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$\boxed{50}$

Exam 1: NE533: Nuclear Fuel Performance
Show all work. Label question number in your response.

it will be much faster to hand write answers

1. (12 pts) Derive the relationship for temperature drop over the fuel in cartesian coordinates assuming the following boundary conditions: $T'(x_0) = 0$; $x_0 = 0$; $x_1 = X$; $T(x_1) = T_1$; and the simplified equation below:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + Q = 0$$

7/12

What assumptions were made to get to the provided equation?

Assumptions: steady state, axisymmetric, T is constant in z-direction, constant k ✓

Starting with:

$$\nabla \cdot (k\nabla T) + Q = 0$$

you didn't actually work through the integration to solve for $T(x)$

Axisymmetric:

$$\frac{\frac{1}{r}d}{dr}\left(\frac{rk(t)dt}{dr}\right) + \frac{d}{dz}\left(\frac{k(T)dT}{dz}\right) + Q(r,z) = 0$$

Constant in z:

$$\frac{\frac{1}{r}d}{dr}\left(\frac{rk(t)dT}{dr}\right) + Q(r) = 0$$

Constant k:

$$\frac{\frac{1}{r}d}{dr}\left(\frac{rkdT}{dr}\right) + Q = 0$$

Boundary conditions:

Type equation here.

2. (16 pts) A fuel pellet has a corrosive coating. Calculate the centerline temperature with and without the coating.

Coating k: 0.015 W/cm-K; Cladding k: 0.15 W/cm-K; Fuel k: 0.05 W/cm-K; Gap k: 0.004 W/cm-K; T(coating surface): 600 K; $Q = 250$ W/cm^3; R_F=0.6 cm; t_g=0.005 cm; t_{clad}=0.05 cm; t_{coat}=0.01 cm. Assume that T_{CO} without the coating is 600 K.

4/16

$k_{coat} = 0.015$
$k_{clad} = 0.15$
$k_{fuel} = 0.05$
$k_{gap} = 0.004$
$T_{Coatsurf} = 600$
$T_{CO} = 600$
$Q = 250$
$R_F = 0.6$

Robert Gentile

coating outside of cladding

$t_g = 0.005$
$t_{clad} = 0.05$
$t_{coat} = 0.01$
Find T_o:

$$T_{gap} - T_{clad} = \frac{Qt_{clad}}{2k_{clad}} R_F \quad ✓$$

$$T_{gap} = T_{Coatsurf} \quad ✗$$

$$T_{coatsurf} - T_{clad} = \frac{(250)(0.05)}{(2)(0.15)}(0.6) = 25$$

$$T_{clad} = T_{coatsurf} - 25 = 575\ K$$

Next:

Type equation here.

3. (14 pts) Uranium mononitride (UN) is a fuel being considered for use in light water reactors. Consider UN to have an enrichment of 19.5% and a density of 12.3 g/cm^3. Assume the fission cross section is 570 barns. Nitrogen atomic number=14. 0/14
   a. What is the heat generation rate, given a neutron flux of 5E12 n/cm^2-s?
   b. What enrichment of UO_2 would be required to obtain the same heat generation rate? UO2 density is 10.97 g/cc.

4. (12 pts) Given a rod of 3.5 m in length, LHR^0 = 350 W/cm, and γ=1.3: 0/12
   a. What is the LHR at z=1.4 m?
   b. Which is the change in outlet to inlet temperature for water: C_P = 4200 J/kg-K, mdot = 0.22 kg/s-rod

5. (12 pts) Perform a backward Euler time stepping to approximate the function. Compute with a timestep of dt=0.5, expanding to t_n=1.5.

   dy/dt = t*exp(-2t); t_0 = 0; y_0 = 4 0/12

6. (4 pts) Explain the difference between fertile, fissile and fissionable. 4/4

   Fertile – a non-fissionable material that can be converted into fissile material via neutron absorption and subsequent nuclei conversions ✓
   Fissile – material capable of maintaining a fission chain reaction with neutrons of any energy (thermal and fast) ✓
   Fissionable – material capable of undergoing fission after capturing a high energy neutron ✓

7. (4 pts) List two reasons why we don't use pure metallic U as a fuel form? 4/4

   One reason is that pure uranium swells dramatically during thermal cycling. ✓ Another is that pure uranium has three phases, each of which have different crystal structures (α – orthorhombic, β – tetragonal, γ – BCC structure). These phases are changed at different temperatures and pressures. The α phase also ✓ has both anisotropic thermal expansion and irradiation growth.

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8. (4 pts) What is smear density? Why is this necessary?

4/4

Smear Density – ratio of fuel volume to total internal volume of fuel element
This is necessary as different fuel types swell differently under thermal stress. Thus, the smear density helps us find the appropriate fuel volume to maximize efficiency (in this aspect) without creating an oversized pellet that, when swelling, undergoes FCMI or FCCI processes and compromises reactor safety.

9. (8 pts) Why do we need to enrich U? What compound is utilized in the enrichment process? Describe the centrifuge-based enrichment of U, including why it works.

8/8

Enrichment is needed to ensure that there is enough fissile material in the fuel for a given reactor design.
Compound – HF
Centrifuge enrichment is when UF_6 gas is placed in a gas centrifuge cylinder and rotated at a high speed. The non-U_{235} uranium (typically the leftover U_{238}) left is spun to the edges of the centrifuge and removed due to their heavier molecules, while the enriched U_{235} is removed via a central pipe.

10. (6 pts) What are the three ways that space is discretized for numerical solutions? Name a strength or weakness of one of these types.

Three types of numeral solutions for spatial discretization:

6/6

1. Finite difference
   a. Advantage – Simple
2. Finite Volume
   a. Advantage – can model any geometry
3. Finite Element
   a. Advantage – Continuous representation

11. (8 pts) What are the departure from nucleate boiling and the critical heat flux?

8/8

Critical Heat Flux – the heat flux limit before a phase change occurs
Departure from Nucleate Boiling – the ratio of the heat flux that causes dryout (the critical heat flux) to the actual heat flux

12. (5 pts) Identify the layers in a TRISO particle. Provide an example of a reactor that utilizes TRISO-based fuel.

5/5

Layers:
- Fuel kernel
- Buffer
- Inner Pyrolitic Carbon (IPyC)
- SiC
- Outer Pyrolitic Carbon (OPyC)

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Reactor that uses TRISO fuels – HTGR and MSR