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NE-591 (Nuclear fuel Performance)

Exam-3

Q.3 =)

There are various types of products form from fission such as fission fragments, neutrons, γ-photons, β-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., ~~the~~ this ~~ga~~ 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. => There are 3 different stages 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.

~~Intragranular bubbles which don't get trapped within the~~

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

② Stage 2: This is sub divided into 3-parts.

ⓐ Gas bubbles nucleate on grain boundaries.

ⓑ They grow in size with certain mechanism.

ⓒ 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.=) There are different types of creep that occurs in nuclear fuel and cladding that causes changes in materials.

(a) Dislocation creep :-)

This is deformation mechanism in materials.
It's basically involves, movement of dislocations through the lattice of given material.

(b) Irradiation creep:-)

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

(c) Bulk diffusion based creep is also known as Nabarro-Hearing creep. This occurs and low stresses and high temperature in fine grained materials.
N-H creep rate is inversely proportional to square of grain size.
It is solely controlled by diffusional mass transport.

Q.8.=) Previously it was thought that HBS reduces efficiency of fuel performance but recent research 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 position of the pellet.
3. In pellets with 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 rim formation.

Q.9.:)

Microstructure based fuel permance 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 accont of different microsturctural features and their changes/evolution.

For microsture 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 deffect con. crack parameters etc.

eg. of thermal conductivity.

$$K = \frac{K_{GB} K_B K_{pr}}{\underbrace{A + BT + CT^2}_{\text{Bulk Conductivity}} + \underbrace{C_v c_v + C_i c_i}_{\text{vacancies \& interstitials}} + \underbrace{C_g c_g}_{\text{fission gas}}}$$

Q.10.:) There are multiple benefits of Zr-allys used as cladding like,

(1) Low neutrons cross-section = so, cladding doesn't act as neutron trap and allowed effective transport.

(2) It is corrosion resistant to watero even at temp. like 300°C or 573.1K making it little bit safer.

(3) It has good thermal conductivity, so heat transport is from fuel to coolant is better than some other types of claddings.

Q.11.=)

Metallic fuel undergoes constituent redistribution ~~and~~ due to reasons like,

(a) (1) If we take example of U-Zr fuel,
at different ~~diffe~~ temperature ~~Zr~~ U-Zr fuel has different phases like

(a) Gamma Phase - with high Zr content in region with high temp.

(b) β-Phase - low Zr conte. (c) α/δ-Phase with fabrication level Zr content.

As Zr diffuses by Sorret diffusion through tempera-ture gradient, it has different type of material at different radial posion in fuel pellet.

This shows the reason that medallic fuel u... Shows constituent redistribution due to different phase developement at different temperature.

Q.12.=) U-Zr fuel is alloying U with Zr which increases its melting point and has higher temperature for stable β-phase.

Temperature range for this fuel is 800-1100 K.

But at different ~~a~~ temperature there is different phase like, around 95-1100 K, γ-phase is stable which has higher Zr-content.

As we decrease the temperature phase changes to β-U with γ-phase with moderate to low Zr-content, further below its α-U ~~+~~ γ with ~~very low Zr content~~ fabrication level Zr content and further below its α-U and δ-phase.

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

Q.4.⇒

ⓐ Burnup - $B = \dot{f}t/N_u$.

- $N_u = \frac{N_a \delta_u}{M_u} = 2.44 \times 10^{22}$ $\frac{\text{atoms}}{cm^3}$

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

$$= 0.00105 \, FIMA$$

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

$$= 0.0143$$

We are higher than 750°C, $C_D = 1$

$$\varepsilon_D = \Delta \rho_0 \left(e^{\frac{B \ln 0.01}{C_D B_D}} - 1 \right)$$

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

$$= -0.0059 \approx -0.006$$

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

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

$$\varepsilon_{gfp} = 1.96 \times 10^{-28} \times 10.97 \times 0.00105 (2800 - 1600)^{11.73} \times e^{-0.0162(2800-1600)} \times e^{-17.8 \times 10.97 \times 0.00105}$$

$$= \cancel{0.0088} \; 0.00144.$$

total! ⇒ $\varepsilon_{tot} = 0.001047$

Q.3.=) (a)

oxide thickness

δ^* (um) = $5.1 \times e^{-\frac{550}{600}}$

= 2.0392

$t^*(d)$ = 295.01

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

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

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

= 2.5082 um.

(b) =

ρ_{ZrO_2} = 5.68 g/cc =) 1.44 g/cm³ (f)

1 umresorb 14.7 mg/dm3

for 2.5082 =) 36.871 mg/d3.

$\frac{0.036 \times N_A}{16}$ = 1.355×10^{21} atoms/dm3

f = 15%. ∴ ingress = $0.15 \times 2 \times 1.355 \times 10^{21}$ = 4.0649×10^{20} atoms/dm

uncorroded thickness =) $600 - \frac{2.5082}{1.56}$ = 598.39 microns.

vol^m of Zr = $598.39 \times 10^{-4} \times 10 \times 10$ = 5.98 cm³.

total mass of Zr =) 6.5×5.98 =) 38.87 g.

hydro conc. -) $\frac{0.00225}{38.87}$ = 5.7886×10^{5} = 57.885 wt. ppm.

∴ 600+57.885 = 657.885 ppm

Q.1.=)

~~B~~ from dig. (1)

for pt. (1)

(C) ~~It~~ Temperature at fuel centere reach its peake for smeared ~~p~~ellet with linear, const rate.

and Gap width is just starting to increase so no much pressure ~~or~~/stress on cladding yet.

for. Point (2).

fuel centerline temperature is at it's peak for smeared pellet at low burnup region.

for temperature trend is same for smeared and discreet pellet.

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

Point (3).

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

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

Pt. (4).

sudden rise in temperature for fuel centre.

& gap decrease is stopping at (4).

pt (5)

Temperature at this burnup is continuosly increa-sing for fuel centre.

but Gap is 0 μm as fuel and cladding are touched.