Status of NRC Research on High Burnup Fuel Issues

RE Einziger, Ph.D.
Sr. Materials Scientist
Division of Spent Fuel Storage & Transportation
USNRC
March13, 2013
Regulatory Information Conference
W24- Storage and transportation of High Burnup Fuel

1

Current High Burnup Research Topics

- Ductile to brittle transition temperature (DBTT) studies at ANL
- Fatigue measurements at ORNL
- Use of demonstration information in storage license renewal

2

NRC Test Program Objective at ANL

- Determine if cladding has sufficient residual ductility after cooling slowly under a decreasing stress commensurate with a decreasing temperature as would be experienced during and after vacuum drying –

3

What do we know?

- Early data base (Chung) contained significant scatter
  - variety of cladding materials,
  - cladding of different burnup,
  - fast cooling rates,
  - a wide range of hydrogen contents straddling the solubility limits,
- No clear cut quantitative measurement of the reorientation.
  - fraction of hydrides within a certain angle of radial. Does not work when the uncertainty of the hydride content of the cladding straddles the solubility limit.
  - hydride length,
  - hydride continuity.
- Appeared that if stress at temperature was below 90 MPa that hydride reorientation did not occur. Recent trend (Daum, Chu, Aomi, etc) is that the critical stress for reorientation appears to be dropping into the 75 to 80 MPa range

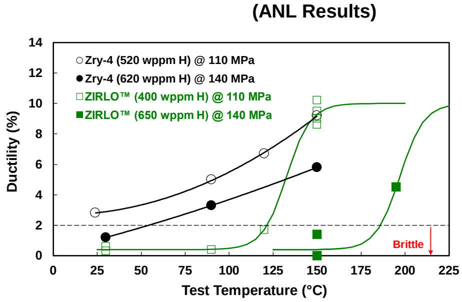
3/18/2013 4

Test Methodology

- **Cladding Preparation**
  –Prehydride as-fabricated cladding; anneal for 24-72 h in flowing argon
  –High-burnup cladding; defueled, anneal for 24-72 h in flowing argon
- **Rodlet Fabrication**
  –Determine RT pressure for target hoop stress after 1-h hold at 400ºC
  –Measure cladding profilometry
  –Pressurize/weld
- **Radial Hydride Treatment (RHT)**
  –Heat to 400ºC, hold for 1-h at 400ºC, cool at 5ºC/h to 200ºC, cool to RT
  –Depressurize; measure post-RHT cladding profilometry; determine creep
  –Measure hydrogen, image hydrides , cut test rings
- **Post-RHT Ring Compression Testing**

5

Ductile to Brittle Transition Temperature
(ANL Results)



6

ANL Testing Results

- Hydrogen distribution differences between unirradiated and HBU cladding affect results
- Different cladding alloys behave differently
- Ductile to brittle transition (DBTT)
  - depends on reorientation stress, hydride content, material
- Protocol established to determine ductile to brittle transition after hydride reorientation.
- Enough data to determine there is a regulatory issue. Insufficient data to support a licensing position.
- Results have had external review and acceptance.
- Will form the basis for guidance on materials properties for HBU cladding.

7

Reference to ANL work

MC Billone, TA Burtseva, RE Einziger "Ductile-to-brittle transition temperature for high-burnup cladding alloys exposed to simulated drying-storage conditions" Journal Nuclear Materials, **433** (2013) p 431-448

8

Shortcomings of ANL Data

- Limited data points -Uncertainty in DBTT due to scatter in data
- Only two cladding materials
  - Both PWR
  - No BWR
- Only one drying temperature – lower maximum temperature may decrease the DBTT
- Hoop stress was chosen to be bounding – distribution of hoop stresses in inventory might be less

9

U.S.NRC

ORNL Studies

- Purpose –
  - Determine effect of fuel pellets on cladding stiffness for HAC analysis,
  - Fatigue behavior of irradiated HBU cladding for normal transport
    - Condition of fuel at arrival -71.89
    - Ability to meet 72.122(h) if shipped to a central facility
- Status –
  - Equipment designed and being tested out of cell.
  - Fuel samples available
- Completion of work (to determine if there is a regulatory issue) - 3rd quarter CY 2013

10

U.S.NRC

NRC View of Purpose of DOE HBU Fuel Demonstration

1. Serve the same role that the previous demonstration at Idaho in the late 1990s serves for low burn-up fuel
2. Confirm with longer term data that the predictions of fuel behavior based on short term separate effects tests, many on lower burnup fuel, are still valid
3. Provide data to benchmark and confirm predictive models
4. Provide confidence in the ability to predict performance, and identify any aging effects that could be missed through short-term studies
5. Determine, if after storage, when the fuel cladding temperature has dropped below the DBTT under normal conditions of transport that there is reasonable assurance that the fuel maintains its configuration
6. Anticipation by NRC that the demonstration will not be terminated until the ultimate duration of dry storage has been determined.

11

U.S.NRC

Potential Role of NRC in Demonstration Project

- Planning Discussions
- Licensing Review
- Independent Observation
- Independent Data review and conclusions
- Guidance to reviewers based on results

12

Demonstration Criteria

- The burnup of fuel in demonstration program to bound burnup of fuel in license application.
- Same cladding type as fuel in license application.
- Canister dried by a recognized method with peak cladding temperatures (PCT) that bound PCT in license application.
- Interior of a He-filled canister continuously or periodically monitored for H_2O, H_2, O_2 and fission gas.
- Temperature profile of fuel typical of that expected in full canister.
- Data from demonstration program must be indicative of a storage duration long enough to justify extrapolation to the total storage time requested. Evaluation of the data from the monitoring available prior to the end of the currently approved storage period.

13

Uses of Monitoring

(sufficient but not optimal if there is no fuel evaluation)

- Gives storage performance data from the start of demo
- Monitoring before and after tells if fuel is disrupted during transportation. Monitoring during transport desired but not necessary.
- Monitoring required
  - Temperature –evaluate degradation models, code benchmark
  - Kr – fuel rod failure
  - O_2, N_2 – cask leakage, radiolysis, corrosion
  - H_20 – drying
  - H_2 - flammability
- Optional monitoring
  - Testing of remote monitoring systems if it doesn't delay demo
  - accelerometers

14

Potential Uses for Fuel Evaluations

(necessary if there is no monitoring other then temperature)

- Benchmark point for codes used for TLAA of the fuel future performance
- Profilometry – creep confirmation
- Gas analysis – cladding stress, gas release from fuel pellets
- Destructive evaluation-
  - Extent of hydride reorientation under normal conditions,
  - signs of DHC depending on mechanism,
  - signs of DCCG in cladding,

15

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Summary

- ANL testing has been completed and results have been published.
  - Sufficient to make regulatory position and develop guidance on acceptable cladding properties
  - Addition work needed by applicants to make licensing arguments
- Work progress at ORNL to determine rod fatigue characteristics
- NRC will monitor results of a high burnup cask demonstration . Results of demonstration can be used to support applications for storage renewals

16