Used Fuel Disposition Campaign

FY15 Focus for the Used Fuel Disposition (UFD) Campaign

Storage and Transportation Research & Development

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INMM Spent Fuel Management Seminar XXX
January 12, 2015
Washington DC

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UFD Storage &Transportation R&D Focus

Objectives:

Contribute to –

1. the technical bases to demonstrate used fuel integrity for extended storage periods
2. the technical bases for fuel retrievability and transportation after long term storage
3. the technical basis for transportation of high burnup fuel

Focus of this presentation:

1. Three major topic areas incorporating experimental and analytical R&D
2. Collaborating with industry to integrate the R&D work with the DOE/Industry High Burn-up Storage Cask R&D Project

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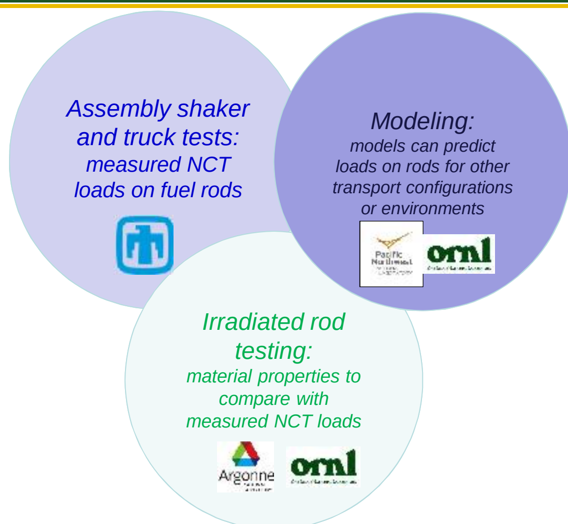
Topic 1:
Can high burnup irradiated rods withstand Normal Conditions of Transport (NCT)?



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Topic 1:
Can high burnup irradiated rods withstand NCT?

Cladding and fuel behavior of high burnup used fuel under NCT loading

Fundamentally: ***applied stress/strain < material strength***

Requires determination of:
- ***Applied loads on the fuel***
- ***Measured strains***
- ***Calculated stresses***

Requires determination of:
- ***Material properties***
  - ***Yield/ultimate strength***
  - ***Ductility***
  - ***Fracture toughness***
- ***Constitutive relationships***
- ***Pellet-clad interaction***

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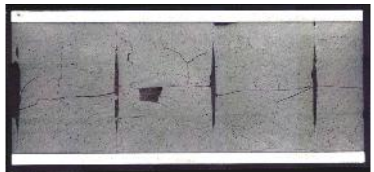
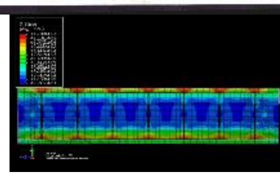
Material properties:
- Cladding and fuel response to cyclic loadings
- Pellet/clad interaction (PCI)

Note: NRC initiated and funded development of test apparatus, procedures and data collecting. Funding for FY14 efforts was shared by NRC and DOE.

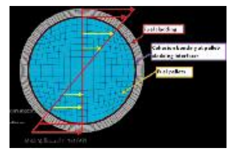


Pellet-Clad & Pellet-Pellet Bonding

CIRFT test apparatus developed at ORNL
CIRFT: Cyclic Integrated Reversible-bending Fatigue Tester



In-cell measured displacements and applied moment provides necessary data for strain/stress calculations



Due to PCI, fuel provides structural support to applied load

Jy-An Wang; Oak Ridge National Laboratory, 2014 ASTM C26 Committee Meeting, June 2014

Jy-An Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

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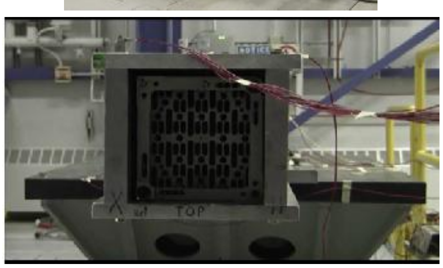
Normal Conditions of Transport: Fuel Assembly Loadings



2013 Shaker Table Test

2014 Over-the-road Test

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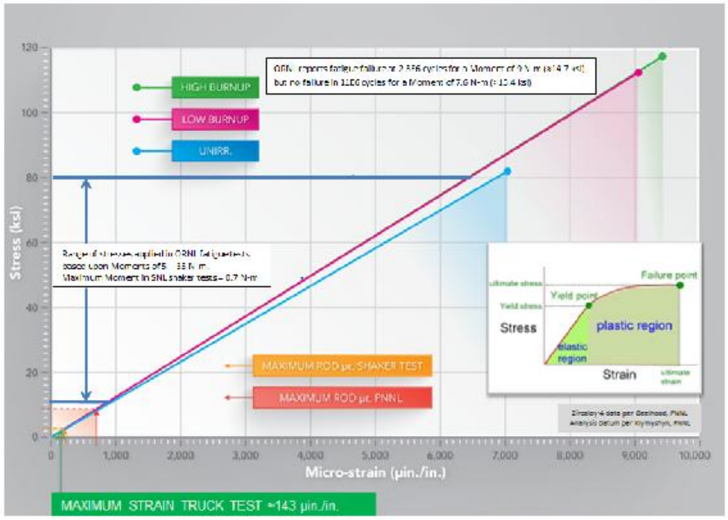
Measured strains very low relative to elastic limit of Zircaloy



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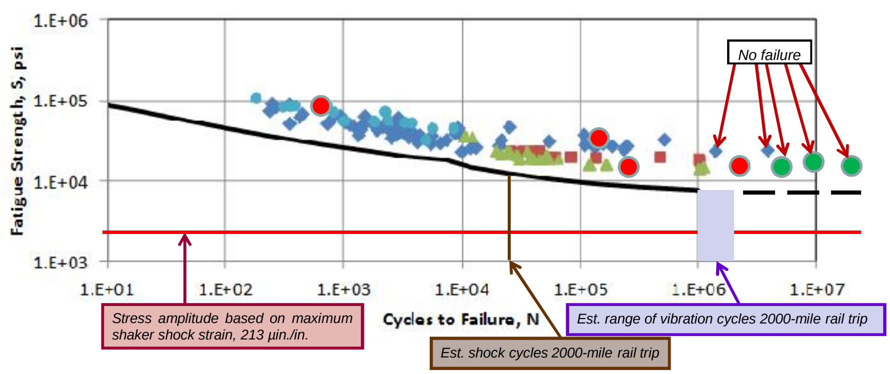
NCT vibrations unlikely to result in fatigue failure



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, PNNL
The large circles are courtesy of ORNL

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Topic 1
NCT Conclusions

- The strains measured on the rods in the surrogate PWR 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
- Preliminary investigations suggest that HBU spent fuel will maintain its integrity when subjected to NCT loading conditions

Anecdotal evidence from transport experience in France:

- 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

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

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

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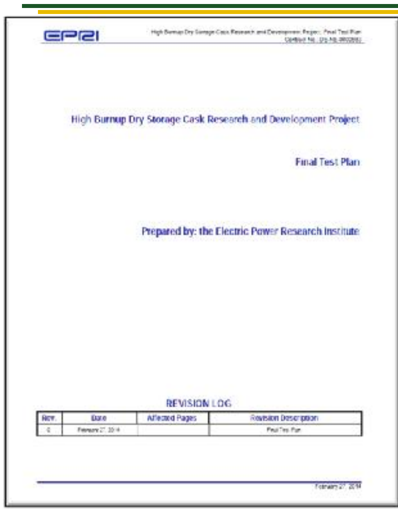
Topic 2
High Burn-up Storage Cask R&D Project: Specific activities supported to date


High Burnup Dry Storage Cask Research and Development Project

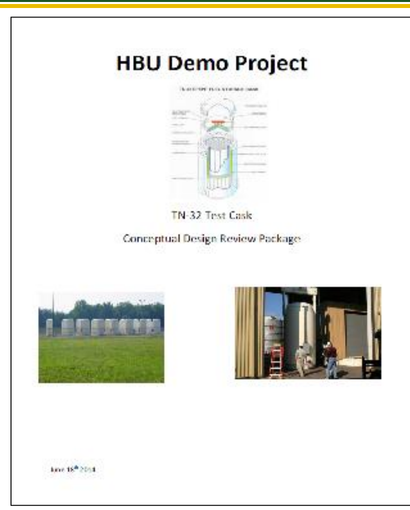
Final Test Plan

Prepared by: the Electric Power Research Institute

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	February 27, 2014		Final Test Plan

Test Plan review and comment
- *Final Test Plan published February 2014*



Conceptual design review
- *June 2014*

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High Burn-up Storage Cask R&D Project: Specific activities supported to date

Identify specific fuel assemblies to place in the demo cask

- *High burnup fuel (>45 GWd)*
- *All typical cladding types*
  - *Zr-4*
  - *Low tin Zr-4*
  - *Zirlo*
  - *M5*
- *Drive internal temps as close to 400º C as possible (regulatory limit)*

- *Impact*
  - *Prototypic storage conditions*
  - *Realistically high thermal loadings*
  - *Addresses regulatory hydride concerns*

	1 6T0 Zirlo, 54.2 GWd 4.25%, 3cy, 11yr 1013/819W	2 (TC Lance) 3K7 M5, 53.4 GWd 4.55%, 3cy, 8yr 1167/838W	3 3T6 Zirlo, 54.3 GWd 4.25%, 3cy, 11yr 1015/821W	4 6F2 Zirlo, 51.9 GWd 4.25%, 3cy, 13yr 909/757W	DRAIN PORT
5 3F6 Zirlo, 52.1 GWd 4.25%, 3cy, 13yr 914/762W	6 (TC Lance) 30A M5, 52.0 GWd 4.55%, 3cy, 6yr 1276/832W	7 22B M5, 51.2 GWd 4.55%, 3cy, 5 yr 1637	8 20B M5, 50.5 GWd 4.55%, 3cy, 5 yr 1608	9 5K6 M5, 53.3 GWd 4.55%, 3cy, 8yr 1163/834W	10 5D5 Zirlo, 55.5 GWd 4.2%, 3cy, 17yr 906/797W
11 Vent Port 5D9 Zirlo, 54.6 GWd 4.2%, 3cy, 17yr 885/779W	12 28B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1629	13 F52 Zirc-4, 58.1 GWd 3.59%, 4cy, 28yr 858/805W	14 (TC Lance) 57A M5, 52.2 GWd 4.55%, 3cy, 6yr 1281/835W	15 30B M5, 50.6 GWd 4.55%, 3cy, 5 yr 1614	16 3K4 M5, 51.8 GWd 4.55%, 3cy, 8 yr 1162/803W
17 5K7 M5, 53.3 GWd 4.55%, 3cy, 8yr 1165/836W	18 50B M5, 50.9 GWd 4.55%, 3cy, 5 yr 1625	19 (TC Lance) 3U9 Zirlo, 53.1 GWd 4.45%, 3cy, 10yr 1037/806	20 0A4* Low-Sn Zy-4, 50 GWd 4.0%, 2cy, 22yr 725/665W	21 15B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1629	22 6K4 M5, 51.9 GWd 4.55%, 3cy, 8 yr 1162
23 3T2 Zirlo, 55.1 GWd 4.25%, 3cy, 11yr 1036/838W	24 (TC Lance) 3U4 Zirlo, 52.9 GWd 4.45%, 3cy, 10yr 1031/802W	25 56B M5, 51.0 GWd 4.55%, 3cy, 5 yr 1628	26 54B M5, 51.3 GWd 4.55%, 3cy, 5 yr 1645	27 6V0 M5, 53.5 GWd 4.4%, 3cy, 8yrs 1178/844W	28 (TC Lance) 3U6 Zirlo, 53.0 GWd 4.45%, 3cy, 10yr 1035/804W
	29 4V4 M5, 51.2 GWd 4.40%, 3cy, 8yr 1109	30 5K1 M5, 53.0 GWd 4.55%, 3cy, 8yr 1155/829W	31 (TC Lance) 5T9 Zirlo, 54.9 GWd 4.25%, 3cy, 11yr 1031/833W	32 4F1 Zirlo, 52.3 GWd 4.25%, 3cy, 13yr 918/765W	High Priority Assys

- *Outcome*
  - *Initial thermal analyses showed surprisingly low internal temperatures (~300º C)*
  - *Solution was to surround the middle four candidate assemblies with shorter-cooled assemblies to drive the temperatures up.*
  - *Final analyzed temperatures ~330º C, limited by the external neutron shield*

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High Burn-up Storage Cask R&D Project: Specific activities supported to date

Identify candidate fuel rods for t_0 testing

- *All typical cladding types*
  - *Zr-4*
  - *Low tin Zr-4*
  - *Zirlo*
  - *M5*
- *Range of burnups and duty cycles*
- *Use rods from assemblies that go into the demo*
- *Up to 25 rods will be pulled for testing (maximum payload for the NAC LWT cask)*

- *Impact*
  - *t_0 properties critical to understanding degradation mechanisms and rates during storage periods*
  - *Direct relation of sister rods to assembly rods in the demo cask; reduced uncertainties*

- *Outcome*
  - *Sister rod characterization provides the baseline data to assess cladding degradation and integrity*

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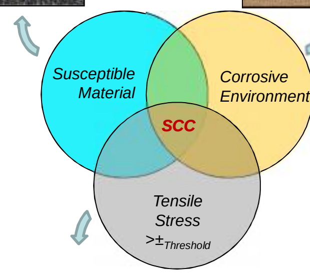
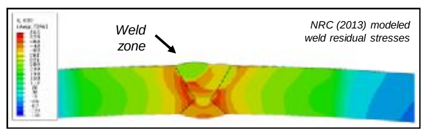
Topic 3: Stainless steel canister integrity during extended dry storage

- Dry storage casks currently in use may be required to perform their function for decades beyond their original design criteria
- SCC of welded stainless steel (304SS) canisters (85% of existing storage systems) is considered the most important potential failure mechanism (PNNL 2012)
- For SCC to occur, 3 criteria must be met;
  - *A susceptible material—304SS is susceptible to SCC*
  - *A corrosive environment — deliquescence of Cl-rich salts deposited as aerosols on the canister surface*
  - *Sufficient through-wall tensile stress—likely to be present in weld regions*
- UFD is working to evaluate each of these

Weld zone, 304 SS plate

Dust on canister surface at Calvert Cliffs (EPRI 2014)





NRC (2013) modeled weld residual stresses

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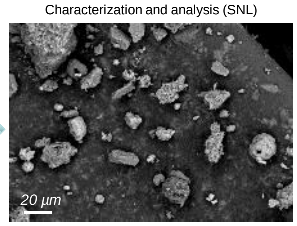
Stainless steel canister integrity during extended dry storage: Characterizing the Environment

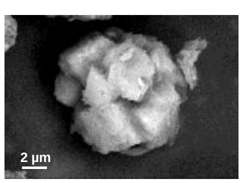
- Near-marine ISFSIs are of greatest concern (sea-salt aerosols)
- SNL is working with EPRI (CRADA) to sample, analyze, and interpret surface deposits on in-service storage canisters

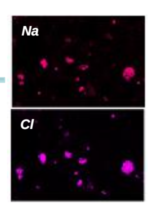
Sampling canister surface dust within an overpack (EPRI)

Characterization and analysis (SNL)



Spherical aggregate of sea-salts collected from canister surface





SEM/EDS element maps highlight NaCl-rich sea-salt grains in dust collected from an in-service canister surface

For example, Diablo Canyon ISFSI

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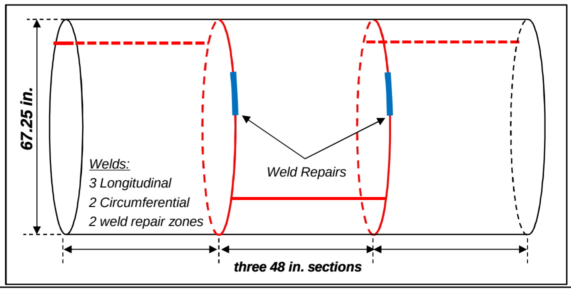
Characterizing Material Susceptibility and Weld Residual Stresses

Full-diameter storage canister mockup purchased in FY14

Made by Ranor Corp., former supplier for canister vendor Transnuclear (now Areva/TN)

Made as per specifications for NUHOMS-type canister (material, size, wall thickness, weld schedules)

- *304L stainless steel*
- *5/8" wall thickness*



UFD will characterize, for a prototypical storage canister:

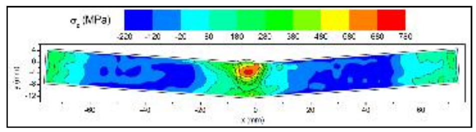
- *Weld residual stresses (deep hole drilling method, contour method, neutron beam diffraction)*
- *Weld and heat-affected zone (HAZ) textural changes*
- *HAZ Sensitization (material susceptibility)*
- *Cold-working*

http://www.veqter.co.uk/residual-stress-measurement/deep-hole-drilling

Deep hole drilling

Methods for measuring weld residual stresses

Contour



Prime et al. (2004)

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Conclusions

- The UFD ST R&D program is focused on collaboration with industry to develop the technical basis for extended storage and retriveability for used fuel as well as for the transport of high burnup used fuel.
- The program will continue to interact with external organizations in a continuous effort to obtain feedback to assess program goals, objectives, and progress.
- Progress to date indicates that dry storage of used fuel is done in a safe manner and that used fuel responds to dry storage environments according to our current state of knowledge and understanding.