Aidan Furlong

EXAM

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#4

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1. a) ZIRLO 650K for 300 days $\delta(\mu m) = 500 \mu m$

$$t^* = 6.62 \times 10^{-7} \exp\left(\frac{11949}{T}\right) = 63.757 \text{ days}$$

300 days >> 63.757 days → linear region

$$\delta^*(\mu m) = 5.1 \exp\left(\frac{-550}{T}\right) = 2.188 \mu m$$

$$K_L\left(\frac{\mu m}{day}\right) = 7.48 \times 10^6 \exp\left(\frac{-12500}{T}\right) = 0.03327 \; \mu m/d$$

$$\delta(\mu m) = \delta^* + K_L(t - t^*) = 2.188 \mu m + 0.03327 \tfrac{\mu m}{d}(236.243 d)$$

$$\boxed{\delta = 10.0 \mu m}$$

b) $f = 0.18$ $PBR = 1.56$ $\rho_{Zr} = 6.5$ g/cc $\rho_{ZrO_2} = 5.68$ g/cc

$C_H^{\infty} = 35$ wt. ppm

$$C_H^{clad} = \frac{2 f \delta \rho_{ZrO_2} f^0_{ZrO_2} \left(\frac{M_H}{M_O}\right)}{\left(t - \frac{\delta}{PBR}\right)\rho_{metal}} = \frac{2(0.18)(10)(5.68)(0.26)\left(\frac{1}{16}\right)}{\left(500 - \frac{10}{1.56}\right)6.5} \times 10^6$$

$C_H^{clad} = 103.5678$ wt. ppm

$\boxed{\text{Total H Pickup}} = 103.5678 + 35 = \boxed{138.57 \text{ wt. ppm}}$

2. $2.5 \text{ cm} \times 2.5 \text{ cm} \times 0.01 \text{ cm}$ Zr Coupon $\delta = 0.005 \text{ cm} = 50 \mu m$

Δmass = ?

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$$\delta(\mu m) = \frac{w}{14.7} = 50 \rightarrow w = 735 \text{ mg/dm}^2 \checkmark$$

$$w = \frac{\Delta mass}{A} = \frac{\Delta mass}{2.5 \times 2.5 (0.01)} = 735 \text{ mg/dm}^2 \checkmark$$

$$\boxed{\Delta mass = 45.9375 \text{ mg} \approx 45.9 \text{ mg gain}} \checkmark$$

3. Particularly in U-Zr fuels, Zr species will diffuse along the temperature gradient creating "zones" of Zr content at various radial locations. In U-Zr this can lead to three major phases: 1) γ-phase at the center, 2) β-phase in the center, 3) α/δ-phase along the exterior. The γ-phase holds the most Zr content.

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4. Fuel centerline temperatures are far higher in MOX vs. traditional fuel with higher heating rates and higher burnups. These assemblies (in SFRs) are cooled with liquid sodium and are contained in hexagonal lattices with steel cladding (compared to typical square lattices w/ Zircaloy). High neutron flux leads to higher damage in MOX materials.

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5. Regions:

1) Central void – Accumulation of voids/pores travel along ∇T
2) Columnar Growth – Pore transport destroys original microstructure when moving inwards
3) Equiaxed Growth – Temp. low enough to inhibit pore transport destruction of grain, but hot enough to experience grain growth
4) As-sintered – Low T limits grain growth and leaves microstructure as-fab

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6. Reactivity Initiated/Insertion Accident (RIA): A large rise in reactivity from a withdrawal of control mechanisms leading to a power spike (and then fuel temp. spike). Can push fuel to failure and initiate cladding failure / radioactive release to primary. Other core internals / pressure boundary may be damaged from the thermal hydraulic response. Probability of fuel damage greatly depends on the length of time the spike occurs in.

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7. Loss-of-Coolant Accident (LOCA): Loss of coolant inventory or reduction in cooling. Different than RIA in the sense that in an RIA the coolant flow/inventory is still nominal/op with a nuclear initiating event vs. a TH initiator in a LOCA. In a LOCA, primary material impacts are in the cladding as heat-up commences. Can lead to clad-water reactions and ballooning from internal P rise and then fuel failure.
-emphasize oxidation of cladding

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8. 1) Cladding Oxidation (Clad must be $< 2200\,^{\circ}F$)

2) Departure from Nucleate Boiling (MDNBRs vary but above 1.3 typically)

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9. Hydrogen water chemistry sets ranges on the desired dissolved H_2 in the primary, which would scavenge stray Oxygen molecules and reduce oxidation of the cladding. The VCT in a PWR is hydrogen-covered.

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10. 1) Pressure Build-up : CO can form due to liberated oxygen binding with buffer layer carbon, leading to increase in particle pressure

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2) Irradiation Growth : fuel kernel swells, initially with PyC shrinkage, but then PyC swells leading to increased stress on the "containment" layers

11. With the oxidation process, hydrogen products will diffuse through the Zr cladding to form a hydride phase leading to embrittlement, delayed cracking, irradiation growth acceleration, and corrosion acceleration. Hydride concentrations respond to temperature and stress gradients, leading to heterogeneous concentrations with max C at higher stress + lower Temp.

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12. Oxygen transport (diffusion) is the rate limiting factor in $Zr-H_2O$ corrosion as O ions are only transported by diffusion. There are no sources or sinks in the oxide, leaving the diffusion as a driver.

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13. The Pilling-Bedworth Ratio (PBR) is the ratio of the volume per unit of metal oxide to volume per unit of the metal. It describes how protective, or "passivating" an oxide layer is. If the oxide coating is too thick (PBR > 2), the coating chips off, but if it is too thin (PBR < 1), the layer will be broken.

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