Materials in the Nuclear Reactor Environment
NE/MS 4XX/5XX, Spring 2022

Course Syllabus

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Class Meetings: T TR, 11:45AM – 1:00PM 406, Mann Hall
Office Hours: T TR, 10:00:AM – 11:00AM (AND by Appointment/Email)

1. Course Objectives:

In this course, most of the materials issues encountered in the operation of nuclear power reactors are discussed. The objective of the course is to give students a background in materials for nuclear power reactors and to discuss the unique changes that occur in these materials under the reactor environment, so that students understand the limitations put on reactor operations and reactor design by materials performance. In the first part of the course we review basic concepts of physical metallurgy to develop an understanding of the relationship between microstructure and material properties outside of irradiation. In the second part of the course, we describe the process of radiation-material interaction, present the methods to calculate atomic displacement damage produced by exposure to irradiation, and describe the changes in material properties that results from irradiation exposure. In the third part of the course, special attention is given to property changes affecting the fuel and cladding performance and operational safety such as corrosion of the cladding, hydriding, fuel expansion, Pellet-Cladding Interactions, stress corrosion-cracking; Reactor accident scenarios such as loss of coolant accident (LOCA) and reactivity insertion accident (RIA) will be reviewed as well. Both mathematical methods and experimental techniques are emphasized.

2. Learning outcomes:

By the end of this course, the successful student will be able to:
1) understand the basics of physical metallurgy and of the relationship between material microstructure and macroscopic properties, outside of irradiation.
2) understand the basic mechanisms of materials degradation in the reactor environment (radiation damage, corrosion, hydriding etc) (in structural and cladding materials as well as fuel materials).
3) understand and be more knowledgeable about materials degradation issues in nuclear reactor environment.

3. Pre or Co Requisite: MSE/NE 201, MSE/NE 409
No background is required in either Materials Science or Nuclear Engineering beyond ***sophomore physics* and *materials science and engineering basics*.**

4. Required text(s):

Light Water Reactor Materials Volume I: Fundamentals, Arthur Motta and D.R. Olander in addition to class notes.

Suggested Readings/Reference Books:
An Introduction to Nuclear Materials, K.L. Murty and I. Charit
Materials Science and Engineering: An Introduction, W. D. Callister
Phase Transformations in Metals and Alloys, D.A. Porter and K.E. Easterling

Useful Books for Consultation:

P. Haasen	Physical Metallurgy
C. Kittel	Introduction to Solid State Physics
M.W. Thompson	Defects and Radiation Damage in Metal
B.R.T. Frost	Nuclear Materials

5. Course Requirements:

- Grading and Exams:

- There will be homework assignments, announced and un-announced quizzes and three exams.
- In addition, graduate students will have an extra assignment that will require them to research the literature and go deeper in topics treated in class; the graduate student assignment may be in the form of a literature review assignment on a particular subject or a critique of a published research article.

- The distribution of weights is the following:

Assignment	Graduate students	Undergraduate students
Quizz/Participation	5%	5%
Homework	15%	20%
Exam 1	20%	25%
Exam 2	20%	25%
Exam 3	20%	25%
Extra assignment*	20%	X

- Grading scale:

A+ ≥ 95; A ≥ 92.5; A- ≥ 90; B+ ≥ 85; B≥ 82.5; B- ≥ 80; C+ ≥ 75; C ≥ 72.5; C- ≥ 70; D+ ≥ 65; D ≥ 62.5; D- ≥ 60; F<60

6. Topical outline:
1. Introduction/ Reactor types/ Materials selection criteria;
2. Materials used in LWRs: Zr alloys, steels, UO_2
3. Crystal structures; Lattice defects; Diffusion Transport processes
4. Radiation interaction with matter, Dynamics of damage creation; Methods for calculating atomic displacement;
5. Dimensional changes under irradiation;
6. Irradiation Hardening and Embrittlement;
7. Waterside Corrosion and Hydriding of fuel cladding;
8. Fuel evolution under irradiation; Fission gas release and fuel swelling;

Proposed schedule:

Date	Class Topic
Class 1	Syllabus / Introduction
Class 2	Reactor types/ Materials selection
Class 3	Illustrations of In-reactor Materials Degradation
Class 4	Crystal structures
Class 5	Crystal structures / / Miller indices
Class 6	Lattice defects I
Class 7	Lattice defects II (dislocations)
Class 8	Mechanical Properties
Class 9	Diffusion /Transport processes
Class 10	Phase Diagrams
Class 11	Radiation interaction with matter
Class 12	Dynamics of point defect creation (collision cascades)
Class 13	Methods for calculating atomic displacement I
Class 14	Methods for calculating atomic displacement II
Class 15	Radiation enhanced diffusion
Class 16	Microstructure evolution under irradiation
Class 17	Dimensional changes under irradiation I: Swelling
Class 18	Dimensional changes under irradiation II : Creep
Class 19	Dimensional changes under irradiation III: Growth
Class 20	Irradiation Hardening and Embrittlement
Class 21	Waterside Corrosion and Hydriding of fuel cladding I
Class 22	Waterside Corrosion and Hydriding of fuel cladding II
Class 23	Waterside Corrosion and Hydriding of fuel cladding III
Class 24	Stress Corrosion Cracking
Class 25	Irradiation Assisted Stress Corrosion Cracking
Class 26	Fuel evolution under irradiation
Class 27	Fission gas release and fuel swelling
Class 28	Fuel evolution under irradiation at high burnup
Class 29	Materials for next generation of nuclear reactors

7. Office of Student Disability Services policy statement:
Any student with a documented disability should contact the Office of Disability Services to make arrangements for appropriate accommodations.

8. General Remarks:

Code of conduct:
Attendance to class for on-campus students is not optional. If a student misses more than 2 classes, they may have their final grade reduced by 10%. In any case, any student missing a class should provide valid justification. Punctuality is de rigueur: because classes are being recorded

for the distant learning students, it is critical that on-campus students are on time i.e. properly seated at their desk at least 5 minutes before the class starts.

Logistics:
Class notes are provided to students to print prior to class.

On homeworks and exams: in order to get full credit, calculations should be presented in a literal form prior to plugging the numbers in the formula. No points will be credited for a "correct" numerical answer if the steps leading to the answer are not clearly shown. The instructor will not accept copies which are not neat; if the students have trouble keeping their work neat when handwriting, they are invited to type their homework and take home exams.