Rashed Alrkasti

Q1.) $T = 625K$ 500 μm.

(a) $t = 400$ d.

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- first, we need to measure the trans. ~~thickness~~ time:

$$t^* = 6.62 \times 10^{-7} \exp(11949/625) = 133 \text{ d}$$

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- trans. thickness:

$$\delta^* = 5.1 \exp(-550/625) = 2.12 \ \mu m.$$

- Oxidation rate:

$$K_L = 7.48 \times 10^6 \exp(-12506/625) = 0.0153.$$

- Oxide thickness:

$$\delta = \delta^* + K_L(t - t^*) = 2.12 + 0.0153(400 - 133) = 6.2051 \ \mu m$$

days ??

total oxide thickness –

$$500 + \delta = 506.2 \ \mu m.$$ ✗ – this is not total wall thickness either...

(b) $f^H = 0.18$. $R_{BP} = 1.56$ $\rho_{Zr} = 6.5$ g/cc $\rho_{ZrO_2} = 5.68$ g/cc.

$$C_H = \frac{2f \cdot \delta \cdot \rho_{ox} \cdot f^o_{ZrO_2} \cdot \left[\frac{M_H}{M_O}\right]}{\left[t - \frac{\delta}{R_{BP}}\right] \cdot \rho_{metal}} \times 10^6.$$

$O/ZrO_2 \simeq 0.22$. atoms ratio. ~0.26 $\frac{32}{92+32}$

ρ_O

$\rho_{ZrO_2} = 5.68$ g/cc. ⟶ $5.68 \times 0.22 = 1.25$ g/cc

$$= \frac{2 \times 0.18 \times 506.2 \times 5.68 \times 0.22 \times \frac{1}{32}}{\left[400 - \frac{506.2}{1.56}\right] \cdot 6.5} \times 10^6 = 14.498 \times 10^3 \simeq 1.5 \times 10^4$$

(6.2 ↑, 1/16 ↑, 500, 6.2)

– this would be a LOT of H...

– also, looking for this @ t = 365 dy in part B ...

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2. The diffusion of the O ions & electrons through the oxide layer.

3. It is the ratio of volume of the oxide to the volume of the metal. It tells us how would the oxide layer might affect the rate of oxidation.

4/4 PBR < 1, Then the layer is too thin & would break away. If PBR > 2, then it is too thick & brittle & would break into fragments. But if 1 < PBR < 2, then it will form a protective layer.

4. The hydrides form near the surface, specially the rims. That is because H has slow diffusitivit in Zr & tends to form Hydrides quickly. Hydrides increases the brittleness of the clad & might even increase the SCC with the migration of hydrides to the crack tips. Blisters form locally & deeper than the rims, & eventually the might form radially as well.

- solubility of H w/ T
- Soret
- stressed

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5, Reactivity Insertion Accidents, where a rapid increase in reactivity occurs due to a sudden & full pull of CRs in PWRs, or a drop of the control blades in BWRs.

When RIA occurs, a power pulse occurs, that increases the temperature, preassure, & fission rate dramatically. That might cause the fuel fission fragments to increase, increasing the internal pressur of the fuel, swelling the cladding, potentially causing it to fracture & for the fragments or even the fuel it self to be released into the coolant, an example would be Chyrnobel where a huge increase in the gas production caused also an explosion.

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, LOCA is when the coolant is cut from the core due to a leak or a drop of pressure, The process is much slower than RIA, so we don't see the dramatic power increase pulses here. But due to the pressure decrease we might get a big increase of internal pressure that cause plastic deformation & sometimes fracture of the cladding. A drop in heat transfer will cause the fuel Pellet temperature to increase as well, where the Zr undergoes phase change affecting t's mechanical behaviour as well. Eventually, melting of the cladding might occur & a release f fuel fragment would happen, or the re-wetting of the clad might quench it and causing it ter breaking as well.

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7. 1. Advanced cladding that shows improved corrosion resistance.
   e.g. - FeCrAL, which Al_2O_3 formation provides corrosion resistance
   - SiC shows even more superior corrosion resistance.

   2. Advanced fuels with better thermal conductivity & stability.
   eg. USi, UZO

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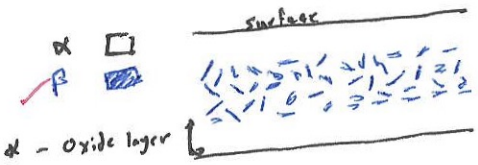
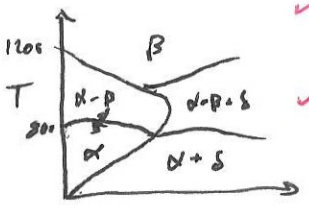
8. Zr starts to exist in both α & β phases above 800 °C, & totally transforms to β phase above 1200 °C. With a much higher temperature oxidation rates are increased. More Oxides stabilizes the α phase near the surface, & even stabilize the α - β phase in the cladding as well.
- more hydrides





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0%.

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9. One way to mitigate oxidation is by providing a corrosion resistant coating like Al based coatings that would act as a protective layer.

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10. 1. internal cladding fuel pressure :- With a higher burn-up, more fission products are released which increases the internal pressure, specially due to gas fission products. This higher pressure put a big stress component on the cladding that might cause it to fail. a limit of 5 MPa if internal pressure increase is put.

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2. Cladding elongation ; Due to the azimuthal nature of Zr in the α phase (HCP) it elongates axially with the increasing stresses & has a strain in the z-direction A limiting of 10% strain or elongation is considered in the design & operation

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11. CRUD is the accumulation of steam generator corrosion products like Ni & Cr on the fuel cladding surface. This might affect the chemistry of the fuel-clad-coolant interactions, but most importantly, it affects the thermal conductivity (decrease it).
- activating Ni/Co, radiation source

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12. LiOH is added To The water to maintain and stabalize the pH at 6.9 for the coolant.

5/6 H_3BO_3 is added to control the excess reactivity specially at the early operation stages.

- Boric acid is more neutronics control than water chemistry control.

Both are gradully decreased with time.

13. MOX fuel g can has a centerline temp. of 2000°C, causing it to have a differe. HB structure, with voids migrating to the center. It also uses a Na coolant, & a Stainless Steel cladding. It utilizes fast neutrons fissions, making it suitable for fast breeder reactors, different values of LHR & Thermal conductivities. Shorter rods, smaller pellets & hexagonal fuel assembly design.

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- higher burnup, high FP inventory