89/100

Jarrod Gesualdi   Exam 2 Fuel Performance   April 21 2017

Question 1   -1, 24/25

1. The fuel initially thermally expands, and heats up due to fission.

2. At maximum thermal expansion, there is a slight densification effect due to grain growth. This shrinks the pellet gradually, increasing the gap thickness and raising the Temperature

-1 densification is due to loss of initial porosity, not grain growth

3. Solid + gaseous Fission product swelling begins to increase the pellet size, shrinking the gap and lowering the centerline temperature gradually.

4. Gaseous fission product swelling peaks as it is balanced by fission gas release. Solid fission product swelling continues. Fission gas release raises the centerline temperature of the fuel by lowering thermal conductivity. PCMI as fuel eventually contacts cladding then drops the temp.

5. Fuel and clad are in contact, additional fission products accumulate within fuel. HBS forms reducing thermal conductivity in addition to the stoichiometry shift in the fuel. Centerline T continues to steadily rise.

Exam 2 Fuel Performance

April 21 2017

Question 2

-5, 20/25

a.) $a = 8\,\mu m$, $\dot{F} = 2.0\times10^{13}/cm^3 s$, $T = 900°C = 1173$

$D = D_1 + D_2 + D_3$

$D_1 = 7.6\times10^{-6}\exp\left(-3.03/(8.61733\times10^{-5})(1173)\right) = 7.285\times10^{-19}\,cm^2/s$

$D_2 = 1.41\times10^{-18}\exp\left(-1.19/(8.61733\times10^{-5})(1173)\right)\sqrt{\dot{F}}$

$(1.08772\times10^{-23})(\sqrt{2\times10^{13}}) = 4.8631\times10^{-17}\,cm^2/s$

$D_3 = 2.0\times10^{-30}\dot{F} = (2.0\times10^{-30})(2\times10^{13}) = 4\times10^{-17}$

$\boxed{D = 8.9360\times10^{-17}\,cm^2/s}$

b.) $N_{gas} = y\dot{F}t$ $\quad y = 0.3017 \quad t = 63072000\,s$

$N_{gas} = (0.3017)(2\times10^{13}/cm^3\cdot s)(63072000) = 3.8058\times10^{20}\,atoms/cm^3$

$N_{released}$ $\quad \tau = \frac{Dt}{a^2} = \frac{(8.9373\times10^{-17}\,cm^2/s)(63072000)}{(8\times10^{-4})^2} = 8.8064\times10^{-3}$

$\pi^{-2} = 0.1013$ $\quad \boxed{\tau < \pi^{-2}}$

$f = 4\sqrt{\frac{\tau}{\pi}} - \frac{3}{2}\tau = 4\sqrt{\frac{8.8077\times10^{-3}}{\pi}} - \frac{3}{2}8.8064\times10^{-3}$

$0.2117 - 0.1321 = 0.1985$

$N_{release} = f N_{gas} = 0.1985(3.8058\times10^{20}) = \boxed{7.554\times10^{19}}$

Gesualdi

2/6

Exam 2 Fuel Performance

April 21 2017

Question 2

c.) $T = 2000°C$ $a = 8\times10^{-4}$ cm

$$D = D_1 + \cancel{D_2}^{0} + \cancel{D_3}^{0} \qquad \dot{F} = 0$$

$$D_1 = 7.6\times10^{-6} \exp\left(-3.03 / (8.61733\times10^{-5} \cdot 2273)\right)$$

$$\boxed{= 1.4541\times10^{-12}\ \text{cm}^2/\text{s}}$$

Out of Pile

$$f = 6\sqrt{\frac{Dt}{\pi a^2}} - \cancel{3\frac{Dt}{a^2}}^{0}$$

For a conservative estimate we use just the first term

$$\frac{\left(\frac{f^2}{36}\right)\pi(8\times10^{-4})^2}{1.4541\times10^{-12}} = \boxed{t = \underline{384.1\ \text{s}} = \underline{6.4\ \text{minutes}}}$$

Fast, but the diff. coeff is high.

-5, How much gas was released?

Gesualdi 3/6

Exam 2 Fuel Performance April 21 2017

Question 3 -0, 30/30

600 μm

a.) $T = 600K$ $t = 1year$ $\delta_0 = 0.6mm = 0.06cm$

$$t^* = 6.62\times10^{-7} \exp\left(\frac{11949}{600}\right) = 295.01 \text{ days}$$

$$\delta^* = 5.1 \exp\left(\frac{-550}{600}\right) = 2.039 \mu m$$

$$\delta(\mu m) = \delta^* + K_L(t - t^*) = 2.039 + (6.7\times10^{-3})(365 - 295.01)$$
$$= 2.508 \mu m$$

$$K_L = 7.48\times10^6 \exp\left(\frac{-12500}{600}\right) = 0.0067 \mu m/d$$

$$w = \delta_{ox}(14.7) = 2.508 \cdot 14.7 = \underline{36.87 \ mg/dm^2}$$

b.) $$\delta_{Zrlo} = \left(\delta_0 - \frac{\delta_{ox}}{1.56}\right) = \left(600 - \frac{2.508}{1.56}\right) = \boxed{598.4 \mu m}$$

↳ PBR

c.) $w = 36.87 \ mg/dm^2$ Oxygen

MW Oxygen = 16 g/mol

$N_A = 6.022\times10^{23}$ atoms/mol

$1 dm^2$ clad = 36.87 mg oxygen

$$\frac{0.03687 g \ O \cdot (6.022\times10^{22})}{16 g/mol} = 1.388\times10^{21} \text{ atoms O} = 2.7754\times10^{21} \text{ atoms H}$$

$$H_{abs} = f N_H = (0.15)(2.7754\times10^{21}) = 4.1631\times10^{20} \text{ atoms H}$$

Gesualdi 4/6

Question 3 | Exam 2 Fuel Performance | April 21 2017

c. Continued...

$H_{abs} = (0.15)(2.7754 \times 10^{21}) = 4.1631 \times 10^{20}$ atoms H absorbed

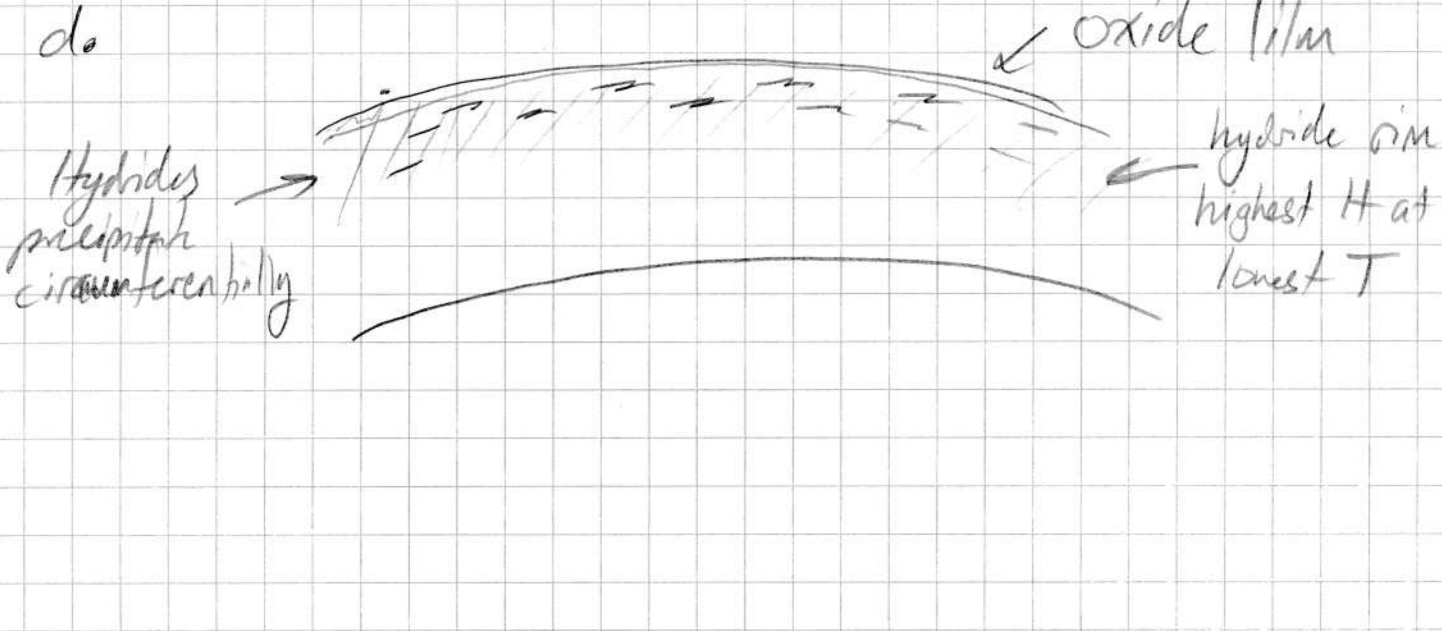
$m_H = \frac{H_{abs}}{N_a} \cdot MW_H = \frac{4.15518 \times 10^{20}}{6.022 \times 10^{23}}(1.01\ g/mol) = 6.982 \times 10^{-4}\ g\ H$

$m_{Zr} = (\delta_{Zr})(A)(\rho_{Zr}) = (0.05984\ cm)(100\ cm^2)(6.5\ g/cm^3)$

$= 38.896\ g$

$H_{wtppm} = \frac{m_H}{m_{Zr}} \times 10^6 = \frac{6.982 \times 10^{-4}\ g\ H}{38.896\ g\ Zr} \times 10^6 = \boxed{17.95\ wtppm}$

d.



Gesualdi
5/6

Exam 2 Fuel Performance

April 21 2017

Question 4

-0, 15/15

a.) In a LOCA, the coolant temperature rises and pressure drops. The cladding suffers breakaway oxidation, increased hydrogen pickup, and may balloon and rupture due to low coolant pressure. There are also microstructure changes as cladding transitions from α to β phase above 865°C

and inc. hydrogen gas prod.

The fuel encounters thermal stress, increased fission gas release, and may crack into many pieces.

In a RIA it is mostly fuel effects as it rapidly expands. This can cause it to contact the cladding, which may result in cracking or burst of clad. There is little time for temperature effects on the cladding.

b.) In both, the cladding may burst. The fuel is also subject to thermal expansion, which may make it crack.

c.) Cladding coatings could help extend the lifetime of the cladding in a LOCA scenario by providing a barrier to resist corrosion. This would reduce the likelihood of a cladding rupture, and buy more time for engineers and technicians to resolve the LOCA.

Gesualdi
6/6