Progress and Results of NRC's Cladding Programs

R. E. Einziger, Ph.D.

Senior Materials Scientist

Division of Spent Fuel Storage and Transportation

USNRC

November 1, 2011

Role of Materials Mechanical Properties

- Determine correct cladding materials properties to use – correct alloys, mechanical treatment, irradiation, drying procedure, temperature range of use
- Structural engineer determines behavior and configuration of fuel in S&T
- Criticality, shielding, containment reviewer determines if fuel in given configuration meets regulation

The Hydride Reorientation Phenomena

- During irradiation hydrogen diffuses into the cladding
- During reactor shutdown and fuel removal, hydrogen precipitates as circumferential hydrides – mostly in the outer 1/3 of the cladding wall.
- Cladding temperature rises to ≤400ºC during vacuum drying.
- When cooled, depending on the cladding hoop stress, some of the hydrogen will precipitate as radial hydrides.

Why Hydride Reorientation is of Interest –

- **Regulatory Issues**

  Normal Conditions – The geometric form of the package contents should not be substantially altered

  Accident Conditions – Determine the most credible reactive configuration of contents for criticality and shielding determinations

  Security – Determine if cladding will fail under impulse

- **Hydride reorientation may affect ductility of cladding**

What do we know?

- Early data base contained significant scatter
- No clear cut quantitative measurement of the reorientation.
- Appeared that if stress at temperature was <90 MPa, hydride reorientation did not occur.
- Recent trend (Daum, Chu, Aomi, etc.) is that the critical stress for reorientation appears to be in the 75 to 80 MPa range

NRC Test Program Objective

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

Test Methodology

- Unirradiated and High Burnup Cladding used
  –
- Rodlet Fabrication
- Radial Hydride Treatment (RHT)
- Post-RHT Ring Compression Testing

ANL Testing Results

- Unirradiated and HBU cladding behave differently
- Different cladding alloys behave differently
- Ductile to brittle transition
  - depends on reorientation stress, hydride content, material
- Protocol established to determine ductile to brittle transition after hydride reorientation.

ORNL Studies

- Purpose –
  - Determine effect of fuel pellets on cladding stiffness for HAC analysis,
  - Fatigue behavior of irradiated HBU cladding for normal transport
- Status –
  - Equipment designed and being tested out of cell.
  - Fuel samples available
- Completion of work - this fiscal year

Regulatory implications

- Hoop ductility of high burnup cladding may be significantly lower due to hydride reorientation causing cladding fracture during side drop
- Hydride reorientation is a function of maximum storage temperature but ductility is a function of transport temperature. Ability of cladding to withstand transport accident may depend on the length of time the fuel cools in storage prior to transport
- Guidance on number of allowable drying cycles may be change
- If transportation is above ductile/brittle transition temperature, data base for circumferential hydrided alloy can be used
- If temperature cycling remains within solvus-precipitous hysterias bounds for maximum temperature then data base for circumferential hydrided alloy can be used

Future Work

- NRC
  - Publish results of the ANL testing - this spring
  - Either revise ISG-11 Rev 3 or issue new ISG detailing guidance on properties to use for HBU cladding and suggested protocol to establish properties under different conditions or alloys
  - Continue to survey new results for influence on guidance
- Industry
  - Provide test data for different alloys, as needed, and/or stress and temperature conditions to justify use of materials properties.
  - Better lower cladding temperature distributions are needed