ENGINEERING PHYSICS 4D03/6D03

DAY CLASS Dr. Wm. Garland
DURATION: 3 hours

McMASTER UNIVERSITY FINAL EXAMINATION December 11, 2004

Special Instructions:
1. Closed Book. All calculators and up to 6 single sided 8 1/2" by 11" crib sheets are permitted.
2. Do all questions.
3. The value of each question is as indicated. TOTAL Value: 100 marks

THIS EXAMINATION PAPER INCLUDES 3 PAGES AND 9 QUESTIONS. YOU ARE RESPONSIBLE FOR ENSURING THAT YOUR COPY OF THE PAPER IS COMPLETE. BRING ANY DISCREPANCY TO THE ATTENTION OF YOUR INVIGILATOR.

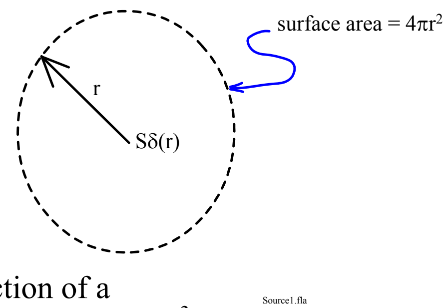
1. [10 Marks]
   a. (5 marks) Boron is a common material used to shield against thermal neutrons. Estimate the thickness of boron required to attenuate an incident thermal neutron beam to 0.1 % of its intensity. Use $\Sigma_a = 103\ \text{cm}^{-1}$.
   b. (5 marks) Consider the case where 10^{10} neutrons / sec cross a unit area in the positive direction and 0.5 x 10^{10} neutrons / sec cross the same unit area in the negative direction. Compute the neutron flux and the neutron current.

2. [10 Marks]Briefly:
   a. (1 mark) distinguish between neutron flux and neutron current.
   b. (1 mark) distinguish between reactivity, ρ, and multiplication factor, k.
   c. (1 mark) describe ε of the four factor formulae.
   d. (1 mark) describe η of the four factor formulae.
   e. (1 mark) describe f of the four factor formulae.
   f. (1 mark) describe p of the four factor formulae.
   g. (2 marks) distinguish between geometric buckling and material buckling.
   h. (1 mark) describe fission product poison.
   i. (1 mark) describe xenon over-ride.

3. [10 marks] What is the obvious error in the following expressions? Explain briefly.
   a. (2 marks) Steady state one-group neutron balance equation (2 errors):
      $D(r)\nabla^2\phi - \Sigma_a(r)\phi(r) = \nu\Sigma_f\,\phi(r)$.
   b. (1 mark) $\Sigma_{\text{total}} < \Sigma_{\text{absorption}}$.
   c. (1 mark) The gradient of the flux is continuous at an interface
   d. (1 mark) ρ=2.
   e. (1 mark) For a reactor operating at constant power, as the fuel is burned up, the flux remains constant over time.
   f. (1 mark) I-135 decays with a half life of 9.17 hours to Xe-135 which decays with a half life of 6.58 hours.
   g. (2 marks) Neutron current is defined as: $\mathbf{J} = -D\nabla\phi$.
   h. (1 mark) For the same power, the smaller the reactor, the lower the flux.

…continued on page 2

4. [10 marks] For a neutron source, $S\delta(\mathbf{r})$, as shown in the figure, in a medium defined by some Σ_a and D:



a. Solve the one-speed neutron equation to show that the neutron flux is $\phi = \frac{S}{4\pi D r} e^{-r/L}$, where the usual definition of L holds. *[Hint, try making the substitution* $\omega = r\phi$ *.]*

b. Derive a general expression for the flux as a function of a general source distributed throughout space, S(r) neutrons / cm^3-s. This source is a continuous distribution, as opposed to the point source in part (a).

5. [10 marks] For a simple one group neutron diffusion in an infinite medium with a planar source of neutron at the origin:
   a. Write down the governing neutron balance equation in steady state and give the dimensions of <u>each variable</u> and <u>each term</u>, including the planar source term $S\delta(x)$.
   b. For the finite difference approximation used in the numerical solution, special treatment needs to be made for the source term. Mathematically derive this special treatment and physically explain its meaning.

6. [10 marks] Consider a large one dimensional reactor composed of many replicated identical cells, each containing fuel and moderator. Each cell consists of a central fuel region of thickness "a" surrounded on either side by a reflector of thickness "b". Near the centre of the reactor, we can assume that one cell looks and behaves like its neighbours since the reactor is large. Thus, the flux distribution in each central cell can be calculated independently. Assume one speed neutrons.
   a. What are the governing flux equations for the steady state?
   b. What are the boundary conditions?
   c. If you were solving this numerically, what boundary conditions would you use?
   d. Why are the B.C.s different for the numerical and analytical cases?

7. [10 marks] For a homogeneous, critical, one dimensional, bare slab reactor (modelled by the two-group neutron diffusion model):
   a. Derive the steady state xenon spatial distribution.
   b. Sketch this distribution in space for several cases (low flux, medium flux, high flux).

…continued on page 3

8. [20 marks] As a young and upcoming nuclear engineer, you have been assigned the task of building an "All Singing, All Dancing" reactor physics computer program, named ASAD, to solve the general transient multigroup neutron diffusion equations with delayed precursors and associated equations. The code is to be three-dimensional, Cartesian geometry, transient reactor core solver for McMaster Nuclear Reactor. Assume the cell properties are known. In the x and y direction, each cell is a fuel assembly, control assembly, or reflector assembly, etc. roughly 7 cm by 7 cm. The vertical dimension, z, is to be divided up into 10 grid points or so. Model the pool by a few exterior water cells. The core is a 6 by 9 grid of assemblies. Don't get hung up on the details. I am looking for the overall approach.
   a. Derive the difference equations for the numerical solver for the time and space dependent equations. Show the procedure for a simple forward-stepping marching scheme in time (like Euler) and some space-sweeping scheme (like Gauss-Seidel) as per the assignments. Don't forget the precursors, poisons and fuel depletion equations. And don't forget to include a reactivity control scheme.
   b. Show how you can efficiently and effectively use the same code to solve a variety of problems ranging from short term flux response to reactivity perturbations like prompt jumps and reactor trips, to flux control simulations where the delayed precursors need to be tracked accurately, to poison calculations, to long term fuel management and associated reactivity control. Focus on adjusting the time constants of phenomena that does not need to be tracked accurately for the problem at hand. It's trivial really.

9. [10 marks] You have been asked to augment ASAD by adding a thermal hydraulics model. Coolant enters the top of the core and exits at the bottom. The flow, W kg/s per fuel assembly, is known. Assume uniform properties within each ‘cell' of the x-y plane. Also assume that the fuel plates are thin, highly conductive and with negligible heat capacity so that you need not be concerned with the temperature distribution within the fuel plates. Derive the difference equations for the axial temperature distribution of the coolant as a function of time.

…..END…..