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MEASUREMENT OF STRAIN AND ACCELERATION INDUCED ON FUEL RODS IN A SURROGATE PWR ASSEMBLY SUBJECTED TO NORMAL CONDITIONS OF TRUCK TRANSPORT LOADINGS

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INTRODUCTION

Long-term storage and subsequent transportation of high-burnup used nuclear fuel (UNF) is an issue requiring quantitative knowledge of UNF material properties and its response to mechanical loadings during transport. The fuel cladding is the first line of defense for containment of the used nuclear fuel; therefore, it is important to understand if cladding can maintain its integrity during Normal Conditions of Transportation (NCT), as defined in the U.S. Nuclear Regulatory Commission (NRC) regulations, 10CFR71.71 [1].

The objective of the test series conducted at Sandia National Laboratories was to gather strain and acceleration shock and vibration loadings on simulated fuel rods in a representative 17x17 PWR assembly. Data from these tests will then be coupled with degraded cladding mechanical property data to conduct finite element analyses. This work will provide important insights on the ability of used fuel, particularly high burnup used fuel, to maintain its integrity during normal conditions of transport.

This work has been reported at the PATRAM 2013 conference [2].

BASIS OF TEST

The *ideal test* would be to place an *irradiated fuel assembly* in an *actual cask* and do *over-the-road/rail tests* to measure the vibrational and shock response of the rods to the transport conditions. But, performing such a test with an irradiated assembly would be costly and instrumenting high-burnup cladding would be impractical due to high personnel radiation exposures.

Due to these conditions, the practical alternative was to place an unirradiated surrogate fuel assembly on a shaker table and subject the assembly to vibration and shock loadings that simulating normal conditions of transport during a truck shipment.

TEST PARAMETERS

Surrogate PWR Fuel Assembly

Zircaloy-4 rods were placed within the assembly at the top-middle rod location; a top-side location; and the bottom-side location below the top-side Zircaloy-4 rod. Copper tubes were placed at the other locations. Pre-test modeling [3] indicated that all the rods should experience similar loading and so the location of the instrumented rods within the assembly was arbitrary. Based on the pre-test modeling, instrumentation was placed at various locations on these three rods at the midpoint between selected spacer grid supports and adjacent to the spacer grids to provide a representative profile of the loading on the rods. The tests employed 16 strain gages and 25 accelerometers.

Figure 1 shows the surrogate PWR assembly in the basket and strain gage and accelerometer placement.

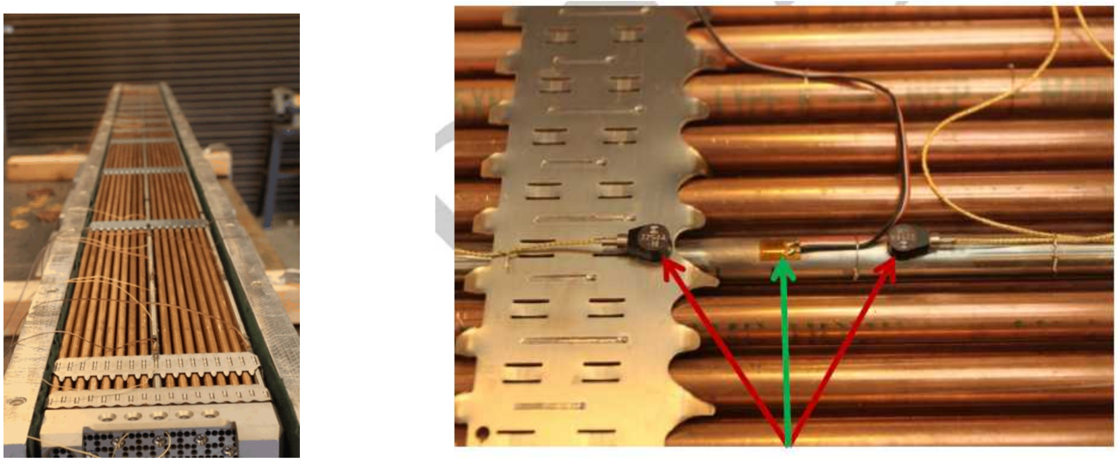

Figure 1. Left photo showing the surrogate assembly in the basket and right photo showing strain gage (green arrow) and accelerometer (red arrows) placement.

Shaker Table Input Specifications

Figure 2 shows a picture of the surrogate assembly in the basket on the shaker table. Input for the shaker was derived from data in "Shock and Vibration Environments for a Large Shipping Container During Truck Transport (Part II)", NUREG/CR-0128 (SAND Report 78-0337), 1978 [4]. Key details from NUREG/CR-0128 are:

- Vibration and shock data were measured by accelerometers over a 700-mile (1127 km) journey. Two tests, two casks.
- 56000-pound (25401 kg) cask and 44000-pound (19958 kg) cask.
- Measurements were taken on the external body of the casks.
- Speeds ranged from 0 to 55 mph (0 to 89 km/h).

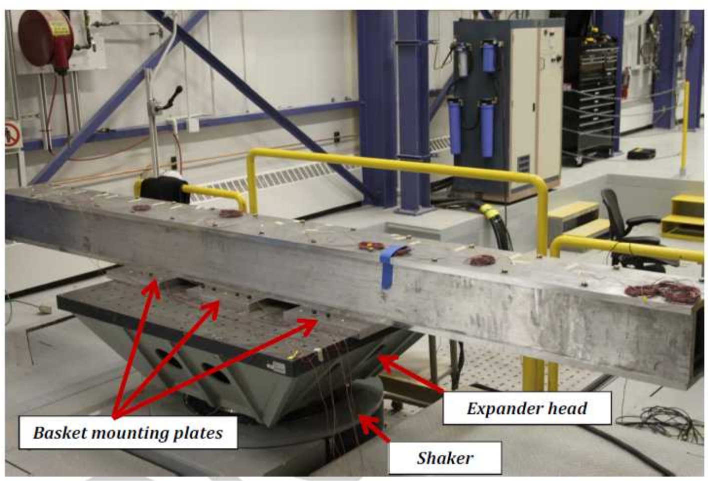

Figure 2. Basket containing assembly on the shaker.

RESULTS

Figure 3 provides a roll-up of the strain data and relates it to yield stress for elastic conditions. In general, the recorded strains are well below yield level strains. This provides an indication that the fuel operating under elastic conditions will survive normal conditions of transport. There is work that needs to be done to better understand performance under inelastic conditions (i.e., brittle fracture behavior). This is especially important for high burnup used fuel.

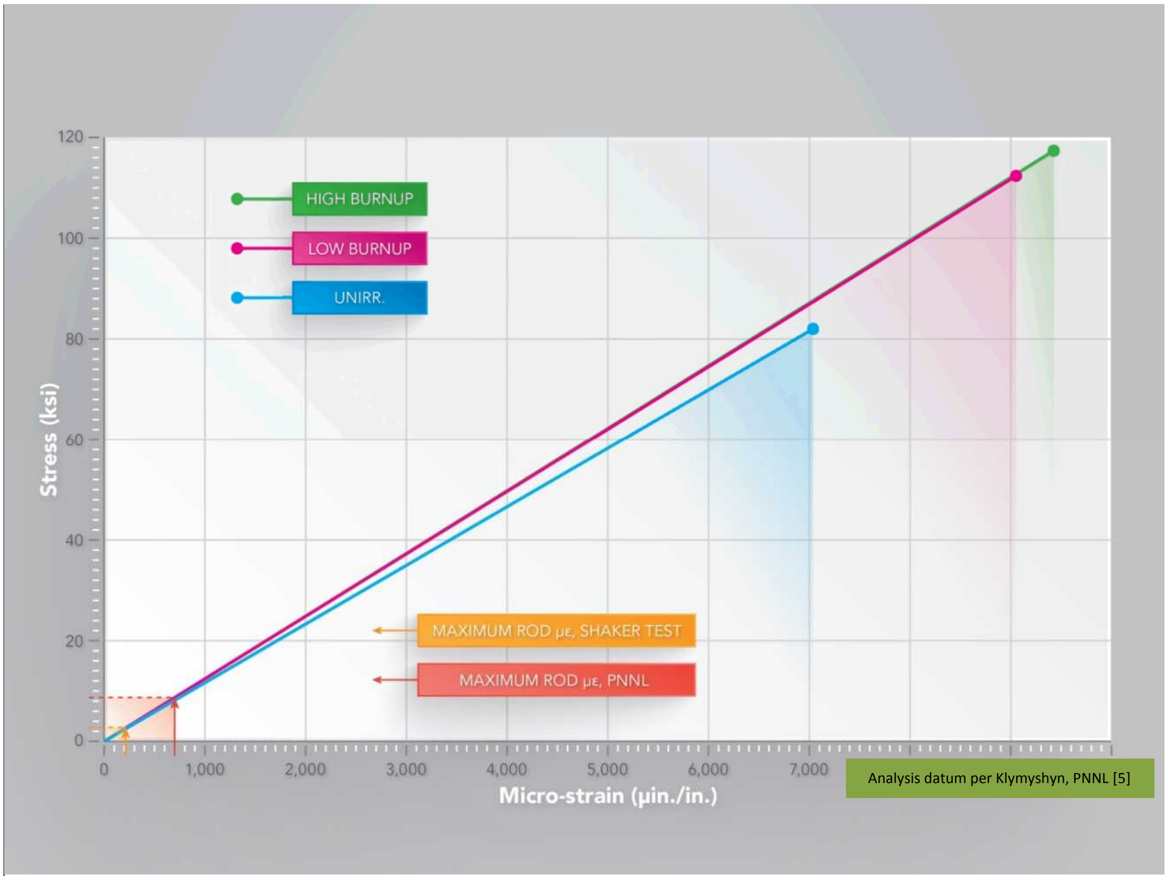

Figure 3. Elastic portion of stress—strain curve for Zircaloy-4 [7], unirradiated, 100°F; low burnup, 250°F; and high burnup, 250°F.

CONCLUSION AND FUTURE PLANS

The strains measured in the shaker 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.

Future plans for measuring strains on an assembly are to 1) perform tests on the assembly/basket test unit on the Sandia shaker using rail vibration and shock inputs; 2) perform tests on the assembly/basket test unit on a seismic shaker down to 1 - 2 Hz using truck and rail vibration and shock inputs; and 3) instrument an assembly for actual over-the-road testing.

REFERENCES

[1] Code of Federal Regulations, Title 10, Part 71, "Packaging and Transportation of Radioactive Material."
[2] McConnell, Paul; Ammerman, Doug; Sorenson, Ken; "Loading on Fuel Rods in a Surrogate PWR Assembly Subjected to Simulated Normal Conditions of Truck Transport", Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2013, August 2013.
[3] Klymyshyn, Nicholas; "Shaker Table Modeling Progress Report," #UFDCST-120927-1, Pacific Northwest National Laboratory, September 2012.
[4] Magnuson, Cliff F., "Shock and Vibration Environments for Large Shipping Container During Truck Transport (Part II)," NRC NUREG/CR-0128, May 1978; and Magnuson, Cliff F., "Shock and Vibration Environments for Large Shipping Container During Truck Transport (Part I)," SAND77-1110, September 1977.

[5] Klymyshyn, Nicholas, Sanborn, Scott, Adkins, Harold, and Hanson, Brady; "Fuel Assembly Shaker Test Simulation," FCRD-UFD-2013-000168, Pacific Northwest National Laboratory, May 2013.