Mohammed

$\boxed{100}$

$\boxed{1}$ $T = 650\,K$ $t = 300\,d$ $\delta_{tot} = 500\,\mu m$

a) $t^* = 6.62 \times 10^{-7} \exp\left[\frac{11949}{T}\right] = 63.757\,d$ ✓ $t > t^*$

$\delta^* = 5.1 \exp\left[-\frac{550}{T}\right] = 2.188\,\mu m$ ✓

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$K = 7.48 \times 10^{6} \exp\left[-\frac{12500}{T}\right] = 0.0333$ ✓

$\delta = \delta^* + K(t - t^*) = \boxed{10.049\,\mu m}$ ✓

b) $$C_H = \frac{2 f \delta_{ox} \rho_{ZrO_2} * \frac{32}{32+91} * \frac{1}{16}}{\left[\delta_{tot} - \frac{\delta_{ox}}{R_{PB}}\right] * \rho_{Zr}} * 10^6 + C_H^0 = \boxed{139.14 \text{ wt. ppm}}$$ ✓ ✓

$\boxed{2}$ $d = \frac{W}{14.7} = 0.005 \times 10^{+4}\,\mu m = \frac{W\,(mg/dm^2)}{14.7}$ ✓

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$W = 735\,mg/dm^2 = \frac{\Delta M}{(0.25)^2}$ ✓

$\Delta M = 735 \times (0.25)^2 = \boxed{45.9375\,mg}$ ✓

[3] In U-(Pu)-Zr fuel, Zr diffuses up the temp gradient via Soret effect and because it has different solubilities in different U phases we see:

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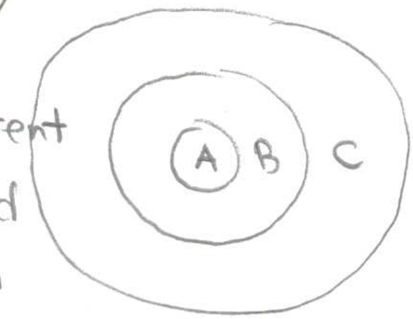
1) A region: γ-U phase: rich Zr content
2) B region: β-U phase: Zr-depleted
3) C region: α+δ phase: as-fabricated Zr content.



* lower Zr content = low melting temp.

[4] * Can achieve higher burn-up.
* Higher centerline temperatures
* Higher fission gas release → larger gas plenum.

6/8 * Utilized in SFRs; sodium cooled; and have stainless steel cladding.
* MOX fuels restructure into three regions (inside-out): central void, columnar grains, as-fabricated grains.
* central void is the accumulation of bubbles that travel by a fuel evaporation-condensation mechanism due to the difference in vapor pressure.
* Fabricated hypostoichiometric; O travels up the temp gradi Pu is inriched in the columar grain region.
* Gap closes, fission product accumulate in the small gap forming joint oxide gain (Cs_2MoO_4) which has higher thermal conductivity than the gap and is soft; works as a buffer for FCMI; and reduces fuel swelling.

7 LOCA: a design basis accident; reduced or lost coolant flow due to e.g. coolant pipe break. ✓

- Power transient is less sever and takes longer time than the RIA transient. ✓

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- The cladding deforms plastically (ballooning) due to decrease of coolant pressure → can lead to rupture. ✓
- Steam forms; clad reacts with steam; oxidation and brittle fracture ✓

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8 ① PCMI: ✓

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② Cladding and assembly bow. ✓

9 The problem of Intergranular SCC of stainless steel clad in BWR has to be solved by control of the electrochemical potential by hydrogen injection which reduces IGSSC. ✓

-also LWR

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Meaning: controlling water properties and its effect on clad internal by adjusting the concentration of hydrogen and consequently pH instead of e.g. Lithium-Boron chemistry. ✓ ✓ ✓

$\boxed{5}$ Three regions:

1) Central void: accumulation of pores and voids; have a lenticular shape and are normal to the thermal gradient; gas has low thermal conductivity and thus larger temp gradient. Voids move through a fuel evaporation-condensation mechanism due to difference in vapor pressure.

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2) Columar grains: destroyed microstructure due to the movement of the pores.

3) As-fabricated grains: appear when $T < 1800\,°C$.

Reason: higher temperatures in the fuel 1800-2000°C is required for movement and forming of central void.

$\boxed{6}$ Reactivity intiated accident: a design basis accident that is caused by a large and rapid insertion of reactivity caused by inadvertent ejection (PWR) or drop (BWR) of a control rod; mostly due to mechanical failure of the drive mechanism or change in void fraction or coolant/moderator T.

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Effects of RIA: - DNB: isolation of fuel rod via coolant bubbles; partial melting of fuel.

- Rapid increase of temp and gas pressure inside fuel bubbles → cracking of fuel.
- Rise in power and temp; significant accumulation of fission gases; grain boundary separation; PCMI; ballooning and rupture of fuel; fuel fragmentation; hydrid formation in clad; oxidation in clad; brittle failure of clad.

(10) - Pressure buildup: fission liberates O which forms CO with the C from the buffer; this gas increase the pressure on the carbon layer in TRISO pellets.

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- Irradiation growth: Fuel kernel swells whereas the pyrolitic carbon layers initially shrink and then reach a turnaround point where they swell.

- SiC layer is compressed → positive; delayed fracture.

(11) - Hydrides form because the hydrogen librated during Zr oxidation/corrosion diffuses into the Zr clad; H has low solubility in Zr so it forms hydrides.

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- Temp and stress gradient; H moves up the stress gradient; Hydrides prefer areas with tensile stress.

- Loss of ductility due to platelets or blisters (embrittlement)
Hydrides move to stress concentrations at crack tips leading to delayed hydride cracking.

(12) 1) Oxygen diffusion through the oxide layer ✓

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2) Electron diffusion through the oxide layer.

- #2 isn't rate limiting, its much faster than #1

(13) Pilling-Bedworth ratio: ratio of volume per atom of the metal oxide ✓ vs. volume per atom of the corresponding metal ✓

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$R_{PB} < 1$: oxide layer is thin; breaks; no protective layer ✓

$R_{PB} > 2$: oxide layer flakes off; no protection ✓

$1 < R_{PB} < 2$: oxide layer is passivating; provides a protective layer. ✓