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SAND2015-4409C

High Burnup Spent Fuel Data Project

IAEA International Conference on Management of Spent Fuel from Nuclear Power Reactors

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Why Do the High Burnup Spent Fuel Data Project?

- **We need data to confirm our understanding of degradation mechanisms over extended periods of time.**
  - Need the capability to store fuel for more than 20 years and then be capable to transport
  - Little data are publicly available on the behavior of high burnup fuel during dry storage and its subsequent handling and transportation.
  - The physical state of high burnup cladding when fuel is placed into dry storage
  - Cladding-degradation mechanisms, their interactions with fuel pellets, and the expected behavior of cladding
  - Conditions that affect degradation mechanisms, such as predictions of the fuel temperatures over time and the amount of residual water present after drying.

TN 32 that is very similar to the cask that will be used for the project

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Goals of the High Burnup Spent Fuel Data Project

- **The near-term activities focus on experimental and analytical work that can be conducted immediately, without any modification to existing facilities.**
  - Test plan development
  - Fuel assembly selection
  - Instrumentation
- **The long-term activities will focus on an actual research and development (R&D) program for the inspection and monitoring of spent fuel in storage over a longer period of time.**
  - Gas sampling
  - Thermal monitoring
  - Sister pin evaluation to get baseline data
- **The goals for such R&D include the following:**
  - Benchmarking the predictive models and empirical conclusions that will be developed from short-term laboratory testing for aging of dry storage cask system components; and
  - Building confidence in the ability to predict the performance of these systems over extended time periods.
  - Validating used fuel performance, especially high burnup fuel, over extended storage periods, followed by transportation.

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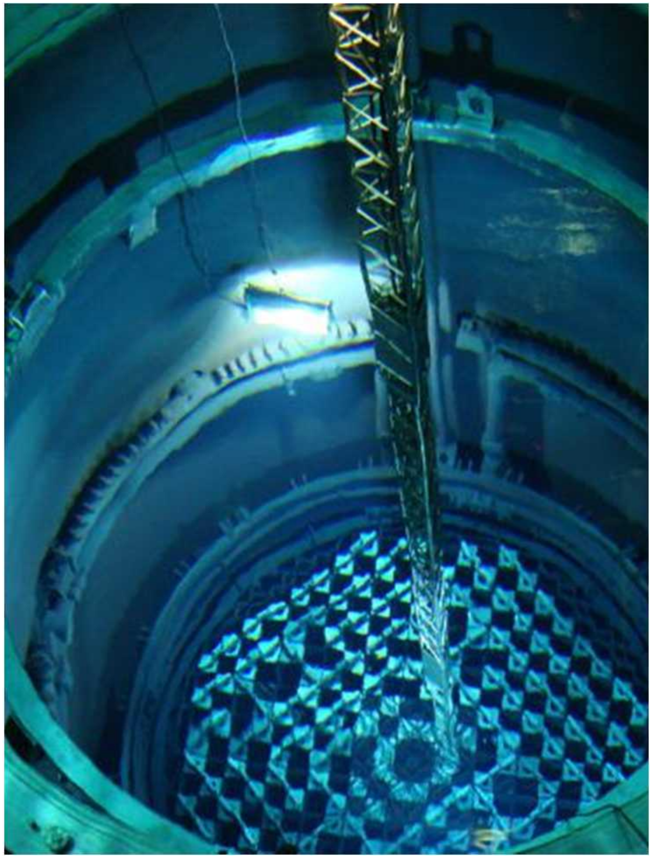
High Burnup Spent Fuel Data Project

Involves

- Loading a commercial TN-32B storage cask with high burn-up fuel in a utility storage pool
  - Well characterized fuel (using Z-4, Zirlo, and M5 high burnup fuels)
  - Cask outfitted with additional instrumentation for monitoring
  - License amendment required for lid design and additional heat load
- Drying of the cask contents using typical process
- Cask will be housed at the utility's dry cask storage site
  - Gas sampling and externally inspection before transferring out to the pad
- The issue of where and how the cask will be opened after the storage period will be solved at a later date.



High Burnup Spent Fuel Data Project Participants

- **Industry:** contract was awarded to EPRI on April 16, 2013

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Dominion

AREVA Federal Services
AREVA Transnuclear
AREVA Fuels

Westinghouse

- **National Labs**

Sandia National Laboratories

INL Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

Savannah River National Laboratory™
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EPRI Contract Summary

Contract Requirement	EPRI Contract
PWR Reactor	North Anna
Cladding Types	Zircaloy 4 – Westinghouse Zirlo, - Westinghouse M5 – AREVA
Demo Cask	Trans-nuclear 32B - -Certified for General License use -The lid will be redesigned to support instrumentation and transportation -A design and licensing basis document (DLBD) will support licensing the cask for use at North Anna
Contract Duration	5 years (April 2018)
Cost Share	20%

Activities for the EPRI Contract 2013-2018

- Acquire the cask
- Modify the cask lid for instrumentation
- Develop a design and licensing basis document
- Extract sister rods
- Plan the fuel loading
- Ship sister rods
- Secure the license amendment
- Load fuel in the cask
- Store and monitor the cask at North Anna

Next Contract Activities 2018 to 2027

- **Ship the cask to a DOE facility**
  - Eliminates the need to re-wet the cask and fuel
- **Open the cask and pull selected fuel rods**
- **Perform testing on the rods for comparison to initial conditions from previously tested sister rods**
- **Prepare report on the effects of aging on the fuel**

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Monitoring the Cask 2017

- **Cask cavity data acquisition will begin before the cask is drained**
  - Thermocouple data recorded on a data logger at regular intervals
- **After backfill and pressurizing, the cask will remain in cask prep bay for 2-3 weeks for cavity temperature, pressure, and gas composition monitoring**
- **Periodic cavity gas samples will be obtained and analyzed**
  - Fission gas
  - Hydrogen content
  - Oxygen content
  - Moisture data will provide immediate valuable insight to cask drying method

Monitoring the Loaded Cask 2017 to 2027

- **While on the pad…**
  - Cask fuel and cavity monitoring will continue
  - Fuel thermal data measured on regular basis (e.g. twice daily)
  - Data downloaded and reported on periodic basis (e.g., quarterly)
  - Cask cavity samples for composition analysis are planned on an infrequent basis
- **This process will continue until the cask is shipped offsite**

Licensing

- **Cask to be loaded is a TN-32B cask**
  - Initially fabricated and certified to meet CoC 72-1021 requirements
  - Cask is capable of storing high burnup fuels, but storage of high burnup fuel wasn't a priority at the time this cask was originally licensed
- **Dominion will seek a license amendment to North Anna's site specific ISFSI license**
- **The Design and Licensing Basis Document provides the analytical bases and conclusions for departures from the existing approved analyses in the General License TN-32 FSAR**
  - New lid design
  - New criticality safety analysis
  - Including additional neutron absorbers
  - New thermal analysis
  - New radiological analysis
- **North Anna is currently preparing the License Amendment Request (LAR)**

Current Project Schedule

High Level Milestones

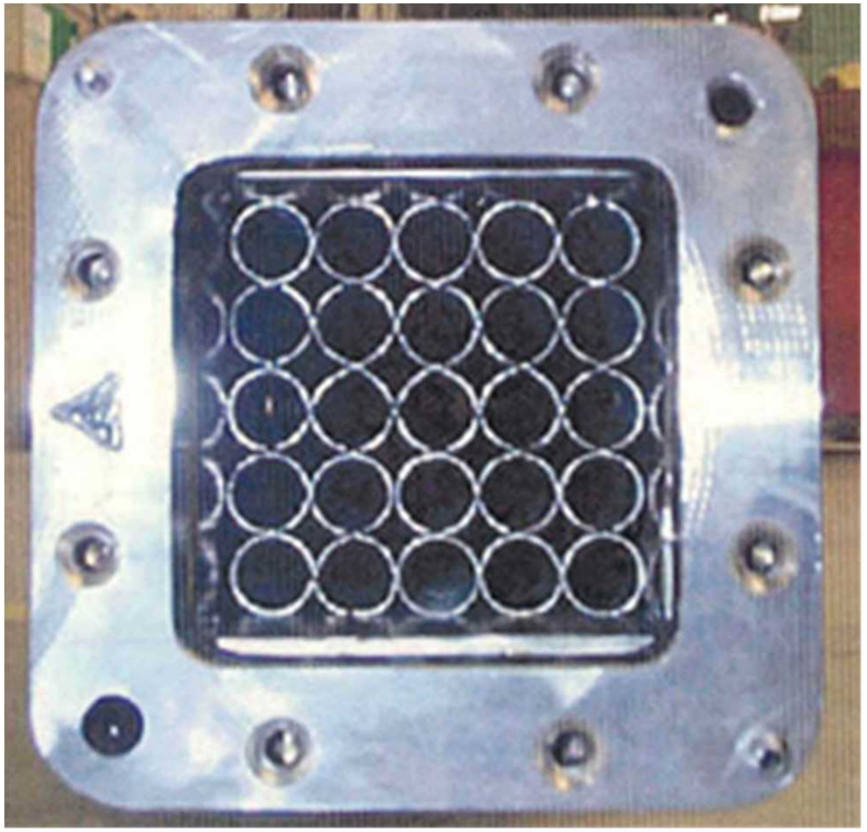
- 12/31/14: TN completes DLBD
- 1/31/15: Phase 1 sister rods extracted
- 6/30/15 Phase 2 sister rods extracted
- **7/31/15: Dominion submits LAR to NRC**
- 1Q16: Sister rod shipment
- 1/31/17: Expected NRC review completion
- 3/15/17: Cask Delivered to North Anna
- 6/30/17: Dry run and functional tests complete
- 7/31/17: Cask loading complete – begin initial monitoring
- 8/21/17: Cask emplaced at pad/Begin at-pad monitoring

Sister Rod Selection

Objective of sister rod tests:

Obtain initial data on fuel to provide benchmark comparisons for test data obtained from the demo fuel after long term storage.

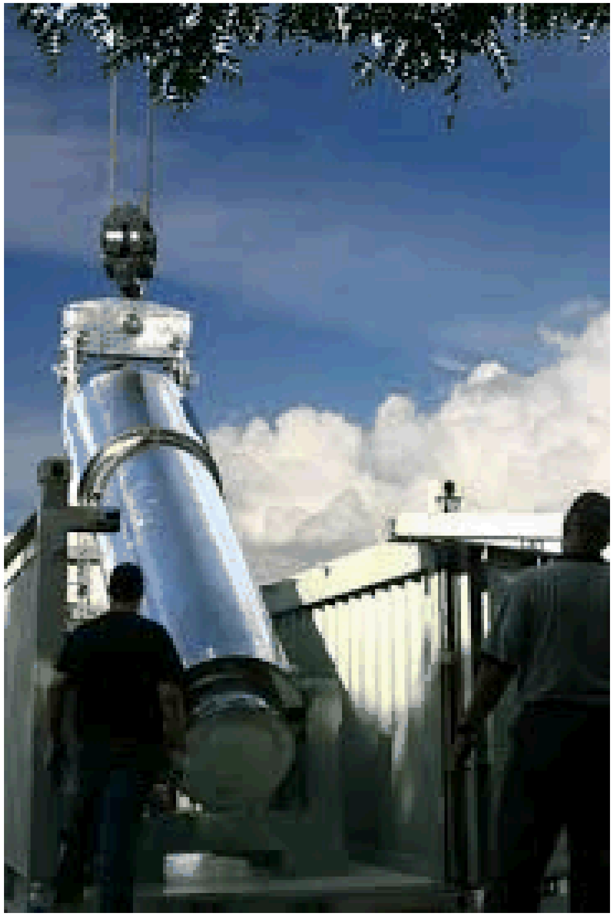
- **25 fuel rods from representative fuel assemblies**
- **These rods form the basis for pre-storage characterization**
  - Nine Areva M5™ rods
  - Nine Westinghouse Zirlo™ rods
  - Four Westinghouse Low-tin zircaloy-4 rods
  - Three Westinghouse standard zircaloy-4 rods



NAC LWT basket for shipping rods

Sister Rod Schedule

- **Rod extraction efforts underway**
  - Areva rods were pulled in January 2015
  - Westinghouse rods were pulled in June 2015
- **Rods will be shipped in first quarter of 2016**



Sister Rod Data Gaps to be Filled

- **Subcriticality (burn-up credit and moderator exclusion) – radionuclide inventory in fuel rods**
- **Stress profiles – mechanical strength of the fuel rod**
- **Fuel Transfer Options – ensure fuel is handled in a prototypic manner**
- **Cladding – annealing of radiation damage**
- **Cladding – H_2 effects, reorientation and embrittlement**
- **Cladding – H_2 effects, delayed hydride cracking**
- **Cladding – oxidation**
- **Cladding – creep**
- **Fuel Assembly Hardware – stress corrosion cracking (SCC) of lifting hardware and spacer grids**

Possible Sister Rod Tests

- Receipt Visual Inspection
- Visual Examination
- Rod Profilometry
- Eddy Current Examination
- Gamma Scanning
- Metrology
- Neutron Radiography
- Destructive Post-Irradiation Examination
- Gas Pressure
- Fission Gas Sampling
- Free Volume Determination
- Fuel Microstructure
- Optical Microscopy
- Hydrogen in Cladding
- Rod Bow Determination
- Microhardness Testing
- Electro-Optical Examinations
- Radio-Analytical Chemistry
- Microchemistry
- Micromechanical Testing
- Fuel Fines Capture and Analysis
- Thermal Treatment to Mimic Drying
- Retained Water on Clad
- Ring Compression Test
- CIRFT
- 4 Pt. Bent Test
- Fuel Density

Possible Sister Rod Testing Program

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Donor Assemblies and Fuel Rods

		30A					5K7				6U3							3F9			3D8		3A1 (2 Cycles)		F35 (4 Cycles)	
Fuel Information	Cladding and initial enrichment	M5 Cladding, 4.55 wt% U-235					M5 Cladding, 4.55 wt% U-235				Zirlo Cladding, 4.45 wt% U-235							Zirlo Cladding, 4.25 wt% U-235			Zirlo Clading 4.2 wt% U-235		Low-Tin Zircaloy-4 Clad, 4 wt% U-235		Zircaloy-4 Cladding 3.59 wt% U-235	
Fuel Information	Sister Rod	G9	K9	D5	E14	P2	P2	C5	K9	D14	I7	M9	K9	L8	O5	M3	P16	N5	D7	P2	E14	B2	B16	F5	P17	K13
Fuel Information	Key Characteristics	Sister rod to assembly rod in assembly 57A lance position - close proximity to peak (hotest) rod position (I-7) in the cask	Sister rod to assembly rod in assembly 57A lance position - close proximity to peak (hotest) rod position (I-7) in the cask	D5 & E14 rods represents locations next to guide tubes that saw burnable poisons (E14) and ones that saw none (D5), this will influence power output during irradiation so pins are expected to have different characteristics even though they have burnups that are very close	See Rod D5	Next to area with core baffle jetting; based on final location in core for last irradiation cycle	Next to area with core baffle jetting; based on final location in core for last irradiation cycle being close to the canister edge in 3K7	Equivalent to the rod with peak burnup in othe sister assembly (3K7)	Sister rod to rod with proximity to thermocouple in assembly (3K7)	Approximately average assembly burnup	This rod mimics the 3 rods that will be isolated and heated to mimic conditions in the cask	Rod is next to a thermocouple lance position	Rod is next to a thermocouple lance position	Rod is next to a thermocouple lance position	Baseline rod at close to max burnup	Basline rod for comparison to 3U4 near max burnup in middle ring zone	Baseline rod for comparison to rod that should see fastest cooling rate in 3U6 (outer zone)	Pin for baseline parameters (selected based on matchup with sister assemblies)	Approximately average assembly burnup for baseline parameters	Approximate lowest burnup in assembly and close to edge of assembly	Highest burnup rod in assembly	Close to lowest burnup rod in assembly (selected based on pulling restriction)	Lowest burnup rod in assembly; reasonably close to outer edge of assembly	Highest burnup rod in assembly; reasonably close to center of assembly	Edge rod (likely to be of most interest from science standpoint)	Inner region rod for comparison against other Zirc-4 rods
Fuel Information	Planned Testing	Isolation/Heated	PIE	PIE	PIE	PIE	PIE	PIE	Isolation/ Heated	PIE	PIE	Isolation/ Heated	Isolation/ Heated	Isolation/ Heated	PIE	PIE	PIE	PIE	PIE	PIE	PIE	PIE	PIE	PIE	PIE	PIE
Fuel Information	Sister Assemblies	57A	57A	57A	57A		5K6,3K7,5K1	5K6,3K7,5K1	5K6,3K7,5K1	5K6,3K7,5K1	3U4,3U9,3U6	3U4,3U9,3U6	3U4,3U9,3U6	3U4,3U9,3U6	3U4,3U9,3U6	3U4,3U9,3U6	3U4,3U9,3U6	4F1,3F6,6F2	4F1,3F6,6F2	4F1,3F6,6F2	5D9,5D5	5D9,5D5	0A4	0A4	None (F40)	None (F40)
Fuel Information	Sister to this Rod in the Sister Assembly	I-7	I-7							C-4(5K6)	I-7(3U4); I-11(3U9); I-11(3U-6)	E-9(3U4)	K-9(3U9)	F-10(3U6)	C-5(3U4); O-13(3U9); C-13(3U6)	E-3(3U4)	B-2(3U6)	N-5(4F1); N-5(3F6); N-5(6F2)	D-7(4F1); D-7(3F6); D-7(6F2)		M-4(5D5); N-13(5D9)	P-16(5D5); B-16(5D9)	B-16	F-5		
Characterization and Testing	Full-Length High Resolution Visual Examination	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Eddy Current Oxide Thicknes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Eddy Current Clad Defects	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Rod Bow Determination	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Rod Length	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Rod Profilometry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Gamma Scan	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Characterization and Testing	Neutron Radiography		X	X				X						X	X			X			X					
Characterization and Testing	Thermal Heat Treatment for Hydride Reorientation	X							X			X	X	X												
Characterization and Testing	Pin Puncture, Interal Rod Pressure, Fission Gas Sampling	X	x	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X			X	X	
Characterization and Testing	Fission Gas Analysis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X			X	X	
Characterization and Testing	Isotopics (composition, burnup)	X		X	X	X			X		X	X			X	X		X								
Characterization and Testing	Total Hydrogen in Clad	X	X	X	X	X			X		X	X			X	X		X								
Characterization and Testing	Optical Microscopy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X			X	X	
Characterization and Testing	Optical Microscopy Hydrides	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X			X			X	X	
Characterization and Testing	SEM	X	X			X			X		X	X				X		X								
Characterization and Testing	TEM	?							?		?	?						?								
Characterization and Testing	FIB Mechanical Properties of rim, bond layer	X	X						X			X	X					X								
Characterization and Testing	RCT	X	X	X		X		X	X	X	X	X			X			X								
Characterization and Testing	CIRFT	X	X	X		X		X	X	X	X	X			X			X								
Characterization and Testing	4-Point Bend	X	X	X		X		X	X	X	X	X			X			X								
Characterization and Testing	Hardness Testing	X	X	X		X		X	X	X	X	X			X			X								
Characterization and Testing	Fuel Density	X	X	X		X		X	X	X	X	X			X			X								
Characterization and Testing	Retained Water on Clad	X	X						X		X	X												X	X	
Characterization and Testing	Capture Fuel Fines from a Ruptured Pin					X									X											

High Burnup Spent Fuel Confirmatory Data Project:

Questions, Concerns, Comments?