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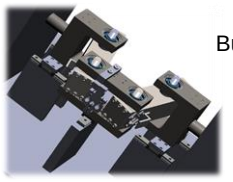

Mechanical Testing of High Burnup Fuel for Transportation Applications

An NRC sponsored research program at Oak Ridge National Laboratory

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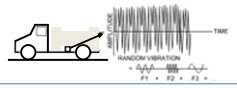
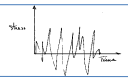
Motivation: Vibration normally incident to transport must be analyzed for fuel in transportation casks.

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

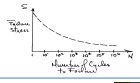


That oscillation will be transmitted in some way to the contents of the cask, the fuel elements.

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. High burnup material in particular may be highly brittle. In addition, it is not clear how the ceramic fuel will effect the potential for cladding failure.



Current regulation state: "Evaluation of each package design under normal conditions of transport must include a determination of the effect on that design of the conditions and tests specified in this section" 10 CFR 71.71(c)(5) specifies the condition: "*Vibration.* Vibration normally incident to transport."

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Objective: Investigate a number of important attributes of the fuel/clad system. These attributes include (but are not limited to):

- The bending stiffness of fuel rods while taking into account the presence of fuel inside the cladding, particularly when fuel is bonded to the cladding at high burnup.
- The number of cycles to failure for high burnup fuel rods at a range of stress levels

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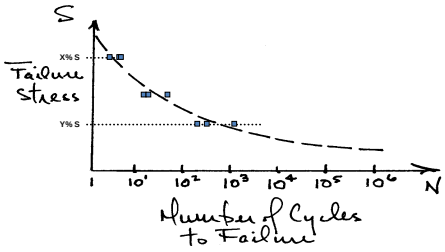
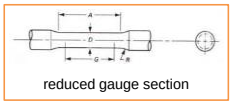
Planned Measurements: Static bending stiffness of high burnup, fueled cladding and vibration fatigue strength of the same material at three stress levels relative to the bending stiffness. Repeat testing will be used to characterize variability.

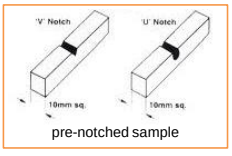


Challenges: There were a number of unique challenges to meeting the objective.

The objective of this testing program is to measure properties of **high burnup, irradiated fuel rods**. Normal vibration testing devices utilize **reduced gauge sections** or **pre-notched samples** to prevent failure in the grip section and ensure meaningful data. Neither of these testing approaches was acceptable to measure the failure behavior of high burnup, irradiated fuel rods to obtain meaningful indication of failure conditions during transportation. We also do not have the ability to weld local **strain gauges or utilize laser readings** on high burnup material in-cell. Finally, hot-cell space and time is extremely costly, as is testing material. **The size of the testing device, sample size and test duration all had to be kept to a minimum.** Therefore, an entirely new fatigue testing device had to be developed for this project.



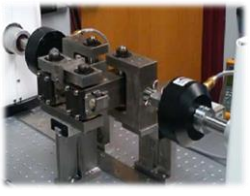
reduced gauge section



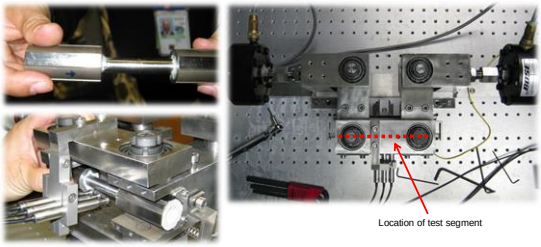
pre-notched sample

Testing equipment: A reversible pure bending test system has been developed to support this NRC research project

The test system can be used to test and characterize static bending stiffness as well as the vibration integrity of spent nuclear fuel. The reversible bending is conducted utilizing a U-frame setup with the push-pull force applied at the loading point. The deformation of the rod specimen is measured directly using three-point deflection, and therefore the curvature of deformed rod specimen can be easily estimated. The functionality of the test system has been demonstrated using surrogate rods in out-of-hot cell tests.



Unique features: A number of unique features of the equipment have been integral to successfully meeting the project objectives.

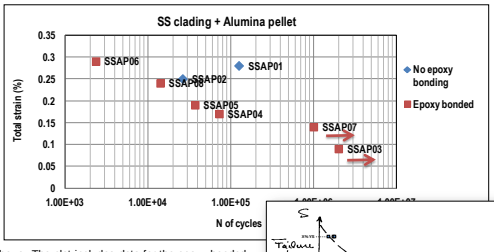


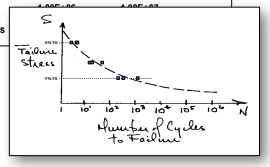
Top Left: The grip sections have been uniquely designed to induce uniform bending moment (without local pinching loads) across the gauge sections

Bottom Left: The grip design provides for easy loading into the test device and enables frictionless grip in combination with roller bearing design

Right: Test device seen from above. Final design utilizes two electro-magnetic motors, a U-frame design and a horizontal setup, enabling pure reversible bending with versatility in input functions (frequency, magnitude etc) and frictionless operation.

Demonstration: The functionality of the test system has been demonstrated using surrogate rods in out-of-hot cell tests





Above: The plot includes data for the epoxy bonded samples at a number of strain levels and their respective cycles to failure, the data falls in the expected trend (see **right** schematic of a typical S-N curve) and confirms that device is operating, in principle, as intended.

Irradiated testing: A test matrix has been developed to measure important attributes of irradiated fuel.

- Cladding is Zircaloy
- Burnup is approximately 65 GWd/MTU
- Hydrogen content ranges from 350 – 750 wppm
- 5 repeat tests will measure static bending stiffness
- 3 repeat tests at 3 stress levels will measure fatigue strength
- Testing is scheduled to be completed during the first half of 2013

Conclusions

- Unique and novel testing equipment has been developed to perform these measurements in-cell on as-irradiated, high burnup fueled rods
- Equipment has been extensively tested and demonstrates intended functionality with surrogate materials
- First of a kind measurements will be made of high burnup fuel in the next few months to investigate critical questions on the response of high burnup fuel under transportation conditions