

Bending and Fatigue Testing of High Burnup Fuel

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Research Objectives

- To support the safe transport of High Burnup (HBU) Spent Nuclear Fuel (SNF) under Normal Transport Conditions (NTC) and Hypothetical Accident Conditions (HAC)

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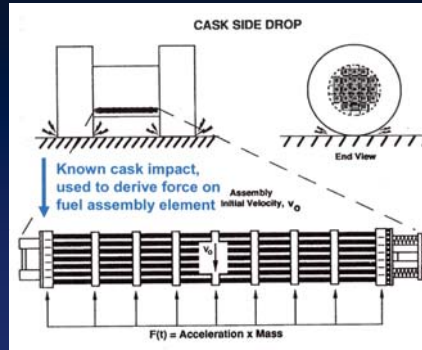
Fuel Rod Structural Integrity Depends on the Following:

- Accident Conditions
 - Bending Stiffness (Flexural Rigidity, EI)
 - Strength (Cladding Failure Strain)
- Normal Transport Conditions
 - Bending Stiffness (Natural Frequency of Vibration)
 - Fatigue Strength (Number of Vibration Cycles to Failure)

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Accident Conditions (Side Drop)

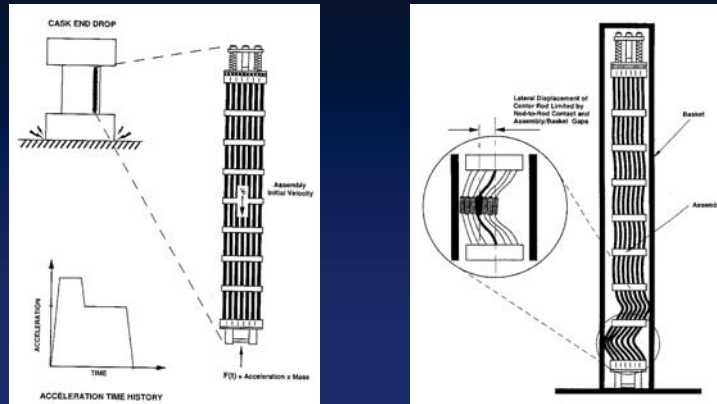
(Figure Courtesy Sandia National Laboratories)



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Accident Conditions (End Drop)

(Figures Courtesy Sandia National Laboratories)



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Normal Transport Conditions

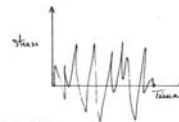
A transportation cask will experience some level of oscillation due to normal conditions of transport.



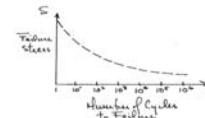
That oscillation will be transmitted in some way to the contents of the cask, the fuel elements.



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



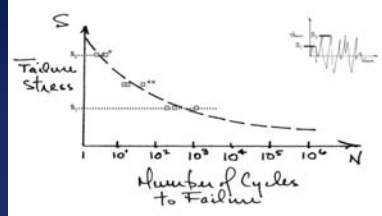
The fuel cladding has the potential for fatigue failure if a large number of cycles are seen during transport, even if the maximum stresses seen by the cladding are far below the yield stress of the material. High burnup material in particular may be highly brittle (see next slide). In addition, it is not clear how the ceramic fuel will effect the potential for cladding failure.



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Specific Research Objectives To Answer Two Questions

- How much does the fuel participate with the cladding to increase the bending stiffness and strength of the fuel rod?
- What are the fatigue characteristics of HBU SNF?



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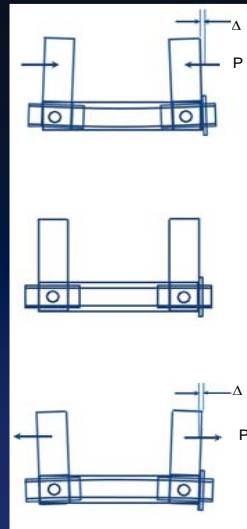
Test Setup and Test Equipment

- Designed to produce pure bending or constant curvature (Moment= $P \times L$)
- Grips designed to produce no axial load in rod

Figure goes Here

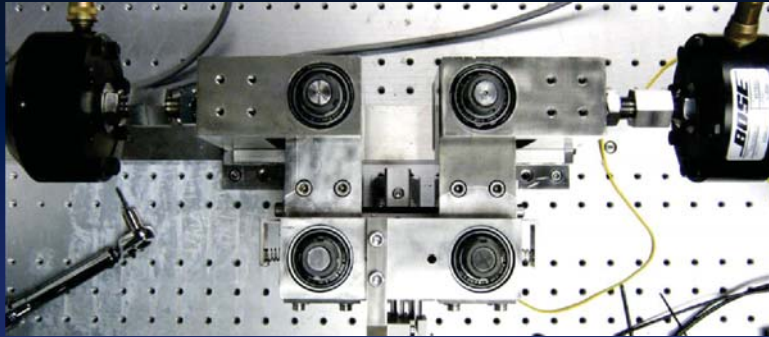
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Test Setup and Test Equipment



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Test Setup and Test Equipment



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Testing Strategy: Measure Fuel Rod Curvature

Three points define a circle.

Radius = R

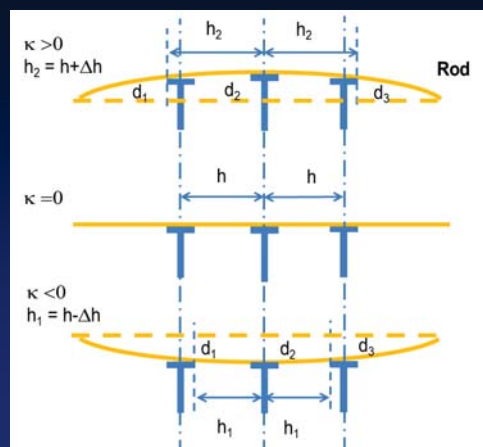
Curvature = $1/R$

Moment in rod = $P \times L$

Slope of the Moment – Curvature diagram
is the Flexural Rigidity (Bending Stiffness)

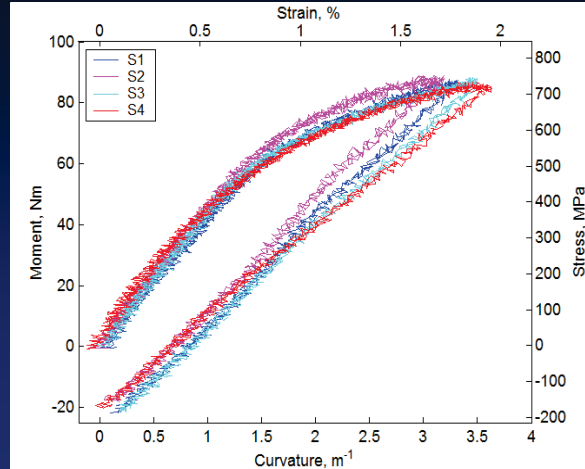
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Testing Strategy: Measure Fuel Rod Curvature



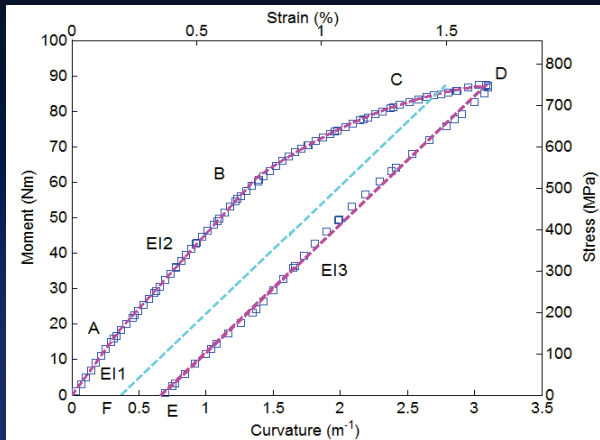
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Bending Test Results (Consistent Response)



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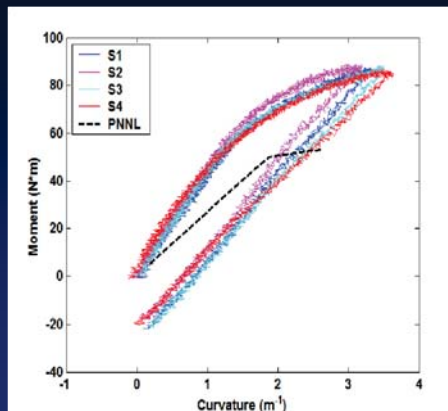
Bending Test Results



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Compare to Response of Cladding Only (PNNL Data)

- How much does the fuel contribute to flexural rigidity?
- Compare Slopes
- Ratio of EI of fuel rod to EI cladding only
- In Region E1 the Ratio = 2.0
- In Region E2 the Ratio = 1.5



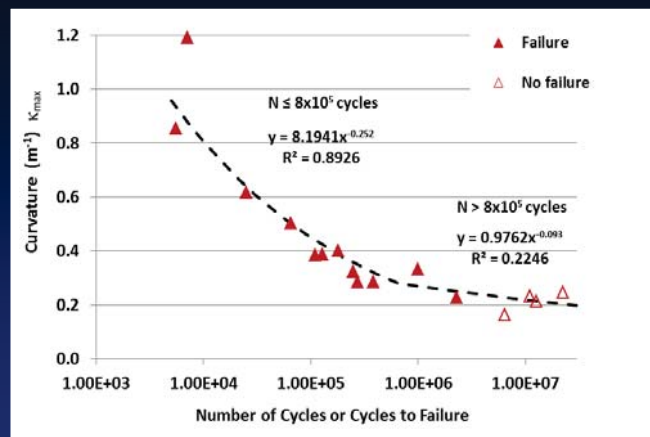
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Fatigue Test Results

- 16 Specimens Tested
 - 12 Failed
 - 4 No Failure
- Load Controlled
- Cycled at 5 Hertz

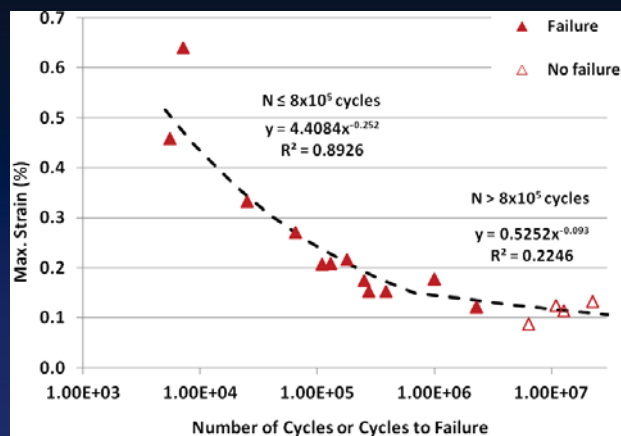
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Fatigue Test Results



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Fatigue Test Results



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Questions