

### Exam - 3

late  
turn in:  
-5



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Q.3=)

There are various types of products form from fission such as fission fragments, neutrons,  $\gamma$ -photons,  $\beta$ -decay fragments or what could we call as fission products are of types,

#### ① Soluble oxides

- This are some rare earth elements like Y, La, etc. they can get dissolved in lattice. Due to low thermal conductivity they also decrease thermal conductivity of overall system.

#### ② Insoluble oxides

- This are metal oxides ( $ZrO_2$ , etc.) insoluble into fuel crystal but can cause swelling.

③ Metal precipitates or metals that are formed after fission reaction. This actually increase the thermal conductivity of overall system. eg. (Mo, Ru, etc.)

#### ④ Volatile products

This are products like Br, Rb, etc. have different phase behaviour according to temperature. At fuel interior with high temp., ~~this~~ this exist as gases.

#### ⑤ Noble gases

This are products that are largely responsible for fuel swelling and also clad swelling later on.

Due to being insoluble in fuel matrix they get released into fuel cladding gap.

eg. (Xe, Kr).

Q.6.  $\Rightarrow$

There are 3 - different 6/6 ~~gas~~ through which fission gas release of inert gases like Xe, Kr etc happens.

(1) Stage 1: In this stage gas atoms are formed within the grains but this are only in the range of few nm radius.

~~Inter-granular~~ bubbles which don't get trapped within the

Gas atoms which are not trapped in this kind of bubbles travel or migrate towards grain boundaries.

(2) Stage 2: This is subdivided into 3 - parts.

(a) Gas bubbles nucleate on grain boundaries.

(b) They grow in size with certain mechanism.

(c) This grown gas bubbles interconnect and percolate.

(3) Stage 3: In this stage Gas in the interconnected bubbles travels to the free surfaces.



Q.7.  $\Rightarrow$  There are different types of creep that occurs in nuclear fuel and cladding that causes changes in materials.

(a) Dislocation creep  $\Rightarrow$

This is deformation mechanism in materials.

It's basically involves, movement of dislocations through the lattice of given material.

(b) Irradiation creep  $\Rightarrow$

This is stress induced dimensional / microstructural changes that occurs in crystalline materials at intermediate temperature.

(c) Bulk diffusion based creep is also known as Nabarro-Herring creep. This occurs at low stresses and high temperature in fine grained materials.

~~The~~ N-H creep rate is inversely proportional to square of grain size.

It is solely controlled by diffusional mass transport.

Q.8.  $\Rightarrow$  Previously it was thought 6/6 HBS reduces efficiency of fuel performance but recent research 6/6 shows that it has positive effects, like,

- (1) High burnup structures due to presence of no. of voids and pores in fuel, causes more retention of fission gas thus reducing fission gas release.
- (2) They also cause increased toughness and softness in outer ~~radial~~ radial position of the pellet.
- (3) In pellets with ~~interior~~ high burnup structure or HBS increase in thermal conductivity was observed at certain temperature. Reason for this is not fully known but it could be due to grain formation.

Q.9.3)

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Microstructure based fuel performance modeling or models provides structure or property based relationships. In this kind of model, we evaluate different fuel properties like thermal conductivity, fracture stress, melting temperature etc. based and taking into account of different microstructural features and their changes/evolution.

For microstructure based modeling we consider different property values of fuel and cladding with different microstructural variables for fuel and cladding like,

Average grain size, dislocation density

U-defect concentration (fuel), H-concentration (cladding).

Point defect conc. & crack parameters etc.

eg. of thermal conductivity.

$$K = \frac{K_B K_P K_R}{A + BT + CT^2 + C_U U + C_H H + C_G G}$$

~~~~~

Bulk conductivity

~~~~~

Variables & interrelationships

~~~~~

Fission gas

Q.10.3)

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There are three benefits of Zr-alloys used as cladding like,

- (1) Low neutron cross-section = so, cladding doesn't act as neutron trap and allowed effective transport.
- (2) It is corrosion resistant to water even at temp. like 300°C or 573.15 K making it little bit safer.
- (3) It has good thermal conductivity, so heat transport from fuel to coolant is better than some other types of claddings.



Q.11. =)

Metallurgical undergoes 5/5 significant redistribution ~~and~~ due to reasons like,

① It we take example of U-Zr fuel,

at different ~~date~~ temperature ~~Zr~~ U-Zr fuel has different phases like

① Gamma phase - with high Zr content in region with high temp.

②  $\beta$ -Phase - low Zr concn. ③  $\alpha/\delta$ -Phase with fabricator level Zr content.

As Zr diffuses by Sorret diffusion through temperature gradient, it has different type of material at different radial position in fuel pellet.

This shows the reason that metallurgical fuel ~~used~~ shows considerable redistribution due to different phase development at different temperature.

Q.12. =)

U-Zr fuel is 5/6 of U rich Zr which increases its melting point ~~has~~ higher temperature for stable  $\beta$ -phase.

Temperature range for this fuel is 800-1100 K.

But at different temperature there is different phase like, around 95-1100 K,  $\gamma$ -Phase is stable which has higher Zr-content.

As we decrease the temperature phase changes to  $\beta$ - $\alpha$  with  $\gamma$ -Phase with moderate to low Zr-content & further

below its  $\alpha$ - $\delta$  &  $\gamma$  with ~~very low Zr content fabricator~~ - level low Zr content and further below its  $\alpha$ - $\delta$  ~~and~~  $\delta$ -Phase.

Across pellet temperature decreases from centre to outer periphery, this with distribution nature of different phase of Zr in U-Zr fuel makes U-Zr varied & very complex fuel.

(1)

Q.4.3)

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Q Burnup -  $B = f t / M_u$

$$- M_u = \frac{M_a S_u}{M_u} = 2.44 \times 10^{22} \text{ atoms cm}^{-3}$$

$$B = \frac{3.5 \times 10^{13} \times 3600 \times 24 \times 85}{2.44 \times 10^{22}}$$

$$= 0.00105 \text{ fTMA}$$

$$E_{th} = \alpha \Delta T = 11 \times 10^6 (1600 - 300)$$

$$= 0.0143$$

We are higher than @ 750°C,  $C_D = 1$

$$E_D = \Delta S_0 \left( e^{\frac{B \ln 0.01}{C_D B_D} - 1} \right)$$

$$= 0.01 \left( e^{\frac{0.00105 \ln(0.01)}{1 \times 0.0053} - 1} \right)$$

$$= -0.0059 \approx -0.006$$

$$E_{sfp} = 5.577 \times 10^{-2} \beta$$

$$= 6.35 \times 10^{-4}$$

$$E_{sfp} = 1.96 \times 10^{-28} \times 10^{-97} \times 0.0005 (2800 - 1600)^{11.73}$$

$$\times e^{-0.062 (2800 - 1600)} - 17.8 \times 10^{-4} \times 0.00105$$

$$= 0.0088 \quad 0.00144$$

total  $\Rightarrow E_{tot} = 0.001047$

(1)



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Q.3.2)

(a)

oxide thickness

$$S^*(\mu m) = 5.1 \times e^{-\frac{550}{600}}$$

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$$= 2.0392$$

$$f^*(d) = 295.01$$

$$k_L = 7.48 \times 10^6 \exp \frac{-12500}{T}$$

$$= 6.7 \times 10^{-3}$$

$$S = 2.0392 + 6.7 \times 10^{-3} (365 - 295)$$

$$= \underline{2.5082 \mu m}$$

Q.3.2)

(b)

$$\rho_{FeO_2} = 5.68 \text{ g/cc} \Rightarrow 1.47 \text{ g/cm}^3$$

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$$1 \mu m \text{ mass} \Rightarrow 14.7 \text{ mg/dm}^3$$

$$\text{for } 2.5082 \Rightarrow 36.871 \text{ mg/dm}^3$$

$$\frac{0.036 \times N_A}{16} = 1.355 \times 10^{21} \text{ atoms/dm}^3$$

$$f = 15\% \therefore \text{ingress} = 0.15 \times 2 \times 1.355 \times 10^{21} = 4.0649 \times 10^{20} \text{ atoms/dm}^3$$

$$\text{un corroded thickness} \Rightarrow 600 - \frac{2.5082}{1.56} = 598.39 \text{ microns}$$

$$\text{Vol}^n \text{ of } Zr = 598.39 \times 10^{-4} \times 10 \times 10 = 5.98 \text{ cm}^3$$

$$\text{total mass of } Zr \Rightarrow 6.5 \times 5.98 = 38.87 \text{ g}$$

$$\text{hydro conc.} \Rightarrow \frac{0.00225}{38.87} = 5.7886 \times 10^{-5} = 57.885 \text{ wt. ppm}$$

$$\therefore 600 + 57.885 = \underline{657.885 \text{ ppm}}$$

Q.1. =)

from fig. (1)

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for pt. (1)

- (1) Temperature at fuel center reaches its peak for smeared pellet with linear, constant gap, and gap width is just starting to increase so no much pressure/stress on cladding yet.

for point (2).

fuel centerline temperature is at its peak for smeared pellet at low burnup region.

for temperature there is some for smeared and discrete pellet.

Gap width increases and it's at highest value so ~~no~~ stress on cladding.

point (3).

Temperature is decreasing for fuel center at this region with low to intermediate burnup.

Gap width is decreasing at this burn-up region so PCI can happen.

pt. (4).

sudden rise in temperature for fuel center.

Gap decrease is stopping at (4).

pt (5)

Temperature at this burnup is continuously increasing for fuel center.

but gap is 0  $\mu\text{m}$  as fuel and cladding are touched.