GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam – Spring Semester 2020

Day 2: Reactor Physics

EXAM AREA

Assigned Number (DO NOT SIGN YOUR NAME)

✷ Please sign your **name** on the back of this page —

Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering

Nuclear and Radiological Engineering/Medical Physics Program

PhD Qualifying Exam

Spring 2020

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(Your ID Code)

NE Reactor Physics

(Day 2)

Instructions

1. Use a separate page for each answer sheet using only the front side of the paper. DO NOT write on the back of the answer sheet
2. The **question nuclear and your ID Code** should be shown clearly on each answer sheet
3. **ANSWER 4 OF 6 Questions**
4. Staple your question sheet to your answer sheet and turn in

Reactor physics:

Q1

A bare spherical core is composed of a binary homogeneous mixture of fissile and moderator isotopes. Only of 10% of the neutrons are absorbed in the moderator isotope. The reproduction factor of the fissile isotope is 2.20. The following values are given: L_T^2=8.1 cm^2 and τ=27 cm^2.

a) Calculate the critical dimensions of the reactor. Neglect the extrapolation length.
b) An infinite reflector is added around the core. Write the differential diffusion equations in the core and reflector and state the boundary and interface conditions required for the solution. How would the material buckling change compared to the previous section (bare core). Briefly explain your answer.

Q2

Critical core fueled with 30×10^6 g of uranium (5% enriched by weight) operates at a nominal power of 3500 MW. Given the following transmutation chain:

$$ {}^{235}_{92}U \underset{fission}{\rightarrow} {}^{135}_{53}I \underset{\substack{\beta- \\ 6.6h}}{\rightarrow} {}^{135}_{54}Xe \; \begin{matrix} \overset{(n,\gamma)}{\rightarrow} \\ 2.6\times10^{6}b \\ \underset{\substack{\beta- \\ 9.1h}}{\rightarrow} \end{matrix} $$

a) Write the differential equations that describe the rate of change for all the isotopes.
b) Estimate xenon reactivity worth in equilibrium following the reactor's operation of 10 days.
c) Estimate xenon reactivity worth following a shutdown of 6 hours.
d) Draw the concentration and reactivity worth (two separate figures) of Xe^{135} from the reactor's start point (t=0) to shutdown (t=10 days) and a sequential restart at (t=10 days + 6 hours). The draw should cover 20 days. Please provide explanation for your drawing.
e) Describe the procedure to estimate xenon reactivity worth after the reactor-core operated for 100 days. In your description do NOT include spatial dependence and assume that all the microscopic cross-sections are constant. There is no need to solve - only to describe.

Use the following data:
$\sigma_a^X = 2 \times 10^5$b, $t_{1/2}^I = 6.6h$, $t_{1/2}^X = 9.1h$, $\gamma^I = 0.061$, $\sigma_f^{U235} = 25$b, $\sigma_a^{U235} = 30$b, $\sigma_a^{U238} = 1$b

Q3

A critical bare slab (void, no reflector) with homogeneously distributed fuel is given. Neglect the
extrapolation length. The group constants are given in the following table:

Group constant	Group 1	Group 2	Group 3
χ	0.580	0.430	0.000
$\nu\Sigma_f$ (cm^{-1})	0.010	0.020	0.180
Σ_a (cm^{-1})	0.005	0.030	0.120
$\Sigma_s^{g\to g+1}$ (cm^{-1})	0.083	0.124	0.000
D	2.160	1.720	0.350

Comment: there is no up-scattering, except from group 3 to 2 ($\Sigma_s^{3\to 2} = 0.05\ cm^{-1}$) and the system is
directly coupled (scattering only to adjacent groups).

a) Write the differential set of equations for all the groups and the boundary conditions.
b) Use the Helmholtz relation and obtain the algebraic set of equations, from which the critical size of the slab can be identified.
c) Calculate the critical size of the slab.
d) A finite reflector is added around the core with non-uniform material distribution. Explain the numerical procedure to solve the multi-group problem using the multi-group finite elements method. For simplicity, ignore up-scattering and describe the method in details.

Q4

1. Suppose we have a bare 1D slab reactor ($0 \le x \le a$).
    a. Write down the two group diffusion equation and the boundary conditions ignoring the extrapolation distance, up scattering cross section ($\sigma_{21} = 0$) and thermal fission neutrons ($\chi_2 = 0$).
    b. Assuming the diffusion coefficient in the thermal group is very small and the thermal leakage term can be ignored derive the criticality condition.

Q5

Suppose that a cell (lattice) calculation was performed for a given region and various reaction rates and fluxes are obtained and listed in the following table.

Group	Fast	Thermal
Total reaction rate (s^{-1})	7.8E9	1.2E10
Absorption rate (s^{-1})	3.1E8	1.4E9
Fission reaction rate (s^{-1})	4.3E8	1.1E9

Fission neutron creation rate (s^{-1})	1.3E9	2.4E9
Cell averaged flux ($cm^{-2}.\ s^{-1}$)	3.3E10	4.3E10

(a) If the volume of the region is 10 cm^3, calculate the two-group homogenized cross sections σ_{tot}, σ_a, σ_f and $\nu\sigma_f$ for the region so that all group reaction rates are preserved.

(b) If we also know the two-group entering and exiting partial currents on the bounding surface, explain how to calculate the homogenized two-group scattering cross sections.

<u>Q6.</u>

Find the natural (omega) modes of the equations given below.

$$\frac{\partial n(z,t)}{\partial t} = \left[Dv\frac{\partial^2}{\partial z^2} + \frac{\rho}{\Lambda}\right] n(z,t) + S(z,t),$$

$$n(0,t) = n(a,t) = 0$$

$$n(z,0) = h(z) = 0$$