Nuclear Reactor Theory
UEA – 630/630G
KSU – NE630

Prerequisites: NE 495 Elements of Nuclear Engineering (K-State)
NE 690 Radiation Protection and Shielding (K-State)
Or, 1) basic nuclear science including radioactivity, neutron interactions, and reaction kinematics and 2) mathematical analysis through solution of ordinary and simple partial differential equations

Description: Theory of diffusion and slowing down of neutrons with application to critical and subcritical nuclear reactors.

Instructor

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Required Text

Lamarsh, J.R., Introduction to Nuclear Reactor Theory, Addison-Wesley, Reading, Mass. 1966.
This book is currently out of print. You will find a PDF version of the text on K-State Online in the Handouts directory.

Course Description and Goals

1. Formulate and calculate radioactive decay/buildup problems, neutron reaction rate problems, fission energy/burnup problems. Apply the six-factor formula to criticality problems.
2. Derive Fick's law and the diffusion equation. Discuss the inherent approximations.
3. Formulate diffusion equation boundary conditions for various configurations in three basic geometries.
4. Solve the inhomogeneous diffusion equation analytically by (1) variation of constants (2) Green's functions, and (3) eigenfunction expansions.
5. Solve the inhomogeneous diffusion equation numerically using finite differences.
6. Solve the slowing down equation for the collision and slowing down densities in an infinite homogeneous medium.
7. Derive the Fermi-age equation and solve it using Laplace transforms
8. Calculate thermal-neutron reaction rates
9. Apply slowing down and diffusion theories to multiplying media
10. Design and calculate geometries or masses for critical bare cores

11. Describe effects of reflected cores, homogeneous versus heterogeneous cores, and feedback effects.
12. Produce written reports of technical analyses in a professional manner
13. Elucidate, in words a liberal-arts graduate could understand, the importance or physical meaning of nuclear jargon terms introduced in the course, such as flux, slowing down density, Fermiage, diffusion length, etc.

Topics

1. Introduction (3 hours)
   Review of ordinary differential equations
   Review of reaction rates, cross sections and nuclear reactions
   Review of fission mechanism, cross sections and energetics
   Neutron chain reactions, criticality and keff
2. Diffusion of One-Speed Neutrons
   Description of neutron field; uncollided flux (1 hour)
   Derivation of diffusion equation and Fick's law (2 hours)
   Boundary conditions for the diffusion equation (1 hour)
   Methods for solving diffusion equation; examples (8 hours)
   (i) variation of constants
   (ii) Green's function approach
   (iii) eigenfunction expansion technique
   Physical significance and measurement of diffusion length; reciprocity theorem (1 hour)
3. Neutron Slowing Down
   Review of scattering kinematics (2 hours)
   Moderation in hydrogen without absorption (1 hour)
   Moderation for A > 1 without absorption (2 hours)
   Fermi-age theory for moderation in finite medium (2 hours)
   Slowing down with absorption (1 hour)
4. Description of Thermal Neutrons
   Thermal equilibrium and Maxwellian spectrum (1 hour)
   Reaction rates for thermal neutrons (2 hours)
   Diffusion of thermal neutrons (1 hour)
   Neutron lifetimes (1 hour)
   Measurement of thermal neutron parameters (1 hour)
5. Multiplying Media and Reactor Criticality
   Diffusion and slowing down with multiplication (1 hour)
   Harmonics and time-dependent solution; buckling (2 hours)
   Criticality for bare reactors (1 hours)
   Minimum critical mass, size and composition (1 hour)
   Effect of reflectors (2 hour)
   Effect of heterogeneous cores (1 hour)
6. Reactivity Feedback Effects
   Temperature feedback (1 hour)
   Fuel and fission product poisons (2 hours)
   Delayed neutrons and reactor kinetics (intro) (1 hour)

Course Policies and Administration

1. Homework: There will be five homework assignments, each worth 50 points. You may work with others on the solutions but each person should prepare his or her own write-up and scan into a PDF file. Sign the cover sheet; this signature indicates compliance with the Honor system

described below. Drop the PDF file in the drop box on the K-State Online web site by the date indicated on the course schedule.

2. Preparation for Class: Please complete the reading assignment before viewing the lecture for the class. In addition, there will be one on-line experiment in which we will determine the half-life of a radioisotope. You are to write a short summary of your findings and submit this through the drop box on the course web site. This write-up will be worth 50 points
3. Examinations: There will be a mid-term examination (worth 300 points) during the semester and a final examination (worth 400 points).
4. Grades will be determined as follows. A score will be determined on the basis of homework (250 points), the half-life experiment write-up (50 points), and examinations (700 points), for a total of 1,000 points.

Student Evaluation:

1. In-class quizzes
2. Online quizzes for distance students
3. Midterm and final examinations
4. In-class participation and responses
5. Message board discussion for distance students
6. Individual and group homework assignments

Examination Dates:

Midterm: to be announced
Final: Friday, December 17

Classroom Conduct:
All student activities in the University, including this course, are governed by the Student Judicial Conduct Code as outlined in the Student Governing Association By Laws, Article VI, Section 3, number 2. Students who engage in behavior that disrupts the learning environment may be asked to leave the class.

Relationship of Course to Professional Component:
This course strengthens and extends the analysis and design tools unique to the nuclear engineering profession. It hones both the analytical and numerical skills of the students as well as introduce them to important technical concepts for neutrons in a diffusing and multiplying media. Professional presentation of technical material is emphasized in the biweekly homework assignments, and use of a wide variety of data sources, particularly through the internet, is required.

Evaluations:
You will be assigned to a small group with which you will participate in (1) completing the bi-weekly homework assignments and (2) completing the exercises assigned in class. Each group will submit a single report for each assignment signed by all members of the group.

There will be short (15 minute) in-class quizzes on the days homework assignments are due. These quizzes will generally be on some topic related to the homework or to a recently assigned exercise. In addition, there will be two examinations, the midterm and the final.

Grades will be assigned on the basis of a weighted average of scores from group assignments and individual efforts (exams and quizzes). Typically 50-70% of your grade will be from your individual scores and the remainder from the greater of your group scores or your individual scores.