NucE 497A RAMP
Class #1
This course is designed as an intensive course providing an introduction to nuclear engineering (NucE) for graduate students with non-NucE background and to returning students.

After successfully completing this course, students will be able to effectively follow the regular NucE curriculum.
COURSE OBJECTIVES

NucE 497A - a compressed version of:

Fundamentals of Reactor Physics

Nuclear reactions and interactions relevant to nuclear engineering including fission, cross-sections, reaction rate calculations, energy depositions rates, and radioactive decay

9 classes based on Chapters 1, 2, 3 and 4 from course textbook
Introduction to Reactor Design

Static and dynamic reactor theory applied to basic reactor design problems

11 Classes based on Chapters 5, 6, and 7 from Course Textbook
Knowledge and Skills Required for Success

*NucE 497A requires a background in Physics and Math*

**Physics**

- Skills should include: Mechanics, Electricity & Magnetism, and Wave Motion & Quantum Physics

**Math**

- Skills should include: Calculus III, Differential Equations and Integrals
REQUIRED TEXTBOOK


Optional Reference Books
(they are good for additional concept explanations)


Contact Information

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Technical Support: Contact the C&DE Office at 814-865-7643 or email Michael Sechrist at mss32@PSU.EDU
ASSIGNMENTS and GRADES

On Line Quizzes (total of two) – 20%

Homework (total of five) – 30%

Exams
  – Exam 1 25%
  – Exam 2 25%

Submission of homework and exams via ANGEL, fax, or e-mail.
COURSE TOPICS
(based on 7 Chapters from Course Textbook)

1. Introduction: Scope of Nuclear Engineering
2. Atomic and Nuclear Physics
3. Interaction of Radiation with Matter
4. Nuclear Reactors and Nuclear Power
5. Neutron Diffusion and Moderation
6. Nuclear Reactor Theory
7. Reactor Kinetics
COURSE SCHEDULE of TOPICS

Class #1 – Nuclear Engineering

*Introduction to the Course* - Course objectives, grading, homework, exams, attendance…

*Chapter 1* - The Scope of Nuclear Engineering
COURSE SCHEDULE of TOPICS

Chapter 2 – Atomic and Nuclear Physics

Class #2 – Fundamental Particles

Class #3 – Radiation, Radioactive Decay and Calculations

Class #4 – Nuclear Reactions
COURSE SCHEDULE of TOPICS

Chapter 3 – Interaction of Radiation with Matter

Class #5 – Neutron Interactions and Cross-sections

Class #6 – Poly-Energetic Neutrons and Fission

Class #7 – Gamma-Ray Interactions and Charged Particles
COURSE SCHEDULE of TOPICS

Chapter 4 – Nuclear Reactors and Nuclear Power

Class #8 – Types of Nuclear Reactors

Class #9 – Nuclear Fuel Cycles
Chapter 5 – Neutron Diffusion and Moderation

Class #10 – Neutron Flux and Current, and Diffusion Equation

Class #11 – Solutions of the Diffusion Equation

Class #12 – The Group Diffusion Method, Thermal Neutron Diffusion, and Two-group Calculation of Neutron Moderation
COURSE SCHEDULE of TOPICS

Chapter 6 – Nuclear Reactor Theory

Class #13 – One-group Reactor Equation, the Slab Reactor, and other Reactor Shapes

Class #14 – The One Group Critical Equation, and Thermal Reactors

Class #15 – Reflected Reactors, and Multi-group Calculations

Class #16 – Heterogeneous Reactors
Chapter 7 – The Time Dependent Reactor

Class #17 – Reactor Kinetics

Class #18 – Control rods and chemical shim

Class #19 – Temperature effect on reactivity

Class #20 – Fission product poisoning and core properties during the lifetime
SCOPE of NUCLEAR ENGINEERING

✓ Nucleus of an atom – a tremendous source of energy

✓ Practical applications of nuclear energy

✓ For peaceful purposes

✓ Nuclear power systems:
  • *Electricity generation*
  • *Propulsion*
SCOPE of NUCLEAR ENGINEERING

✓ 20 % of energy generation in US

✓ Environmental benefits – free of greenhouse gas emissions

✓ Propulsion benefits – submarines, aircraft carriers, icebreakers, spacecraft, and rockets

✓ Medical applications of radiation
SCOPE of NUCLEAR ENGINEERING

✓ Production of radioisotopes
✓ Activation analysis
✓ Food preservation
✓ Chemical processing
SCOPE of NUCLEAR ENGINEERING

Reducing Carbon Emissions Requires All Technologies

2030 Projected Annual CO₂ Emissions (2008) (due to economic and population growth)

CO₂ Annual Emissions (2008)

EPA 2008 Reference* | Target**
---|---
Efficiency | Load Growth ~ -1.05%/yr | Load Growth ~ -0.75%/yr
Renewables | 55 GWe by 2030 | 100 GWe by 2030
Nuclear Generation | 15 GWe by 2030 | 64 GWe by 2030
Advanced Coal Generation | Improvement for Existing Plants | 1-3% Heat Rate Improvement for 130 GWe Existing Plants
 | 40% New Plant Efficiency by 2030 | 46% New Plant Efficiency by 2020; 49% in 2030
CCS | None | Widely Deployed After 2020
PHEV | None | 10% of New Light-Duty Vehicle Sales by 2017; 33% by 2030
DER | < 0.1% of Base Load in 2030 | 5% of Base Load in 2030

President’s CO₂ emission target
SCOPE of NUCLEAR ENGINEERING

- By 2030, U.S. domestic demand for electricity is projected to grow by 20%. During the same time, global demand is expected to nearly double.
- Cost to replace the current fleet exceeds $500B in addition to the capacity that will be added as the U.S. builds new plants.

- 20yr extension: 52 units granted; 20 under review; 13 intend to review; 19 unannounced.
The USA is the world's largest producer of nuclear power, accounting for more than 30% of worldwide nuclear generation of electricity.

The USA has 104 nuclear power reactors in 31 states, operated by 30 different power companies.

There are 69 pressurized water reactors (PWRs) and 35 boiling water reactors (BWRs).

Following a 30-year period in which few new reactors were built, it is expected that 4-6 new units may come on line by 2020.
SCOPE of NUCLEAR ENGINEERING
August 15, 2005, Penn State's Breazeale Nuclear Reactor celebrated 50 years as the longest continuously operating university reactor in the United States.
SCOPE of NUCLEAR ENGINEERING

SCOPE of NUCLEAR ENGINEERING

- TRIGA Mark III research reactor
- Light water cool reactor
- Natural circulation cooling
- 1 MW steady-state operation up to
- 2000 MW when pulsing
- Triangular pitch, hexagonal lattice
- U-ZrH 20% enriched fuel elements containing 8.5 wt% and 12 wt% uranium
Fukushima Accident

1-1. 2011 off Tohoku Pacific Earthquake

- Occurred 14:46 March 11, 2011
- Magnitude: 9.0 Mw
- Epicenter location: 38° 6′N and 142° 51′E, and 24km in depth
- It is said that the height of tsunami attacked Fukushima NPP was more than 14m
Fukushima Accident

1-3. Nuclear reactors near epicenter of the earthquake

Location of the Nuclear Installations

- **Fukushima I**
  - Unit 1: 524 MW, 1984-
  - Unit 2: 825 MW, 1995-
  - Unit 3: 825 MW, 2002-
- **Fukushima II**
  - Unit 1: 460 MW, 1971-
  - Unit 2: 784 MW, 1974-
  - Unit 3: 784 MW, 1976-
  - Unit 4: 784 MW, 1978-
  - Unit 5: 784 MW, 1978-
  - Unit 6: 1,100 MW, 1979-
- **Tokai II**
  - 1,100 MW, 1978-
Fukushima Accident

Outline of Fukushima Dai-ichi NPS
# Fukushima Accident

## 2-1. Summary of Fukushima Dai-ichi NPS

<table>
<thead>
<tr>
<th></th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCV Model</td>
<td>BWR-3</td>
<td>BWR-4</td>
<td>BWR-4</td>
<td>BWR-4</td>
<td>BWR-4</td>
<td>BWR-5</td>
</tr>
<tr>
<td>Electric Output (MWe)</td>
<td>460</td>
<td>784</td>
<td>784</td>
<td>784</td>
<td>784</td>
<td>1100</td>
</tr>
<tr>
<td>Max. pressure of RPV</td>
<td>8.24MPa</td>
<td>8.24MPa</td>
<td>8.24MPa</td>
<td>8.24MPa</td>
<td>8.62MPa</td>
<td>8.62MPa</td>
</tr>
<tr>
<td>Max. Temp of the RPV</td>
<td>300°C</td>
<td>300°C</td>
<td>300°C</td>
<td>300°C</td>
<td>302°C</td>
<td>302°C</td>
</tr>
<tr>
<td>Max. Pressure of the CV</td>
<td>0.43MPa</td>
<td>0.38MPa</td>
<td>0.38MPa</td>
<td>0.38MPa</td>
<td>0.38MPa</td>
<td>0.28MPa</td>
</tr>
<tr>
<td>Max. Temp of the CV</td>
<td>140°C</td>
<td>140°C</td>
<td>140°C</td>
<td>140°C</td>
<td>138°C</td>
<td>171°C(20°C)</td>
</tr>
<tr>
<td>Emergency DG</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3*</td>
</tr>
<tr>
<td>Electric Grid</td>
<td>275kV × 4</td>
<td></td>
<td></td>
<td></td>
<td>500kV × 2</td>
<td></td>
</tr>
<tr>
<td>Plant Status on Mar. 11</td>
<td>In Operation</td>
<td>In Operation</td>
<td>In Operation</td>
<td>Refueling Outage</td>
<td>Refueling Outage</td>
<td>Refueling Outage</td>
</tr>
</tbody>
</table>

* One Emergency DG is Air-Cooled
Fukushima Accident

2-2. Overview of Mark-1 Type BWR (Unit 1, 2, 3 and 4)
Fukushima Accident

Before the earthquake

After the earthquake (before explosion)

Many structures facing the bay are destroyed
Fukushima Accident

Note:
- All operating units when earthquake occurred were automatically shut down.
- Emergency D/Gs have worked properly until the Tsunami attack.

① Loss of offsite power due to the earthquake

② D/G Inoperable due to Tsunami flood

① + ② \Rightarrow Station Black Out

All Motor Operated pumps (including ECCS pumps) became inoperable
Fukushima Accident

3-7. Major event progression at Unit 1 (1/4)

Effort to sustain reactor water level

- Inoperable since the battery was soaked in water
- Core Cooling by Isolation Condenser
- Operable
- Inoperable

Diagram showing the reactor system with various functional and non-functional components.
Fukushima Accident

3-7. Major event progression at Unit 1 (2/4)

Decrease in reactor water level due to loss of cooling capability of emergency condenser, followed by uncovering the core

- Decrease in reactor water level
- Uncovering the Core
- Hydrogen Generation due to the Zirconium-Water reaction
- Possible Fuel Rod damage

Function has not been correct
Fukushima Accident

3-7. Major event progression at Unit 1 (3/4)

Hydrogen explosion in the operation floor
- Sea water injection using fire water pump
- S/C Venting to depressurize the PCV
Fukushima Accident

3-8. Accident Progression at Unit 2 through 4 reactors
4-1. Possible concerns about Spent Fuel Pool

Possible concern:
- Decrease in spent fuel pool water level
- Uncovering the spent fuel
- Hydrogen generation
- Fuel rod damage

Lack of cooling capability

Reactor Bldg.
PCV
RPV
Spent Fuel Pool
Fuel Pool Cooling (FPC) pump

Explosion

Reactors Building Closed Cooling Water System
Fukushima Accident

4-3. Measures taken to cool the Spent Fuel Pool (3/4)

**Unit 4**

- **[1st Stage]** Sea water injection
  - Water Spray from the ground by Self Defense Force and Fire Department
  - Sea water
- **[2nd Stage]** Fresh water injection
  - Water spray using concrete pump truck
  - Spent Fuel Pool
  - Reservoir tank
  - Dam
  - Pump
  - Filtrate Tank
  - Fire extinguishing basin
Fukushima Accident

MISSION REPORT

THE GREAT EAST JAPAN EARTHQUAKE EXPERT MISSION

IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP, Japan

24 May – 2 June 2011

IAEA MISSION REPORT
DIVISION OF NUCLEAR INSTALLATION SAFETY
DEPARTMENT OF NUCLEAR SAFETY AND SECURITY
Fukushima Accident

Conclusion 3: There were insufficient defence-in-depth provisions for tsunami hazards. In particular:

- although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Dai-ichi NPP as described during the meetings and the expected tsunami height was increased to 5.7 m (without changing the licensing documents) after 2002, the tsunami hazard was underestimated;

- thus, considering that in reality a ‘dry site’ was not provided for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the high tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and dynamic impact of large debris with high energy);

- moreover, those additional protective measures were not reviewed and approved by the regulatory authority;
Conclusion 5: An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Earthquake and Tsunami, fulfilling the requirements and using also the criteria and methods recommended by the relevant IAEA Safety Standards for comprehensively coping with earthquakes, tsunamis and external flooding and, in general, all correlated external events. The national regulatory documents need to include database requirements compatible with those required by IAEA Safety Standards. The methods for hazard estimation and the protection of the plant need to be compatible with advances in research and development in related fields.
Lesson 1: There is a need to ensure that in considering external natural hazards:

- the siting and design of nuclear plants should include sufficient protection against infrequent and complex combinations of external events and these should be considered in the plant safety analysis – specifically those that can cause site flooding and which may have longer term impacts;

- plant layout should be based on maintaining a ‘dry site concept’, where practicable, as a defence-in-depth measure against site flooding as well as physical separation and diversity of critical safety systems;

- common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;
Lesson 2: For severe situations, such as total loss of off-site power or loss of all heat sinks or the engineering safety systems, simple alternative sources for these functions including any necessary equipment (such as mobile power, compressed air and water supplies) should be provided for severe accident management.

Lesson 3: Such provisions as are identified in Lesson 2 should be located at a safe place and the plant operators should be trained to use them. This may involve centralized stores and means to rapidly transfer them to the affected site(s).
Class #1 - SCOPE of NUCLEAR ENGINEERING

Assignment: Before viewing Class #2

1. Write a note (free format) on “Nuclear Energy’s Future after Fukushima” and submit this to the Drop Box in Angel

2. Read Chapter 2 in Course Textbook
   - 2.1 FUNDAMENTAL PARTICLES
   - 2.2 ATOMIC AND NUCLEAR STRUCTURE
   - 2.3 ATOMIC AND MOLECULAR WEIGHT
   - 2.4 ATOMIC AND NUCLEAR RADII
   - 2.5 MASS AND ENERGY
   - 2.6 PARTICLE WAVELENGTHS