Physics 139S: Nuclear Energy
Spring 2021

General Information:

Professor: Calvin R. Howell, howell@tunl.duke.edu
Office: room 221 in the DFELL, (919) 660-2632
Office hours: Monday and Wednesdays, 10:30 am – 12:00 pm
By appointment; email subject = "Physics 139S"

Class Meetings: Tuesdays and Thursdays, 5:15 pm - 6:30 pm (USA/ET), online

Class Meeting Format: Mixture of lecture and discussion

Synopsis:

This course covers the economics, societal impact and geopolitical issues of generating electrical power using nuclear fission reactors. Core topics include: science and technology of mass-scale generation of electrical power; history, science and technology of nuclear fission reactors; methods for comparing the cost of different energy generating technologies (from mining raw materials, to constructing power plants, to disposal of byproduct and environmental cleanup, to decommissioning of power plants); and political and international security issues associated with nuclear fission power reactor technology. This course is highly recommended for sophomores, juniors and seniors with non-science majors. Prerequisites: none. This course is not recommended for students having credit for or currently enrolled in Physics 137S.

Overview:

The economic prosperity of a nation depends critically on its capabilities for producing and distributing electrical energy at a cost that is globally competitive. The growing demand for electric power worldwide is motivating the development of new and efficient energy producing and distribution technologies. Also, mounting concerns about global climate change is causing nations to favor technologies with low carbon emissions and that are based on renewal fuels, i.e., "green" technologies. Under these circumstances nuclear fission reactors will likely be a part of energy solutions for many nations. Students taking this course will explore the economics, societal impact and geopolitical issues of generating electrical power using nuclear fission reactors.

Goals:

An organizing theme of the course is the use of science and technical knowledge along with quantitative information in developing policies and guiding economic and business investments. Assessments will be intentionally based on analyses from the perspective of physics with input from other disciplines. Students will gain experience with developing questions that require quantitative input to answer and with determining the appropriate importance to assign to quantitative information in the analysis of energy production and distribution systems. For example, because an aspect of a problem can be reliably quantified shouldn't by that virtue raise its importance. Also, the course activities will give students opportunities to discern the benefit versus effort in quantifying an aspect of a system in an analysis and to evaluate the "softness" of numbers, i.e., uncertainties due to assumptions or data collection methods.

An organizing goal of this course is to help students develop the ability to perform critical analyses in assessing the positive and negative aspects of using nuclear fission reactors to generate electrical power on an industrial scale relative to other large-scale electrical energy sources. This course covers the basic science of extracting energy from matter, converting heat to mechanical work, electrical energy production and distribution, the nuclear fission reaction, the types of radiation inside nuclear reactors, and the interaction of radiation with matter. The two most recent major nuclear reactor accidents, the Chernobyl and the Fukushima Daiichi plant disasters, will be analyzed. The first half of the course will include a lecture series on the physics concepts relevant to analyzing electric power systems: mechanical work, kinetic energy, energy density, matter-energy conversion, heat, thermal dynamics, magnetic induction, electrical conductivity, the structure of the atom, properties of the nucleus, nuclear reactions with focus on nuclear fission, the nuclear chain reaction, and nuclear weapons. The students' comprehension of the physics concepts covered in the lectures will be assessed with an in-class exam and through their participation in class discussions.

Students taking this course will explore the economics, societal impact and geopolitical issues that result from generating electrical power using nuclear fission reactors. The driving goal of this course is to assist students in developing the scientific foundation and analysis skills that enable them to identify and pursue answers to critical questions in assessing the feasibility of sustaining electrical generation on a national scale using a particular fuel, e.g., petroleum, natural gas, coal, hydrodynamics, wind, solar, nuclear fission, and on projecting the long-term consequences of the choices. Students will gain experience in identifying the most important factors when comparing electrical energy generation using nuclear fission reactors to other technologies. The class will survey current technologies and concepts that have the potential of severing the connections between electrical power generation and nuclear weapons. Also, the issue of stewardship responsibilities associated with long-term management of nuclear waste will be discussed.

Course Materials: (mostly posted on Sakai)

- Lecture notes
- Excerpts from introductory level physics text books
- Special topics materials, e.g., publications by the National Academy Press and the American Association for the Advancement of Science, and excerpts from reports sponsored by the U.S. government and private foundations

Assignments:

- Homework problems during the first half of the semester (associated with the lecture series)
- Reading – preparation for class discussions
- Presentations – three (two associated with writing assignments)
- Peer review of papers by other students – part of class participation
- Papers – two (see description below)

Course Grade Based on:

The final course grade will be determined from the weighted average of the scores on the graded activities. The relative weighting of each activity towards the final grade is as follows.

Description	Weight
Class participation	10%
Quizzes	10%
One in-class exam	25%
Three presentations*	25%
Two papers	30%
Total	**100%**

**The weight of the first two presentations is 10% and that of the third presentation is 5%.*

Class participation includes presentation of assigned homework problems, demonstration of preparedness for classroom discussions, and peer review of papers.

Each homework assignment will be discussed in class. Students will lead the discussions. A quiz will be given following the discussion of each homework assignment.

One exam will be given to assess the students' understanding of the core scientific concepts and problem analysis methods relevant to electrical power generation and distribution, nuclear fission reactors, nuclear waste and radioactivity, and the interaction of radiation with matter. The exam will be given near the middle of the term.

Presentations and Papers:

Students will give three presentations and write two papers. Each paper has an associated presentation. The paper assignments and associated presentations will be carried out by pairs of students. These assignments are described below. In addition, each student will give a presentation on the detailed analysis of the levelized cost of electricity produced by a particular electrical power plant in the U.S., e.g., the Sharon Harris nuclear power plant in North Carolina.

Presentation: Levelized Cost Analysis of an Electrical Power Plant

This assignment is the first presentation by students. A comparative analysis of the cost of different energy sources for producing electrical power is a primary consideration in long-term public planning. Each student will be asked to choose an operating electrical power plant in the U.S.A. and perform a bottoms-up analysis of its levelized cost of producing electrical energy. The sources for all the numbers used in the analysis must be cited. Whenever the value for a quantity can't be found, you should make an informed estimate of the value. The reasoning applied and assumptions in making the estimate must be described. It is preferred for the class to report on a variety of types of power plants, i.e., plants that use different types of fuel and renewable resources, e.g., oil, natural gas, coal, nuclear, hydrodynamic, wind, and solar. The electrical output of the plant should greater than 25 MW. The levelized cost analysis should be performed with and without decommissioning cost. The levelized cost should not include the cost of electricity distribution. Reference sources must be cited in the presentation.

Papers and Presentations:

Students will research and write two papers. The assignments will be carried out by pairs of students. For each writing assignment, the student team will submit a draft of the paper for the purpose of receiving peer review feedback from two students. The peer review assignments will be made by the instructor. After the draft is submitted but before the feedback is given, the student team will present their draft to the class. The authors will consider the feedback of the reviewers in preparing the final version of the paper for submittal to the instructor.

The first paper will be an analysis of the electrical energy generation and use in a state in the U.S.A. The paper should include information important for long-term electrical energy infrastructure planning, e.g., population, population distribution in the state (urban verses rural), electrical energy consumption over the most recent 50 years, the main industries and expected growth, electrical energy consumption by sector (residential, commercial, industry) over the most 50 years, the production of electrical energy by fuel type over the most recent 50 years, and planned investments in the electrical power infrastructure. The paper should present an informed projection of the electrical energy demands in the state in the coming 10 years. Also, the authors should speculate on the optimum location for installing a nuclear power plant with electrical output of about 1.0 GW in the next decade, describing the pros and cons of the site choice.

The second paper is on a course-relevant topic proposed by the student team. Examples of topics covered in the second paper include: (1) Is there a global strategy for dealing with spent-fuel nuclear waste? (2) How much nuclear power is too much? (3) How can nuclear power be distributed worldwide without spreading nuclear weapons capabilities? (4) Will uranium rich countries become the OPEC of the future? (5) What is the current promise of fusion energy? (6) Comparison of solar power or wind to nuclear fission power?

Each paper should be 8 to 15 pages long with 1.5 line spacing and 12 pt Times New Roman font. The estimated page length includes figures, tables and bibliography. The papers will be peer reviewed for the purpose of providing feedback on content and style to the authors. The instructor will serve as the editor with duties including assigning reviewers, collecting the comments of the reviewers and transmitting the feedback to the authors. Each paper will have two reviewers. The reviewers will have one week to provide feedback after the presentation of the draft paper, and the authors will have one week after receiving the reviewers' comments to submit the final version of the paper to the instructor.