Westinghouse

A BNFL Group company

DRAFT

Dry Storage and Transport of Spent LWR Fuel

Westinghouse Electric Company

March 24, 2005

AGENDA

- Typical Fuel Rod Designs
- Fuel Rod Cladding Material Evolution
- Burnable Absorbers
- Irradiation Impact on Fuel
- Fuel Design Criteria
- Post Irradiation Exams (PIEs)
- Feedback from PIEs
- Spent Fuel Impacts

Fuel Rod Designs for Westinghouse Designed PWRs

a, c

Fuel Rod Designs for CE Designed PWRs

a, c

Fuel Rod Cladding Materials

- Standard Zircaloy-4 (1.5 wt% tin)
- Low tin Zircaloy-4 (1.3 wt% tin)
- ZIRLO™ (1% Nb, 1% Sn, 0.1% Fe)
  - Future Use
- Optimized ZIRLO™ [ ] a, c
- AIOM

ZIRLO™ trademark property of Westinghouse Electric Company LLC

Burnable Absorbers

- Westinghouse now uses five burnable absorbers
  - Discrete burnable absorbers
    - BPRAs
    - WABAs
  - Integral absorbers
    - ZrB_2 coating
    - UO_2-Gd_2O_3
    - UO_2-Er_2O_3
- All absorbers are licensed and have significant operational experience.

Irradiation Impact on Fuel

- Fuel rod internal gas volume decreases: Cladding creep down and fuel swelling reduce the fuel rod internal gas volume.

- Fuel rod internal pressure increases: The reduction in internal volume combined with fission gas release (FGR) and for IFBA rods helium release from the ZrB2 coating increase the fuel rod internal pressure.

- The cladding corrodes: Corrosion of the cladding results in a loss of load caring cross section of the cladding and a pickup of a fraction of the hydrogen generated by corrosion in the cladding. Hydrogen is concentrated toward the outside diameter.

- The cladding becomes stronger: Due to irradiation hardening the cladding yield and UTS increases while the ductility decreases. Some additional decrease in ductility occurs with increasing hydrogen values, but the primary cause of ductility decrease is irradiation hardening.

Irradiation Impact on Fuel

- Fuel rod length increases: Due to irradiation growth, growth from hydride formation and growth from lockup with the fuel column and the cladding the length of the fuel rod increases.
- The zirconium alloy structural material corrodes: Corrosion of the guide thimbles and spacer grids results in a loss of load caring cross section of these components and a pickup of a fraction of the hydrogen generated by corrosion in the metal.
- The zirconium alloy structural material grows: Due to irradiation growth and growth from hydride formation, the overall fuel assembly length increases as well as the width of the spacer grids.

Fuel Design Criteria

- Fuel Rod Internal Pressure
  - No Lift-Off or Gap opening due to creep out
  - No DNB propagation due to RIP > system pressure
- Cladding Stress
  - Transient Stress ≤ yield
    - or
  - Pressure induced stress with ASME limits
- Cladding Transient Strain ≤ 1%

Fuel Design Criteria (Cont'd)

- Cladding Steady State Strain ≤ 1%
- Cladding Corrosion
  - Oxide ≤4 mils
- Fuel Temperature – No Centerline Melting
- Clad Fee Standing – No Buckling
- Cladding Fatigue – Fatigue Usage Factor ≤ 1

Fuel Design Criteria (Cont'd)

- Plenum Clad Support – No Collapse of cladding over plenum due to creep ovalization
- Clad Flattening – No Collapse of cladding over the fuel stack due to creep ovalization
- Fuel Rod Growth – No Closure of total gap between fuel rod and top and bottom nozzle.

Limiting Design Criteria with Impact on Dry Storage

- RIP – No Clad Lift-off
- Cladding Corrosion

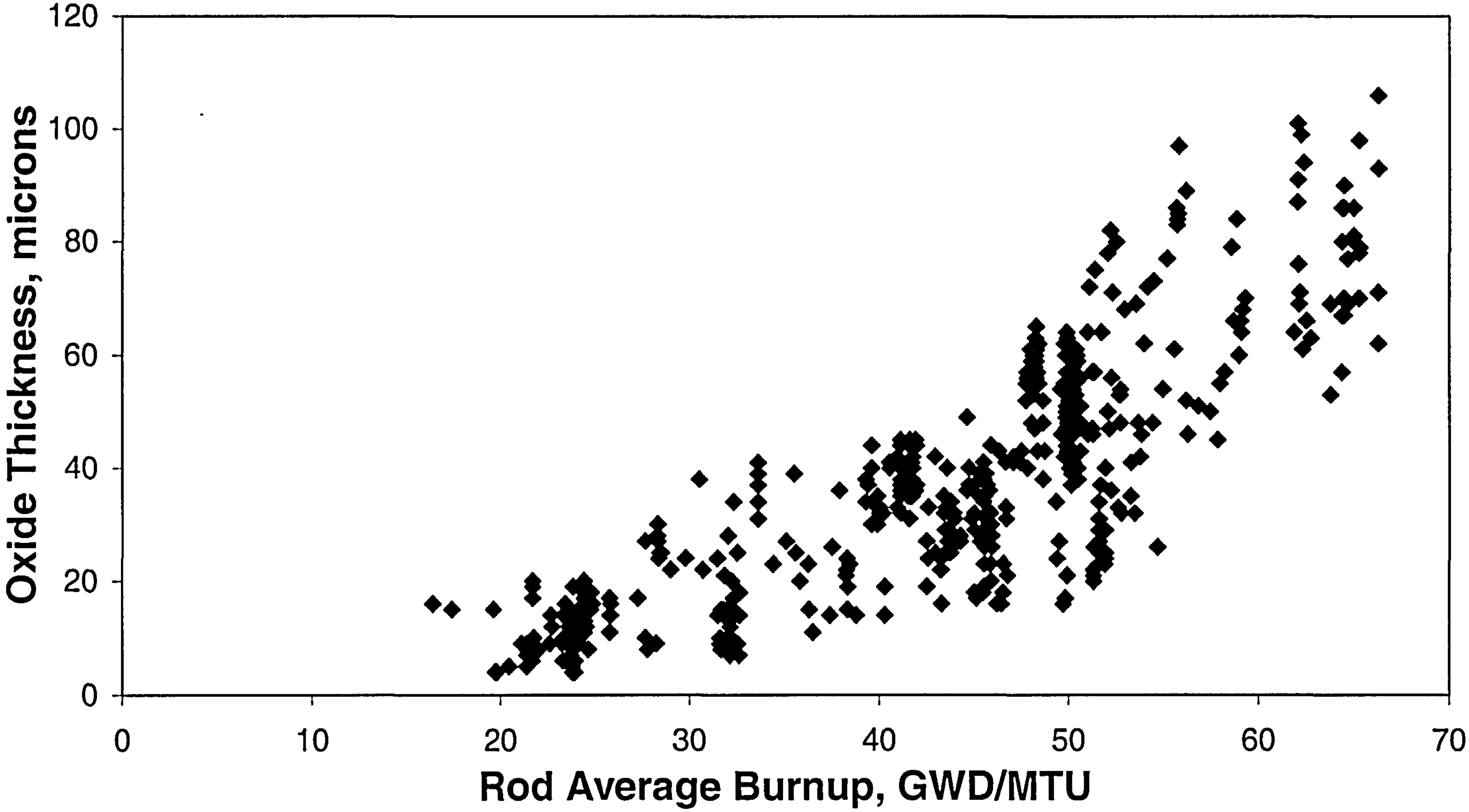
High Burnup Study – Demonstrates RIP Behavior for IFBA and Standard Fuel

a, b, c

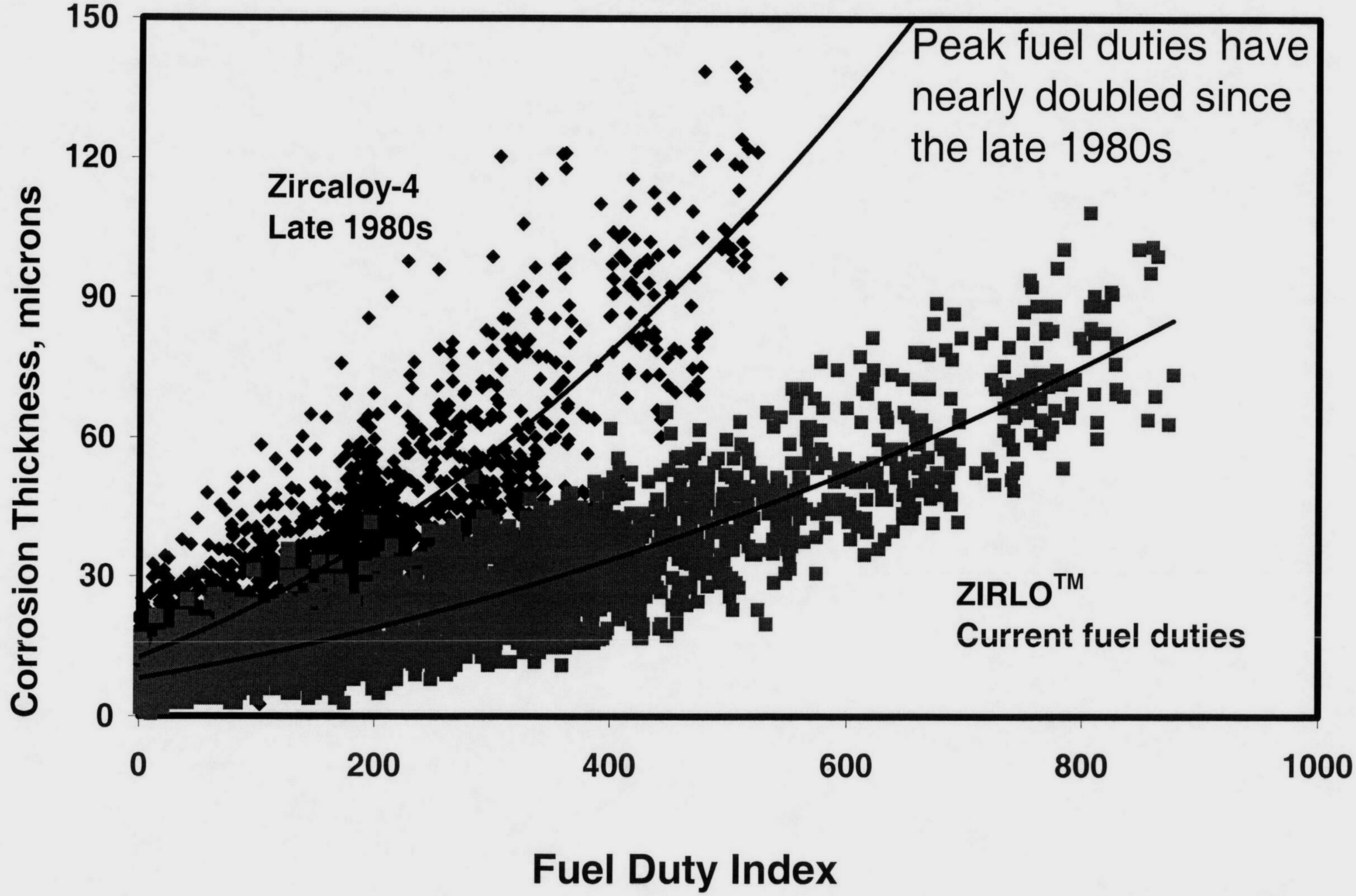
Post Irradiation Exams

- Zircaloy-4 Fuel Examined
  - 58.3 GWD/MTU from Commercial Reactors
  - 61.5 (Peak of 70) from Test Reactor
- ZIRLO Fuel Examined
  - [ ] a, c

Maximum Rod Oxide Thickness vs. Rod Average Burnup, ZIRLO



Cladding Corrosion Thickness vs. Fuel Duty Index



G1

Westinghouse High Burnup ZIRLO LTA Summary

a, b, c

Other Test Programs

a, b, c

Creep and Growth Program - Status

a, b, c

ZIRLO Hotcell Exams

a, b, c

Feedback from PIE Exams

- No unexpected behavior at High Burnup
  - Fuel Rod Growth
  - FGR and RIP
  - Oxide thickness and hydrogen distribution
  - Cladding mechanical properties
    - Strength
    - Ductility

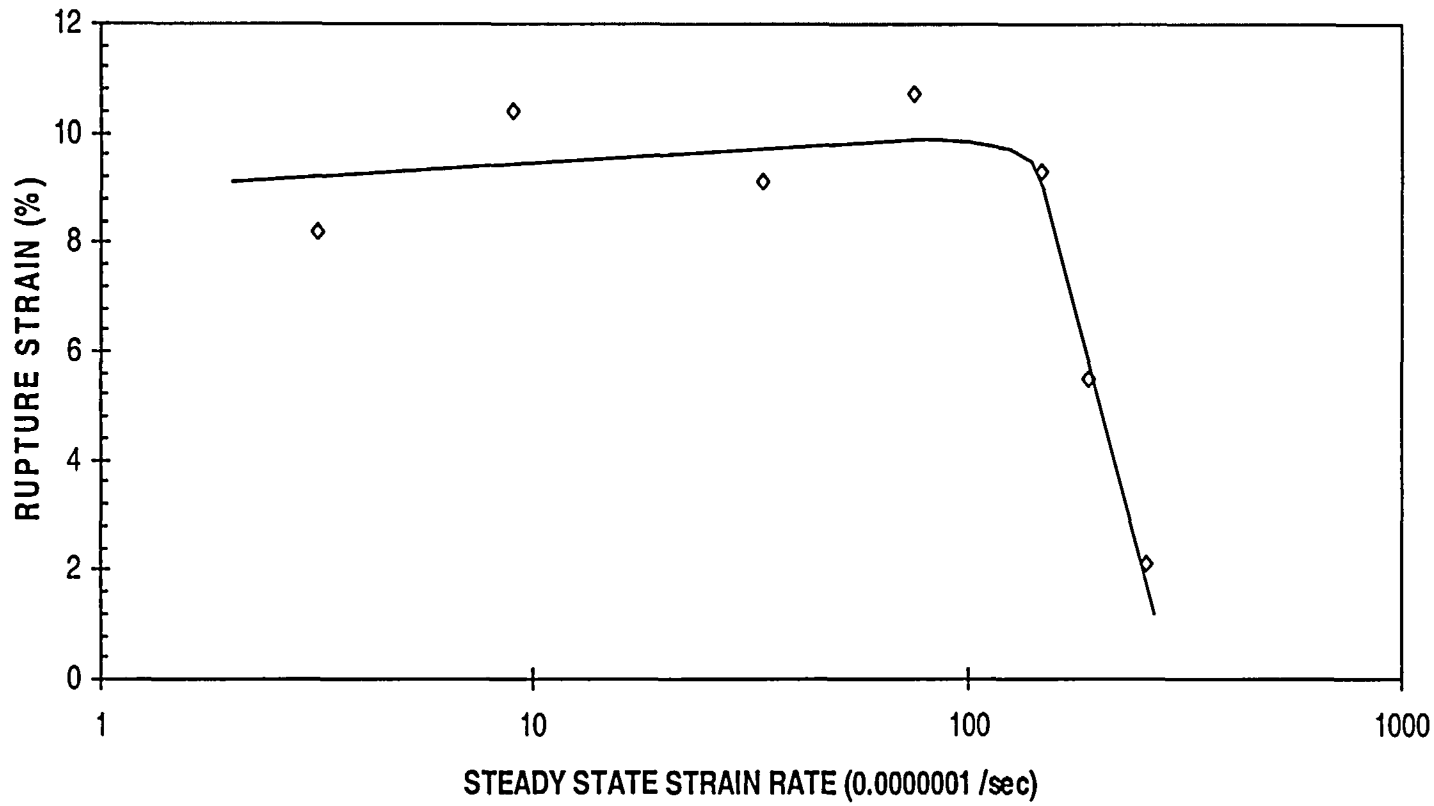
Spent Fuel Impacts - WCAP-15168

- FGR from fuel representative of PWR operation has FGR less than the 30% NUREG-1536 guidance.
- The best estimate fuel design criterion for oxide of 4 mils bounds the vast majority of oxide observed in spent fuel.
- Cladding hydriding increases with burnup and corrosion. However sufficient ductility remains especially at temperature
- Stress induced from PCI are not of concern in dry storage

Spent Fuel Impacts (Con't)

- Maximum creep strain expected under dry storage will be < 1% and is within the capability of the cladding
- Cladding Strength increases early in burnup and does not experience any decrease beyond the loss of material to corrosion.
- Isotopic Codes ORIGEN and SAS2H do not under predict actinide levels.
  - Heat loads are not under predicted.
  - External doses are not under predicted.

Reference 2: Rupture strain versus steady state strain rate at 673K for CWSR Zr-4 (3.0x1021 n/cm2 (E>1).



References

- 1. WCAP-15168, Dry Storage of High Burnup Spent Nuclear Fuel, March 1999.
- 2. Creep, Hydride Orientation and Oxide Spalling Issues Associated with Fuel Cladding: Impact on High Burnup Dry Fuel Assembly Storage, John Paul Foster, et-al. ANS 2002 Annual Meeting ICAPP, June 9-13, Holywood Fl.
- 3. ISG-11, Rev 3, Spent Fuel Project Office Interim Staff Guidance, November 17, 2003.
- 4. NUREG/CR6831, ANL-03/17, Examination of Spent PWR Fuel Rods after 15 Years in Dry Storage.