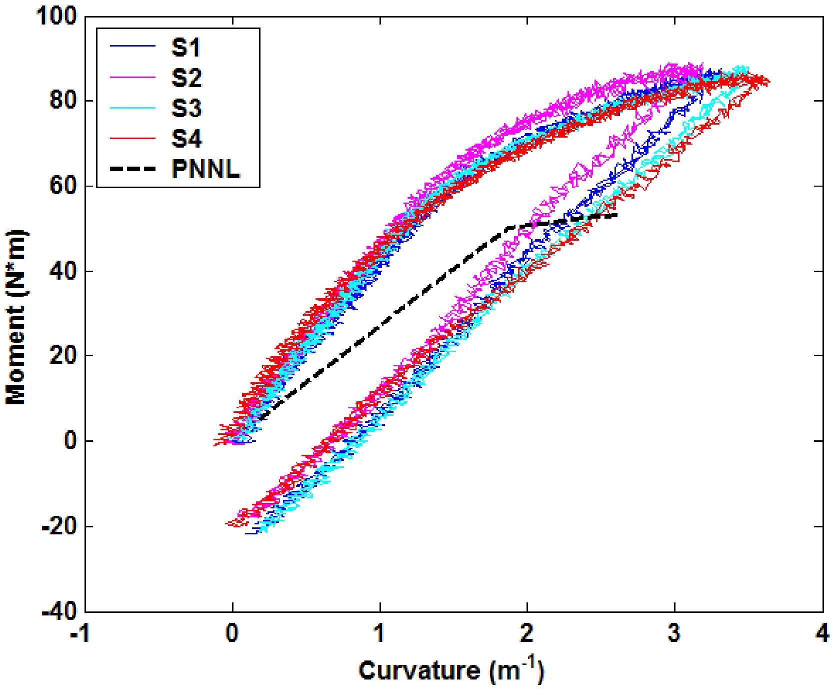


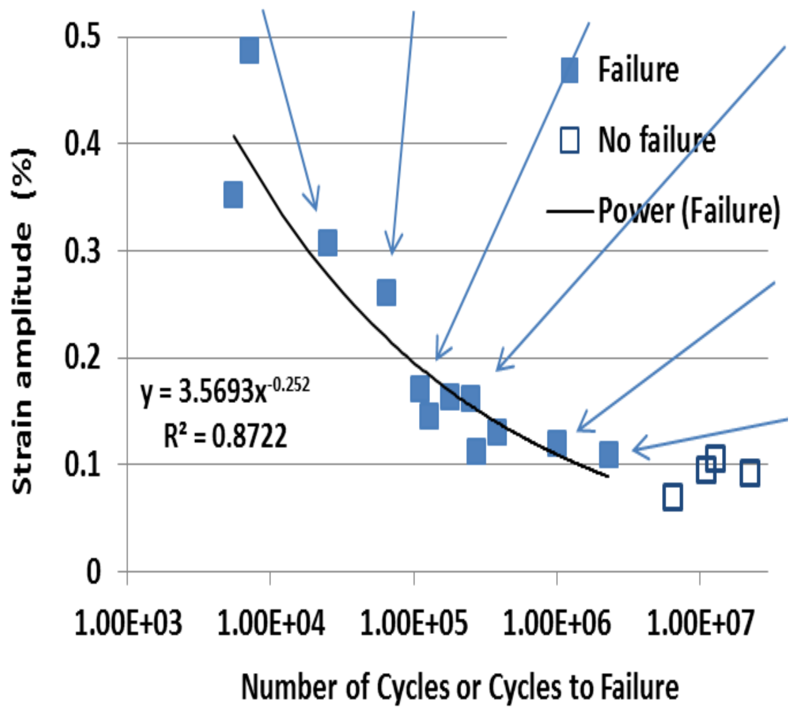
Push-pull force applied to U-Frame results in bending moment on the test segment



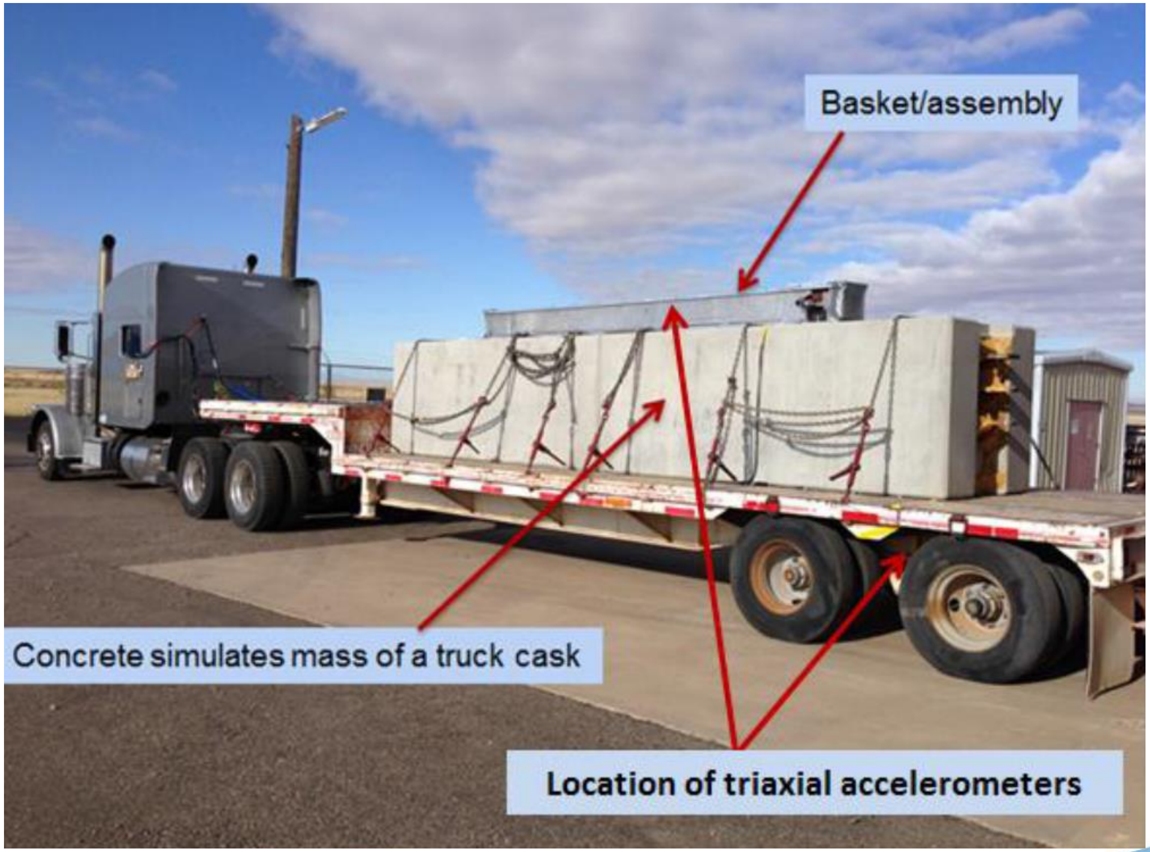
Location of test segment

Hydride Reorientation: Bending and Fatigue Testing





Over-the-Road Vibration Studies



Are these the only technical issues for HBF?

- Draft report “Managing Aging Processes in Storage” evaluated additional age-related phenomena for potential to compromise HBU fuel integrity
  - Applies to periods of extended operation (20–60 yrs)
  - Reviewed up-to-date technical literature and operating experience to define credible and non-credible degradation mechanisms
  - Concludes that creep and hydride reorientation are only mechanisms of concern
- Report will be issued for public comment

Conclusions

- NRC has assessed multiple technical issues related to potential degradation of high burnup fuel during both storage and transportation
- Storage
  - Accelerated short-term testing results support the conclusion that creep and radial hydride reorientation will not compromise cladding integrity during dry storage up to 60 years
  - Confirmation of these studies is provided per a surrogate program consistent with the guidance in ISG-24

Conclusions

- Transportation:
  - NRC and DOE-sponsored bending and fatigue testing results support the conclusion that cladding with reoriented hydrides will perform adequately
    - Use of cladding-only mechanical properties is sufficient
  - Until all data is gathered, applicants may conservatively assume that the cladding loses ductility at low temperatures, or perform consequence analyses that assume some degree of fuel reconfiguration

More Information

- NRC website:

  http://www.nrc.gov/waste/spent-fuel-storage.html

- NRC background on high burnup fuel:

  http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bg-high-burnup-spent-fuel.html

- *Information Handbook on Independent Spent Fuel Storage Installations*

  (NUREG-1571, ML010450036 on NRC ADAMS document database)

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