Mechanical Engineering Dept. Department

Syllabus
ME 454: Materials in Nuclear Power Plants (3-0-3)

Course Catalog Description:

The behaviour of materials under the harsh environment of a nuclear reactor and their responses to neutron irradiation. structural materials and fuels used in Light-Water Reactors, defects creation and evolution due to radiation damage, microstructure-property relationships in cladding and fuels, mechanical properties, corrosion, limitations put on reactor operations and reactor design by materials performance.

Course Pre-requisites:

- ME 205: Materials Science
- ME 207: Materials Science for CHE
- ME 216: Materials Science and Engg.
- ME 448: Engineering of Nuclear Reactors

Course Co-requisites:

- ME 449: Introduction to Atomistic Simu

Course Objectives:

1. 1. To introduce materials science and nuclear engineering topics needed to understand the behaviour of materials and their aging processes inside a nuclear reactor.
2. 2. To apply basic assessment methods in radiation damage, defect creation and evolution, prediction of aging mechanical properties, estimate corrosion rates, and basic correlation of microstructure-property of structural and cladding materials in light-water reactors.
3. 3. To analyse basic monitoring data for the major materials degradation mechanisms in the reactor environment due to radiation damage, electrochemical corrosion, creep, and embrittlement.

Course Learning Outcomes:

CLO1. Describe the service conditions (i.e., mechanical and thermal loads, radiation fields, coolant chemistry) for materials and fuels in LWR plants

CLO2. Identify atomic-, nano-, and micro-structure of alloys and ceramics, and interpret its relation to macroscopic mechanical and chemical behavior of select materials

CLO3. Describe the impact of materials selection and degradation in the design and operation of LWR components and structures

CLO4. Apply prediction models for the effect of radiation on the compositional, structural, and mechanical properties in alloys and ceramics, based on the fundamental interactions of radiation with the material

CLO5. Use basic electrochemistry to predict the general corrosion behaviour of metallic alloys in LWR environment

CLO6. Predict conditions in LWR environment accelerating localized corrosion mechanisms and analyze possible mitigation methods

CLO7. Explain risks associated with materials degradation on the overall safety of the nuclear power plants.

Learning Resources:

- Arthur T. Motta, Donald R. Olander, Light Water Reactor Materials, Volume I: Fundamentals, 2017.
- K. Murty, I. Charit, An Introduction to Nuclear Materials: Fundamentals and Applications, Wiley, 2013 G.S. Was, D. Petti , S. Ukai , S. Zinkle. Materials for future nuclear energy systems, Journal of Nuclear Materials 527 (2019) W. D., Jr. Callister, Materials Science and Engineering: An Introduction, 2006 M. W. Barsoum, Fundamentals of Ceramics, 1997
- https://www.iaea.org/ https://www.energy.gov.sa/en/Pages/fq.aspx
- SPECTER code to quantitatively evaluate neutron damage and use simple analytical models that describe microstructural evolution and property changes under irradiation.

Lecture Assessment Plan:

Assessment Task	Week Due	Weight
term project	10-14	20.0%
Final	16	30.0%
quizzes	3,6,9,12,15	15.0%
HW	3,6,9,12, 15	15.0%
Mid-term	7-8	20.0%

Lecture Weekly Schedule:

Week#	Topics
1	Course intro and review of the LWR designs and operating conditions.
	Requirements for materials selection and performance in LWRs.
2	Review of basic materials concepts: defects (point, line, surface, and volume), phase diagrams and stability, thermodynamics,
3	Radiation damage – radiation damage process, displacement of atoms, defect formation and diffusion, defect reactions in solids, radiation induced segregation, swelling, growth
4	Radiation damage – radiation damage process, displacement of atoms, defect formation and diffusion, defect reactions in solids, radiation induced segregation, swelling, growth (Continue)
5	Radiation damage – radiation damage process, displacement of atoms, defect formation and diffusion, defect reactions in solids, radiation induced segregation, swelling, growth (Continue)

Week#	Topics
6	Radiation damage – radiation damage process, displacement of atoms, defect formation and diffusion, defect reactions in solids, radiation induced segregation, swelling, growth (Continue)
	Review of plastic deformation and dislocation motion, strengthening mechanisms
7	Fracture toughness and embrittlement in nuclear reactor materials.
8	Fracture toughness and embrittlement in nuclear reactor materials. (Continue)
9	Radiation effects – radiation hardening, swelling, fracture, creep.
10	Corrosion – thermodynamics and kinetics in electrochemistry, corrosion reactions, forms of corrosion.
11	Corrosion – thermodynamics and kinetics in electrochemistry, corrosion reactions, forms of corrosion. (Continue)
12	Corrosion –stress corrosion cracking and irradiation assisted stress corrosion cracking (SCC).
	LWR materials management and water chemistry.
13	LWR materials management and water chemistry. (Continue)
14	Fuels – Properties, in-core behavior including swelling, restructuring, cracking, creep, corrosion.
15	Fuels – Properties, in-core behavior including swelling, restructuring, cracking, creep, corrosion. (Continue)