SAND2014-20101C

Used Fuel Disposition Campaign

Normal Transport Loads on Fuel Rods and Assemblies

Paul McConnell

Sandia National Laboratories

EPRI ESCP

December 2, 2014

Charlotte, North Carolina

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2014-XXXXP

The UFDC has a story to tell: Can irradiated rods withstand NCT?

Assembly shaker and truck tests: NCT loads on rods (very low ε)
SNL

Assembly modeling: validation (good agreement with test results)
PNNL

Irradiated rod testing: material properties (ductility, DBTT, stiffness, fatigue)
ANL / ORNL

These projects are complementary.

Results suggest that UNF may be able to withstand NCT without failure.

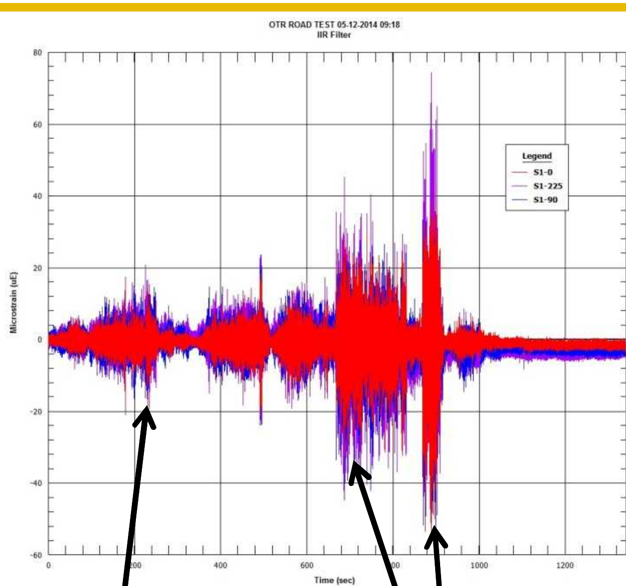
Where the UFDC R&D is leading us…

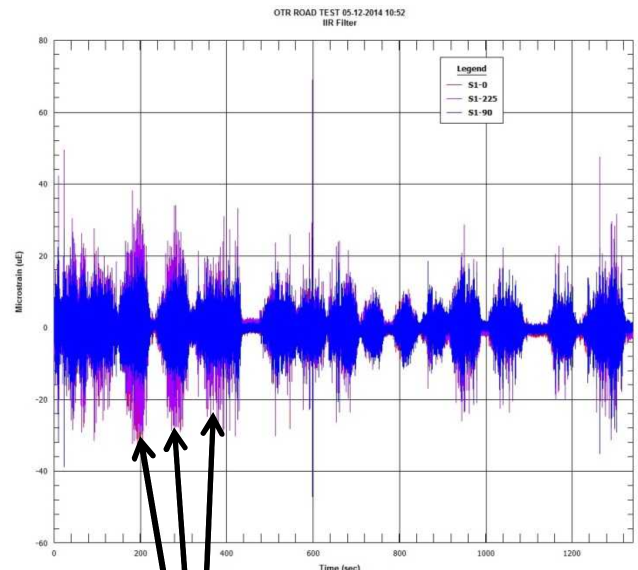
- The strains measured in the assembly NCT test program were in the micro-strain levels – well below the elastic limit for either unirradiated or irradiated Zircaloy-4
- Based upon the test results, which simulated normal vibration and shock conditions of truck transport, strain- or stress-based failure of fuel rods during normal transport seems unlikely
- Strains on irradiated rods with fuel during NCT may be less than the strains measured on unirradiated tubes due to increased stiffness
- Fatigue during transport does not appear to be an issue

Test unit on concrete blocks on trailer for over-the-road test

Used Fuel Disposition

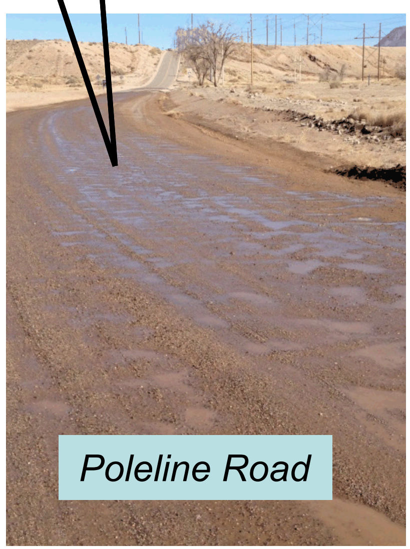
Low strains measured on instrumented rod during over-the-road test





Strains correlated with road conditions

dip on Area III Access Road

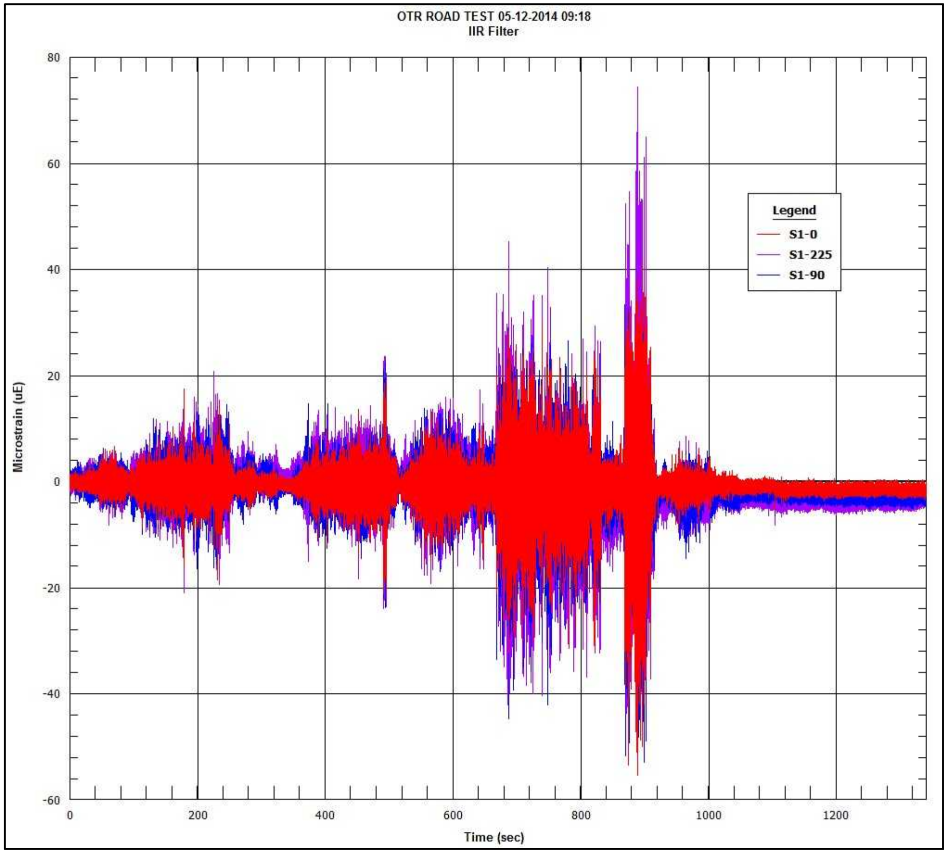


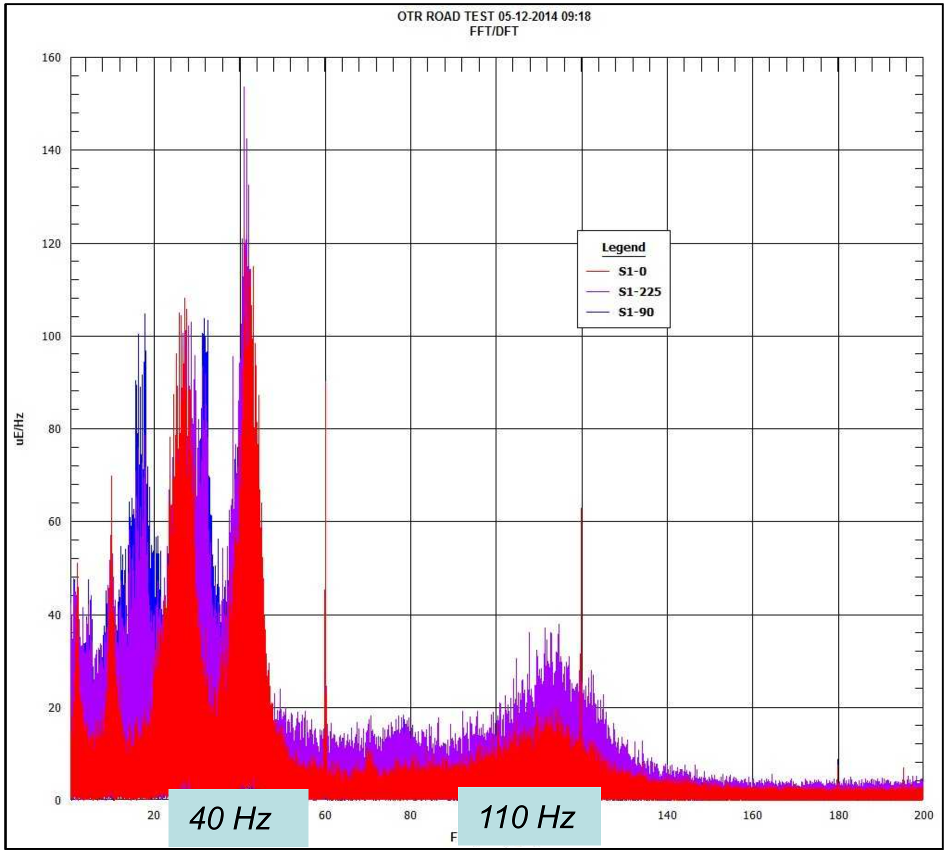
Poleline Road

Gibson Blvd.

Used Fuel Disposition

Rod strains (με *v.* time) and FFT (με/Hz *v.* Hz) for over-the-road test *maximum strains occurred at low Hz*



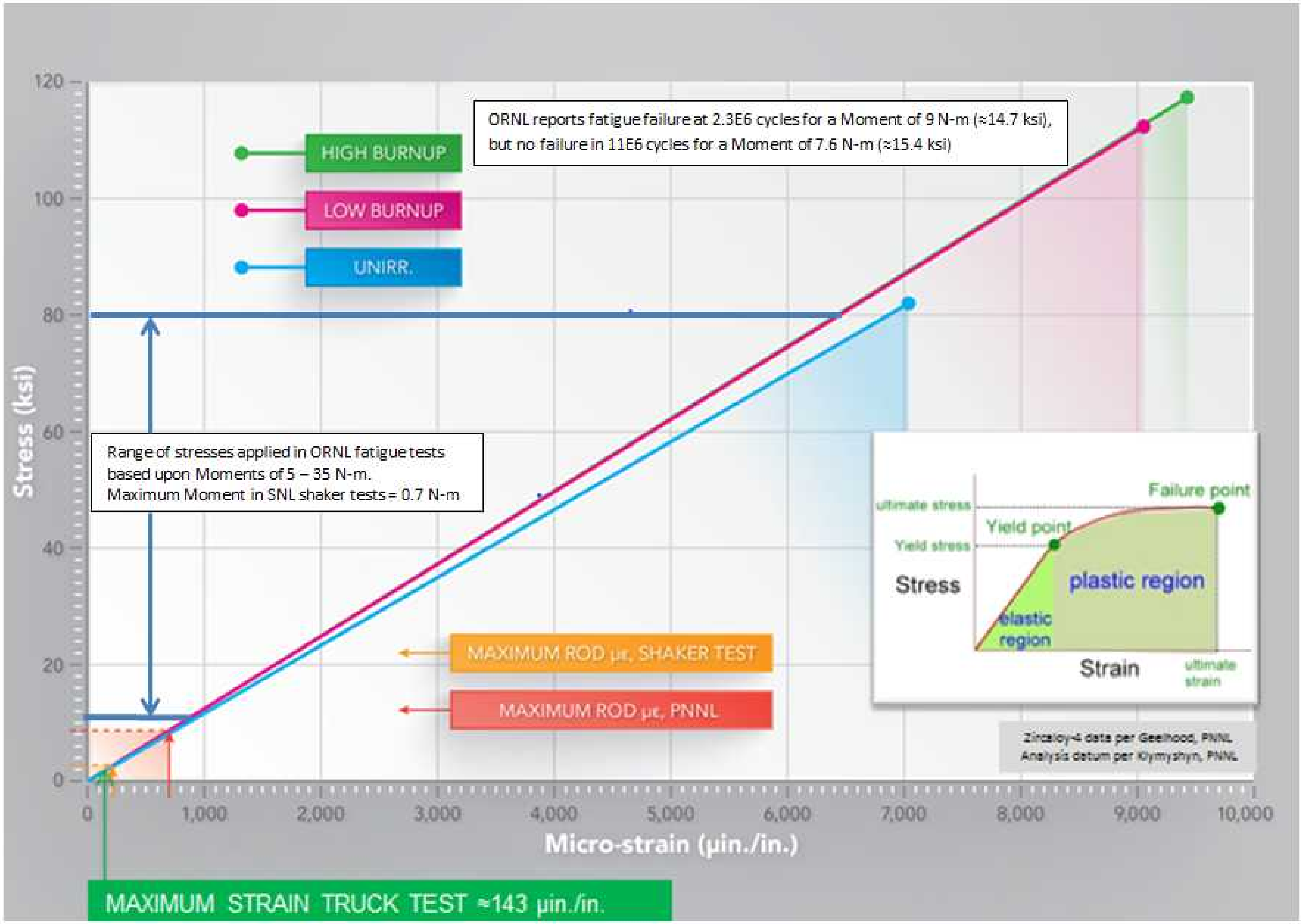


Comparison of maximum strains measured on Zircaloy-4 rods in truck and shaker tests

Strain Gauge ID (Truck/Shaker)	Location on Assembly (Top-middle Rod)	Truck Test Maximum Strain Absolute Value (μin./in.)	Shaker Vibration Test Maximum Strain Absolute Value (μin./in.)	Shaker Shock Test Maximum Strain Absolute Value (μin./in.)
S1 - 0°	Adjacent to first spacer grid, Span 10	55		
TMR-G-S10-3			89	80
S2 - 0°	Mid-span, Span 10	94		
TMR-G-S10-2			207	213
S3 - 0°	Adjacent to first spacer grid, Span 5	143		
TMR-G-S5-2			97	119
S4 - 0°	Mid-span, Span 5	69		
TMR-G-S5-1			156	114

Used Fuel Disposition

Measured strains very low relative to elastic limit of Zircaloy



Irradiated rods are stiffer than unirradiated tubes. Strains decrease with stiffness.

1. Bending stiffness (=*EI*) of HBR high burnup irradiated Zircaloy-4 rod *with pellet-clad interaction* (per ORNL): $EI_{Zirc4\text{-}irr} \approx 52\ N\text{-}m^2$

Range of irradiated rod EI ≈ 16.5 – 87 N-m² (depending upon interfacial bonding condition)

2. Bending stiffness of unirradiated Zircaloy-4 *tube* (SNL assembly tests):

$EI_{Zirc4\text{-}unirr} = 17.7\ N\text{-}m^2$ [includes contribution of Pb]

3. Bending stiffness ratio: Zircaloy-4 (irradiated/unirradiated) = 52/17.7 = 2.9

The maximum strain measured in the truck test was 147μm/m so, for the same loading environment, the NCT strain on an irradiated rod would be: ≈ 147(17.7/52) = 50 μm/m

(or ≈ 70 μm/m considering difference in natural frequency of irradiated rod and unirradiated tube)

Range irradiated rod NCT strain: ≈ 157 – 30 μm/m
(depending upon interfacial bonding condition)

Used Fuel Disposition

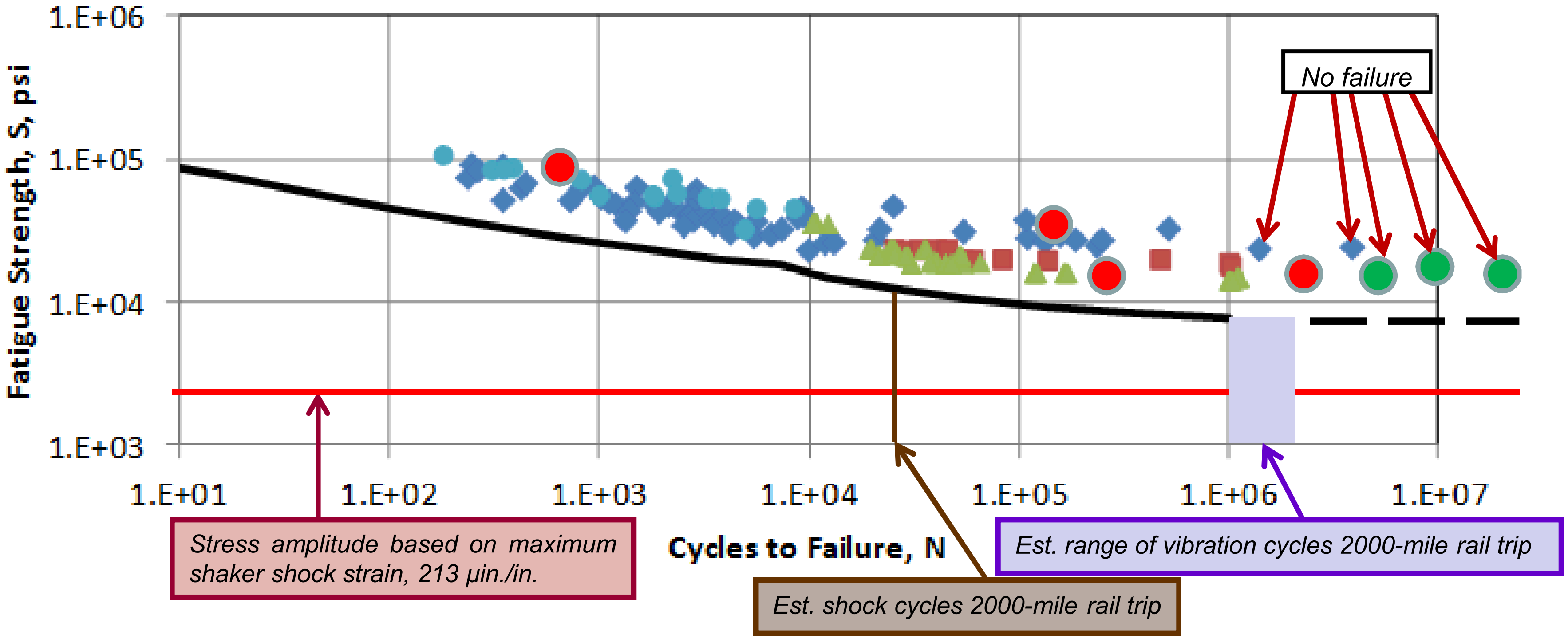
Bending moments applied in ORNL tests exceed NCT bending moments

Specimen	Burnup (GWd/MTU)	Applied Bending Moment, M (N-m)	Curvature, κ_{max} (m^{-1})	Strain (μm/m)	Stress (lb/in^2)	Cycles $x10^6$	Failure ?
Selected ORNL HB Robinson Zircaloy-4 fatigue test data							
D2	63.8	5	0.16	862	1.15E4	6	NO
D4	66.5	7.6	0.23	1239	1.65E4	11	NO
D5	66.5	9	0.22	1185*	1.58E4	2.3	YES
D9	66.5	35	1.2	6464	8.60E4	0.007	YES
D13		13.72	0.44	2370	3.15E4	0.129	YES
D14		8.89	0.27	1454	1.93E4	0.27	YES
D15		7.62	0.22	1185	1.58E4	22.3	NO
Conditions for SNL NCT assembly tests							
		0.7	0.04	≈ 200			

**strain calculated via $r_o(\kappa_{max})$*
r_o^{Zirc4} = 5.385 mm (HBR cladding)
(other strains based upon ratio of $[\kappa_{max}/.22] \times 1185$)

Q: How many cycles to failure for a bending moment of 0.7 N-m?
Answer: cycles to failure should be ≫ 22.3×10^6

NCT vibrations unlikely to result in fatigue failure



Fatigue design curve (▬▬): O'Donnel and Langer, "Fatigue Design Basis for Zircaloy Components," Nucl. Sci. Eng. 20, 1, 1964. (cited in NUREG-0800, Chapter 4)

Data plot courtesy of Ken Geelhood, PNNL
The large circles are ORNL HBR data

Conclusion

- The strains measured on the rods in the assembly NCT test program were in the micro-strain levels
- Strains on irradiated fuel rods during NCT may be less than strains measured on the unirradiated Zircaloy-4
- Strain- or stress-based failure of fuel rods during NCT unlikely
- Fatigue during NCT does not appear to be an issue

Empirical evidence for these conclusions:

↓

Transport experience France

Experience and gap analysis on used fuel and dry cask components behaviour in transport and storage (Slide 9)
Herve ISSARD, TN International - ESCP International subcommittee meeting, Tokyo 2014

More than 75,000 LWR used fuel assemblies transported

(from France, Japan, Germany, Belgium, Switzerland, the Netherlands, Italy)

About 7,500 loaded casks with LWR assemblies

La Hague reprocessing plant has received 15,156 assemblies … with burn-up greater than 45GWd/tU (from EDF)

No assemblies have ever been damaged during transport

No damage to or leaks of the casks has ever occurred

*"The information is associated to **AREVA TN packages, transport means and operational experience.**"*

AREVA

AREVA TN information EDF website:
http://www.edf.com/fichiers/fckeditor/Commun/En_Direct_Centrales/Nucleaire/General/Notes_Info/Note_info_transport_comb._dechets_nucl_082010.pdf