SAND2016-0097C

Used Fuel Disposition Campaign

Normal Transport Loads on a Surrogate PWR Fuel Assembly

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Used Fuel Disposition

SNL Shaker 2013	Over-the-Road Truck Test - 2014	DCL Multi-axis Shaker 2015
		
Normal Conditions of Transport Truck	*Normal Conditions of Transport Truck*	*Normal Conditions of Transport Truck and Rail*

Used Fuel Disposition

SNL Shaker	Over-the-Road Truck Test	DCL Multi-axis Shaker
Truck NCT shock and vibration: • Loadings taken from NUREG/CR-0128: "Shock and Vibration Environments for a Large Shipping Container During Truck Transport (Part II)" **Vertical accelerations only** • 6 vibration/5 shock tests • ≥ 3 Hz	**Over-the-road truck test:** • Simulated over-the-road test to compare strains with the shaker table tests • Simulated mass of trailer plus package • Conducted test over 40 miles to simulate various road conditions and speeds	**Multi-axis (6) shaker tests:** • Truck NCT shock and vibration: NUREG/CR-0128 • Rail NCT shock and vibration: constructed load vibration and shock data from TTCI to simulate deck loading expected on the S-2043 rail car • Added lead pellets and Mo pellets to better simulate fuel **Six degrees of freedom** • 5 truck shock/5 truck vibration • 5 rail shock/5 rail vibration • 9 rail coupling shock • ≥1 Hz

Shaker Tests at Dynamic Certification Laboratories

Used Fuel Disposition

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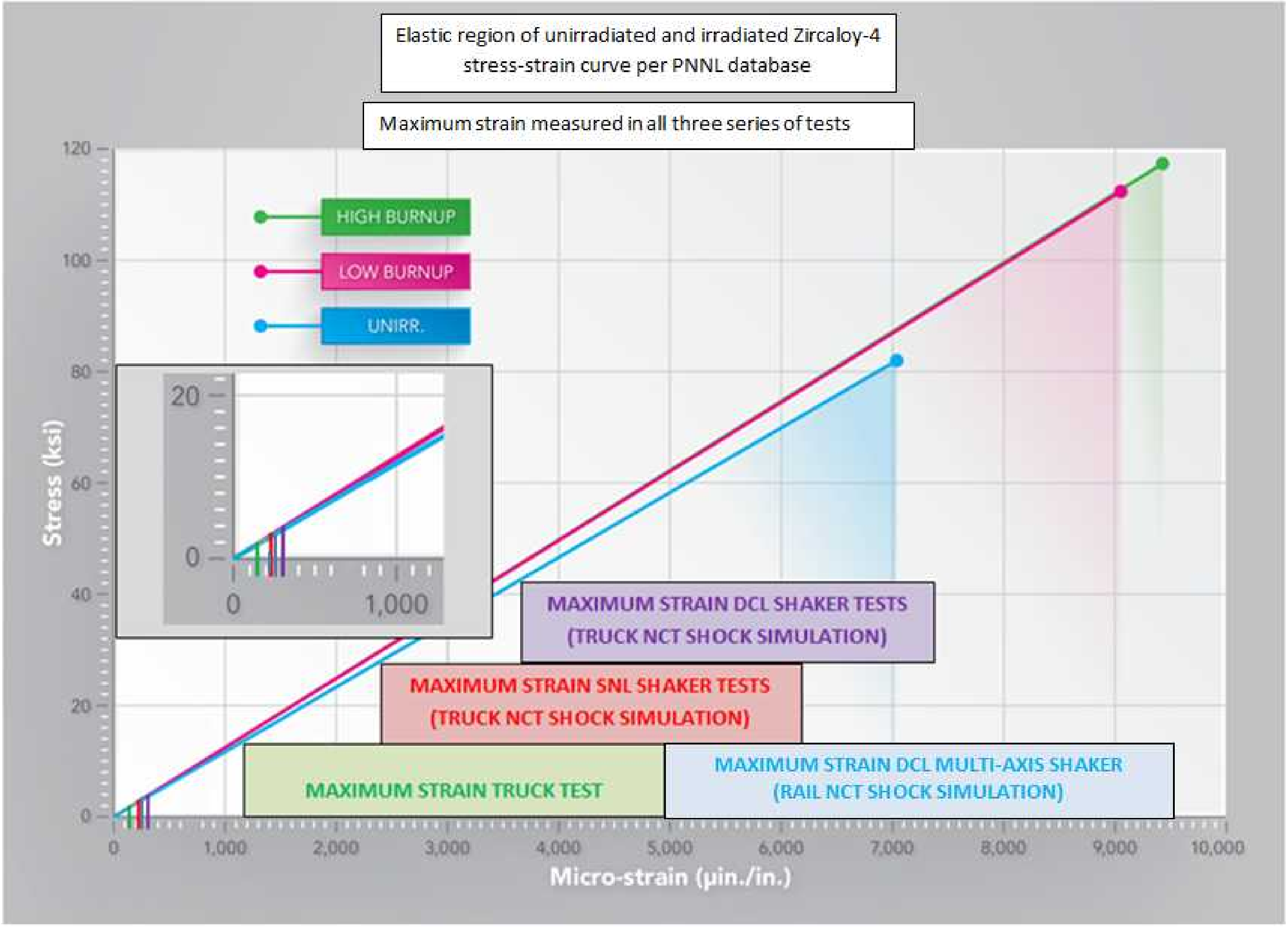
Maximum measured strains relative to elastic limits

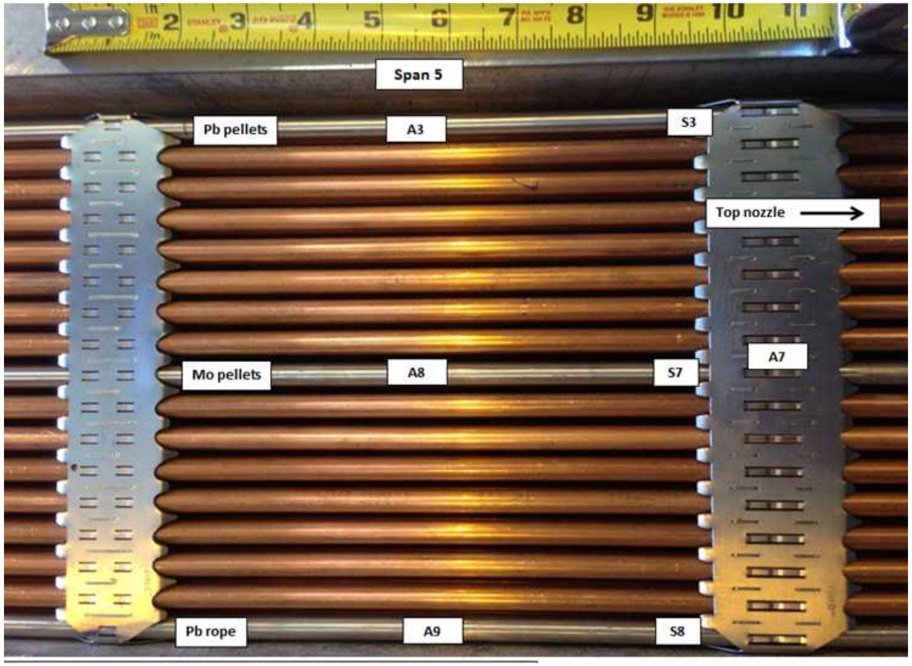


Comparison of strains from all three test series at similar locations on assembly

Strain Gauge ID	Location on Assembly: Adjacent to first spacer grid, Span 5	Sandia Shaker Truck Shock Test Maximum Strain Absolute Value (µin/in)	Truck Test Maximum Strain Absolute Value (µin/in)	DCL Shaker Truck Shock Test Maximum Strain Absolute Value (µin/in)
S3 - 0° Pb "rope"	Middle rod		143	
TMR-G-S5-2 (0°) Pb "rope"	Middle rod	119		
S3 - 0° Pb pellets	Right-edge rod			160
S7 - 0° Mo pellets	Middle rod			214
S8 - 0° Pb "rope"	Left-edge rod			301

Comparison of micro-strains on different rods: no significant differences in rods with pellets and rod with Pb "rope"

TEST 9 Rail Shock – Basket Loadings	Pb-"rope" rod	Mo-pellet rod	Pb-pellet rod
	S8	S7	S3
0°	172	44	112
90°	171	225	241
225°	109	182	209
TEST 12 Truck Shock	Pb-"rope" rod	Mo-pellet rod	Pb-pellet rod
	S8	S7	S3
0°	192	214	160
90°	165	108	95
225°	301	146	135

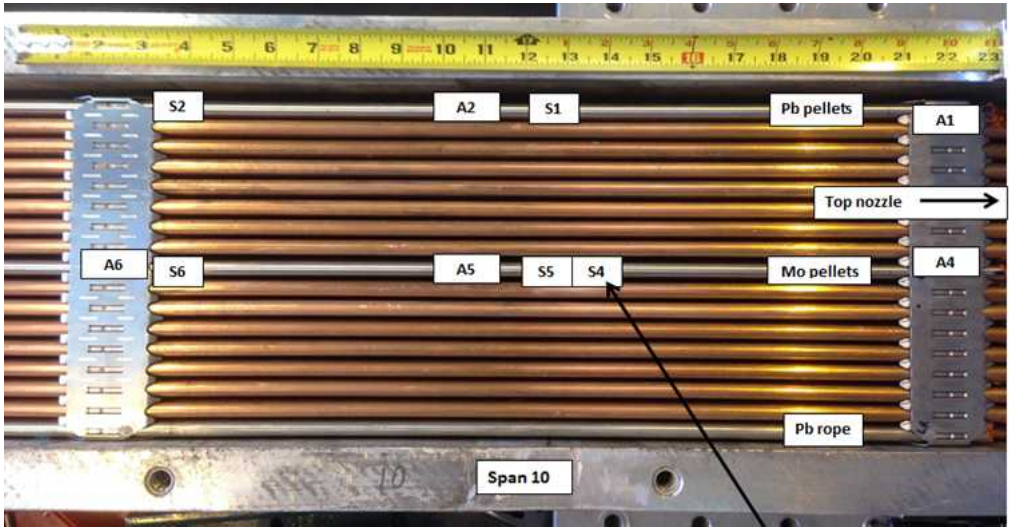


TEST 10xyz-3 Rail coupling	Pb-"rope" rod	Mo-pellet rod	Pb-pellet rod
	S8	S7	S3
0°	130	91	104
90°	82	34	30
225°	208	47	77

Comparison of micro-strains at pellet-pellet interface v. strain on single pellet: virtually no difference in strains measured

TEST 9 Rail shock – Basket Loadings	Mo-pellet rod S.G. straddled pellet-pellet gap	Mo-pellet rod S.G. straddled single pellet
	S5	**S4**
0°	67	52
90°	118	108
225°	83	81

TEST 12 Truck Shock	Mo-pellet rod S.G. straddled pellet-pellet gap	Mo-pellet rod S.G. straddled single pellet
	S5	**S4**
0°	149	158
90°	52	56
225°	104	114



Fatigue assessment:

Bending moments applied in ORNL irradiated fuel tests exceed NCT bending moments

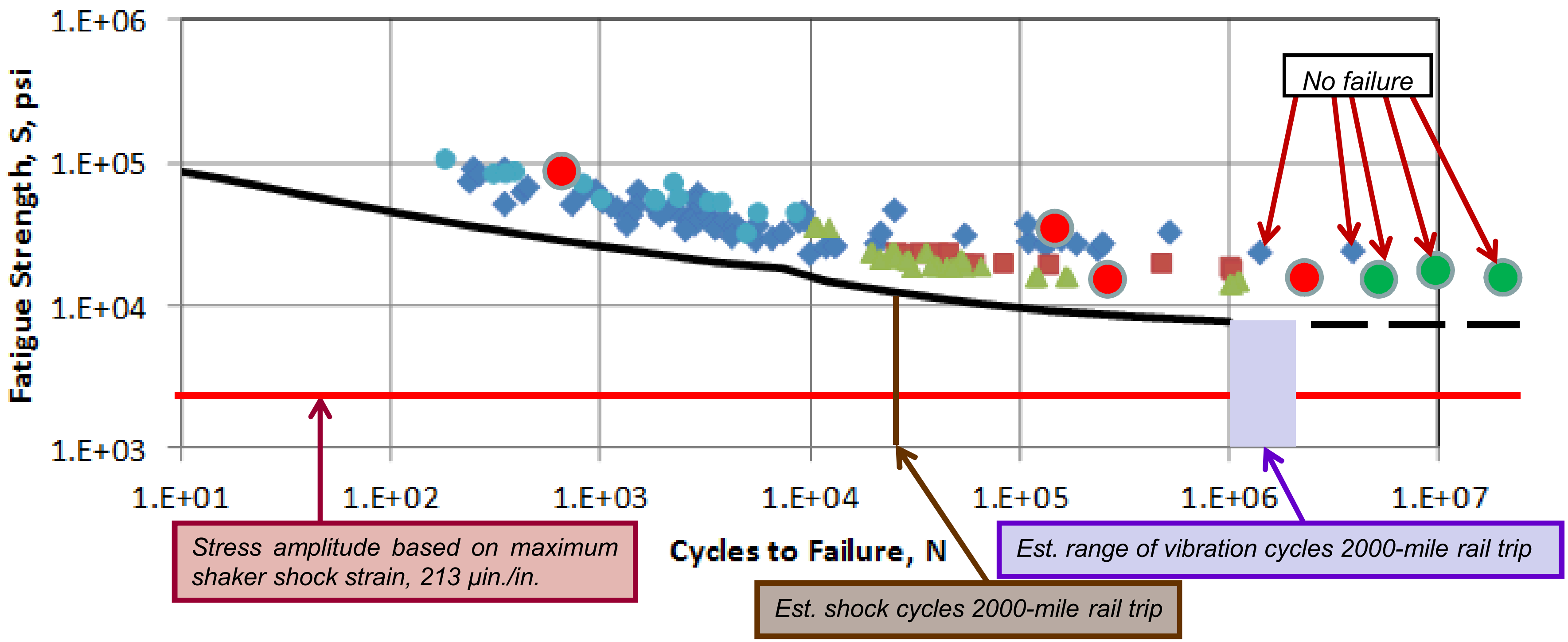
Selected ORNL HB Robinson Zircaloy-4 fatigue test data							
Specimen	Burnup (GWd/MTU)	Applied Bending Moment, M (N-m)	Curvature, κ_{max} (m^{-1})	Strain (µm/m)	Stress (lb/in^2)	Cycles $x10^6$	Failure?
D2	63.8	5	0.16	862	1.15E4	6	NO
D4	66.5	7.6	0.23	1239	1.65E4	11	NO
D5	66.5	9	0.22	1185*	1.58E4	2.3	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 $[\kappa_{max}/.22]$ x 1185)

Q: How many cycles to failure for a bending moment of 0.7 N-m?

Answer: cycles to failure should be > 22.3 $x10^6$

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

What these tests tell us:

- **The strains measured on the rods during the NCT test simulations 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 and rail transport, failure of fuel rods during normal transport seems unlikely**
- **Fatigue during transport does not appear to be an issue -**
  We still need to assess cumulative effects from shock
- **These results have received positive feedback from the NRC, NWTRB, and the technical community**
- **These results correlate with the used nuclear fuel transportation experience of Areva in France, i.e.: no rod failures during NCT**

Plans for completing this work

- **Prepare Test Plan (FY16) for tests (FY17) of PWR assemblies…**
  - within a rail-cask basket which is…
  - within an actual rail cask which is…
  - on a rail car which will then be…
  - transported over commercial rail lines, and

  at the AAR Transportation Technology Center, Inc.

- **Rail cask tests plan to use an Ensa ENUN 32P cask**

These rail tests will:
- *Add to the library of NCT rail loadings*
- *support future licensing and transport of UNF*
- *support public acceptance of rail transport*