Ans to Q1

Exam grade: 95

11/15

Point	FUEL	CLAD	GAP
1 (starting)	as manufactured	as manufactured	as manufactur
2	both centerline and surface temperature increased to maximum value. thermal expansion has not started yet	clad temperature reaches max value. Clad expansion starts	gap width increased
3	Both centerline and surface T decreases, because of gap change; as $k_{fuel}\downarrow$, difference between surface and centerline increases.	Clad temperature remains same as coolant temperature is as it is	Gap with decreases so, gap conductance increases
4.	fuel is just started to touch the clad at center position. Due to gap reduction $T_{surface}\uparrow$	clad is starting to become bamboo structure streats to generate	Gap with is reducted. So. gap conductant is increasing
5.	Fuel completely touches the clad $T\uparrow\uparrow$.	Clad Temperature Remains same comple bamboo structure.	No gap, so, $T_{surface}$ and T_{clad} as appoximately equal

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Ans. to the Q 2

$a = 8\ \mu m$ $T = (900 + 273)K = 1173\ K$, $t = 2$ year

volumetric neutron flux, $\dot{F} = 2 \times 10^{13}$ fission/cm³-s

a) Using 4/5 model

$D = D_1$ (intrinsic) + D_2 (radiation enhanced) + D_3 (radiation induced)

$D_1 = 7.6 \times 10^{-6}\ e^{-\frac{3.03}{k_b T}} = 7.28 \times 10^{-19}\ cm^2/s$

$D_2 = 1.41 \times 10^{-18} \left(e^{\frac{-1.19}{k_b T}}\right) \sqrt{\dot{F}} = 4.863 \times 10^{-17}\ cm^2/s$

$D_3 = 2.0 \times 10^{-30} \dot{F} = 4 \times 10^{-17}\ cm^2/s$

$\therefore$ diffusion coefficient $= 9.798 \times 10^{-17}\ cm^2/s$

b) In 5/5 model using

$\tau = Dt/a^2 = \frac{D \times (2 \times 12 \times 30 \times 24 \times 3600)\ sec}{(8 \times 10^{-4})^2\ cm^2}$

$= 0.0095 < \pi^{-2}$

$\therefore$ FG release fraction, $f = 4\sqrt{\frac{Dt}{\pi a^2}} - \frac{3}{2}\frac{Dt}{a^2}$

$= 0.2202$

FG produced $= \gamma \dot{F} t = 0.3017 \times \dot{F} \times t$

$= 3.7536 \times 10^{20}$ fission/cm³

Atoms released $= 8.265 \times 10^{19}$ atom/cm³

c) post radiation annealing process 6/10

assuming $\tau > \pi^{-2}$

$\therefore$ FG release fraction

$f = 1 - \frac{6}{\pi^2} e^{-\pi^2 \frac{Dt}{a^2}}$

given $f = 0.6$

$T = 2273$ K

$$\therefore \; 0.6 = 1 - \frac{6}{\pi^2} e^{-\pi^2 \frac{D \times t}{a^2}}$$

$$\Rightarrow -0.4186 = -\pi^2 \frac{D \times t}{a^2}$$

$$t = 277033371.8 \text{ sec}$$

$$\approx 8.9 \text{ years.}$$

Ans. to the ques. no. 3

12/16

$t = 1$ years $\quad T = 600$ K

$t = 600\ \mu m$

a) -7/8 ition time of oxidation to linear.

$$t^*(d) = 6.62 \times 10^{-7} \exp \frac{11549}{T}$$

$$= 295.007 \text{ days.} < (12 \times 30) \text{ days}$$

linear coefficient of thickness w.r.t (time)

$$K_L = 7.48 \times 10^6 \exp \frac{-12500}{T} \ \mu m/d$$

$$= 0.0067 \ \mu m/d$$

upto' transition' oxidation thickness

$$\delta^* = 5.1 \exp^{-550/T} \ \mu m$$

$$= 2.039 \ \mu m$$

$\therefore$ total thickness

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

$$= 2.475 \ \mu m$$

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5/8

b) $f_H = 0.15$, $PBR = 1.5$ $\rho_{Zr} = 6.5 g/cm^3$

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

weight PPM of H in cladd after 1 year, C_H

$$= \frac{m_H}{m_{Zr}} \times 10^6$$

$m_{Zr} = (\rho_{Zr}) \times V_{clad} = \rho_{Zr} \times$ clad unaffected thickness $\times$ surface area

$$= \rho_{Zr} \times \left(t - \frac{\delta}{PBR}\right) \times S$$

$$= 0.3889 \; S(cm^2) \; g.$$

$$m_H = f \times \left(H_{generated} \times \frac{M_H}{A}\right)$$

$$= 2f \times O_{generated} \times \frac{M_H}{A}$$

$$= 2f \times \left(\frac{\text{mass gain (mg)}}{\text{surface area } (dm^2)}\right) \times \frac{A}{1000 \times M_O} \times \frac{M_H}{A}$$

$$\times S \; (dm^2)$$

$$= 2f \times \left(\delta(\mu m) \times 14.7\right) \frac{M_H}{1000 M_O} \times S (cm^2) \times 100$$

$$= 0.000682 \; S(cm^2) \; g.$$

$\therefore C_H = 117.46$ wPPM (Ans)

Ans. to the Q 4

15/15

Volume strain $\epsilon = \epsilon_{th} + \epsilon_D + \epsilon_{gfp} + \epsilon_{sfp}$

$$\epsilon_{th} = \alpha_{th}(T - T_{ref})$$

$$= 11\times10^{-6}(k^{-1})(1600-300)(k)$$

$$= 0.0143$$

$$\text{Burnup}, \beta = \frac{\dot{F}\times t}{N_u}$$

$$N_u = \rho_{UO_2} \times \frac{A}{M_{UO_2}} \times \frac{1}{J}$$

$$= 10.97 \times \frac{6.023\times10^{23}}{238+2\times16} \text{ atm/cm}^3$$

$$= 2.447\times10^{22} \text{ Uatom/cm}^3$$

$$\therefore \beta = \frac{(3.5\times10^{13})\times(85\times24\times3600)}{2.447\times10^{22}} \text{ FIMA}$$

$$= 0.0105 \text{ FIMA}$$

$$\therefore \epsilon_D = \Delta\rho_0\left(e^{\frac{\beta \ln 0.01}{C_D \beta_D}} - 1\right)$$

$$= 0.01\times\left(e^{\frac{(0.0105 \ln 0.01)\text{FIMA}}{1\times(5/950)\text{FIMA}}} - 1\right)$$

as $T > 750°C$, $C_D = 1$

$$= -0.0099$$

$$\epsilon_{gfp} = 1.96\times10^{-28}\rho\beta(2800-T)^{11.73} \times e^{-0.0162(2800-T)} \times e^{-17.8\rho\beta}$$

$$= 0.01378$$

$$\left[\begin{array}{l}\rho = 10.97 \text{ gm/cc} \\ T = 1600 k\end{array}\right]$$

$f_{sfp} = 5.577 \times 10^{-2} \rho B$
$= 0.0069$

$\therefore$ total volume change
$= 0.0246$

Ans. to the Q 5

5/5

five types of fission products

1. soluble oxide
2. insoluble oxide
3. noble gases
4. metals
5. Volatiles.

Ans. to the Q 6

6/6

3 stages of fission gas release

1. intragranular fission gas bubble production and diffusion to grain boundary
2. At grain boundary FG bubbles nucleation, growth and finally interconnection
3. FG escape through the interconnected bubble channel to sufoce

Ans to the Q7

3/5

Two types of creep

1. Thermal creep
2. Irradiation creep

Bulk diffusion creep is thermal creep as it occures as high temperature

Ans to Q 8

6/6

High Burnup structure effects

1. increase thermal conductivity
2. increase toughness
3. as it has large pores which are stable it can effectively hold the fission gas.

Ans. to Q9

6/6

Microstructure based fuel performace model

As the available fuel performance codes are based on temperature and burn-up, they can no shows a good performance at all condition except the correlated conditions. For a versatile fuel performance code.

material structure or properties correlation with temperature, displacement, stoichiometry is very necessary. In microstructure base fuel performance code, both cladding and fuel microstructure from nanoscale to mesoscale to macroscale will be incorporated.

Ans to Q 10

5/5

Benefits of Zr cladding

1. Zr is a very cost effective material as cladding
2. low nutron cross section
3. good thermal conductivity

Ans to Q 11

5/5

Metalis fuel undergo constituent redistribution because of Temperature gradiant.

For temperature gradiant at high temperature zone we found γU, then βU and at low temp αU. Also Zr flows the Soret diffusion (thermal diffusion) And Zr has much affinity for γU

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So, at high temp zone we get more Zr. At βU phase, Zr has a depletion, and at low temp Zr stays as the intial stage.

Ans. to Q 12

6/6

Microstructure of U-Zr based fuel varied so much because the temperature range it is generally operating is 800K - 1000K with 23% Zr. In this region, both of them have a large range of phases, which transform from one phase to another phase by varing temperature. So, we have different phases of it which have completely different geometry. This variation not only found in radial direction, but also found along the axial direction of fuel slug.