ENGINEERING PHYSICS 4D03 / 6D03

DAY CLASS — M.P. Butler

DURATION: 3 hours —

MCMASTER UNIVERSITY FINAL EXAMINATION — December 10, 2002

Special Instructions:

1. Closed Book. All calculators and one 8½ x 11 inch crib sheet (both sides) are permitted.
2. Candidates must attempt all questions.
3. The value of each question is as indicated.
4. Point form is acceptable for discussion-type questions.

TOTAL MARKS: 105

THIS EXAMINATION PAPER INCLUDES 3 PAGES AND 10 QUESTIONS. YOU ARE RESPONSIBLE FOR ENSURING THAT YOUR COPY OF THE PAPER IS COMPLETE. BRING ANY DISCREPANCY TO THE ATTENTION OF YOUR INVIGILATOR.

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1. *(2 marks each)* Define, in words:
   a. β, in the neutron sense
   b. Neutron current
   c. Macroscopic cross-section
   d. Reactivity coefficient
   e. Prompt critical
   f. Delayed neutron
   g. Diffusion length
   h. Moderation
   i. Extrapolation distance
   j. Neutron flux.

2. *(12 marks)* Consider the neutron continuity equation:

$$\frac{1}{v}\frac{\partial\varphi(\vec{r},E,t)}{\partial t} = -\nabla\cdot\vec{J}(\vec{r},E,t) - \Sigma(\vec{r},E,t)\,\varphi(\vec{r},E,t) + \chi\int_0^\infty \nu\Sigma_f(\vec{r},E',t)\,\varphi(\vec{r},E',t)\,dE' + \int_0^\infty \Sigma_s(\vec{r},E'\to E,t)\,\varphi(\vec{r},E',t)\,dE'$$

We have discussed many approximations to this equation. Outline <u>but do not derive</u> them.

3. *(5 marks)* Consider the equation

$$-\nabla\cdot D_g\nabla\varphi_g + \Sigma_g\varphi_g = \chi_g\sum_{g'=1}^{G}\nu_{g'}\Sigma_{fg'}\varphi_{g'} + \sum_{g'=1}^{G}\Sigma_{g'g}\varphi_{g'}$$

What physical process is represented by each term? Do <u>not</u> define individual symbols.

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4. *(10 marks)* Consider the point kinetics "power" equation:

$$\frac{dP}{dt} = \left(\frac{\rho - \beta}{\Lambda}\right) P + \sum_{j=1}^{6} \lambda_j C_j$$

Discuss how the terms on the right-hand side affect the time behaviour of the reactor power when a reactivity change takes place, particularly when the magnitude of the effect is compared to β, the delayed neutron fraction.

5. *(7 marks)* Develop finite-difference equivalents for the following equations:

$$\frac{dP}{dt} = \left(\frac{\rho - \beta}{\Lambda}\right) P + \sum_{j=1}^{6} \lambda_j C_j \qquad \frac{dC_j}{dt} = \frac{\beta_j}{\Lambda} P - \lambda_j C_j \ ; \ j = 1,6$$

Which quantities affect the implementation of the numerical method? Why?

6. Consider a neutron interacting with U-235.
   a. *(6 marks)* Draw a sketch showing the possible processes and particles.
   b. *(12 marks)* Write down appropriate differential equations which describe the time behaviour of the populations of particles associated with fission.

7. *(8 marks)* Use the appropriate rate equations to develop an expression for the steady-state concentration of xenon-135. Show that this quantity has a limiting value as flux increases.

8. A reactor is operating at a steady power of 120 MW when it is tripped by its emergency shutdown system, which has a total reactivity worth of -80 milli-k. Assume a U-235 reactor with one delayed neutron group such that $\beta = 0.0065$ and $\lambda = 0.08\ s^{-1}$.
   a. *(4 marks)* Determine the power immediately after the trip.
   b. *(4 marks)* How long does it take for the power to reach 1% of the steady-state operating power?

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9. *(10 marks)* An infinitely-long and -thick bare slab of width $2w$ consists of a fissile, absorbing material. It also contains a distributed neutron source of the form

$$S(x) = S_0 e^{-\alpha|x|}, \quad -w \le x \le w$$

where α is a constant. The slab is bounded by vacuum. Assume all material properties are independent of position. Ignore any explicit consideration of the extrapolation distance. Develop an expression for the flux as a function of position. Work through the problem solution to the point where you need to determine the expressions for the unknown constants in the homogeneous solution of the differential equation; then, <u>outline only</u> how you would calculate these constants.

10. *(7 marks)* A reactor is operating at a steady-state power P. The measured reactor power is given by

$$P = c_p \dot{m} (T_{outlet} - T_{inlet})$$

where T_{inlet} is fixed. A small positive step reactivity perturbation of magnitude ρ_0 occurs. Assume a single temperature coefficient α is an adequate model for the behaviour. Estimate the power at which temperature feedback stops the power increase.

Hint: use an average temperature to represent the core's thermal behaviour.

THE END