ENGINEERING PHYSICS 4D3/6D3

DAY CLASS — Dr. Wm. Garland
DURATION: 3 hours —
McMASTER UNIVERSITY FINAL EXAMINATION — December 1997

Special Instructions:

1. Open Book. All calculators and reference material permitted.
2. Do all 8 questions.
3. The value of each question is as indicated.
4. Point form is sufficient for discussion type questions.

TOTAL Value: 100 marks

THIS EXAMINATION PAPER INCLUDES 3 PAGES AND 8 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) If a concrete shield of thickness 37 cm attenuates 50% of a thermal neutron beam, what thickness is required to attenuate 100% of the beam?
b) What target isotope must be used for forming $_{11}Na^{24}$ when the incident projectile is: (i) a neutron, (ii) a proton, or (iii) an alpha particle?
c) In the context of the 6 factor formula, what is the maximum value of the multiplication factor that can be achieved in any conceivable reactor design.

2. [10 marks]

Derive an expression for η for uranium as a function of enrichment, γ, at thermal neutron energies, given:

σ_f^{235}= 577 b
σ_a^{235}= 678 b
σ_a^{238}= 2.73 b

and where γ is defined as the atom fraction of U^{235}.

3. [10 marks]

Consider an initially pure sample of radioactive material parent, concentration $N_1(t)$, which decays to a daughter product, $N_2(t)$, that is itself radioactive. Determine the long term concentrations of the two isotopes given that the daughter decays much more quickly that the parent. [Hint: This can be solved without much math by considering what N_1 looks like from the point of view of N_2. Alternatively, if you prefer a more mathematical solution, try $N_2(t) = A \exp(-\lambda_1 t) + C \exp(-\lambda_2 t)$ where λ_1 and λ_2 are the decay constants for N_1 and N_2 respectively.]

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4. [10 marks]
a) What is the flux shape and what is the peak to average flux ratio for a rectangular parallelopiped reactor (ie boxed shape like the McMaster Nuclear Reactor)? Assume a bare homogeneous core.
b) Discuss the ramifications of the flux peaking from the point of view of:
(i) Xe poisoning
(ii) burnup
(iii) control rod placement
(iv) flux measurement for control purposes.

5. [15 marks]
From the information given below, estimate the diffusion length, L, for H_2O and D_2O based on one group diffusion theory. Discuss the differences between two reactors of the same size, both critical, but one contains H_2O moderator while the other contains D_2O moderator. What does this imply for reactor design?

Parameter	H_2O	D_2O
Σ_a	0.022 cm^{-1}	3.3 x 10^{-5} cm^{-1}
Σ_s	3.45 cm^{-1}	0.449 cm^{-1}
μ_0	0.676	0.884

[Hint: Compare $B^2 = \frac{(\nu\Sigma_f/\Sigma_a - 1)}{L^2}$] [Recall: $D = \frac{1}{3(\Sigma_t - \mu_0\Sigma_s)}$]

6. [10 marks]
Assume the point kinetics model for a reactor. The reactor has been operating at neutron level n_1 for a very long time. Using the point kinetics equations to justify your answers:
a) What are the values of ρ and C_i for the above condition?
b) The operator moves the control rods to raise the neutron level up to n_2 and to hold it at this new level. What are the values of ρ and C_i as a function of time for this situation? Qualitatively plot ρ and C_i as functions of time before, during and after the event. Consider carefully what ρ is required after the neutron level has reached the desired value.

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7. [20 marks]

For a simple reactor concept such as the McMaster pool-type reactor with an array of fuel elements cooled by water, outline a computer program to numerically solve the three dimensional, two group, transient neutron diffusion equations with delayed precursors. Consider the reactor to be a heterogeneous collection of vertical fuel assemblies, control assemblies and light water moderator assemblies. Consider each assembly to be a homogeneous cell. Assume that there is no up scatter, that only thermal neutrons cause fission and that neutrons are born only in the fast group. The time frame of interest is milli-seconds to minutes. For the flux and precursor concentrations:

a) What is the geometry and what are the governing equations?
b) What are the boundary conditions?
c) What are the initial conditions?
d) What are the finite difference equations?
e) What is the solution algorithm? Include a flow chart.
f) Discuss time step control and what could be done to get around the limits set by the inherent stiffness of the problem.
g) Show where the reactivity control interfaces with the flux equations (but defer discussion to question 8).

8. [20 marks]

Given the code from question 7, outline a computer sub-program to provide reactivity control. Consider the following algorithm to determine the control rod(s) position change:

$$\Delta z_{in} = a_0 \, (\varphi_{measured} - \varphi_{setpoint}) + a_1 \frac{d\varphi_{measured}}{dt}$$

where a_0 and a_1 are positive constants and Δz_{in} is the requested change in control rod insertion.

a) In general, how does a control rod work, i.e. what parameters in the governing equations of question 8 are affected?

b) Would the above controller work? If so, how? If not, why not? Explain the function of the two terms on the right hand side. Compare the above controller with the iteration control algorithm typically used in the steady state solution. Why are they different?

c) Where should the control rod or rods be placed? Would more than one rod be necessary or desirable? Consider possible undesirable effects of control rods on the flux distributions in all directions. How could you achieve flux shape control as well as flux amplitude control?

d) How fast does the control rod movement need to be? Why?

e) Limits should be placed on the maximum rate of control rod movement. Why? Suggest an algorithm to implement these limits.

f) Where should the flux be measured? Why?

THE END