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Exam 3

(1) Given: Zir 10 clad $T = 625K$

$t = 400$ days

$t_{wall} = 500\ \mu m$

Find a) t_{ox} @ $t = 400$ days

$$t^*(d) = 6.62E-7 \exp\left(\frac{11949}{T}\right) = 133.01 \text{ days}$$

$t > t^*$ thus,

$$\delta^* = 5.1 \exp\left(\frac{-500}{T}\right) = 2.29\ \mu m$$

$$\delta = \delta^* + k_L\left(t - t^*\right)$$

$$\hookrightarrow k_L = 7.48\times10^{-6} \exp\left(\frac{-12500}{T}\right) = 0.0154 \ \mu m/d$$

$$= 2.29 + 0.0154\left(400 - 133\right)$$

$$\boxed{= 6.4018\ \mu m}$$

b) $f_{HP} = 0.18$

$t = 1$ year

$PBR = 1.56$

$\rho_{Zr} = 6.5 g/cm^3$

$\rho_{ZrO_2} = 5.68\ g/cm^3$

$$C_H^{wt.ppm} = \frac{2 f_{HP} \cdot \delta_{oxt} \cdot \rho_{ox} \cdot f_{ZrO_2} \cdot \frac{1}{16}}{\left(t_{clad} - \frac{\delta_{oxt}}{PBR}\right)\rho_{Zr}} \cdot 10^6$$

$$f_{ZrO_2} = \frac{16 \cdot 2}{16 \cdot 2 + 91} = 0.26$$

$$\boxed{= 66.034 \text{ wt.ppm H}}$$

(2) Given:
$\alpha_{th} = 11 \cdot 10^{-6}$

$\dot{F} = 3.5 \times 10^{13}$ f/s-cm^3 → $B_{FIMA} = \frac{(3.5\times10^{13})(7344000\,s)}{2.45\times10^{22}\ U/cc}$

T_{fuel} 1200 K $= 0.0105$

$T_{ref} = 300$ K

$\Delta\rho_0 = 0.01$

$B_D = 5$ MWD/kgU $/950 = 0.0053$ FIMA

$\rho_{UO_2} = 10.97$ g/cc

$t = 85$ days $= 7344000$ s

Find ϵ_{tot} ??

$$\epsilon_{th} = \alpha\,\Delta T = (11\times10^{-6})(1200-300) = 0.0099$$

$$\epsilon_D = \Delta\rho_0\left(\exp\left(\frac{B_{FIMA}\cdot \ln(0.01)}{B_D}\right)\right) = -0.0099$$

$$\epsilon_{SFP} = 5.577\times10^{-2}\,\rho_{UO_2}B_{FIMA} = 0.0064$$

$$\epsilon_{GFP} = (1.96\,E{-28})(\rho_{UO_2}B_{FIMA})(T_F - T_{ref})\exp(-0.0162(2800-T_F))\exp(-17.8\rho_{UO_2}B_{FIMA})$$

$$= 0.00380$$

$$\epsilon_{tot} = \epsilon_{th} + \epsilon_D + \epsilon_{SFP} + \epsilon_{GFP} = 0.0102$$

$$\boxed{= 1.02\%}$$

③ Given: $\sigma_{VM} = 200\ MPa$; $T = 600K$; $LHR = 150\ W/cm$

$t = 1.5$ years $= 4.73 \times 10^{7}\ s$

Find $\epsilon_{tot} = ?$

$$\dot{\epsilon}_{ss} = A_0 \left(\frac{\sigma_{VM}}{G}\right)^n \exp\left(\frac{-Q}{kT}\right) =$$

$A_0 = 4 \times 10^{+24}\ s^{-1}$; $G = 4.1 \times 10^{10} - 2.3 \times 10^{7} T = 27200\ MPa$

$n = 5$; $Q = 2.7 \times 10^{5}\ J/mol$

$$\Rightarrow 4 \times 10^{+24} \left(\frac{200}{27200}\right)^5 \exp\left(\frac{-2.7 \times 10^5}{8.314 \cdot 600K}\right) =$$

$$= 8.597 \times 10^{13} \cdot 3.116 \times 10^{-24} = \underline{2.679 \times 10^{-10}\ s^{-1}}$$

$$\dot{\epsilon}_{ir} = C_0\, \Phi^{C_1}\, \sigma_{VM}^{C_2}$$

$C_0 = 2.714 \times 10^{-24}$

$C_1 = 0.85$

$C_2 = 1$

$\Phi = 3 \times 10^{11}(150) = 4.5 \times 10^{13}$

$$\rightarrow = 2.714 \times 10^{-24} (4.5 \times 10^{13})^{0.85} \cdot (200)^1$$

$$= \underline{2.187 \times 10^{-10}\ s^{-1}}$$

$$\dot{\epsilon}_{tot} = \dot{\epsilon}_{ss} + \dot{\epsilon}_{ir} = 4.857 \times 10^{-10}$$

$t = 4.73 \times 10^{7}\ s$

$$\epsilon_{tot} = (\dot{\epsilon}_{tot})\, t = 0.023 \quad \boxed{= 2.3\%}$$

4) Five types of FPs in fuel; 1) Solid solution
2) Oxide Precipitates
3) Metallic precip.
4) Volatile Gases
5) Noble Gases

5) Microstructure-based fuel perf modeling and why it's beneficial:

Lower scale models provide insight into microscale mechanisms that explain macroscale behaviors. Microstructure fuel perf. modeling takes Grain growth/plasticity/defect transport/densification, and model fission gas behavior to predict evolution of microstructure, to inform property or structure relationships. Benefit: It can provide as structure/property relationship that can replace burnup dependant models, and can develop things like K as a function of their microstructure evolution (Grain boundary bubbles/porosity/fission precipitates) to parameterize the model and get better correlation to data as it provides a more prototypic model with better accuracy.

6) 3 benefits of using Zr clad: 1) Low n cross-section
2) Good therm. conductivity
3) corrosion & void swell resistant

7) Metallic-fuel const. redistribution: Zr diff up thermal gradient, has different solubilities is each U-phase, thus goes out radially into distinct radial zones. Different Zr-melt-temps @ diff phases/content

8) Difference in MOX fuel vs. LWR fuel

MOX fuels like PuO_2 can be used in fast reactors, allows ability to burn weapons grade Pu. Has diff. neutronics, FGR, therm cond, higher operation LHR (400-500 W/cm) vs. LWR (250 W/cm). Smaller than classical rod dia in MOX, thus Power dens. and heat flux much higher. Much higher neutron flux, higher Burnup. Provides reliable/robust fuel @ higher Powers.

9) SCC requires:
1) Corrosive Env.. Fission Products in fuel-clad gap diffusion/crack penetration.
2) Susceptible Mat. All Zr-alloys are prone to PCI
3) Sufficient stress. Fuel expansion/swelling, creep, and Pressures due to env.
4) Sufficient time. Long operation of terrestrial Power reactors... on order of years.

10) Fuel Pulverization in HBS cand occur during LOCA, trapped gas bubbles heat up and over-pres, causing cracking and has been seen in regions with partial/completely formed HBS. as grain size decr. Being addressed by modeling in BISON, to develop criteria req'd to form. Addressed also by reducing LOCA risk.

(11) RIA - Radiation induced, while LOCA is loss of coolant induced. RIA caused by fast rise in power, while LOCA caused by slower ballooning of clad and rapid oxidation. RIA causes high rise in power and temp. RIA occured at chalk River, SL-1, and chernobyl. caused by operator errors and exceedance of ops. guidelines and safety systems turned off.

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(12) Can make fuel more tol by: (1) Improve fuel perf. by operating at lower temp or raise melt temps. (2) Improve reactor kinetics w/ steam or better retention of GFP & SFP

(13) LWR Ops is limited by: (1) PCI, Clad oxidation
(2) Power to melt, fuel rod int. pres
or dept. from DNBR.