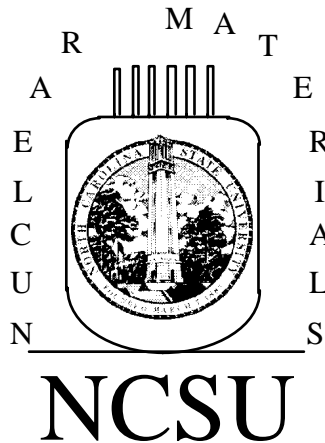


NUCLEAR MATERIALS

**NE/MSE 409 & 509
&
NE/MSE 409L & 509L**

Spring 2009



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NE/MSE 409 & 509 Nuclear Materials

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“We physicists can dream up and work out all the details of power reactors based on dozens of combinations of the essentials, but it’s only a paper reactor until the metallurgist tells us whether it can be built and from what.” – CO Smith

Objective

- Introduces the student to the basic issues concerned with the selection of materials for various components in nuclear reactors. The effects of radiation and environment on various properties of materials in nuclear applications will be dealt with to get an appreciation of the materials' limitations on the operation of reactors. •

Prerequisite: MAT 201 or equivalent

Course Outline

1. *Overview of Nuclear Systems*
 - a. Various types
[LWR, PHWR, GCR, FBR, Fusion]
 - b. Materials - Selection
2. *Nature of Materials*
 - a. Crystal Structure
 - b. Imperfections
 - c. Diffusion in Solids
3. *Radiation Damage*
 - a. Binary Elastic Collisions
 - b. Displacements due to PKA
4. *Properties of Materials*
 - a. Mechanical Properties
 - b. Fracture, Fatigue and Creep
 - c. SCC (& corrosion)
5. *Dislocation Theory*
 - a. Types
 - b. Stress Fields and Strain Energy
 - c. Forces on Dislocations
 - d. Dislocation Interactions
- e. Dislocation Sources and Pile-ups
- f. Hardening: Dislocation, Precipitation, Grain-boundary, Solution, Strain
6. *Radiation Effects*
 - a. Microstructural Changes
 - b. Friction and Source Hardening
 - c. Fracture and DBTT
 - d. Embrittlement and Fracture
7. *Reactor Materials*
 - a. LWR Core Materials
Radiation Growth - Zircalloys
 - b. Void Swelling (Stainless Steels)
 - c. Radiation Induced vs Radiation Enhanced Creep
 - d. Pressure Boundary Materials
 - e. Fusion Materials

Graduate students enrolled in NE509 will in addition be required a term-long project (report due in 3rd week of April)

References

- D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, NTIS, ERDA (1975)
D.Hull and D.J. Bacon, Introduction to Dislocations, Pergamon Press (1965)
C.O. Smith, Nuclear Reactor Materials, Addison-Wesley (1967)
W.D. Callister, Materials Science and Engineering, Wiley (1991)
G.S. Was, Fundamentals of Radiation Materials Science, Springer (2007)

Grading

NE 409

Homeworks : 10% ; due on the assigned date
(by 5pm) [no exceptions !]
Quizzes (~1 per wk): 10%
Tests #1 (15%); #2 (20%) TU
Final - (30%)
NE/MSE 409L: 15%

NE 509

Homeworks : 10% ; due on the assigned date
(by 5pm) [no exceptions !] Quizzes: 10%
Term-long Project: 10% due 3rd week of April
Tests #1 (10%); #2 (20%) TU
Final - (25%)
NE/MSE 509L: 15%

(the notes contains the lab manual also)

NE/MSE 409 & 509

Contents

Chapter 1. Nuclear Energy and Materials
Ch.1. J.T.A. Roberts, Structural Materials in Nuclear Energy Systems, Plenum Press, 1981
Materials Selection (notes)
Chapter 2a. Crystal Structure
Ch.3. D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, NTIS, ERDA, 1975
Chapter 2b. Imperfections / Point Defects in Solids
Ch.6. D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, NTIS, ERDA, 1975
Chapter 2c. Imperfections / Diffusion in Solids
Ch.7. D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, NTIS, ERDA, 1975
Chapter 3. Radiation Damage (notes)
(Ref. Ch.17. D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, 1975)
Chapter 4a. Mechanical Properties
notes & Ch.6. W.D. Callister, Materials Science and Engineering, Wiley, 2nd Ed. 1991
Chapter 4b. Fracture, Fatigue and Creep
Ch.8. W.D. Callister, Materials Science and Engineering, Wiley, 2nd Ed. 1991
Chapter 4c. SCC {and Corrosion - MAT 201}
Chapter 5. Dislocation Theory (handout)
Ch.8. D.R. Olander, Fundamental Aspects of Nuclear Reactor Elements, NTIS, ERDA, 1975
Chapter 6. Radiation Effects (notes)
(Ch.5. C. O. Smith, Nuclear Reactor Materials, Addison Wesley, 1967 & Ch. 18 of DRO)
Chapter 7. Reactor (LWR Core) Materials
(notes and Ch.1. J.T.A. Roberts, Structural Materials in Nuclear Energy Systems)
{also, Chapter 2 of Roberts, pp. 65-93}

Appendix : Old Assignments and Tests

NE/MSE 409L & 509L : 20% of the total grade (5 experiments with lab reports)

• Policies and Procedures •

- *Tests* As stated in the note package, there will be 3 tests as per the schedule shown along with the weights indicated - the final (3rd test) will be a comprehensive one. All tests will be **closed book** with all relevant information summarized at the end of the tests.
- *In-Class Quizzes* Will try to have a **minimum** of 1 per 2 weeks with a total weight of 10%; will allow to have 1 missed (i.e., will count the total number of quizzes less 1); equivalent (not equal) weight will be given to the quizzes and all quizzes will be **open book**. *No make-ups*.
- *Home Works* Required homework is due on the assigned date (by 5pm to the TA). **Use regular rule paper and fold the pages vertically when you hand them in, and on the outside put your name(s) clearly.**
 - +/- grading will be adopted (no curving) : 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

See Academic Regulation at: http://www.ncsu.edu/provost/academic_regulations/syllabus/reg.htm

NE/MSE 409 / 509

• Instructional Objectives •

At the end of the course you will be able to

- *evaluate* the effect of radiation on mechanical property changes
- *estimate* the damage accumulated in a material in reactors and thus the *remaining* useful life of the structure made of these materials
- *describe* the various materials comprising the structures in nuclear reactors
- *compare* two competing materials for a given application
- *explain* why a specific material was chosen for a given application
- *identify* problems (materials related) encountered in nuclear reactor structures
- *choose* the best and optimum material for a given application
- *predict* the reliability (dimensional stability) of a given component in a nuclear reactor
- *outline* procedure(s) for detecting the problems and *suggest* plausible remedial solutions
- *distinguish* between various effects resulting in the deterioration of a given component in-service

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- The course requires reading the appropriate sections of the text as well as references.
 - The course is built up on basic Materials Science concepts and thus a thorough review of MAT201 will be very helpful. A knowledge of MAT201 is a **prerequisite** and repetition will be minimized. Many HW assignments will require such background or you may refer to the references (Callister or Askeland or Carter or equivalent)
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NE/MSE 409 / 509 - Nuclear Materials

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References

1. B.M. Ma, *Nuclear Reactor Materials and Applications*
2. C.O. Smith, *Nuclear Reactor Materials*
3. D.R. Olander, *Fundamentals Aspects of Nuclear*
4. L.H. Van Vlack, *Elements of Materials Science & Engineering*
5. G.F. Carter, *Principles of Physical & Chemical Metallurgy*
6. J.T.A. Roberts, *Structural Materials in Nuclear Power Systems*
7. **G.S. Was, *Fundamentals of Radiation Materials Science***
8. G.E. Dieter, *Mechanical Metallurgy*
9. S.H. Bush, *Irradiation Effects in Cladding and Structural Materials*
10. R.E. Reed-Hill, *Physical Metallurgy Principle*