Radiation Effects
NE/MSE 757, Fall 2022

Course Syllabus

Instructor: Dr Djamel Kaoumi,
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Class Meetings: M W, 10:15 – 11:30am, Mann Hall #406
Office Hours: T Th, 9am – 10am,
For off campus students email me to set a convenient phone appointment

Prereq: NE/MSE 409/509 or Dr Kaoumi's approval. No exception.

1. Course Objectives:

This is an advanced course on nuclear materials for students with background in fundamentals of materials, defects and dislocation theory, and mechanical properties. It is important for students to refer to various books, monographs, reviews and journal papers on many of the subject areas.

The objective of the course is to discuss the unique changes that occur in materials under irradiation, so to understand the limitations put on nuclear reactor operations and reactor design by materials performance. In the first part of the course we briefly review basic concepts of physical metallurgy necessary to develop an understanding of the relationship between microstructure and nuclear material properties outside of irradiation. In the second part of the course, we describe the process of radiation damage formation, present the methods to calculate atomic displacements produced by exposure to irradiation, and describe the microstructural evolution that results from irradiation both qualitatively, and quantitatively through the use of rate theory. In the third part, we show how irradiation-induced changes in the microstructure evolve into changes in macroscopic behavior of the material. The possible dimensional changes due to irradiation (swelling, creep and irradiation growth) are discussed, as well as the effects of irradiation on mechanical properties and irradiation-induced microchemistry changes and phase transformations. Note that the focus will be put on radiation damage and effects in metallic systems (cladding and structural alloys will serve for examples).

By the end of this course, the successful student 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 rate theory applied to radiation damage in metals.
3) understand the basic *mechanisms* of materials degradation induced by irradiation, including radiation-induced phenomena such as irradiation growth, swelling, creep, embrittlement and hardening, phase transformations, and irradiation induced segregation.

2. Required textbook:
Light Water Reactor Materials by D. R. Olander and A. T. Motta in addition to class notes.

Reference Books:
Fundamental of Radiation Materials Science, G. S. Was
An Introduction to Nuclear Materials, K.L. Murty and I. Charit
Fundamental Aspects of Nuclear Reactor Fuel Elements, D.R. Olander
Phase Transformations in Metals and Alloys, D.A. Porter and K.E. Easterling

Useful Books for Consultation:
Materials Science and Engineering: An Introduction, W. D. Callister

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

3. Course Assessments:

- Graded Homework

- Three written exams

- One project which will consist on a literature review on a special topic related to radiation damage in materials

Assignment	Grading weight
Homework	20%
Project	20%
Exam 1	20%
Exam 2	20%
Exam 3	20%

- 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

4. Course outline:

I. **Materials behavior outside irradiation (Brief review):** Alloys used in nuclear applications; Crystallographic Structure of Materials; Lattice Defects; Transport Processes; Phase Stability and Phase Diagrams

II. **Materials under irradiation:** Radiation Interaction with Matter; Primary Damage Creation; Defect Annihilation; Rate Theory of Point Defect Balances Under Irradiation

III. **Radiation Effects:** Microstructural Evolution Under Irradiation; Dimensional changes under irradiation (swelling, creep and irradiation growth); Irradiation Hardening and Embrittlement; Irradiation-Induced microchemistry changes (segregation); Phase transformations under irradiation (low of corresponding states); Grain growth under irradiation (if time permits), and Materials for advanced reactors (if time permits)

Proposed schedule:

Class order	Class Topic
Class 1	Introduction/motivations
Class 2	Crystal structures
Class 3	Lattice defects
Class 4	Transport processes
Class 5	Phase diagrams
Class 6	Radiation interaction with matter
Class 7	Damage Creation: Collision dynamics and displacement cascades, thermal spike concept
Class 8	Damage creation: cross-sections, damage functions: Kinchin-Pease, NRT, Linhard models (I)
Class 9	Damage creation: cross-sections, damage functions: Kinchin-Pease, NRT, Linhard models (II)
Class 10	Displacement rates for neutron vs. charged particle irradiation, SRIM simulations I
Class 11	SRIM simulations II
Class 12	Rate theory of point defect balances under irradiation I
Class 13	Rate theory of point defect balances under irradiation II
Class 14	Microstructural evolution under irradiation
Class 15	Rate theory applied to dimensional changes under irradiation I: Swelling
Class 16	Rate theory applied to dimensional changes under irradiation II : Creep
Class 17	Rate theory applied to dimensional changes irradiation III : Growth
Class 18	Irradiation Hardening and Embrittlement
Class 19	Radiation Enhanced Diffusion
Class 20	Irradiation-Induced microchemistry changes I
Class 21	Irradiation-Induced microchemistry changes II
Class 22	Irradiation-Induced microchemistry changes III
Class 23	Phase transformations under irradiation I
Class 24	Phase transformations under irradiation II
Class 25	Special topic I: Dose rate effect on radiation effects and concept of temperature shift
Class 26	Special topic II: Grain-Growth under irradiation
Class 27	Advanced radiation-resistant materials for advanced reactors

5. General Remarks and logistics:

- Class notes are sent via email prior to class for the students to print.
- On homework 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.