COURSE APPROVAL FORMS

CHE 505 New Course

CEE 512 Modification—Changing description

CEE 554(X-Listed with ARCH 595 and MFG 551) Modification—Adding X-Listing with ARCH 595, Removing MFG 551; Changing title from: Materials in Engineering Design ***to: Materials Selection for Sustainable Design***; Changing description; Changing Prereq from: CEE 351 or permission of instructor ***to: CEE 212 or ARCH 324 or equivalent***

CEE 650 Modification—Changing title from: Fracture and Micromechanics of Fibrous Composites ***to: Advanced Fiber Reinforced Concrete for Sustainable Infrastructure***; Changing description; Changing Prereq from: Advised Graduate Standing ***to: Enforced CEE 351 or graduate standing***

ENGR 255 New Course

ENGR 355 Modification—Changing Pre-req from: Engineering 100, ENGR 354 simultaneously or before, or p.i. ***to: Permission of Instructor***

ENGR 455 Modification—Changing Pre-req from: Engr 355 or 450 or permission ***to: Permission of Instructor***

NERS 535 New Course

NERS 545 New Course

NERS 573 New Course

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number 2301
Date 2/13/2012
Effective Term Fall 2012
Course Offer Freq ☒ Indefinitely ☐ One term only

Action Requested
◉ New Course
○ Modification of Existing Course
○ Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

A. CURRENT LISTING

Home Department | Course Number

Cross Listed Course Information

Course Title

TITLE ABBREVIATION: Time Sched Max = 19 Spaces; Transcript Max = 20 Spaces

Course Description

PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k

Degree Requirements ○ Degree Requirement ○ Core Course ○ Free Elective ○ Tech Elective ○ Other

Prereq
○ Enforced
○ Advised

Credit Restrictions

Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ R

Credit Hours Min Max | Contact Hrs/Wk | Number of Wks

B. REQUESTED LISTING

Home Department	Course Number
CHE Chemical Engineering	505

Cross Listed Course Information

Course Title
Math for Chemical Engineers

TITLE ABBREVIATION	
Time Sched Max = 19 Spaces	Math for ChE
Transcript Max = 20 Spaces	Math for ChE

Course Description for Official Publication (Max = 50 words)

Analytical and numerical techniques applicable to statistical mechanics, transport phenomena, fluid mechanics, and reaction engineering. Groups and linear spaces; tensors and linear operators; computational approaches to nonlinear systems and integration; special functions; spectral theory of ordinary and partial differential equations; series expansions; coordinate transformations; complex algebra and analysis; integral transformations.

PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k

Degree Requirements ○ Degree Requirement ◉ Core Course ○ Free Elective ○ Tech Elective ○ Other

Prereq Graduate standing
○ Enforced
◉ Advised

Credit Restrictions

Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☒ All Credit types ☐ I

Credit Hours Min	Credit Hours Max	Contact Hrs/Wk	Number of Wks
3	3	3	14

C.

Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ○ Yes ◉ No   Max Hours? ____   Max Times? ____   Can it be repeated in the same term? ○ Yes ○ No

Class Type(s)
☒ Lec ☐ Sem ☐ Dis ☐ Other ____ ☐ Rec ☐ Lab ☐ Ind

Graded Section
☒ Lec ☐ Sem ☐ Dis ☐ Other ____ ☐ Rec ☐ Lab ☐ Ind

Grading
☒ A-E ☐ CR/NC ☐ P/F ☐ S/U

Location
☒ Ann Arbor ☐ Biological Station ☐ Camp Davis ☐ Extension

Course Is Y Graded ☐

Cognizant Faculty Member:	Title
Charles Monroe [signature]	Assistant Professor
Phillip Savage [signature]	Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info | **Approved by Name** | **Approved Date**
☐ Curriculum Comm.
☐ Faculty
☐ Cross listed Unit 1
☐ Cross listed Unit 2

Submitted By: ☐ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	**Chair Signature**
Home Dept.	Chemical Eng, Mark Burns	[signature]
Cross-listed Dept(s).		

Form Number

2301

SUPPORTING STATEMENT

This class is going to replace the existing multi-course math requirement. It was taught as ChE 696 (Special Topics) in Fall 2011 and the evaluation scores are: Q1 = 4.22; Q2 = 4.63.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

ChE 696: Applied Mathematics for Chemical Engineers (Fall 2011 Syllabus)

Prof.	Charles Monroe	3018 Dow	cwmonroe@umich.edu
TA	Priyamvada Goyal	3216 Dow	priyamg@umich.edu
Text	Varma and Morbidelli, *Mathematical Methods in Chemical Engineering*		

Grading event		**Date**
1 Take-home midterm TBA	30%	TBA
1 Final exam	40%	16 December
Problem sheets	30%	~Weekly

Overview of Topics

1. Vectors and vector operations; tensors
2. Group and field theory; inner product spaces and linear operators
3. Linear algebra: solutions of linear systems of equations; the eigenproblem
4. Complex algebra and elementary functions of complex numbers
5. Solution of first-order ordinary differential equations and systems thereof
6. Second-order linear ordinary differential equations
7. Sturm-Liouville theory
8. Special functions for mathematical analysis:
   Gamma func., error func., hyperbolic funcs., orthogonal polynomials
9. Bessel's equation and Legendre's equation
10. Numerical solution of 2^{nd}-order boundary value problems
11. Classification of partial differential equations
12. Solution of parabolic ODEs and Laplace's equation by Fourier series
13. Coordinate transformations
14. Fourier-Bessel and Fourier-Legendre series solutions
15. Functions of complex variables; Laurent series; Cauchy's theorem of residues
16. Laplace transformation

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number 2291

Date 1/23/2012

Effective Term Fall 2012

Course Offer Freq ☒ Indefinitely ☐ One term only

Action Requested
- ○ New Course
- ● Modification of Existing Course
- ○ Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

A. CURRENT LISTING

Home Department:
Course Number:

☐ Cross Listed Course Information:

☐ Course Title:

TITLE ABBREVIATION
- Time Sched Max = 19 Spaces:
- Transcript Max = 20 Spaces:

X Course Description

Presentation of the direct-stiffness method of analysis for two-dimensional and three-dimensional structures. Overview of analysis techniques for arch and cable supported structures. Brief introduction to theory of plates and shells. Lecture.

PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k

Degree Requirements ○ Degree Requirement ○ Core Course ○ Free Elective ○ Tech Elective ○ Other

☐ Prereq
- ○ Enforced
- ○ Advised

☐ Credit Restrictions

☐ **Level of Credit**
- ☐ Undergrad only
- ☐ Rackham Grad
- ☐ Non-Rckhm Grad
- ☐ Ugrad or Rckhm Grad
- ☐ Ugrad or Non-Rckhm Grad
- ☐ All Credit types
- ☐ Rckhm Grad w/add'l Work

Credit Hours Min ___ Max ___

Contact Hrs/Wk ___ Number of Wks ___

B. REQUESTED LISTING

Home Department: CEE Civil & Environmental Engin
Course Number: 512

Cross Listed Course Information:

Course Title: Theory of Structures

TITLE ABBREVIATION
- Time Sched Max = 19 Spaces: Theory of Structure
- Transcript Max = 20 Spaces: Theory of Structure

Course Description for Official Publication (Max = 50 words)

Applications of energy concepts for determination of forces and displacements in structures; presentation of the direct-stiffness method of analysis for two-dimensional structures; introduction to nonlinear analysis of structures. Lecture.

PROGRAM OUTCOMES: ☒ a ☐ b ☐ c ☐ d ☒ e ☐ f ☒ g ☐ h ☐ i ☐ j ☒ k

Degree Requirements ○ Degree Requirement ○ Core Course ○ Free Elective ● Tech Elective ○ Other

Prereq CEE 312 or equivalent.
- ○ Enforced
- ● Advised

Credit Restrictions

Level of Credit
- ☐ Undergrad only
- ☐ Rackham Grad
- ☐ Non-Rckhm Grad
- ☐ Ugrad or Rckhm Grad
- ☐ Ugrad or Non-Rckhm Grad
- ☒ All Credit types
- ☐ Rckhm Grad w/add'l Work

Credit Hours Min 3 Max 3

Contact Hrs/Wk 3 Number of Wks 14

C.

Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ○ Yes ● No   Max Hours? 3   Max Times? 1   Can it be repeated in the same term? ○ Yes ● No

☐ **Class Type(s)**
☒ Lec ☐ Sem ☐ Dis ☐ Other __
☐ Rec ☐ Lab ☐ Ind

Graded Section
☒ Lec ☐ Sem ☐ Dis ☐ Other __
☐ Rec ☐ Lab ☐ Ind

Grading
☒ A-E
☐ CR/NC
☐ P/F
☐ S/U

Course Is Y Graded ☐

Location
☒ Ann Arbor
☐ Biological Station
☐ Camp Davis
☐ Extension

Cognizant Faculty Member:	Title
Ann E. Jeffers	Assistant Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info	Approved by Name	Approved Date
☐ Curriculum Comm.		
☐ Faculty		
☐ Cross listed Unit 1		
☐ Cross listed Unit 2		

Submitted By: ☒ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	Chair Signature
Home Dept.	Kim F. Hayes, Interim Chair and Professor	
	Civil & Environmental Engin	
Cross-listed Dept(s).		

Form Number

2291

SUPPORTING STATEMENT

A change in the course description is proposed to better reflect material currently covered in CEE-512. Heavy emphasis is now placed on the use of energy methods for structural analysis, and an introduction to nonlinear structural analysis has been added, which replaces the material previously covered on theory of plates and shells.

Program outcomes are now identified for this course due to its recent addition to the undergraduate curriculum as a technical elective in Structural Engineering. For this reason, the course credits now qualify for “all credit types”.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

CEE 512 - THEORY OF STRUCTURES (Fall 2011)

PREREQUISITES:	CEE 312 or equivalent Basic knowledge of matrix algebra
LECTURES:	Monday, Wednesday, & Friday, 1363 G.G. Brown Building 11:30 am – 12:30 pm (Class starts at 11:40 am)
INSTRUCTOR:	Professor Gustavo J. Parra 2370 G.G. Brown Building Phone: 764-6576; e-mail: gjpm@umich.edu
REFERENCES:	Weaver, William Jr., and Gere, James M. (1990). *Matrix Analysis of Framed Structures*, Third Edition. Van Nostrand Reinhold. McGuire, William, Gallagher, Richard H., and Ziemian, Ronald D. (2000). *Matrix Structural Analysis*, Second Edition, John Wiley & Sons. Sack, Ronald L. (1984). *Structural Analysis*, McGraw-Hill. West, Harry H., and Geschwindner, Louis F. (2002). *Fundamentals of Structural Analysis*, Second Edition, John Wiley & Sons.

GRADING SCHEME:

Homework	30%
Midterm Exam (two hours)	35%
Final Exam (two hours)	35%

(scheduled for Monday, December 19, 1:30am-3:30pm)

Homeworks should be submitted at the beginning of the lecture on the due date. Homework submitted between the due date and the next lecture will receive 75% credit. No homework will be accepted during the following lecture unless the instructor specifies otherwise. Students are allowed to work in groups. However, each student must submit his/her own homework.

All examinations will be closed book and closed notes. However, each student will be allowed to use one double-sided equation sheet per exam. Thus, two double-sided equation sheets will be allowed in the final examination (one for the midterm exam and one for the final exam). If by some **VALID** reason you cannot take the exam on the scheduled date or time, please inform the instructor before the scheduled exam date. If that is not possible, contact the instructor as soon as possible in order to reschedule the examination. The Honor Code will apply to all examinations.

Because lectures are 50 minutes long each, the midterm examination will be scheduled at some other time, prior coordination with the students.

OFFICE HOURS: To be announced

COMPUTER PROGRAMS:

In many occasions, you will be asked to use the structural analysis computer program RISA. It is a widely used structural analysis software, and is available on the CAEN network. Various tutorials, manuals and product demos are available from the RISA website (www.risatech.com). For the scope of this class, I recommend that you download RISA-2D (http://www.risatech.com/risa-2d.asp).

Once we begin covering the Direct Stiffness Method, you will need to do some programming. Math programs such as MATLAB and Mathcad are suitable for this purpose. However, you are free to use any program you feel comfortable with.

STUDENTS WITH DISABILITIES:
Students with disabilities are welcome to the course and will be accommodated. They are strongly encouraged to talk to the instructor, with a promise of full confidentiality, and to refer to The University of Michigan Office of Services for Students with Disabilities (http://www.umich.edu/~sswd/).

COURSE OUTLINE:

1. **Introduction and material review**
    a. Types of structural analysis
    b. Support conditions, member releases and connections
    c. Static versus kinematic indeterminacy
    d. Stability
    e. Flexibility versus stiffness
    f. Linear versus nonlinear material behavior
    g. Small versus large deflections
    h. Brief review of beam theory
    i. Calculation of deflections (moment-area theorem; Castigliano's theorems; Crotti-Engesser theorem)

2. **Overview of Stiffness Method**
    a. Kinematic indeterminacy
    b. Review of relationship between member end displacements and actions (truss elements; beam-column elements)
    c. Member loads and equivalent joint loads
    d. Construction of structure (joint) stiffness matrix
    e. Determination of joint displacements, member end actions, and reactions

3. **Direct Stiffness Method (applied to frame and truss structures)**
    a. Global versus local axes
    b. Rotation of axes
    c. Member stiffness matrix (includes application of energy methods, member stiffness matrix from flexibility matrix)
    d. Determination of joint stiffness matrix
    e. Joint and member loads, support displacements
    f. Determination of joint displacements, member end actions, and reactions
    g. Other topics: elastic supports, flexible connections, member releases, incorporation of shear deformations in framed elements, member offsets

4. **Energy concepts**
    a. Stress and strain components
    b. Strain energy
    c. Principle of stationary potential energy (applications)
    d. Virtual work/complementary virtual work (applications)

5. **Introduction to Nonlinear Analysis**
    a. Sources of nonlinearity
    b. First versus second-order analysis; elastic versus inelastic analysis
    c. Inelastic models for framed elements
    d. P-Δ effects

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number 2292

Date 1/24/2012

Effective Term Winter 2013

Course Offer Freq ☒ Indefinitely ☐ One term only

Action Requested
- ○ New Course
- ◉ Modification of Existing Course
- ○ Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

	A. CURRENT LISTING	B. REQUESTED LISTING
	Home Department / Course Number:	Home Department: CEE Civil & Environmental Engin / Course Number: 554
X	Cross Listed Course Information: MFG Manufacturing 551	Cross Listed Course Information: ARCH Architecture 595
X	Course Title: Materials in Engineering Design	Course Title: Materials Selection for Sustainable Design
	TITLE ABBREVIATION – Time Sched (Max = 19 Spaces): Matl in Eng Design	TITLE ABBREVIATION – Time Sched (Max = 19 Spaces): Matl Sel Sus Des
	TITLE ABBREVIATION – Transcript (Max = 20 Spaces): Matl in Eng Design	TITLE ABBREVIATION – Transcript (Max = 20 Spaces): Matl Sel Sus Des
X	Course Description: Integrated study of material properties, processing, performance, structure, cost and mechanics, as related to engineering design and material selection. Topics include design process, material properties and selection; scaling; materials database, processing and design, and optimization. Examples will be drawn from cement and ceramics, metals, polymers and composites.	Course Description for Official Publication (Max = 50 words): Integrated study of materials properties, performance, and economic and environmental cost, as related to engineering and architectural design. Topics include material properties and selection, materials database, processing and design, ecological considerations, and optimization. Examples will be drawn from cementitious materials and ceramics, metals, polymers and composites.
	PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k	PROGRAM OUTCOMES: ☒ a ☐ b ☒ c ☒ d ☒ e ☐ f ☒ g ☒ h ☒ i ☒ j ☒ k
	Degree Requirements: ○ Degree Requirement ○ Free Elective ○ Other ○ Core Course ○ Tech Elective	Degree Requirements: ○ Degree Requirement ○ Free Elective ○ Other ○ Core Course ◉ Tech Elective
X	Prereq: CEE 351 or permission of instructor. ○ Enforced ○ Advised	Prereq: CEE 212 or ARCH 324 or equivalent. ○ Enforced ◉ Advised
☐	Credit Restrictions	Credit Restrictions
☐	Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work; Credit Hours Min ___ Max ___; Contact Hrs/Wk ___; Number of Wks ___	Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☒ All Credit types ☐ Rckhm Grad w/add'l Work; Credit Hours Min 3 Max 3; Contact Hrs/Wk 3; Number of Wks 14

C.

Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ○ Yes ◉ No; Max Hours? 3; Max Times? 1; Can it be repeated in the same term? ○ Yes ◉ No

Class Type(s): ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Graded Section: ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Grading: ☒ A-E ☐ CR/NC ☐ P/F ☐ S/U

Location: ☒ Ann Arbor ☐ Biological Station ☐ Camp Davis ☐ Extension

Course Is Y Graded ☐

Cognizant Faculty Member: Victor C. Li — Title: Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info / **Approved by Name** / **Approved Date**
- ☐ Curriculum Comm.
- ☐ Faculty
- ☐ Cross listed Unit 1
- ☐ Cross listed Unit 2

Submitted By: ☒ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	Chair Signature
Home Dept.	Kim F. Hayes, Interim Chair & Professor	
Cross-listed Dept(s).	Civil & Environmental Engin	

Form Number

2292

SUPPORTING STATEMENT

Cross-listing with Arch is requested by Dean of TCAUP. Contact faculty member at TCAUP is K. Velikov. Increase content on sustainability (displaced previous emphasis on manufacturing/processing) to emphasize student need and alignment with new Infrastructure Systems specialty.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

CEE 554 / ARCH 595 – Materials Selection for Sustainable Design

PREREQUISITES:	CEE 212 or ARCH 324 or equivalent Elementary mechanics of solids
LECTURES:	Tu, Th, 4:00-5:30 pm 1371 GGBL
INSTRUCTOR:	Victor Li 2326 G.G. Brown E-mail: vcli@umich.edu Office Hours: 4:00-5:00 pm M and W, or by appointment
TEXTBOOK:	Materials Selection in Mechanical Design, M. Ashby, published by Elsevier, 2011 Materials and the Environment, M. Ashby, published by Elsevier, 2012
SOFTWARE:	CES EduPack Materials Database by Granta

LIBRARY RESERVES:

Several texts are reserved in the library for this class. Please see separate reserve list.

COURSE NOTES: To be posted on the CTools website before each class.

HOMEWORKS: To be posted on the CTools website.

Homework should be submitted at the beginning of the lecture on the due date. Homework submitted between the due date and the next lecture will receive 50% credit. No homework will be accepted after this. Students are allowed to work in groups. However, each student must submit his/her own homework.

Examinations will be open book and notes. The Honor Code will apply to all examinations.

GRADING:		
	Homework	35%
	Midterm (2 hours)	30%
	Final (Term project)	35%

STUDENTS WITH DISABILITIES:

Students with disabilities are welcome to the course and will be accommodated. They are strongly encouraged to talk to the instructor, with a promise of full confidentiality, and to refer to The University of Michigan Office of Services for Students with Disabilities (http ://www.umich.edu/~sswd/).

COURSE OUTLINE:

Integrated study of materials properties, performance, and economic and environmental cost, as related to engineering and architectural design. Topics include material properties and selection, materials database, processing and design, ecological considerations, and optimization. Examples will be drawn from cementitious materials and ceramics, metals, polymers and composites.

Unit 1 – The world of materials

Unit 2 – The materials life cycle

Unit 3 – Material data: Mechanical, physical and ecological

Unit 4 – Screening and Ranking: the key to optimized selection

Unit 5 – Material and Shape: the design of efficient structures

Unit 6 – Objectives in conflict: trade-off methods & value functions

Unit 7 – Eco-audits

Unit 8 – Eco-informed material selection

Unit 9 – Materials and Sustainability

Unit 10 – Finding the right material: strategy for material advising

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number 2293

Date 1/24/2012

Effective Term Fall 2013

Course Offer Freq ☒ Indefinitely ☐ One term only

Action Requested
- ○ New Course
- ● Modification of Existing Course
- ○ Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

A. CURRENT LISTING	B. REQUESTED LISTING
Home Department / Course Number:	Home Department: CEE Civil & Environmental Engin / Course Number: 650
☐ Cross Listed Course Information:	Cross Listed Course Information:
X Course Title: Fracture and Micromechanics of Fibrous Composites	Course Title: Advanced Fiber Reinforced Concrete for Sustainable Infrastructure
TITLE ABBREVIATION — Time Sched (Max = 19 Spaces): Frac Micromech Comp	TITLE ABBREVIATION — Time Sched (Max = 19 Spaces): Adv FRC Sus Inf
Transcript (Max = 20 Spaces): Frac Micromech Comp	Transcript (Max = 20 Spaces): Adv FRC Sus Inf
X Course Description: Fracture mechanics fundamentals and micromechanics of cement, ceramic- and polymer-based fibrous composites. Topics include elastic crack mechanics, energy principles, interface mechanics; shear lag models; residual stress; nonalignment problems; first crack strength, steady state cracking and reliability; multiple cracking, bridging fracture energy; and R-curve behavior.	Course Description for Official Publication (Max = 50 words): This course surveys scale linkage in built infrastructure systems and its interaction with the natural environment. Fundamental analytic tools from fracture mechanics and micromechanics are introduced. Topics include elastic crack mechanics, energy principles, fiber cement composite design, infrastructure durability, and material damage mechanics as it impacts infrastructure life cycle analyses.
PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k	PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k
Degree Requirements: ○ Degree Requirement ○ Core Course ○ Free Elective ○ Tech Elective ○ Other	Degree Requirements: ○ Degree Requirement ○ Core Course ○ Free Elective ○ Tech Elective ○ Other
X Prereq: Graduate standing. ○ Enforced ○ Advised	Prereq: CEE 351 or graduate standing. ● Enforced ○ Advised
☐ Credit Restrictions:	Credit Restrictions:
☐ Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work	Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☒ All Credit types ☐ Rckhm Grad w/add'l Work
Credit Hours Min: ___ Max: ___	Credit Hours Min: 3 Max: 3
Contact Hrs/Wk: ___ Number of Wks: ___	Contact Hrs/Wk: 3 Number of Wks: 14

C. Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ○ Yes ● No — Max Hours? 3 — Max Times? 1 — Can it be repeated in the same term? ○ Yes ● No

Class Type(s): ☒ Lec ☐ Sem ☐ Dis ☐ Other ___ ☐ Rec ☐ Lab ☐ Ind

Graded Section: ☒ Lec ☐ Sem ☐ Dis ☐ Other ___ ☐ Rec ☐ Lab ☐ Ind

Grading: ☒ A-E ☐ CR/NC ☐ P/F ☐ S/U

Course Is Y Graded ☐

Location: ☒ Ann Arbor ☐ Biological Station ☐ Camp Davis ☐ Extension

Cognizant Faculty Member:	Title
Victor C. Li	Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info	**Approved by Name**	**Approved Date**
☐ Curriculum Comm.		
☐ Faculty		
☐ Cross listed Unit 1		
☐ Cross listed Unit 2		

Submitted By: ☒ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	**Chair Signature**
Home Dept.	Kim F. Hayes, Interim Chair & Professor Civil & Environmental Engin	
Cross-listed Dept(s).		

Form Number

2293

SUPPORTING STATEMENT

Course content has been revised to reflect infrastructure sustainability in alignment with Infrastructure Systems specialty.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

CEE 650 – Advanced Fiber Concrete for Sustainable Infrastructure

PREREQUISITES: CEE 351 or equivalent
Basic mechanics of materials and properties of concrete

LECTURES: Tu, Th, 4:00-5:30 pm 1371 GGBL

INSTRUCTOR: Victor Li
2326 G.G. Brown
E-mail: vcli@umich.edu
Office Hours: 4:00-5:00 pm M and W, or by appointment

TEXTBOOK: Fracture Mechanics – Fundamentals and Applications, 3rd Edition, T.L. Anderson, published by CRC Press.
Text will be supplemented by class handouts.

LIBRARY RESERVES:
Several texts are reserved in the library for this class. Please see separate reserve list.

COURSE NOTES: To be posted on the CTools website before each class.

HOMEWORKS: To be posted on the CTools website.

Homework should be submitted at the beginning of the lecture on the due date. Homework submitted between the due date and the next lecture will receive 50% credit. No homework will be accepted after this. Students are allowed to work in groups. However, each student must submit his/her own homework.

Examinations will be open book and notes. The Honor Code will apply to all examinations.

GRADING:

Homework	35%
Midterm (2 hours)	30%
Final (Term project)	35%

STUDENTS WITH DISABILITIES:
Students with disabilities are welcome to the course and will be accommodated. They are strongly encouraged to talk to the instructor, with a promise of full confidentiality, and to refer to The University of Michigan Office of Services for Students with Disabilities (http ://www.umich.edu/~sswd/).

COURSE OUTLINE:

Part I: Framework for Attaining Infrastructure Sustainability Via Materials Engineering

1. Sustainability Concepts for Civil Infrastructure Systems
   - Life Cycle Assessment of Civil Infrastructure
   - Framework for Studying Materials-Structure and Environmental Systems
2. Composite Material Scale Linking
   - Fiber Concrete Composites
   - Material Microstructure, Micromechanics, and Fracture
   - Scale-linking Paradigm
3. Case Studies
   - Life Cycle Cost for Coastal Structure
   - Life Cycle Assessment for Bridge Deck

Part II: Fracture and Micromechanics of Brittle and Quasi-Brittle Solids – Analytic Tools

1. Linear Elastic Fracture Mechanics: Stress Approach
   - Stress Field Around a Circular and Elliptical Cavity, and Sharp Crack Tip
   - K-Calibration and Measurement of Fracture Toughness
   - Case Studies
2. Linear Elastic Fracture Mechanics: Energy Approach
   - Fracture Energy
   - Relationship between G and K
   - Stability of Crack Growth
   - Case Studies
3. Non-Linear Elastic Fracture Mechanics
   - Observations of Crack Tip Inelasticity
   - The J–Integral
   - Cohesive Models and Tension-Softening Behavior
   - Case Studies

Part III: Micromechanics of Fiber Concrete

1. Fiber-Matrix Interface
   - Characterization
   - Interface Engineering
   - Mechanics of Fiber Debonding and Pullout
2. Composite $\sigma-\delta$ Relation
   - Characterization
   - Micromechanics Based model
3. Non-catastrophic Failure
   - Conditions for Multiple Cracking
   - Strain-Hardening Fiber Concrete
   - Damage Mechanics
4. Case Studies
   - Engineered Cementitious Composites
   - Design for Structural Resiliency
   - Design for Structural Durability
   - Integration of Fiber Concrete Design and Environmental Sustainability

Form Number

2320

SUPPORTING STATEMENT

Are any special resources or facilities required for this course? ☒ Yes ☐ No

Detail the Special requirements

Laboratory with state-of-the-art measurement equipment and isotopic neutron and gamma ray sources. Currently the laboratory is located in 1947 Cooley.

NERS 590-2
Detection Techniques for Nuclear Nonproliferation

Prof. Sara Pozzi
Dr. Marek Flaska
Dr. Shaun Clarke
Mr. Mark Bourne (GSI)
http://www-ners.engin.umich.edu/labs/dnng/

Requirements:
- Personal laptop (can be shared if needed); MCNP5/MCNPX and MCNP-PoliMi RSICC licenses (please request them ASAP at http://www-rsicc.ornl.gov/ – MCNP 4C – already available to students – will be used as backup); MATLAB access
- Class attendance is mandatory

Textbooks and study materials:
1. G. F. Knoll, Radiation Detection and Measurement, 4th Ed.
2. U.S. NRC, Passive Nondestructive Assay of Nuclear Materials (PANDA; can be obtained at http://www.lanl.gov/orgs/n/n1/panda/index.shtml)
3. MCNP5/MCNPX and MCNP-PoliMi manuals
4. Course handouts and notes

Grading: 60% laboratory reports
20% exam
20% laboratory presentation

Office Hours (GSI):
Tuesday/Thursday from 1-3 pm or by appointment
Room 2928 (desk located next to door into 2928B)
E-mail: mmbourne@umich.edu

Format:
Weekly lectures, 2 hours per week.
10 laboratories (6 measurements labs and 4 simulation labs). Each laboratory meets for 4 hours per week.

Syllabus (Lectures are shown in bold)

Week 1
Nuclear nonproliferation; homeland security
Introduction to the physics of nuclear fission (Knoll Ch. 1)
- **Spontaneous/neutron induced fission**
- **Fission chain multiplication, Rossi alpha**
- **Neutron and gamma-ray sources (PANDA Ch. 11)**
- **Neutron and gamma-ray multiplicities**
- **Delayed neutrons and gamma rays**
- **Special nuclear material (plutonium and uranium)**

Weeks 2-3

Introduction to Monte Carlo simulations for nuclear nonproliferation applications
MCNP5/MCNPX, MCNP-PoliMi
Passive detection of nuclear materials

- **Neutron measurement techniques**
- **Gamma-ray measurement techniques**
- **Pulse-height distributions; neutron spectrum unfolding (Knoll Ch. 4.III and Ch. 18)**

Laboratory 1: Hands-on use of Monte Carlo codes (2 weeks) (MCNP5 manual Vol. 1 Ch. 1)
1.1: Simulation of passive and active interrogation of HEU using MCNP5 (MCNPX)
1.2: Simulation of liquid scintillator neutron pulse-height distributions with MCNP-PoliMi

Weeks 4-11

Detectors and safeguards instruments (PANDA Ch. 14)

- **He-3 detectors, gamma-ray detectors (Knoll Ch. 14.III.B.6 and Ch. 12, PANDA Ch. 17)**
- **Liquid and plastic organic scintillation detectors – fast-neutron scattering (Knoll Ch. 8.1.A, 8.1.B and 15.III)**
- **Boron-loaded and lithium-glass scintillators – neutron collisions and capture mechanism (Knoll Ch. 14.II.F and 15.II.A.2)**
- **Pulse-shape discrimination between neutrons and gamma rays (Knoll Ch. 8.1.C, and 15.III.B.6)**
- **Cross-correlation and bi-correlation measurement techniques**

Laboratory 2.1: Measurement of gamma-ray pulses using organic liquid scintillators and algorithm development for pulse-shape discrimination (MATLAB)
Laboratory 2.2: Measurement of mixed neutron/gamma-ray pulses using organic liquid scintillators
Laboratory 3.1: Measurement and identification of gamma-ray sources with organic/inorganic scintillators
Laboratory 3.2: Measurement and identification of gamma-ray sources with a high-purity germanium detector. Uranium enrichment measurement using a surrogate material.
Laboratory 4.1: Measurement of fast-coincidences between neutrons and gamma rays with liquid scintillators using neutron sources
Laboratory 4.2: Measurement of fission neutron energy spectrum

Weeks 12-13

Active interrogation nuclear materials

- **Active interrogation with neutron sources**
- **Active interrogation with photon sources**
- **Photonuclear physics overview**

Laboratory 5: Photoneutron and photofission simulations
5.1: Simulation of bremsstrahlung photon sources
5.2: Simulation of active photon interrogation of HEU

Week 13

Review and exam preparation

NERS 590: Detection Techniques for Nuclear Nonproliferation
Final Exam Examples

1. **Detection in organic liquid scintillation detectors and pulse shape discrimination:**

   a. Describe the interaction mechanisms of neutrons and gamma rays in a liquid scintillation detector.
   b. Discuss and sketch the behavior of light output from the scintillator following interaction of neutrons and gamma rays.
   c. Discuss and sketch the shape of a typical light pulse from an organic liquid scintillation detector. Indicate on your sketch the typical values for rise time and decay time for neutron and gamma-ray pulses.
   d. Describe how the shape of these pulses can be used to discriminate neutron pulses from gamma-ray pulses.
   e. Discuss the procedure for implementing and optimizing a pulse shape discrimination technique.

2. **Special nuclear material detection systems:**

   Describe systems for the timely detection of five kilograms of highly-enriched uranium (HEU). Describe the motivation for each component of your detection system. These descriptions should include, but not be limited to, the radiation emissions to be detected and the types of detectors to be used. Please also give consideration to the time that your system would require to detect each material.

   Consider now that the HEU is surrounded by some high-*Z* or low-*Z* shielding material (not both types simultaneously). How would the presence each shielding type affect the system you described? What changes would be required to your system to maintain a reasonable detection probability?

   What enhancements or simplifications could be made to your detection system to enable the timely detection of bare weapons-grade plutonium (WGPu) of the same mass? What if the WGPu were shielded in the same manner as the HEU described above?

NERS 590-2: Detection Techniques for Nuclear Nonproliferation

Laboratory 5.2: Time-of-flight measurement with liquid organic scintillators

Motivation: In this lab we will measure and analyze the time-of-flight (TOF) distribution of gamma rays and neutrons from a Pu-Be source.

Objectives: To find out if a TOF distribution of a neutron source can be used for material identification

Equipment: 12-bit, 250 MHz waveform digitizer ADC250
Two EJ-309 cylindrical liquid scintillation detectors (Liquids 1 and 2)
CAEN N472 high voltage power supply
1-Ci Pu(Pu-239)-Be neutron source
Laptop with ADC250 data acquisition software

Setup: The EJ-309 detectors will be placed horizontally on the table using the detector holders. The detectors will be connected to the power supply using **Channels 1 and 3** with **negative** voltages **-1170** and **-1130 V**, respectively. The distance between the detectors will be set to **50 cm (80 cm)**. The Pu-Be source will be placed on the face of liquid 1. Liquid 1 will be connected to Channel A of the ADC250, while liquid 2 will be connected to Channel B.

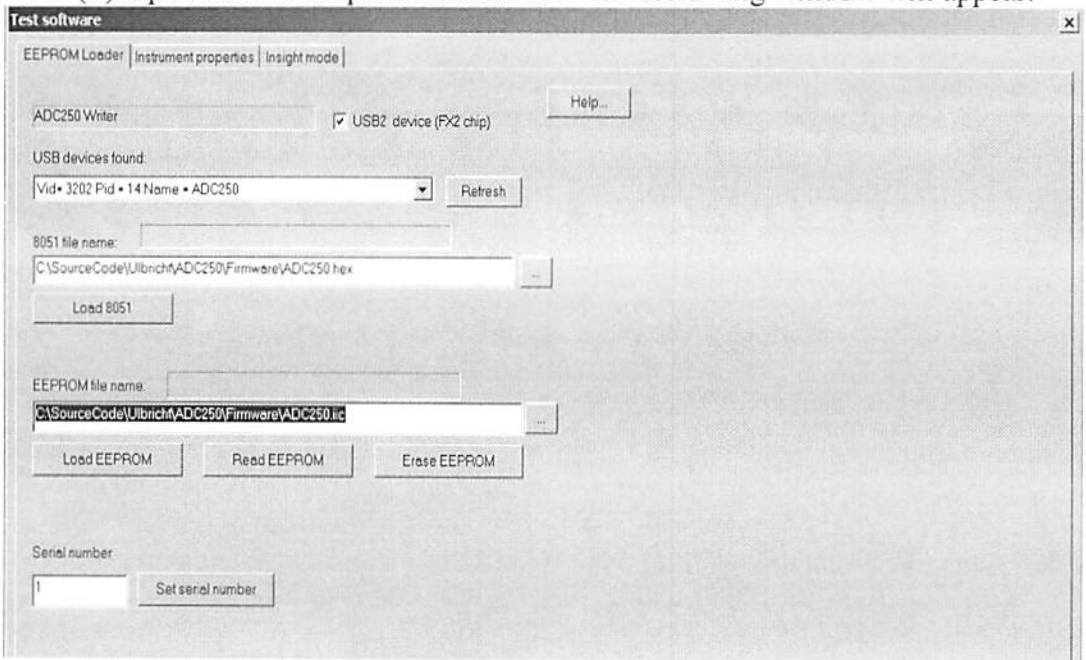
Procedure: This laboratory consists of two parts. In the first part the two liquid scintillators will be used to measure a few millions of pulses from the Pu-Be source. Liquid 1 will be used as START detector, while liquid 2 will be used as STOP detector. In the second part, measured data will be postprocessed to obtain the source TOF distribution.

<u>Part 1: Data acquisition</u>

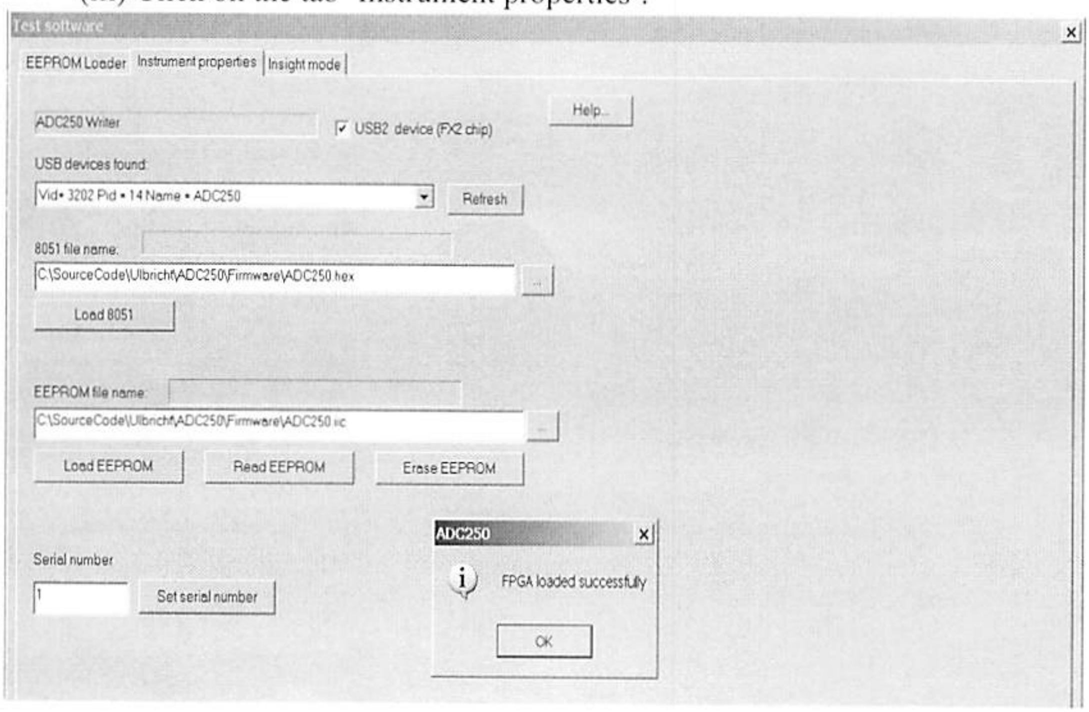
1. **Before connecting** the detector to the power supply and the digitizer set the power supply voltage by doing the following:
   (i) Switch on the power supply
   (ii) Switch on Channel 1
   (iii)Adjust the voltage of Channel 1 to the appropriate **negative voltage** by using the lab multimeter in DC mode (1 V measured corresponds to 1 kV)
   (iv)Switch off Channel 1

   After performing the steps (i)-(iv) and repeating them for Channel 3, connect the detector to the power supply using Channels 1 and 3 and the digitizer using Channel A. Switch Channels 1 and 3 back on.

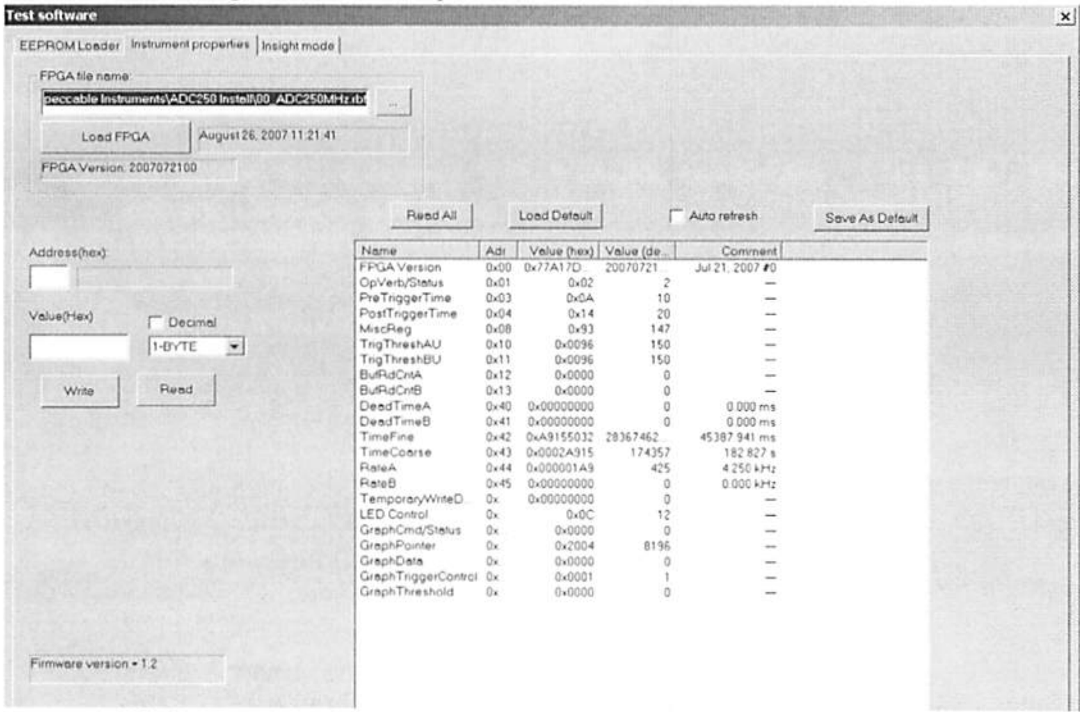
2. The ADC250 data acquisition system has to be activated and appropriate data structure has to be chosen. This will be achieved by the following steps:
   (i) Power on the digitizer
   (ii) Open the data acquisition software. The following window will appear:



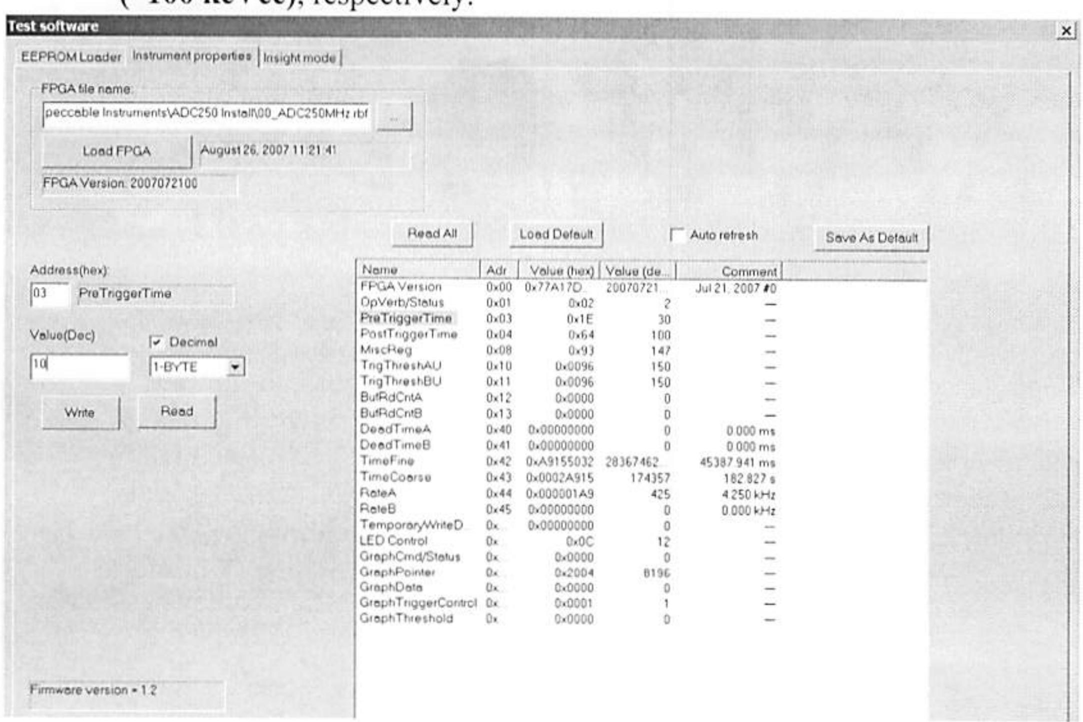
   (iii) Click on the tab 'Instrument properties'.



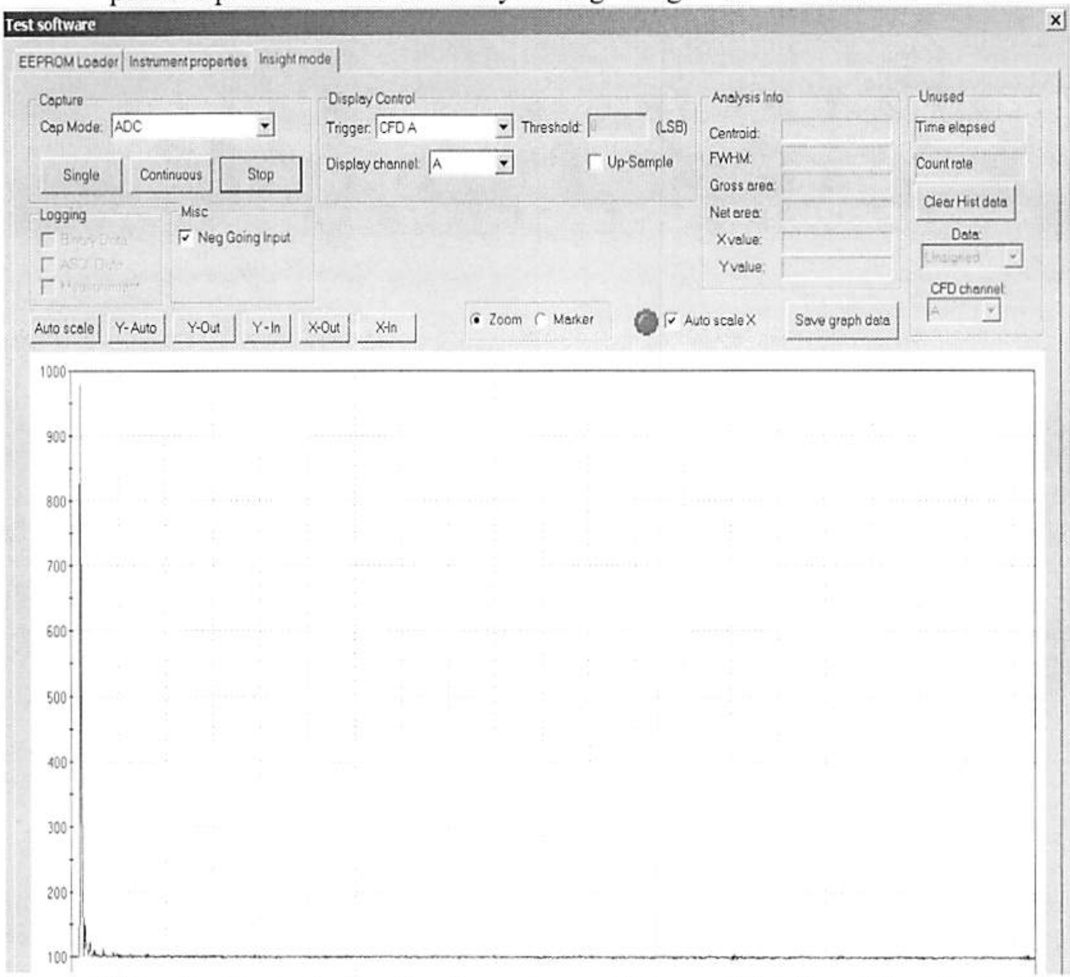
(iv) The system will announce "FPGA loaded successfully." Click 'OK'. The following window will open:



(v) Click on the text "**PreTriggerTime**" in the large white-background window. Rewrite the current value to "**8**" by using the small read/write window on the left-hand side. Before clicking on 'Write' button, make sure to mark the 'Decimal' option. In the same way, change the "**PostTriggerTime**" and "**TrigThreshAU**" values to decimal **8** and **110 (~100 keVee)**, respectively.



(vi)Click on the tab 'Insight mode.' Choose "CFD A" for the trigger option and "A" for the 'Display channel' option. Mark "Neg Going Input". To visualize a single pulse at a time, choose "ADC" in 'Cap Mode.' The pulse is printed to the screen by hitting 'Single' or 'Continuous' buttons.



(vii)To visualize a train of pulses, choose "Snippet Data" in 'Cap Mode.' To record the data, **choose "Fast Capture"** instead, and hit '**Continuous**' button. The pulses have to be recorded in ASCII format ('Logging' option "ASCII Data"). Approximately 300 MB measurement file will be acquired and stored at C:\.

Part 2: Data analysis

The Pu-Be measurement file acquired previously will be postprocessed using a special script. The file contains information on a few millions of pulses (actual pulses are not present!). The file should be loaded by Matlab or another programming language script and the time-difference (TOF) distribution of adjacent pulses from channels 0 and 1 should be obtained between 0 and 100 ns (2-ns step).

Questions:

(1) What are the average count rates at the detectors with and without the Pu-Be source?

(2) Please estimate measured average neutron energy.

(3) How could we speed up the measurement? Would you suggest different measurement approach than for Lab 5.1? Please explain.

Please provide the following graphs in the lab report:

(a) Measured TOF distribution for the Pu-Be - Counts vs. Time (ns). Please describe the distribution.

(b) Measured TOF distribution for the Pu-Be - Counts vs. Energy (MeV). Please describe the distribution.

(c) Comparison of the measured TOF distributions for the Pu-Be and Cf-252 (Lab 5.1) - Counts vs. Energy (MeV). Please explain the differences.

Extra credit:

Simulate the TOF distributions for the sources investigated in Lab 5. Describe the assumptions you made in the MCNP-PoliMi model (IDUM(1) = 1 for Cf-252) and compare the measured and simulated TOF distributions. The energy spectrum for Pu-Be is given below (assume pure neutron source):

```
SI1 L  0.4
       0.8
       1.2
       1.6
       2.0
       2.4
       2.8
       3.2
       3.6
       4.0
       4.4
       4.8
       5.2
       5.6
       6.0
       6.4
       6.8
       7.2
       7.6
       8.0
       8.4
       8.8
       9.2
       9.6
```

		10.0
		10.4
SP1	C	0.04419
		0.08837
		0.13023
		0.16744
		0.20349
		0.25
		0.30814
		0.37093
		0.43605
		0.50116
		0.56395
		0.61744
		0.6593
		0.69535
		0.73256
		0.77209
		0.81221
		0.85174
		0.8907
		0.92093
		0.94186
		0.95581
		0.96977
		0.98372
		0.99535
		1

NERS 590-2: Detection Techniques for Nuclear Nonproliferation

Laboratory 1.2: Simulation of Passive and Active Measurements of HEU using MCNP5

Motivation: Passive and active measurements are typical in the fields of nuclear nonproliferation and homeland security. In this exercise we will acquaint ourselves with some typical sources, and their application to the measurement of highly-enriched uranium (HEU), using the Monte Carlo code MCNP5.

Objective: To characterize the energy- and time-dependant neutron spectra from a HEU sphere incident on an EJ-309 liquid scintillation detector with both passive and active methods using MCNP5.

Setup: The detector, HEU, and shielding materials will be setup on a 60.96-cm × 121.92-cm × 0.2480-cm steel table (see Appendix A). The simulations will be performed with MCNP5 coupled neutron-photon transport (`MODE N P`).

Procedure: This laboratory consists of one basic measurement model and two different simulated measurements. Each simulation contains specific information to be tallied. Plot all tallied data using appropriate software (e.g. Excel) including 2-σ error bars. Comment on the shape, trends, and any distinguishing features (i.e. minimum value, maximum value, unusual shape, etc.) of each distribution. Detailed descriptions of the geometry, materials and neutron sources are in Appendices C and D.

1. <u>Passive measurement of a HEU sphere</u>

   Simulate the passive measurement of the neutron energy spectrum from a 5-kg sphere of HEU metal using a EJ-309 liquid scintillation detector. The neutron source is the spontaneous fission of ^{238}U (neglect the spontaneous fission of ^{235}U). Calculate the following quantities:

   1. The number of neutrons emitted per second from the surface of the sphere and their energy spectrum ($0 < E \leq 10$ MeV) in 100-keV intervals
   2. The average energy of the neutrons leaving the sphere.
   3. The number of neutrons per second entering the front face of the detector and their energy spectrum ($0 < E \leq 10$ MeV) in 100-keV intervals.
   4. The solid angle of this detector placement.

   All tally results must be scaled to the given source strengths to obtain absolute count rates.
   NPS = 5×10^7

2. Active interrogation of a HEU sphere

Interrogate the HEU sphere using one of the neutron sources (^{252}Cf, D-T, or D-D) oriented 90-degrees to the detector (see Appendix A). Calculate the following quantities:

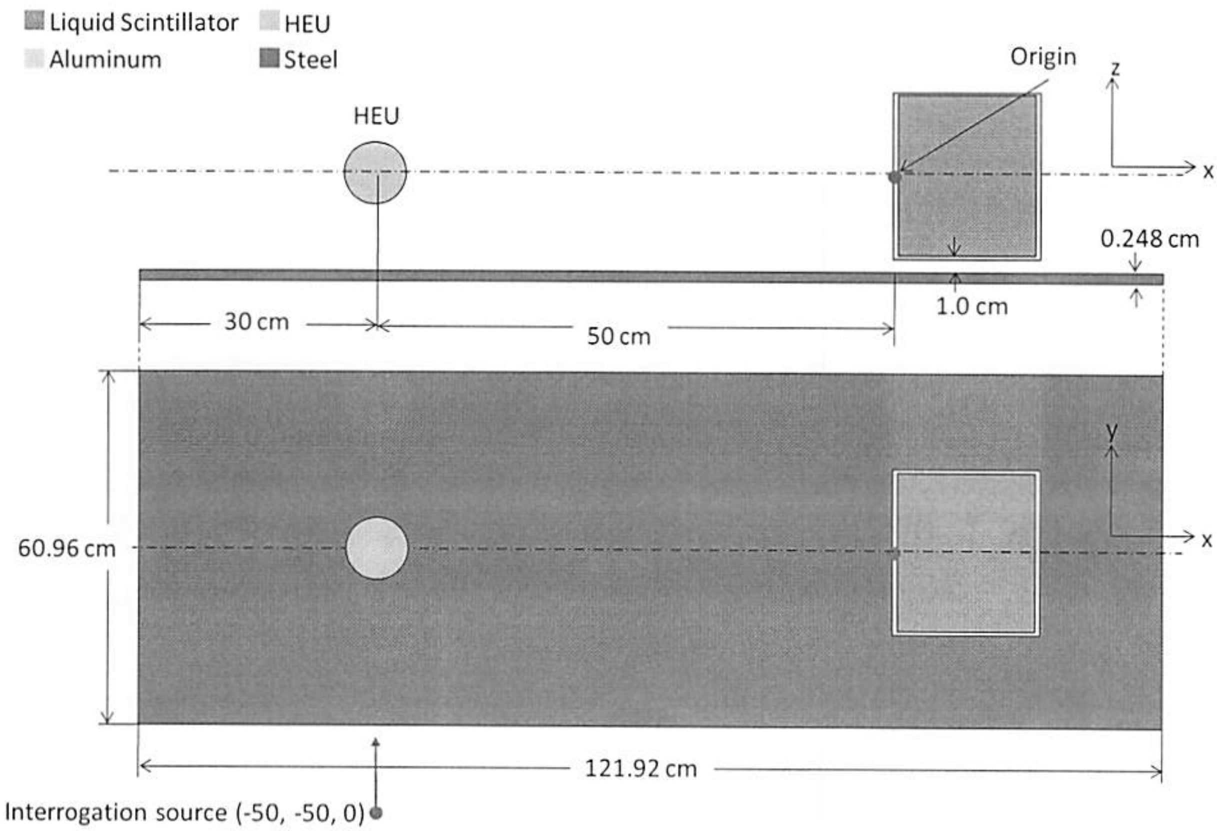
1. The number of absorption and fission reactions occurring in the HEU target per second.
2. The number of neutrons per second entering the front face of the detector, their energy spectrum ($0 < E \leq 15$ MeV) in 100-keV intervals,
3. The average energy of the neutrons entering the detector.

All tally results must be scaled to the given source strengths to obtain absolute count rates.
NPS = 5×10^7

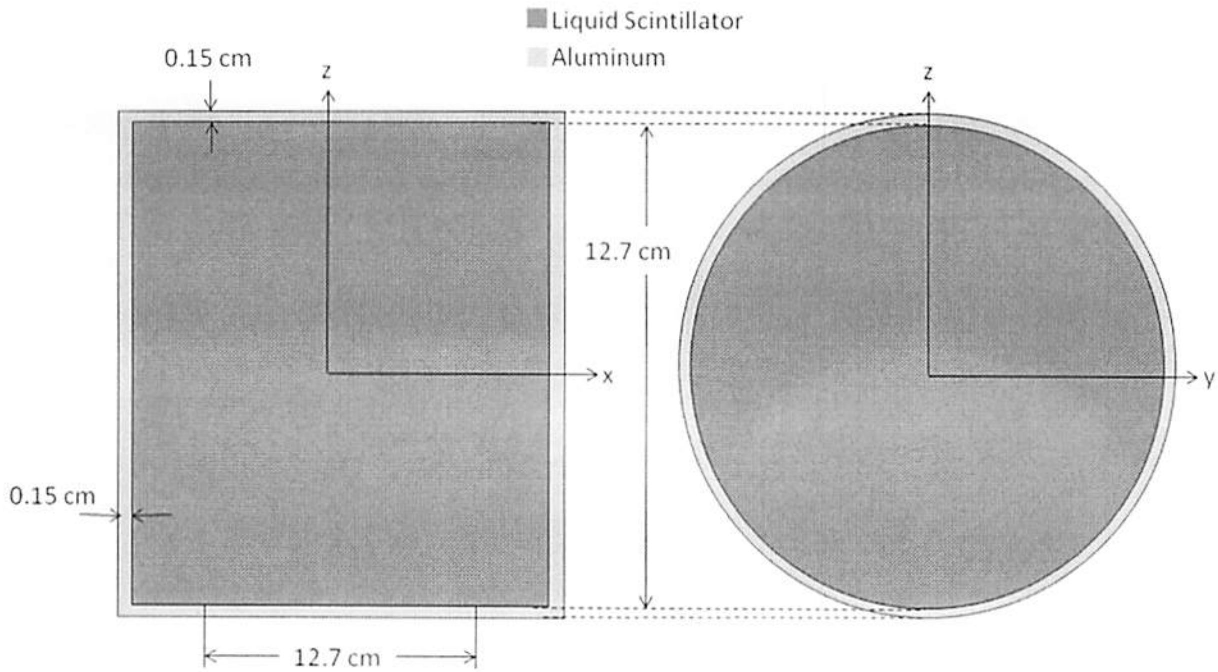
Discuss the shape and trends in the tallied energy spectra. Comment on any similarities or differences in the passive and active interrogation results.

Appendix A: Experimental Setup

The detector, HEU sphere and any shielding materials are placed on a wooden table as shown below. Do not forget to include a surface (box, sphere, etc.) large enough to bound the entire geometry and source (problem truncation). Use `imp:n,p=1` for all cells inside of this surface and `imp:n,p=0` outside.



Appendix B: EJ-309 Liquid Scintillation Detector



Appendix C: Material Specifications

Below are the specifications for all materials to be used in this lab (**negative percentages are weight-percents, positive percentages are atom-percents**). All material densities are given in units of g/cm^3 and should therefore be specified in the MCNP input file as **negative values.** For all materials use the ZZZAAA.60c neutron cross section libraries and the ZZZAAA.04p photon libraries.

- Liquid scintillator: H (55.54%), C (44.46%), $\rho = 0.964$ g / cm^3
- Aluminum: ^{27}Al (100%), $\rho = 2.7$ g / cm^3
- HEU: ^{235}U (-93%), ^{238}U(-7%), $\rho = 18.75$ g / cm^3
- Steel: C (-0.06%), ^{55}Mn (-0.35%), ^{54}Fe (-5.676%), ^{56}Fe (-91.49%), ^{57}Fe (-2.132%), ^{58}Fe (-0.289%) $\rho = 7.872$ g / cm^3

Appendix D: Source Information

Passive HEU simulation: Isotropic source of ^{238}U spontaneous fission neutrons **uniformly distributed** within the HEU sphere. The spontaneous fission neutron energy spectrum of ^{238}U can be approximated using a Watt spectrum with a = 0.6483 and b = 6.811. The specific spontaneous fission activity of ^{238}U is 1.36×10^{-2} *n*/s/g.

Active HEU simulation: A 5-degree half-angle cone* placed at (-50, -50, 0) directed toward the HEU sphere along the *y*-axis with energy specified by:

- ^{252}Cf: a = 1.025, b = 2.926 (Watt spectrum), 2.34×10^{6} *n*/s (1 μg)
- D-T: 14.1 MeV monoenergetic, 10^{8} *n*/s
- D-D: 2.45 MeV monoenergetic, 10^{7} *n*/s

*Note: Tally results using the ^{252}Cf source should be corrected to reflect isotropic neutron emission.

All tally results must be scaled to the given source strengths to obtain absolute count rates.

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number: 2057
Date: 03/15/2012
Effective Term: Fall 2012
Course Offer Freq: ☒ Indefinitely ☐ One term only

Action Requested
- ◉ New Course
- ○ Modification of Existing Course
- ○ Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

A. CURRENT LISTING	B. REQUESTED LISTING
Home Department:	Home Department: NERS Nuclear Engin & Radiolog Sci
Course Number:	Course Number: 546
Cross Listed Course Information:	Cross Listed Course Information:
Course Title:	Course Title: Thermal Fluids for Nuclear Reactor Safety Analysis
TITLE ABBREVIATION – Time Sched (Max = 19 Spaces):	TITLE ABBREVIATION – Time Sched (Max = 19 Spaces): Ther Fluids-Nucl Reac Analy
TITLE ABBREVIATION – Transcript (Max = 20 Spaces):	TITLE ABBREVIATION – Transcript (Max = 20 Spaces): Ther Fluids-Nucl Reac Analy
Course Description:	Course Description for Official Publication (Max = 50 words): The course objective to provide an overview of thermal-fluids for nuclear reactor safety analysis with applications to both light water and high temperature gas reactor. This course will review the basic mass, energy, and momentum conservation equations with emphasis on specific closure relationships and numerical methods for practical reactor applications. Students will perform analytic solution and utilize US NRC computer codes RELAP5 and AGREE for light water and gas reactor applications, Problem sets will be performed in groups of 2 and student will be expected to present results of their work at least one during the term.
PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k	PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k
Degree Requirements: ○ Degree Requirement ○ Core Course ○ Free Elective ○ Tech Elective ○ Other	Degree Requirements: ○ Degree Requirement ○ Core Course ○ Free Elective ◉ Tech Elective ○ Other
Prereq: ○ Enforced ○ Advised	Prereq: Concurrently with or prior to: NERS 441, ME 320 or CEE 325 or equivalent or Graduate standing. ○ Enforced ◉ Advised
Credit Restrictions:	Credit Restrictions:
Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work	Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☒ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work
Credit Hours: Min ___ Max ___	Credit Hours: Min 3 Max 3
Contact Hrs/Wk: ___	Contact Hrs/Wk: 3
Number of Wks: ___	Number of Wks: 13

C.

Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ○ Yes ◉ No Max Hours? Max Times? Can it be repeated in the same term? ○ Yes ○ No

Class Type(s): ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Graded Section: ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Grading: ☒ A-E ☐ CR/NC ☐ P/F ☐ S/U

Course Is Y Graded ☐

Location: ☒ Ann Arbor ☐ Biological Station ☐ Camp Davis ☐ Extension

Cognizant Faculty Member:	Title
Thomas Downar	Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info	Approved by Name	Approved Date
☐ Curriculum Comm.		
☐ Faculty		
☐ Cross listed Unit 1		
☐ Cross listed Unit 2		

Submitted By: ☐ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	Chair Signature
Home Dept.	Nuclear Engin & Radiolog Sci	
Cross-listed Dept(s).		

Form Number

2057

SUPPORTING STATEMENT

Currently, NERS does not offer a course in thermal-hydraulics (TH) and many of the topics in nuclear reactor safety have nuclear specific TH phenomena that deserve a dedicated course of instruction. this course is designed to be dual level and will build on the students basic understanding of mass, energy, and momentum from the undergraduate courses. The objective of the course is to provide the necessary background so that students will be able to solve analytically basic thermal-fluid problems and then to compare their solutions with US NRC code thermal-hydraulic codes for both light water and high temperature gas reactor simulations. The student will then work in groups of two to analyze OECD/NEA benchmark problems using the same US NRC codes for practical reactor transient. The students will also give presentations on the results of their analysis in order to develop their oral presentation skills.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

NERS 590-3

THERMAL HYDRAULICS FOR NUCLEAR REACTOR SAFETY ANALYSIS

Fall, 2009

Prof T. Downar

The objective of this course is to provide an overview of thermal-hydraulics/fluids for nuclear reactor safety with applications to both the light water and high temperature gas cooled reactors. The course will review the basic mass, energy, and momentum conservation equations with emphasis on the specific closure relationships and numerical methods used for practical reactor applications. The students will utilize the U.S. NRC computer codes RELAP5 and AGREE for light water and gas cooled reactor examples, respectively. There will be four problem sets which will be performed in groups of 2 and 3 students and students will be expected to present the results of their work at least once during the semester.

Introduction to TH for Nuclear Applications (1 class)
- Brief Overview of Nuclear Power Reactor Safety
- Application of Coupled Codes for Reactor Analysis

Block I: LWR: Single Phase Flow (5 weeks)

a. Review of Conservation Equations and Constitutive Relations
b. One dimensional formulation
   Problem Set #1: Single channel PWR analysis
   (Analytic Solution Compared to RELAP5)
c. Computer code applications: Introduction to RELAP5 / PARCS
   Problem Set #2: OECD/NEA Benchmark:
   Main Steam Line Break in a PWR

Block II: High Temperature Gas Cooled Reactor Applications (5 weeks)

a. Review of the HTGRs
b. Porous Media Approach and Heterogeneous Fuel Temperature Modeling for Pebble Bed Reactors (PBR)
   Problem Set #3: TH
c. Methods for Neutronic and Thermal analysis of the PBRs
   Problem Set #4: OECD/NEA PBMR-400 Benchmark Problem
   a. Neutronics Only
   b. TH Only
   c. Coupled Code: Steady-state/Transient

Block III: Introduction to Advanced Topics (3 weeks)

a. Two Phase Flow (RELAP5)
b. CFD (STAR-CD)

References:

- *N.E. Todreas , M.S. Kazimi "Nuclear Systems I" Hemisphere (1990)*
- *M. Ishii, "Thermo-Fluid Dynamic Theory of Two Phase Flow" Prentice Hall (1962)*
- *R.T. Lahey, F.J. Moody, " The Thermal Hydraulics of Boiling Water Nuclear Reactor"*
- *L. S. Tong, J. Weisman, "Thermal Analysis of Pressurized Water Reactors"*
- *R.B.Bird et al, "Transport Phenomena"*
- *F. Odar, C. Murray et al., "TRACE V4.0 User's Manual", May 2003.*
- *Information Systems Laboratories, "RELAP5/MOD3.3 CODE MANUAL", March 2006*
- *T. Kozlowski, R. Miller, T. Downar, H. Joo, D. Barber, "Consistent Comparison of the Codes RELAP5/PARCS and TRAC-M/PARCS for the OECD MSLB Coupled Code Benchmark," Nuclear Technology, Vol. 146, No. 1, April, 2004.*
- *Y. Xu, T. Downar, R.Walls, K. Ivanov, J. Staudenmeier,J. March-Lueba, "Application of TRACE/PARCS to BWR stability analysis", Annals of Nuclear Energy, 36 (2009) 317–323*
- *Joo, H. G., Barber, D., Jiang, G., and Downar, T. J., "PARCS, A Multi-Dimensional Two-Group Reactor Kinetics Code Based on the Nonlinear Analytic Nodal Method," PU/NE-98-26, Sept. 1998.*
- *V. Seker, "Multiphysics Methods Development for High Temperature Gas Cooled Reactor", Dissertation, Purdue University, 2007*
- *V. Seker, T. Downar, "Analysis of OECD/NEA PBMR-400 Transient Benchmark Problem with PARCS", September 14-19, Physor2008, Interlaken, Switzerland , 2008.*

09-25-2008

NE590-003

Problem Set – 1

PART I

(Due 10-2-2008)

The porous media fluid energy equation, Eq. 1, is a convective-diffusive type transport equation which is solved to determine the temperature of the fluid. Eq. 1 can be simplified to Eq.2 by assuming a 1-D axial flow at steady state conditions with no heat source from the solid phase. The porosity term is also extracted from the equation for simplicity.

3D-Fluid Energy Equation

$$\frac{\partial}{\partial t}\left[(\varepsilon\rho_f c_{p_f} T_f\right] = -\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho_f c_{p_f} u_r T_f\right) - \frac{1}{r}\frac{\partial}{\partial \theta}\left(\rho_f c_{p_f} u_\theta T_f\right) - \frac{\partial}{\partial z}\left(\rho_f c_{p_f} u_z T_f\right)$$
$$+\frac{1}{r}\frac{\partial}{\partial r}\left(\varepsilon k_f r\frac{\partial T_f}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\varepsilon\frac{k_f}{r}\frac{\partial T_f}{\partial \theta}\right)$$
$$+\ \frac{\partial}{\partial z}\left((1-\varepsilon)k_s\frac{\partial T_s}{\partial z}\right) - \alpha(T_f - T_s) \qquad \text{[Eq. 1]}$$

(Steady State One Dimensional Energy Equation)

$$\frac{\partial}{\partial z}\left(\rho u T\right) = \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) \qquad \text{[Eq. 2]}$$

The solution of this partial differential equation is given by the following equation assuming fixed temperature boundary conditions and constant density.

$$\frac{T - T_0}{T_1 - T_0} = \frac{\exp(Px/L) - 1}{\exp(P) - 1} \qquad \text{[Eq. 3]}$$

where,

$$P = \frac{\rho u L}{k}$$

B.C. at z=0 $T=T_0$ and z=L $T=T_1$

We will investigate the numerical solution of this problem using the AGREE code which will be provided via CTOOLS.

1. First derive the analytic solution of Eq. 2 for the given boundary conditions.

2. Using the AGREE code and the input provided solve the problem with the Central Differencing Scheme.

   a. For ρu=0.1, k=0.1 and δx=0.1 solve the problem with the boundary condition T_0= 200 and T_1=100 and using the central differencing scheme. Compare the results with the analytical solution.
   b. Increase ρu to 10.0 and repeat the calculation and comment on the result.
   c. Suggest a method to improve the solution obtained in part b.

3. Setting ρu=0.1 again solve the problem with the following differencing schemes and compare the results to the analytical result.

   a. Upwind
   b. Hybrid
   c. Power Law
   d. Exponential

4. For ρu=10.0, solve the problem with all the above differencing schemes.

   a. Compare the results with the analytical solution
   b. Give suggestion to improve the numerical results which require improvement.

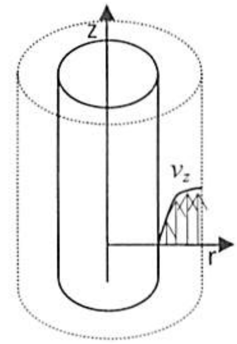
For all the problems, plot results where appropriate and succinctly and concisely discuss the important results.

Appendix INPUT File

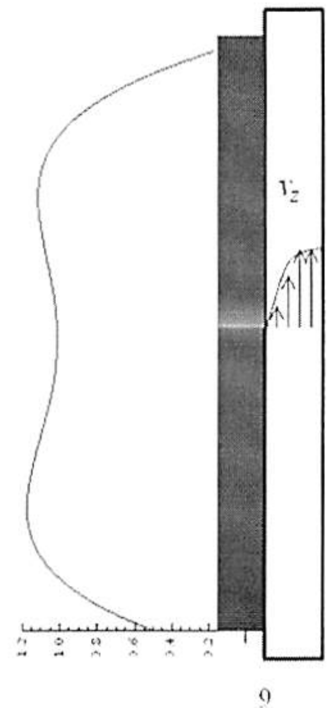
```
CASEID Problem1
CNTL
   transient  F                         ! TRUE if the problem is transient
   stdn_th    T                          ! standalone TH card, to perform a T/H calculation with a given source.
GEOM
 geo_dim   1  1  10                 ! dimension in r-theta-z
 grid_r    1*1.0                      ! radial mesh size
 grid_theta    1*360.0             ! theta mesh size(degree)
 grid_z     10*0.1                   ! axial mesh size
TRAN
 time_step 100.0  0.01              ! time information; final time and time step size.
 theta 0.5                               ! theta for the time discretization.
AGREE
 tmesh_r    1*1                       ! mesh refinement in R direction
 tmesh_th    1*1                     ! mesh refinement in Theta direction
 tmesh_z    10*1                     ! mesh refinement in Z direction
 rinner    0.0                           ! inner location
 num_comp   1                       ! number of compostions
 reac_conf                            ! configuration
  1   1   1   1   1   1    10        ! axial 1 D
 comp_typ                             ! composition type
! cnum cname ifcpl ifflw  lam   rhocp  ffrac  Tin   rhou
  1  fluid   F   T   0.1     3.02   1.0  100.   0.1
    1     6.0    1.0
 bndr_con                              ! boundary condition
  rad  1   1   F   F                   ! boundary type 1=neumann 2=dirichlet (Solid)
    0.0  0.0                            ! boundary values                 (solid)
     1   1   F   F                      ! boundary type 1=neumann 2=dirichlet (Fluid)
    0.0 0.0                             ! boundary values                 (Fluid)
  thet 1   1   F   F
    0.0 0.0
     1   1   F   F
    0.0 0.0
  axl  1   1   F   F
     0.0 0.0
     2   2   F   F
    200.0 100.0
 pow_pro 1 0                              ! 1 uniform power density W/cm^3
 fluid   2                                 ! fluid type 2 for this problem
 convsch 1                                 ! convective diffencing methods: 1=CD ; 2=UD ; 3=HD ;  4=PLD ; 5=ED
 tol 1.0e-10 1.0e-6 1.0e-6 1.0e-5          ! convergence criteria Lin.sys / tolsolT/tolfluT / tolff
 tol_tr 1.0e-10 1.0e-5 1.0e-5 1.0e-4        ! convergence criteria Lin.sys / tolsolT/tolfluT / tolff
!  for  solidT  fluidT  flow  neut
 solver 4      3      2     1
 maxit  100 100
 printo_th  F  F  F  F  T             ! print card, fifth entry is the fluid temperature
```

NERS-590-3

Problem Set 2



Problem 1: In a PWR assembly, a fuel rod together with the surrounding fluid form a pin cell which can be simplified as a cylindrical model with $R_p = \frac{1}{\sqrt{\pi}} L$. Derive the velocity distribution of fully developed SS laminar flow for an isothermal incompressible Newtonian fluid with the assumption $\left.\frac{\partial v_z}{\partial r}\right|_{R_p} = 0$.



Problem 2: A typical PWR pin cell consists of a fuel rod with a diameter 8.2 mm, clad inner diameter 8.5mm and outer diameter 9.5 mm. The average water area of the fluid surrounding the pin is 13.0675mm^2. The height of the pin is 4m and the active (fuel) height is 3.66m with 0.17m unheated regions at the top and bottom. The average power from a pin at full power operation is 65.58606 kW. The average water flow rate is 0.334564 Kg/s with inlet temperature is 559.15 Kelvin. A typical z-direction power profile is given as,

$$f(z) = -0.14z^4 + z^3 - 2.41z^2 + 2.2z + 0.502536782$$

The thermal conductivities (in w/m-k) are: fuel 2.9, clad 16, and gap 0.4. Assume wall heat transfer coefficient is 45kw/m^2-K.

A) Analytically solve for the coolant temperature distribution alone the channel and the r-z temperature distribution within a fuel rod neglecting the z-direction heat transfer, work done by pressure force, the pressure dependence of enthalpy for water. The enthalpy (h) and temperature (T) relation is given as follows with T in Kelvin,
$$h(T) = h(T_{in}) + 5593\left(T - T_{in}\right)\ J/Kg.$$
B) Calculate the same problem with RELAP5 (note: the z-direction heat conduction CAN be turned off in the **solid** off but it cannot be turned in **fluid,** so this will introduce some difference with your analytic solution).
C) Use the temperature dependent thermal properties and constant wall heat transfer coefficient to perform the same problem with RELAP5.
D) Use the constant thermal properties and the Dittus–Boelter correlation for wall heat transfer coefficient to perform the same problem with RELAP5.
E) Use the temperature dependent thermal properties and the Dittus–Boelter correlation for wall heat transfer coefficient to perform the same problem with RELAP5.

Please compare coolant temperatures (T_{fl}), wall surface temperatures(T_{co}) and fuel center line temperatures (T_{cl}) from part A), B), C) ,D) and E) in terms of (T_{fl} ,T_{co} -T_{fl} ,and T_{cl} -T_{co}). Extra credit will be given for parametric studies on both axial nodalization in pipe and heat structure and radial nodalization of the heat structure. Please explain your observations.

The RELAP5 executable (relap5.exe) and manual (InputManual.pdf), three input files, (hw2_2B.i, hw2_2C.i, hw2_2D.i, hw2_2E.i), a batch command file (run.bat) and file for water properties (tpfh2onew) are provided on ctools\Resources\PROBLEM SETS\SET 2.

NERS-590-3
Problem Set 3

RELAP5/PARCS
Analysis of the OECD MSLB Transient

This problem set will use the coupled codes RELAP5/PARCS to analyze the OECD/NEA Main Steam Line Break (MSLB) Benchmark problem. The MSLB is a core overcooling accident that results in a large positive reactivity insertion. The "best estimate" analysis of the event with spatial kinetics has shown that the traditional point kinetics analysis can be overly conservative and has led to a significant recovery of operating margin, particularly for extended cycle length operation when the core moderator temperature coefficient is most negative. The benchmark and results with RELAP5/PARCS is described in the PHYSOR-2000 paper provided on CTOOLS.

1. The first part of the problem set will be to become familiar with the execution of the coupled codes RELAP5 and PARCS. A tutorial will be provided in class to familiarize you with the details of code execution and output file processing. All executables and input files for this problem set are available at:

http://ctools.umich.edu/NERS 590 003 F08 Resources / PROBLEM SETS / SET 3

Run the benchmark and compare your results to those in the paper (ie. Figure 5 and 6). It is important to note that the first set of results in the paper use the "**best estimate**" core model which includes the original set of cross sections for the TMI-1 core used in the benchmark. Using this set of cross sections the core remained several dollars sub critical throughout the transient. The benchmark also provided a second set of cross sections referred to as the "**return to power**" scenario in which the control rod cross sections were modified to simulate a scenario in which the core reactivity approaches zero, but criticality is not achieved. This is the case which will be analyzed in the homework set and for which results are provided in Figure 5 and 6. Plot all quantities shown in the paper and any additional quantities which may contribute to your analysis of the event. Provide a detailed summary of the event and an analysis using the plots.

2. Perform parametrics using RELAP5/PARCS on finite different schemes (semi-implicit vs near-implicit) and step sizes.

Extra Credit will be given for

A. Plotting the RELAP5 model (the NRC software SNAP is available for visualizing the RELAP5 model)
B. Generating movies for pressure wave propagation and density wave propagation. (a software APTplot is available for reading the RELAP5 restart file)
C. Analysis of the subcritical "return to power" using the prompt jump approximation of the point kinetic equation.

THE UNIVERSITY OF MICHIGAN -- COLLEGE OF ENGINEERING
Course Approval Request
College Curriculum Committee, 1420 Lurie Engineering Center Building

Form Number: 2319

Date: 3/15/2012

Effective Term: Fall 2012

Course Offer Freq: ☒ Indefinitely ☐ One term only

Action Requested
- (●) New Course
- ( ) Modification of Existing Course
- ( ) Deletion of Course

Complete the following sections:
New Courses - B & C completely
Modifications - A modified information, B & C completely
Deletions - A & C completely

A. CURRENT LISTING

Home Department:
Course Number:

Cross Listed Course Information:

Course Title:

TITLE ABBREVIATION — Time Sched (Max = 19 Spaces): / Transcript (Max = 20 Spaces):

Course Description:

PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k

Degree Requirements: ( ) Degree Requirement ( ) Core Course ( ) Free Elective ( ) Tech Elective ( ) Other

Prereq: ( ) Enforced ( ) Advised

Credit Restrictions:

Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☐ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work

Credit Hours Min Max | Contact Hrs/Wk ____ | Number of Wks ____

B. REQUESTED LISTING

Home Department: NERS Nuclear Engin & Radiolog Sci
Course Number: 573

Cross Listed Course Information:

Course Title: Plasma Engineering

TITLE ABBREVIATION — Time Sched (Max = 19 Spaces): Plasma Engr / Transcript (Max = 20 Spaces): Plasma Engr

Course Description for Official Publication (Max = 50 words)

This course covers the theory and application of plasma science concepts relevant to plasma engineering subject matter encountered in the workplace. Relevant technology areas addressed include plasma propulsion, semiconductor processing, lighting, accelerator plasma sources, and materials processing. Students will accumulate over the course of the term a toolbox concepts and techniques directly applicable to "real world situations." These include electrostatic probes, sheath physics, plasma formation and maintenance and the design and troubleshooting of vacuum systems relevant to application.

PROGRAM OUTCOMES: ☐ a ☐ b ☐ c ☐ d ☐ e ☐ f ☐ g ☐ h ☐ i ☐ j ☐ k

Degree Requirements: ( ) Degree Requirement ( ) Core Course ( ) Free Elective (●) Tech Elective ( ) Other

Prereq: ( ) Enforced (●) Advised

Credit Restrictions:

Level of Credit: ☐ Undergrad only ☐ Rackham Grad ☐ Non-Rckhm Grad ☒ Ugrad or Rckhm Grad ☐ Ugrad or Non-Rckhm Grad ☐ All Credit types ☐ Rckhm Grad w/add'l Work

Credit Hours Min Max | Contact Hrs/Wk ____ | Number of Wks ____

C.

Repeatability (Indi Research, Dir. Study, Dissertation: Is this course repeatable? ( ) Yes ( ) No Max Hours? ____ Max Times? ____ Can it be repeated in the same term? ( ) Yes ( ) No

Class Type(s): ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Graded Section: ☒ Lec ☐ Sem ☐ Dis ☐ Other __ ☐ Rec ☐ Lab ☐ Ind

Grading: ☒ A-E ☐ CR/NC ☐ P/F ☐ S/U

Location: ☒ Ann Arbor ☐ Biological Station ☐ Camp Davis ☐ Extension

Course Is Y Graded ☐

Cognizant Faculty Member:	Title
John Foster	Assoc Professor

Grad Course: Attach nomination if Cognizant Faculty is not a regular graduate faculty

Approval Info	Approved by Name	Approved Date
☐ Curriculum Comm.		
☐ Faculty		
☐ Cross listed Unit 1		
☐ Cross listed Unit 2		

Submitted By: ☐ Home Dept. ☐ Cross-listed Dept.

	Department Chair Name	Chair Signature
Home Dept.	Nuclear Engin & Radiolog Sci	[signature]
Cross-listed Dept(s).		

Form Number

2319

SUPPORTING STATEMENT

This course has been taught as NERS 590 for 3 terms. The purpose of this course is to introduce the student to a variety of plasma science and vacuum technology topics likely to be encountered in the area of plasma engineering, thereby enabling and empowering the student to apply such principles in the workplace, be it research or development. by the end of the course, the student with a toolbox that can be used to tackle various research and development in this field.

Are any special resources or facilities required for this course? ☐ Yes ☒ No

Detail the Special requirements

COURSE # AND CREDITS: NERS 573 – 3 Credit Hours	**COURSE TITLE: Plasma Engineering**
TERMS OFFERED: Winter terms	**PREREQUISITES:** **Concurrently with or prior to NERS 471 or equivalent or course in electricity and magnetism (advised) or graduate standing**
TEXTBOOKS/REQUIRED MATERIAL: **Principles of Plasma Discharges and Materials Processing, Liebermann and Lichtenberg; Basic Data of Plasma Physics, Sanborn Brown; Introduction to Plasma Physics and controlled Fusion, Francis Chen**	**COGNIZANT FACULTY:** **John Foster**
INSTRUCTOR:	**FACULTY APPROVAL:**
CoE BULLETIN DESCRIPTION: This course covers the theory and application of plasma science concepts relevant to plasma engineering subject matter encountered in the workplace. Relevant technology areas addressed include plasma propulsion, semiconductor processing, lighting, accelerator plasma sources, and materials processing. Students will accumulate over the course of the term a toolbox concepts and techniques directly applicable to "real world situations." These include electrostatic probes, sheath physics, plasma formation and maintenance and the design and troubleshooting of vacuum systems relevant to application.	**COURSE TOPICS:** (approximate number of hours in parentheses) Scope of plasma engineering (1 wk); Plasma Sheaths (2 wks); sheaths in action- plasma diagnostics, plasma thruster (3 wks); elementary processes in plasmas- diffusion , energy losses, confinement (2 wks); electrical breakdown-rf, dc, vacuum (2 wks); Vacuum technology-equations, pumps, gauges, systems (3 wks); Plasma sources-electropositive/electronegative model, rf, flow, microwave, DBD (2 wks)
COURSE STRUCTURE/SCHEDULE: Lecture 2 per week @ 1.5 hours	Required, Selective or Elective? Elective

COURSE OBJECTIVES	Links shown in brackets are to course outcomes that satisfy these objectives. 1. Student will be able to list the primary areas of plasma engineering research and provide examples of contemporary technical problems under current research and development 2. Students will be able to understand the origin, importance, and occurrence of the plasma sheath 3. Students will be able to determine under which conditions the three basic sheaths form 4. Students will be able to describe the basic electrostatic probes and explain their general operation 5. Students will be able to determine under which electrostatic probe technique is most applicable for a particular application given background conditions 6. Students will be able to calculate diffusion loss rates and design multipole confinement geometries for plasma confinement to reduce losses 7. Students will be able to determine the optimum conditions for breakdown given electrode geometry, gas type, and voltage source 8. Students will be able to calculate the pumping speed at any point in a basic vacuum system 9. Student will be able to list and describe the operation of the transfer and capture pumps as well as vacuum gauges 10. Students will be able to model and calculate pump-down characteristics of a simple vacuum system 11. Students will be able to explain the operation of DC, RF, microwave, and DBD plasma discharge and explain the relative advantages of each from an applications point of view.
COURSE	Links shown in brackets are to program educational outcomes. 1. Student will be able to characterize a given plasma system using electrostatic proves, selecting the appropriate probe and analysis technique (4,5,6)

OUTCOMES	2. Student will be able to determine particle and energy transport rates to structures immersed in the plasma (2,3,5,6,11) 3. Student will be able to select appropriate plasma source for a particular process based on process requirements (1,2,3,7,10,11) 4. Student will be able to discuss the application of plasma-based solutions in a variety of engineering areas (1,2,5,11) 5. The student will be able to design a basic vacuum system based on pressure requirements and flow rates (9,10) 6. Student will be able to determine the conditions to start a plasma as well as understand how to avoid unintended breakdown (6,7,11)
ASSESSMENT TOOLS	1. Homework assignments, mid-term and final exams

Course Purpose: Plasma engineering is the application of plasma physics principles to "real world" problems be it plasma processing, environmental mitigation or space propulsion. The purpose of this course is to introduce the student to a variety of plasma science and vacuum technology topics likely to be encountered in the area of plasma engineering, thereby enabling and empowering the student to apply such principles in the workplace, be it research or development. Throughout the course, attempts will be made to engage the student with real-world applications of the principles discussed. Because the field is so diverse, no one text at present comprehensively covers the whole of plasma engineering. In this respect the course will draw upon the references listed above. The course will cover basic plasma physics and gas phase processes such as diffusion, gas breakdown, vacuum technology, plasma sources and applications. By the end of the course, the student should have a working knowledge of key aspects of this increasingly important field. The goal is for the student to come away with a toolbox that can be used to tackle various research and development issues in this amazing field.

Course Outline:

I. What is plasma engineering
  a. Review of basic plasma definitions
  b. General characteristics of plasmas
  c. Technological significance of plasma properties with application areas
II. Plasma sheaths
  a. Floating sheaths
  b. Matrix Sheath
  c. Child-Langmuir Sheaths
  d. Double layers
III. Importance of the sheath in plasma engineering
  a. Plasma diagnostics
    i. Langmuir probe
    ii. Double probe
    iii. Triple probe
    iv. Emissive probe
    v. Electron/ion energy analyzer
  b. Ion thrusters
  c. Vacuum electronics devices
IV. Elementary processes in plasma
  a. Collisions (elastic and inelastic processes)
  b. Ionization methods
  c. Diffusion
  d. Magnetic confinement
V. Electrical breakdown—starting a plasma
  a. DC breakdown
  b. Rf breakdown
  c. Special considerations regarding high voltage standoff—undesired breakdown
VI. Vacuum Technology

a. Units, flow regimes, and the pumping speed equation
b. Vacuum system configuration
c. Pumps
d. Gauges

VII. Plasma sources
a. Electropositive model
b. Rf discharge
c. DC discharge
d. Microwave discharge
e. The dielectric barrier discharge

Textbook

Primary Text: Principles of Plasma Discharges and Materials Processing, by Michael A. Lieberman and Allan J. Lichtenberg
Supplemental References (On reserve at the Media Union): Glow Discharge Processes: Sputtering and Plasma Etching by Brian Chapman
Basic data of plasma physics, by Sanborn Brown
A User's Guide to Vacuum Technology by John F. O'Hanlon
Industrial Plasma Engineering, Vol. 1, by J.R. Roth
Additional Reference: Introduction to Plasma Physics and Controlled Fusion by F.F. Chen

Grade

Grades will be determined by the following formula:

Category	*Percentage of Grade*
Homework assignments	35 %
Quiz (1-2)	30%
Final Exam →Presentation/paper (due by April 27, 1:30 to 3:30)	35%

Problem set 4 Plasma Engineering 590 Due April 6, 2009.

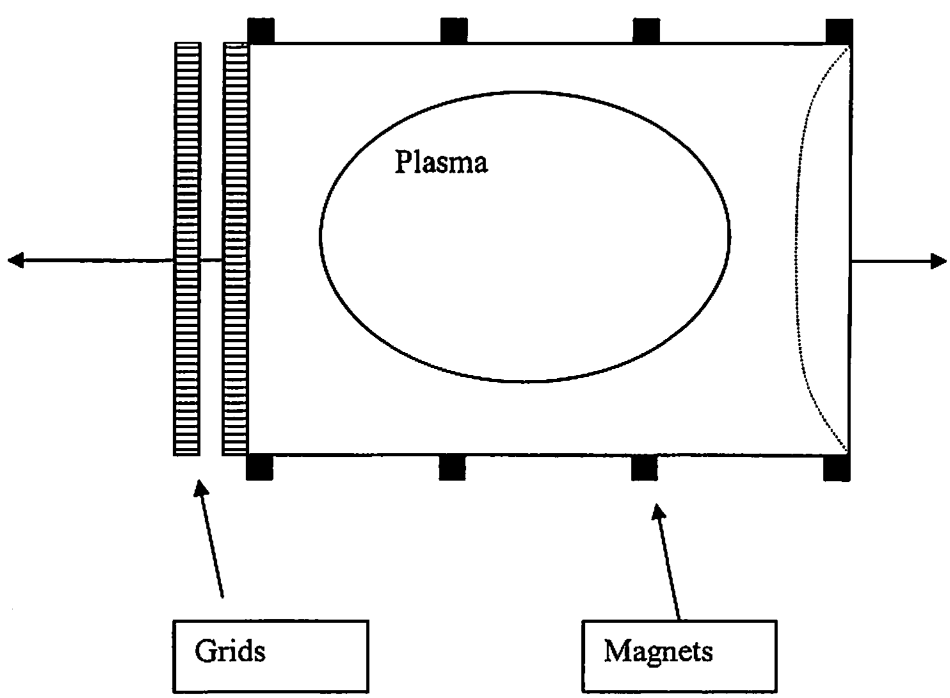
1. Consider a cylindrical discharge chamber containing 4 equally spaced rings of permanent magnets along its sides. The backplate is magnetically isolated. The other end of the container contains a pair of ion extraction grids. The source is 40 cm long and 40 cm in diameter. The surface field strength of the magnets that make up the ring is 1 kG. Neglect wall thickness and end losses; also volume defined above is essentially field free with magnetic field essentially residing at the surface. Argon plasma temperature =3 eV, argon ions are room temperature. Also assume the radial density profile is constant along the axis of the source. Assume that argon mean free path is $(330p)^{-1}$ (cm) and that the chamber pressure is 5×10^{-2} Torr. Assume electron-neutral collision cross section is $2 \times 10^{-20}\,m^2$. Assume plasma end losses do not affect radial profile. Assume that radial losses occur only at the cusps with a loss width equal the hybrid radius.

a) What is the plasma uniformity (ratio of density at sheath edge to density in the bulk)?

b) Estimate the maximum extractable ion current if the plasma density on center-line just upstream of the grids (at the sheath edge) is $10^{11}/cm^3$ for two cases: with magnetic field discussed above and without the magnetic field. Also for part 2, assume for the case of the magnetic field, that the density variation is linear; assume for B=0 case constant ionization=diffusion type spatial profile.

c) Plot the uniformity ratio as a function of the following surface magnetic field strengths: 100 G, 500 G, 1 kG, and 2500 G; explain trends observed.

d) If the ion current were to be extracted using grids with 27,000 apertures at an extraction voltage (between grids) of 2000 V with an ion optics transparency of 80 percent, what is maximum grid spacing that will allow the transport this ion current if one assumes that the current obtained in (2) (B field case) is completely uniform (flat)? Screen grid diameter is 2 mm, 0.5 mm thick. (Side Note ion thruster ion extraction transparency of grids is usually higher than the optical transparency due to the focusing effects associated with the shape of the plasma meniscus at the grid aperture.)



NE590-2. Due Jan. 26
Plasma Criteria and Space tethers:

1. Consider a 10 km tether deployed from a space station with orbital radius of about 350 km. The station has a mass of 200,000 kg. The tether has a spherical collector of radius 1 m. Using the data file, evaluate the criteria for plasma for the ionosphere as is relevant to the collector.

2. Referring to the data in problem 1, answer the following question. Assume that the magnetic field is relatively constant over the length of the tether and neglect contribution to current due to station movement through the ionosphere. A) What is the maximum current that could be collected by the collector neglecting sheath effects and assuming that collection is isotropic? Assume the lower end of the tether as well as the space plasma is at a potential of zero and the sphere attains its maximum possible voltage (e-beam gun on negative end essentially clears what ever current is incident on the collector). B) Locate the magnetic field strength at this altitude, indicate your reference then answer the following question: Relative to the collector size, is particle motion magnetized at this altitude? What is the maximum current that the collector can extract in this case, again neglecting sheath effects. C) Lets now examine sheath effects. Assume that collisional effects destroy the anisotropy and that collection is now influenced primarily by collector voltage. In this case, the sheath thickness may be expressed as: $s = \frac{\sqrt{2}}{3} \cdot \lambda_D \cdot \left(\frac{2V_{collector}}{\frac{k_{Boltz}T_e}{e}} \right)^{3/4}$ where λ_D is the Debye length. Assuming the collector voltage is 500 V, what is the current through the tether? Also, these mysterious collisional effects...are they classical? D.) If the load is 1 kilo-ohm, what is the ratio of the power lost at the collector to the power dissipated in the load for current calculated in parts B and C. E) What is the ratio of the total energy produced by the tether over an orbital period to the kinetic energy of the space station?

Bonus +5 Calculate the drag incurred by the tether on the station due to power generation based on results from part C. Assuming that the station is being deorbited, make a rough estimate the orbit decay rate in km/day by plotting radial position versus time down to 150 km.

Plasma criteria

3. What is the lowest density plasma that can be sustained in a plasma discharge chamber whose smallest dimension is 3 cm and electron temperature is 2 eV? How would that minimum density change if the electron temperature were doubled?

Plasma Applications:

4. Consider an MHD generator in which the a hot gas from a chemical reactions is flowing at velocity of U (+ x direction). The gas stream is seeded with plasma so that the gas has a finite conductivity σ. The gas passes through a magnetic field pointed in the + y direction. The gas passes between two plates separated a distance l apart. The plates have an area of S and are located in the x-y plane. A) Derive an expression from the information given of the open circuit voltage. B) If the plates are connected to a load R_l and the plasma itself has an internal resistance R_p, what is the power delivered to the load? C.) Show that this power is maximum when R_l=R_p and that this maximum power can be expressed as $P = \frac{1}{4} \cdot B^2 \cdot u^2 \cdot l \cdot S \cdot \sigma$

D) For parts A and C, calculate real numbers for this generator if B= 1 Tesla, u=150 m/s, σ= 200 mho/m, d=20 cm, and S= $1 m^2$.

NE 590: MIDTERM-Make UP APRIL27, 2009-CONCEPTUAL QUERY

Closed Book--Closed Notes
No Calculators Needed*

NAME___________________________________

Honor Code

Please write your answers on the exam pages. Use short answers (no more than two sentences per query)

1. A) What is the definition of a plasma ? B) Name at least two of the three parameters used to characterize a plasma?

2. A) What is plasma engineering? B) Name at least four of the many general areas where plasmas are used to serve some technological function giving a specific example (few words only) of at least one application in each area.

3. A) In your own words, what is a Debye length? B) What is the scaling of the Debye length scale with electron temperature and physically what is the origin of the scaling?

4. Consider a steel sphere placed into a large chamber containing a uniform, collisionless, low density plasma with Te>>Ti. The sphere is suspended by a non-conducting wire. A)What is the potential called at which the sphere will acquire relative to the wall potential (assumed to be a ground)?

NE 590: MIDTERM-Make UP APRIL27, 2009-CONCEPTUAL QUERY

5. What three parameters can be calculated from a Langmuir Probe IV characteristic?

6. Sketch and Label the three basic regions of an ideal Langmuir probe IV characteristic:

7. What is an emissive probe used to measure and what is its primary error source?

8. What is the main difference between thin sheath and thick sheath plasma collection for a simple, single Langmuir probe?

9. Sketch an idealized Langmuir probe in the presence of a low energy ion beam where the ion beam energy is δ.

NE 590: MIDTERM-Make UP APRIL27, 2009-CONCEPTUAL QUERY

10. What ion condition must be satisfied for a stable sheath at an isolated body immersed in a plasma provided Te>>Ti and plasma is collisionless?

11. What ultimately limits the power production capacity of a tether of fixed length and fixed collection area A at fixed orbit R? Name at least one means of circumventing this problem.

12. For shielding to take place for a negatively biased electrode immersed in a plasma the curvature of the potential must be what sign and why?

13. Name the three basic equilibrium states that a plasma can exist in. Provide an example for each state.

14. You perturb a plasma by locally modifying the ion density: how does the plasma response time scale with electron density and electron mass?

15. What beneficial role does secondary electron emission play in PSII?

16. What is the physical origin of space charge-limited current flow; focus your attention on the site of emission?

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>>

17. Sketch a swept emissive probe IV characteristic with and without electron emission, labeling each in box below. Label the plasma potential on the sketch.

18. For ion implantation applications, high bias voltage is typically pulsed. What sheath behavior limits the pulse time if conformal implantation is required?

19. What sheath type best describes plasma ion implantation at early very implant/pulse times? Why does it form at such early times?

20. If charge flow between two planar electrodes in a vacuum is space charge limited, name two parameters that can be varied to increase the current. Name one example of a plasma device or system whose operation is space charge limited.

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21. Sketch below a simple circuit to measure a Langmur probe IV charactristic.

22. What are the two basic functions or operating modes of a space electrodynamic tether?

23. What is the voltage drop across the preasheath in a collisionless plasma? If you were to calculate the plasma density at the sheath edge from a negatively biased Langmuir probe trace (ion saturation), how would you expect your calculated density at the sheath edge (assuming no collisions) compare to actual density at the sheath edge if the presheath is collisional?

24. You are depositing a conformal coating onto high aspect ratio structures on a chip by applying a bias voltage in the presence of a plasma. What two qualities of the incident flux are affected by charge exchange in the sheath?

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25. Name at least 3 basic gas ionization methods.

26. How does the electron mean free path and collision frequency vary with input gas pressure? (that is it inversely proportional, directly, exponentially varying ect.)

27. An electron elastically scatters off a neutral particle in a plasma. On average, with such a collision, what fraction of the electron's energy is lost?

28. By the continuity equation, for steady state, plasma production must balance losses. What are the two main plasma loss mechanisms?

29. Why do electrons typically have higher plasma temperatures than ions?

30. What is the physical origin of ambipolar diffusion?

31. What is the fluid equation for an electron in a partially ionized gas without a magnetic field present : assume the electrons are isothermal.

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32. Fill in the chart illustrating scaling of the diffusion coefficient with and without a magnetic field

Diffusion Parameter	**Magnetic Field=0**	**Nonzero Magnetic Field**
Scaling with mass		$\sqrt{m}$
Scaling with collision frequency		
Rough scaling with characteristic length scale and time		

33. Why isnt ambipolar diffusion isotropic when a magnetic field is present?

34. Of the four permanent magnetic plasma confinement schemes discussed in class, sketch your favorite on the back of this page (include name).

35. What conditions must balance for rf breakdown to take place?

36. At what condition is rf breakdown the easiest?

37. Sketch roughly an rf breakdown curve for two different sized plasma containers A and B, where the diameter of A>B

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38. In an rf field, how can an electron gain net energy over cycles?

39. What electrode process is responsible for breakdown and ultimately a self- sustaining DC discharge?

40. How does plasma density decay as a function of time (scaling only) due to a) recombination b) diffusion assuming no additional energy is input into the plasma after formation?

41. If the electron neutral collision frequency is 10^8/s and the axial magnetic field is 2 kG, is electron radial diffusion across the field significantly affected by the field; that is, is electron motion magnetized? Explain answer briefly.

42. Name the two basic categories that vacuum pumps may be classified. Give one example of each

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43. My vacuum chamber is connected to a pump using two pieces of tubing in parallel with equal conductance. How would my effective conductance change if I were to place the two sections in series rather than parallel?

44. Why do symmetric double probes indicate typically higher temperatures that that which is measured by a single Langmuir probe?

45. What is the appeal of the triple probe; that is, what is the main advantage of this probe technique and what parameters can it be used to monitor?

46. What is a retarding potential analyzer used to measure? What is the requirement for grid spacing in this probe?

47. Name at lest two roles or functions that mechanical pump oil plays in a roughing pump?

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Topics For NERS 590-Plasma Engineering.

1. Energy- Fusion Reactor Divertors
2. Energy-Neutral beam injectors for ITER
3. Energy-the vacuum technology of ITER
4. Energy-Physics and engineering challenges of a fusion fission hybrid
5. Energy-energy extraction tech of ITER
6. Technology applications of Dense Warm Matter (High energy density plasmas)
7. Defense-Atmospheric /Ionospheric modification
8. Aerospace-propeller-less propulsion (ion wind)
9. Aerospace, the quest for high specific impulse Hall thrusters: the two stage Hall engine-via helicon
10. Lighting-ECR and the future of the light bulbs
11. Lighting-microdischarges
12. Medical-Plasma knife/jet/needle applications in medical arena
13. Medical-plasma treatment of wounds and disease
14. Defense/Research-Inertial electrostatic confinement neutron source
15. Environment-applications of pulsed plasma discharges in water
16. Environment-Barrier discharge and VOC abatement
17. Manufacturing: Focused ion beam etching
18. Manufacturing: nanoparticle production in plasmas
19. Aerospace: Plasma contactor operation on ISS: astronaut and solar array protection
20. Propulsion: Pulsed Inductive Ion Thruster
21. Propulsion: Lithium magnetoplasmadynamic thruster
22. Propulsion: VISTA (ICF propulsion)
23. Propulsion: Heating in VASMIR
24. Environment: Microplasma discharges for sensing
25. Agriculture: plasma treatment of seeds; Ag plasma applications
26. Medical-plasma-cell interactions: physics and chemistry of plasma healing
27. Transportation: plasma assisted combustion
28. Defense: Plasma cloaking technology
29. Defense: Plasma antennas
30. Aerospace: Plasma actuators for flow control on wings: taken
31. Aerospace/Energy: Power production during hypersonic flight using MHD generator
32. Energy: Harvesting Hydrogen from hydrocarbons using plasma
33. Communication: Active modification of ionosphere to affect radio wave propagation
34. Manufacturing: Multi-frequency rf discharges for plasma processing
35. Manufacturing: Textile industry and plasmas
36. Research/Defense: Plasma based isotope separation
37. Propulsion: Fission Fragment propulsion
38. Propulsion: Nuclear light bulb: uranium plasma
39. Construction: Plasma applications to ground/soil stabilization; plasma welding/ plasma cutters
40. Defense: Plasma based x-ray sources

41. Defense: plasma based neutron sources
42. Transportation: plasma muffler
43. Environment: plasma assisted destruction of volatile organic compounds
44. General: plasma accelerators

UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING

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March 13, 2012

To: College Curriculum Committee
From: Susan Montgomery, UG Program Advisor and ChE UG Program Committee
Re: Substitutions for quantum chemistry course in ChE curriculum
Date: March 13, 2012

It has come to our attention that the following courses address material covered in the one credit course Chemistry 261, Quantum Chemistry, required in our program:

Physics 390	Introduction to Modern Physics, 3 credits
MatScie 242	Physics of Materials , 4 credits

Accordingly, the Chemical Engineering faculty voted to approve these courses as acceptable replacements for Chemistry 261. The number of students affected would be minimal, as both of these courses are more credits than 261, but it would allow students completing Physics minors or Materials Science and Engineering concentrations to avoid duplication of technical content.

We appreciate your consideration of this program change. The updated sample schedule is attached, as are the course descriptions for the three courses.

Sample Schedule 2011

Chemical Engineering

	Total Credit Hours	Terms: 1	2	3	4	5	6	7	8
Subjects Required by all Programs:									
Mathematics 115+, 116+, 215+, 216+	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering +	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers +	4	-	4	-	-	-	-	-	-
Chemistry 130 +	3	3	-	-	-	-	-	-	-
Physics 140 with Lab 141 +	5	-	5	-	-	-	-	-	-
Physics 240 with Lab 241 +	5	-	-	-	5	-	-	-	-
Intellectual Breadth (COE start Fall 2011) or Humanities/Social Science (COE start prior to Fall 2011) (to include a micro or macro economics)	16	4	-	-	-	4	-	4	4
Advanced Chemistry:									
Chemistry 210/211, Structure and Reactivity I and Lab +	5	-	5	-	-	-	-	-	-
Chemistry 215/216, Structure and Reactivity II and Lab +	5	-	-	5	-	-	-	-	-
Chemistry 261 Introduction to Quantum Chemistry+ [3]	1	-	-	-	-	1	-	-	-
Related Technical Subjects									
Biology/Life Science Elective[1]	4	-	-	-	-	-	4	-	-
Materials Elective (MSE 250 or MSE 220) +	4	-	-	-	-	-	-	4	-
Engineering Electives[2]	3	-	-	-	-	-	-	-	3
Program Subjects									
CHE 230 Material and Energy Balances +	4	-	-	4	-	-	-	-	-
CHE 330 Chemical and Engineering Thermodynamics +	4	-	-	-	4	-	-	-	-
CHE 341 Fluid Mechanics +	4	-	-	-	4	-	-	-	-
CHE 342 Mass and Heat Transfer +	4	-	-	-	-	4	-	-	-
CHE 343 Separation Processes +	4	-	-	-	-	4	-	-	-
CHE 344 Reaction Engineering and Design +	4	-	-	-	-	-	4	-	-
CHE 360 Chemical Engineering Laboratory I +	4	-	-	-	-	-	4	-	-
CHE 460 Chemical Engineering Laboratory II +	4	-	-	-	-	-	-	-	4
CHE 466 Process Dynamics and Control	3	-	-	-	-	-	-	3	-
CHE 485 Chemical Engineering Process Economics +	1	-	-	-	-	-	1	-	-
CHE 487 Chemical Process Simulation and Design	5	-	-	-	-	-	-	-	5
General Electives	12	-	-	3	-	3	3	3	-
Total	128	15	18	16	17	16	16	14	16

Notes:

1. See department list for courses that satisfy the Biology/Life Science elective requirement

2. Engineering courses are to be at the 200 or higher level and cannot include seminar courses. Engineering research credits at the 400 level or higher may be used to satisfy this requirement. Up to 8 credits of ChE 490 or ChE 695 research may be taken for a grade. Beyond that, ChE 490 or 695 credits must be take pass/fail.

3. Physics 390 and Materials Science 242 can be taken as replacements for Chemistry 261.

(+) Students must earn a "C-" or better in prerequisite courses indicated by the (+)

COURSE PROFILE

Science Curriculum for Engineering Students **Date: May, 2005**

Prepared by: LSA –Chemistry Department

COURSE #: Chemistry 261	**COURSE TITLE:** Introduction to Quantum Chemistry
TERMS OFFERED: Fall, Winter	**For each prerequisite below, "E" denotes Enforced and "A" denotes Advised.**
TEXTBOOKS/REQUIRED MATERIAL: The Elements of Physical Chemistry, 3rd Edition.	**PREREQUISITES:** Chem 215 (A)
INSTRUCTOR(S): Walter, Geva	**COGNIZANT FACULTY:** Prof. Brian P. Coppola
BULLETIN DESCRIPTION: HEM 261 is an introduction to the quantal nature of matter (the Schrödinger equation and the mathematical machinery of quantum mechanics) and the fundamental principles necessary to understand spectroscopy (electronic, vibrational, and rotational). CHEM 261 is intended for Chemical Engineering students. This course, together with Chem Engin 330, provides the prerequisites necessary for enrollment in CHEM 302. Grading is based on problem sets and one hour exam. CHEM 261 meets only for the first third of the term.	**COURSE TOPICS:** Quantum Mechanics and Atomic States Interaction Between Atoms Interaction Between Light (EM radiation) and Matter
COURSE STRUCTURE/SCHEDULE Lecture: 3 per week @ 50 minutes	

COURSE OBJECTIVES	See information in catalog description.
CONTRIBUTION OF COURSE TO PROFESSIONAL COMPONENT	This course partially fulfills the basic science requirement within the Professional Component, Criterion 4.
RELATIONSHIP OF COURSE TO PROGRAM OBJECTIVES	This course provides a solid grounding in general chemistry that is essential for engineers and increasingly important for everyday life.

UNIVERSITY OF MICHIGAN

Lecture, Assignment, and Exam Schedul

Chemistry 260/26
Winter 201

#	Date	Lecture Topic(s)	Lecturer	Reading	Assignments
	January				
1	W 04	*course introduction*, classical chemistry: forces and potentials	Both	*syllabus*, Ch. 3 ★ 3.2, 3.5, 3.6	
2	F 06	facing the (quantum) facts	Al-Hashimi	Chs. 4.1-4.4	
3	M 09	waves, wave functions, and Schrödinger's theory	Al-Hashimi	Chs. 5, 6 (H)	***Problem Set 1***
4	W 11	Schrödinger's equation and the postulates of quantum mechanics	Al-Hashimi	Chs. 4.5-4.7	
5	F 13	Solving the Scrodinger equation	Dunietz	Ch. 4.7-5.1 pp. 169-174	
	M16	***Martin Luther King, Jr. Day. No Regular Classes.***			
6	W 18	Quantum modeling the hydrogen atom	Dunietz	Chs. 5.1	***Problem Set 2 (owl ch4)***
7	F20	many-electron atoms and the periodic table of elements	Dunietz	Chs. 5.2-5.4	
8	M23	periodic properties and electronic structure	Dunietz	Ch. 5.5	
9	W 25	quantum description of the chemical bond: VB theory	Dunietz	Chs. 6.1, 6.4	***Problem Set 3*** (owl ch5)
10	F27	quantum description of the chemical bond: MO theory	Dunietz	Ch. 6.2	
11	M30	the interaction of molecules with light	Al-Hashimi	Ch. 20.1-20.2	
	February				
12	W 01	rotational and vibrational spectroscopy	Al-Hashimi	Ch. 20.3	***Problem Set 4*** (owl ch6)
13	F 03	electronic spectroscopy	Al-Hashimi	Ch. 20.5	
14	M06	electronic spectroscopy (continued) or NMR	Al-Hashimi	Ch. 20.5, 20.7	
15	W08	***course connections: structure, bonding, and spectroscopy***	Both		***Problem Set 5*** (owl ch2(
	Th09	**MIDTERM EXAM 1: 6:00 – 8:00 pm, ROOM xxx (CHEM 261 ENDS)**			

Instructor: Emmanouil (Manos) Kioupakis
Phone: 734-764-3321
Office: 2106 HH Dow
Homepage:
Textbook:
Cognizant Faculty: Goldman, Millunchick, Mansfield, Shtein, Yalisove
Description:

Basic principles of modern physics and quantum mechanics as pertain to solid state physics and the physical behavior of materials on the nanometer scale. Applications to solid state and nano-structured materials will be emphasized including band structure, bonding and magnetic, optical and electronic response.

Course Topics:

1. Failure of classical physics; black-body radiation, Planck Postulate (TR 1, TR 3)
2. Early experiments exhibiting quantum effects: photo-electric effect, Davisson-Germer results, Compton shift, x-ray production. (TR 3)
3. Early models of the atom: Thompson, Rutherford and Bohr models, their successes and shortcomings. (TR 4)
4. Wave-particle duality; de Broglie postulate and Einstein relation. (TR 5)
5. Introduction to the wave equation and Fourier series analysis. (TR 5)
6. The Heisenberg uncertainty principle. (TR 5)
7. Probability density, expectation values, energy and momentum operations. (TR 5, TR 6)
8. Schrödinger equation, solutions for step, barrier and well potentials (TR 5, TR 6)
9. Scanning Probe Microscopy (TR 6)
10. Periodic well potentials: Kronig-Penney model (TR 11.1 + supplements)
11. Solution of the Schrödinger equation for the hydrogen atom (TR 7)
12. Atomic Physics and the Pauli Exclusion Principle (TR 8)
13. Classical and Quantum Statistics: Bose-Einstein and Fermi-Dirac statistics (TR 9)
14. Origin of Spectra (TR 10)
15. Stimulated Emission and Lasers (TR 10)
16. Thermal and Magnetic Properties (TR 10)
17. Superconductivity (TR 10)
18. Band Theory (TR 11)
19. Semiconductor Devices : Diodes, Transistors and Photovoltaics (TR 11 + supplements)

Additional Examples of the application of quantum theory in the context of materials science and engineering. May include: Quantum Devices, Quantum Computing, Magnetic Media, Spintronics

Course Objectives:

1. To teach sophomore engineering students the historical experimental results and theoretical developments which led to the formulation of quantum mechanics and solid state physics.
2. To teach students the solutions of the time independent Schroedinger?s equation for various potentials.
3. To teach students energy bands in solids and the origin of electronic conduction in metals and

semiconductors.
4. To teach students crystal structure and the Miller index and reciprocal lattice descriptions of crystallography.
5. To teach students Fourier methods and the application to diffraction effects in solids.
6. To teach students diffraction methods for crystallographic and defect analysis in pure and alloyed materials.
7. To provide students with examples of devices and applications for solid state phenomena and materials.

Course Outcomes:

1. Given the energy (E) of a wave/particle, students will be able to determine the de Broglie wavelength and the Einstein frequence for the wave description of the wave/particle.
2. Students will be able to estimate position-momentum and energy-time uncertainties for particles in the quantum size limit.
3. Students will be able to solve Schroedinger?s equation for step, barrier and well potentials, and find energy values for the solution eigenfunctions.
4. Students will be able to describe and sketch the valence and conduction band structure of monovalent, bivalent and trivalent metals, and describe the relative electrical conduction of each type of metal.
5. Students will be able to describe and sketch the band structure of pure and doped semiconductors, and illustrate direct band gap and indirect band gap transitions.
6. Students will be able to provide the Miller indices for arbitrary crystallographic planes and directions in cubic and hexagonal crystal systems.
7. Students will be able to index the reciprocal space lattices for cubic and hexagonal crystal structures.
8. Given a real space lattice students will be able to determine the corresponding Fourier transform reciprocal space latticce.
9. Given an unknown single phase solid material, students will be able to describe the characterization methods required in order to determine the identity and crystal structure of the host element, the single- or poly-crystalline nature of the material, the grain size (if applicable, and the relative defect level.
10. Students will be able to identify the solid state phenomena which provide the basic functionality in many contemporary microelectronic devices.

Assessment Tools:

1. Class ombudspersons will provide continuing feedback from class to the instructor.
2. Weekly homework assignments will test objectives #1-6, results will be discussed in class discussion.
3. Two closed-book mid-term exams will test objectives #1-6.
4. Course mid-term evaluation by CRLT personnel will allow for active feedback to instructor in order to identify areas for greater emphasis and improvement in course presentation.
5. Student reports on microelectronic solid state devices and systems will be presented to entire class (objective #7).

Physics 390, Winter 2008: Introduction to Modern Physics

Room: 1230 USB
Time: MWF 11am-12pm

Instructor: Mark Newman
Office: 322 West Hall
Office hours: Thursdays 2-4pm
Email: mejn@umich.edu

Grader: Justin Wedes
Email: jwedes@umich.edu

Problem session leader: Robert Wilson
Email: roberthw@umich.edu

Description: This course provides an introduction to the physics of the 20th and 21st centuries. The first half of the course deals with the fundamental theory of quantum mechanics, which underlies essentially all of recent physics. The second half deals with applications of quantum mechanics, including atomic physics, statistical and condensed matter physics, nuclear physics and particle physics.

Textbook (required): *Modern Physics, 5th edition*, Paul A. Tipler and Ralph A. Llewellyn, Freeman, New York (2008), ISBN 0-7167-7550-6. There is also an accompanying web site that goes with the book here. The web site was actually created for the old fourth edition of the book, but the editions are similar enough that the web site is still useful. The publisher also has a "preview" web site for the new edition here, which you can look at if you're interested.

Course work and grading: There will be problem sets most weeks. They will be handed out on Fridays and due in a week later in class. Due dates are noted on the schedule below. No late homeworks will be accepted. The problem sets will also be available in electronic form for download from this web site no later than the Friday morning on which they are handed out.

There will be one mid-term and a final. The mid-term will take place on Wednesday, February 20 from 11am to 12pm in 1230 USB (the usual time and place). The final will take place on Tuesday, April 22 from 1:30pm to 3:30pm in 1230 USB (the usual classroom). Both exams will be open-book, meaning you may bring your copy of Tipler & Llewellyn, but you may not use written notes or solutions to coursework problems. Grade for the course will be 35% on the problem sets, 30% on the mid-term, and 35% on the final.

Problem sets

- Homework 1 – Quantization of light and charge
- Homework 2 – Rutherford scattering and the Bohr model
- Homework 3 – De Broglie waves and wave functions
- Homework 4 – The Schrodinger equation
- Homework 5 – The hydrogen atom

- Homework 6 – Systems with many particles
- Homework 7 – Statistical mechanics
- Homework 8 – Solid state physics
- Homework 9 – Nuclear physics

The list of stable nuclei for Homework 9 is here.

Course schedule:

Date	Topic	Reading	On-line resources	Notes
Friday, Jan. 4	Intro and concept review		Relativity review	Take-home math quiz
Monday, Jan. 7	Quantization of mass and charge	3.1		
Wednesday, Jan. 9	Black body radiation	3.2		
Friday, Jan. 11	Photoelectic and Compton effects	3.3-3.4		Homework 1 handed out
Monday, Jan. 14	Atomic spectra	4.1		
Wednesday, Jan. 16	Rutherford scattering	4.2	Animation of Rutherford scattering	
Friday, Jan. 18	The Bohr model of the atom	4.3	Animation of Bohr model	Homework 1 due, Homework 2 handed out
Monday, Jan. 21	**No class**			Martin Luther King Day
Wednesday, Jan. 23	X-ray spectra	4.4-4.5	Animation of x-ray production	
Friday, Jan. 25	De Broglie waves	5.1-5.2		Homework 2 due, no new homework this week
Monday, Jan. 28	Wave functions and wave packets	5.3-5.4	Animation of a wave packet	
Wednesday,	The uncertainty	5.5-5.7		

Jan. 30	principle			
Friday, Feb. 1	The Schrodinger equation	6.1		Homework 3 handed out
Monday, Feb. 4	The square well	6.2		
Wednesday, Feb. 6	Pure states and combinations	6.3	Combination of states applet	
Friday, Feb. 8	Operators	6.4		Homework 3 due, Homework 4 handed out
Monday, Feb. 11	The simple harmonic oscillator	6.5	Solution of the harmonic oscillator	
Wednesday, Feb. 13	Reflection and transmission	6.6		
Friday, Feb. 15	The potential barrier		Potential barrier applet	Homework 4 due, no new homework this week
Monday, Feb. 18	Review session		Summary of topics for exam	
Wednesday, Feb. 20	**Mid-term exam**			Open-book, but no class notes allowed
Friday, Feb. 22	**No class**			
Winter Break	**No class**			Have a great break!
Monday, Mar. 3	Quantum mechanics in 3D	7.1		
Wednesday, Mar. 5	The hydrogen atom	7.2		
Friday, Mar. 7	Angular momentum	7.3		Homework 5 handed out
Monday, Mar. 10	Spin	7.4-7.5		

Wednesday, Mar. 12	More than one electron	7.6		
Friday, Mar. 14	The periodic table	7.7-7.8		Homework 5 due, Homework 6 handed out
Monday, Mar. 17	Statistical mechanics	8.1		
Wednesday, Mar. 19	Quantum statistics	8.2-8.3		
Friday, Mar. 21	The Fermi gas	8.5		Homework 6 due, Homework 7 handed out
Monday, Mar. 24	Structure of solids	10.1		
Wednesday, Mar. 26	Electrical conduction	10.3-10.4		
Friday, Mar. 28	Magnetism, band structure	10.5-10.6		Homework 7 due, Homework 8 handed out
Monday, Mar. 31	Structure of the nucleus	11.1-11.2		
Wednesday, Apr. 2	Nuclear decay	11.3-11.4		
Friday, Apr. 4	The liquid drop and shell models	11.5-11.6	Liquid drop model handout	Homework 8 due, Homework 9 handed out
Monday, Apr. 7	Fundamental particles and forces	12.1-12.2		
Wednesday, Apr. 9	Conservation laws and operators	12.3		
Friday, Apr. 11	Symmetries and quantum numbers	12.4		Homework 9 due
Monday, Apr. 14	Review session		Summary of topics for exam	
	End of classes			

Tuesday, Apr. 22	**Final exam**		List of practice problems for exam	1:30pm–3:30pm in 1230 USB

Mark Newman

The University of Michigan
College of Engineering
Nuclear Engineering and Radiological Sciences

1919 Cooley Building
Ann Arbor, Michigan 48109-2104

Ed Larsen
Chair, NERS Curriculum

(734) 936-0124
(734) 763-4540 fax
edlarsen@umich.edu

TO; College of Engineering
Curriculum Committee

FROM: Ed Larsen
Chair, NERS Curriculum Committee

DATE: March 15, 2012

RE: NERS Curriculum Changes

Attached is a request for changes in the NERS Undergraduate Curriculum. By adding NERS 320 as a required course, it will allow students to be better prepared for summer internships and their senior level required courses. By removing NERS 484 as a requirement, students will have greater flexibility in the selection of NERS elective courses. Students will take at least 2 courses from the following list: NERS 421, NERS 461, NERS 471 or NERS 484.

The effective date for the program change will be Fall 2012. The proposed changes have been approved by the NERS faculty.

If you have any questions or need additional information, please do not hesitate to contact me.

Sample Schedule with requestd Program changes										
Effective Fall 2012										
Nuclear Engineering and Radiological Sciences										
	Credit hrs			Terms						
Subjects required by all programs (52-55 hrs)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Math 115, 116, 215, and 216	16	4	4	4	4					
Engr 100, Intro to Engr	4	4								
Engr 101, Intro to Computers	4		4							
Chemistry 125/126 and 130 or Chem 210 and 211[1]	5	5								
Phys 140 with 141; Phys 240 with 241[2]	10		5	5						
Intellectual Breadth	16	4	4		4			4		
Advanced Mathematics (3 hrs)										
Math 454, Boundary Val Probl for Partial Dif Equ	3					3				
Related Technical Subjects (18 hrs)										
MSE 250, Princ of Eng Materilas or MSE 220, Intro to Materials and Manf	4			4						
CEE 211, Statics and Dynamics	4				4					
EECS 215, Intro to Circuits or EECS 314 Electr Circ, Systems and Appl	4					4				
CEE 325, Fluid Mechs, or ME 320, Fluid Mech[3]	4						4			
ME 235, Thermodynamics I	3					3				
Program Subjects (38 hrs)										
NERS 250, Fundamentals of Nuclear Eng	4				4					
NERS, 311, Ele of Nucl Eng & Rad Sci I	3					3				
NERS 312, ele of Nucl Eng & Rad Sci II	3						3			
NERS 315, Nuclear Instr Lab	4						4			
NERS 320, Prob in Nucl Eng & Rad Sci	3						3			Add as a required course. See new course supporting statement
NERS 441, Nuclear Reactor Theory	4							4		
~~NERS 484, Rad Hlth Eng Fundamentals~~										Delete as a requirement. Students can take as a NERS Elective
NERS Laboratory Course (above NERS 315)[4]	4								4	
Design Course[5]	4								4	
NERS Electives[6]	9							6	3	
Technical Electives (3 hrs)	3							3		
Unrestricted Electives (10 hrs)	10			3			3		4	

	128	17	17	16	16	13	17	17	15	
Notes:										
[1]If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit fromanother institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for CoE.										
[2]If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for CoE.										
[3]If CEE 325 (4 hrs) is elected, additional credit hour will be used as a general elective.										
[4]Laboratory Course (above NERS 315) select one from the following: NERS 425, 575, 586. (NERS 575 needs program advisor's consent.)										
[5]Design Course select one: NERS 442, 554.										
[6]Two courses must be selected from the following: NERS 421, NERS 462, NERS 471 and NERS 484. A maximum of 3 credit hours of independent study (NERS 499) can count as a NERS elective. All credit above 3 can only be counted as a general elective										Added to footnote for NERS electives. Students muc now take 2 courses from list of 4 NERS courses

The University of Michigan
College of Engineering
Nuclear Engineering and Radiological Sciences

1919 Cooley Building
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Ed Larsen
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TO; College of Engineering
Curriculum Committee

FROM: Ed Larsen
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DATE: March 15, 2012

RE: Engr Physics Curriculum Changes

Attached is a request for changes in the Engr Physics Undergraduate Curriculum. Summary of change are requested as follows:

- PHYS 401 (Intermediate Mechanics) is required because of the importance of the physics approach to EP students. There is significant overlap between PHYS 401and the engineering statics/dynamics courses. Therefore, the requirement of statics/dynamics has been eliminated. Exception: students who pursue a concentration in ME can substitute CEE 211 or ME 240 for PHYS 401 in order to satisfy ME prerequisites.
- Students used to be given the choice of ME 320 (fluids) or PHYS 406 statistical and thermal physics). These courses cover different topics. Unlike materials or circuits, knowledge of fluids is not essential to all students. PHYS 406 is very important to a physics-based education. Therefore, a) the requirement of ME 320 has been eliminated, b) PHYS 406 is now an added requirement under "Program subjects, c) The ME 235 requirement has been eliminated because its concepts are a subset of those in PHYS 406 (ME 235 has a larger practical component).
- The advanced math requirement has been reduced from 8 to 6 credits to reflect the fact that most MATH courses are 3 credits.
- An additional category has been added: "Flexible Technical Electives," with a total of 7-10 credits. It allows students more flexibility in selecting courses related to their concentration (Eng. Tech. Electives). Courses in this category are in math, physics or engineering at 300 level or higher. The faculty advisor may approve a 200 level course if it is a co- or prerequisite for an upper-level Eng. Tech. Elective.

The effective date for the program change will be Fall 2012. The proposed changes have been approved by the NERS faculty.

If you have any questions or need additional information, please do not hesitate to contact me.

Students attending the EP Program Meeting make recommendations on changes in the EP curriculum. These changes will better meet the needs of the EP students and allow for greater flexibility in the EP Program. This program is administered by the NERS Department. These changes have been approved by the NERS faculty.

CURRENT Required Technical Subjects		PROPOSED CHANGES Required Technical Subjects		Comments
MSE 250, Prin of Engr Materials	(4)			
CEE 211, Statistics and Dynamics		~~CEE 211, Statistics and Dynamics~~		
or ME 240, Intro to Dynamics	(3/4)	~~or ME 240, Intro to Dynamics~~	~~(3/4)~~	Delete as requirement
				For students pursuing ME in Engr Tech Elective, CEE 211 or ME 240 is a substitute for Physics 401
ME 235, Thermodynamics I	(3)	~~ME 235, Thermodynamics I~~	~~(3)~~	Delete as a requirement
				Phys 406 will be a replacement
ME 320, Fluid Mechanics		~~ME 320, Fluid Mechanics~~		Delete as a requirement
or, Phys 406, Stat/Thermal Phys	(3)	~~or, Phys 406, Stat/Thermal Phys (3)~~		Physics 406 will be a required physics subject
EECS 314, Circuit Analy and Electr				
or EECS 215, Intro to Circuits	(4)			
Total	(17/18)		(8)	

Physics Technical Subjects		Physical Technical Subjects		
Phys 340, Waves, Heat and Light	(3)			
Phys 390, Intro to Modern Phys				
or NERS 311, Elements of NERS I	(3)			
Phys 401, Inter Mechanics	(3)			
Phys 405, Inter Electr and Magn	(3)			
		Phys 406, Stat and Thermal Phys	(3)	Replacement for ME 235
Phys Elective (300L +)	(3)			
Phys Lab Elective	(2)			
(or Directed Study)				
Total	(17)		(20)	

Advanced Math	(8)	Advanced Math	(6)	Reduction of credits to be consistent with the math courses offered (typically 3 cr hr courses)

Flexible Technical Electives**	(7-10)	Additional credits of technical electives allows students more flexibility in selecting courses related to engr technical electives. Courses must be a 300L+ Math, Physics or Engineering. The faculty advisor may approve a 200L course if course is a pre- or co-requisite of an upper level course.

** Students will be advised to elect ME 235 and ME320 if pursuing ME in Engr Tech Electives

All other requirements will remain the same:

Common Requirements	36-39
Elective Humanities/Social Sciences	16
General Electives	12
Engineering Technical Electives	20

Sample Schedule 2012 (with program chnages)									
Engineering Physics									
To be effective Fall 2012									
	Total	**Term:**							
	Credit Hrs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Subjects required by all programs (52-55 hrs)									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engr 100, Intro to Engr	4	4	-	-	-	-	-	-	-
Engr 101, Intro to Com;puters	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211[1]	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with lab 241[2]	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	4	-	-	-	-
Advanced Mathematics (6 hrs)									
Mathematics Electives[3]	6	-	-	-	-	-	3	3	-
Related Technical Subjects (8 hrs)									
Matsci 250, Princ of Engr Materials	4	-	-	4	-	-	-	-	-
EECS 314, Elect Cir, Sys, and Appl or EECS 215, Intro to Circuits	4	-	-	-	4	-	-	-	-
Physics Technical Subjects (20 hrs)									
Physics 340, Waves, het and Light	3	-	-	-	3	-	-	-	-
Physics 390, Intro to Modern Physics or NERS 311, Ele of Nucl Engr & Rad Sci I	3	-	-	-	-	3	-	-	-
Physics 401, Inter Mechanics[4]	3	-	-	-	-	-	3	-	-
Phys 405,Int Elect and Mag	3	-	-	-	-	-	-	3	-
Physics 406, Stat/Thermal Physics	3	-	-	-	-	-	-	-	3
Physics Elective (300 level+)	3	-	-	-	-	-	-	-	3
Physics Lab Elective or Directed Study with Research lab Component	2	-	-	-	-	2	-	-	-
Engr Technical Electives (20 hrs)									
Engineering Electives[5]	16	-	-	-	-	4	4	4	4
Engineering Laboratory Elective (400 level +)	4	-	-	-	-	-	-	-	4
Flexible Technical Electives (7-10 hrs)									
Mathematics, Physics or Engr Courses (300 level +)[6]	7-10	-	-	-	-	3	4	-	-
General Electives (12 hrs)	12	-	-	-	-	3	3	3	3
Total	128	17	17	17	15	15	17	13	17
Notes:									
[1]If you have a satisfactory score or grade in Chemistry AP, A-level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for CoE.									
[2]If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for CoE.									
[3]Math Electives must be 300-level or higher.									
[4]For students pursuing ME in Engr Tech Electives, CEE or ME 240. ME440 or ME 540 can be substituted with faculty program advisor approval.is a substitute for Physics 401.									

[5]Engineering Electives are to be chosen in consultlatono with the facutly advisor to form a coherent sequence that clearly defines professinoal goals for the student. Sample elective sequences for a number of different subject areas are available fro theh academic or faculty counselors.										
[6] For students pursuing ME in Engr Tech Electives, students will be advised to take ME 235 and ME 320 as Flexible Tech Electives. For students pursuing Aero in Engr Tech Electives, students will be advised to take Aero 225 and Aero 325 as Flexible Tech Electives.										