NPRE 402
Nuclear Power Engineering
Fall 2022

<u>Online Temporary Alternative Coverage and access during Covid-19 Pandemic and possible resurgence through mutations and variants</u>

1. Please read the assigned-reading lecture-notes chapters.
2. Then answer the corresponding written assignment,
3. For questions about the assignments, please access the teaching assistants by email:
https://www.mragheb.com/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/talist.htm
4. Submit the corresponding written assignment through email to https://canvas.illinois.edu
5. Please use either the Word or pdf formats
6. In case of internet "rationing" (e. g. to health and government authorities), instability, or collapse through overload, please read the lecture notes and submit the corresponding assignments. Already-taken tests and submitted assignments would be used in assessing the final grade.

Threat of nuclear war:
https://www.youtube.com/watch?v=M7hOpT0lPGI

Regrettably, some 3,278 colleges and universities across the USA have been impacted by the Covid-19 pandemic, with many temporarily closing their campuses and switching to online classes, affecting more than 22 million students.

To all and everyone we wish good health and well-being.

Number	Date Assigned	Due Date	Description
1	8/22	8/29	**Reading assignment** **Preface** **Written Assignment** Define the Quad unit of energy in terms of BTUs and Joules. In 2018, the Earth's world power consumption was 18.40 TW. Calculate its standing on the Kardashev scale using the Carl Sagan formula. Repeat for 10^{16}, 10^{26}, 10^{36}, and 10^{46} Watts of power. In how many years is humanity expected to achieve a Type I status? Use the projected 2025 Sankey diagram to calculate the end use efficiencies of the following energy sectors: 1. Overall system, 2. Residential, 3. Commercial, 4. Industrial, 5. Transportation. What is the percentage share of nuclear energy in: a) The primary energy supply, b) Electrical energy generation?

2	8/24	8/31	**Reading assignment** NEW **Preface** **Written Assignment** List the components of the envisioned Internet of Things (IoT) for the vision of the future electrical energy system. In the French implementation of the IoT electrical energy production daily supply diagram in the lecture notes, construct a table showing: 1. Total energy production in MWe, 2. Nuclear electrical production, 3. Production from other conventional and renewable energy sources, 4. Amount exported. **5.** Amount stored. List the percentage of each energy source used by the USA public utility: **Bonneville Power Authority BPA weekly Power flow"** **https://transmission.bpa.gov/Business/Operations/Wind/baltwg.aspx** You may also like to explore the European electrical energy situation at some given time: **Energy mix in electrical production, France** **https://www.gridwatch.templar.co.uk/france/**
3	8/**26**	9/**2**	**Reading assignment** NEW **1. First Human Made Reactor and Birth of Nuclear Age** **Written Assignment** Identify the following Technical Specifications (Tech Specs) of the Chicago Pile number 1 (CP-1) reactor. 1. Thermal power in Watts(thermal), Wth. 2. Fuel material 3. Moderator material 4. Control rods material 5. Safety (Scram) material Compare the power level of CP1 to some existing nuclear power plant in Watts(th). Hint: Search the www for information about the power level of the electrical power plant. Calculate the speed in meters per second of neutrons possessing the following energies: a. Fast neutrons from fission at 2 MeV, b. Intermediate energy neutrons at 10 keV, c. Thermal energy neutrons at 0.025 eV.
4	8/**29**	9/**5**	**Reading assignment** NEW **1. First Human Made Reactor and Birth of Nuclear Age** **Written Assignment** Data mine the Chart of the Nuclides for the following information on elements used in nuclear applications: 1. Naturally occurring isotopes and their natural abundances. 2. Atomic masses of isotopes in atomic mass units (amu). For the following elements: a) Uranium (U). b) Thorium (Th). c) Carbon (C). d) Hydrogen (H). e) Lead (Pb).

			f) Beryllium (Be). g) Lithium (Li). h) Sodium (Na). i) Boron (B). j) Cadmium (Cd). k) Fluorine (F)
5	8/**31**	9/**7**	**Reading assignment** **1. First Human Made Reactor and Birth of Nuclear Age** **Written Assignment** If a single fission reaction produces about 180 MeV of energy, use Avogadro's law to calculate the number of grams of the fissile elements: 1. U^{235} 2. Pu^{239} 3. U^{233} 4. Np^{237} that would release 1 kT of TNT equivalent of energy. Assume that all the energy release is available, except for the energy carried away by the antineutrinos, as well as the delayed fission products beta particles and gamma rays, which is not fully recoverable. Hint: Use Avogadro's law to estimate the number of nuclei in a given weight of the fissile material: $N[nuclei] = \frac{g[gm]}{M[amu]} A_v, \quad A_v = 0.6 \times 10^{24} [\frac{nuclei}{mole}]$
6	9/2	9/9	**Reading assignment** **4. Nuclear Processes, The Strong Force** **Written Assignment** Balance the following nuclear reactions: 1. ${}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + ?$ (DT fusion reaction) 2. ${}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + ?$ (Proton branch of the DD fusion reaction) 3. ${}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + ?$ (Neutron branch of the DD fusion reaction) 4. ${}_1D^2 + {}_2He^3 \rightarrow {}_2He^4 + ?$ (Aneutronic or neutronless DHe^3 reaction). 5. ${}_0n^1 + {}_3Li^6 \rightarrow ? + ?$ (tritium breeding reaction) 6. ${}_0n^1 + {}_3Li^7 \rightarrow {}_0n^1 + ? + ?$ (tritium breeding reaction) 7. ${}_1T^3 + {}_1T^3 \rightarrow 2\,{}_0n^1 + ?$ (neutron multiplier reaction) 8. ${}_0n^1 + {}_5B^{10} \rightarrow {}_2He^4 + ?$ (neutron absorption reaction) The positron is a positively charged electron, emitted in the process of radioactive decay of proton-rich isotopes. It is the antimatter equivalent of the common negatively charged electron, and each of them has a mass equal to 9.10956x10- 28 gm. When, under the proper circumstances. antimatter meets matter, the positron and the electron undergo a process of annihilation, and a process of matter transforming into electromagnetic radiation in the form of two gamma ray photons, occurs. The antiproton is similarly the antimatter of the common proton, each having a mass equal to 1.67261x10- 24 gm. In a future matter/antimatter space-travel reactor for rocket propulsion, calculate the annihilation energy release for the positron/electron and antiproton/proton reactions in units of ergs, Joules and MeV.
7	9/7	9/14	**Reading assignment** **4. Nuclear Processes, The Strong Force** **Written Assignment**

			Balance then calculate the Q values or energy releases in MeV from the following nuclear reactions: 1. ${}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + ?$ (DT fusion reaction) 2. ${}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + ?$ (Proton branch of the DD fusion reaction) 3. ${}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + ?$ (Neutron branch of the DD fusion reaction) 4. ${}_1D^2 + {}_2He^3 \rightarrow {}_2He^4 + ?$ (Aneutronic or neutronless DHe^3 reaction). 5. ${}_0n^1 + {}_{92}U^{235} \rightarrow 3\ {}_0n^1 + {}_{53}I^{137} + {}_{39}Y^{96}$ (fission reaction) Show the data you used in your calculations and mention their source. Apply conservation of momentum and of mass/energy to estimate the apportionment of kinetic energy among the product nuclei of the following fusion reactions: 1. ${}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + ?$ (DT fusion reaction) 2. ${}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + ?$ (Proton branch of the DD fusion reaction) 3. ${}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + ?$ (Neutron branch of the DD fusion reaction) 4. ${}_1D^2 + {}_2He^3 \rightarrow {}_2He^4 + ?$ (Aneutronic or neutronless DHe^3 reaction) Apply conservation of charge and of nucleons to balance the following fissile breeding reaction: ${}_0n^1 + {}_{92}U^{238} \rightarrow {}_{92}U^?$ ${}_{92}U^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ ${}_?{?}^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ $----------------$ ${}_0n^1 + {}_{92}U^{238} \rightarrow 2\,{}_{-1}e^0 + {}_?{?}^?$ Apply conservation of charge and of nucleons to balance the following fissile breeding reaction: ${}_0n^1 + {}_{90}Th^{232} \rightarrow {}_{90}Th^?$ ${}_{90}Th^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ ${}_?{?}^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ $----------------$ ${}_0n^1 + {}_{90}Th^{232} \rightarrow 2\,{}_{-1}e^0 + {}_?{?}^?$
8	9/9	9/16	**Reading assignment** **4. Nuclear World** **Written Assignment** Write a paragraph description of the Ulam-Teller Configuration. What are the name and yield of the nuclear test in which cryogenic liquid deuterium was used as a fusion fuel? The catalyzed DD reaction would occur in a second-generation fusion reactor using a virtually unlimited fuel supply from the world oceans:

			${}_1D^2 + {}_1D^2 \rightarrow {}_1? + {}_1H^1 + 4.03\ MeV$ ${}_1D^2 + {}_1D^2 \rightarrow ? + {}_0n^1 + 3.27\ MeV$ ${}_1D^2 + {}_1T^3 \rightarrow ? + {}_0n^1 + 17.6\ MeV$ ${}_1D^2 + {}_2He^3 \rightarrow ? + {}_1H^1 + 18.3\ MeV$ ―――――――――――――――――――――――― $6\,{}_1D^2 \rightarrow ? + ? + ? + ?\ MeV$ Complete the following reaction leading to the production of Carbon^{14}, that exists in all living creatures, with a half-life of 5,730 years as an ongoing nuclear transformation from the neutrons originating from cosmic rays bombarding Nitrogen^{14} in the Earth's atmosphere: ${}_0n^1 + ? \rightarrow ? + {}_6C^{14}$ ${}_6C^{14} \rightarrow ? + {}_7N^{14}$ ――――――――― ${}_0n^1 \rightarrow ? + ?$
9	9/12	9/19	**Reading assignment** **4. Nuclear World** **Written Assignment** Write a paragraph describing the doomsday clock by the Bulletin of Atomic Scientists. What do the following nuclear-related acronyms stand for? ICBM, ABM, MIRV, kT, MT, DU, HEU, NPT, EMP, TNT, SALT, MAD. An ICBM has an average speed of 18,566 miles/hour. Calculate its Mach Number M, considering that the speed of sound is 761.2 miles per hour.
10	9/14	9/21	**Reading assignment** **1. Radioactive Transformations Theory, The Weak Force** **Written Assignment** Prove that the heuristic and the differential calculus forms of the law of radioactive decay are equivalent. Carbon Dating: The production of carbon^{14} with a half-life of 5,730 years is an ongoing nuclear transformation from the neutrons originating from cosmic rays bombarding nitrogen^{14} in the Earth's atmosphere: Carbon exists as $C^{14}O_2$ and is inhaled by all fauna and flora. Because only living plants continue to incorporate C^{14}, and stop incorporating it after death, it is possible to determine the age of organic archaeological artifacts by measuring the activity of the carbon^{14} present.

			Two grams of carbon from a piece of wood found in an ancient temple are analyzed and found to have an activity of 20 disintegrations per minute (dpm). Estimate the approximate age of the wood, if it is assumed that the current equilibrium specific activity of C^{14} in carbon has been constant at 13.56 disintegrations per minute per gram.
11	9/16	9/23	**Reading assignment** **1. Radioactive Transformations Theory, The Weak Force** **Written Assignment** Access the Chart of the Nuclides and identify the stable nuclide at the end of the following radioactive decay chains: 1. U^{238} 2. U^{235} 3. Th^{232} 4. Np^{237} Calculate the activity of 1 gm of the radium isotope Ra^{226} in Becquerels and Curies. Discuss the relationship to the Curie (Ci) unit of activity. Tritium, an isotope of hydrogen used in fusion systems and a nanotechnology and Micro Electro Mechanical Systems (MEMS) power source devices, decays through the following reaction: $_1T^3 \rightarrow {}_{-1}e^0 +$ ______ Using the law of radioactive decay calculate the fraction of the tritium isotope $(N_0\text{-}N(t))/N_0$ decaying into the He^3 isotope. The half-life of tritium is 12.33 years. 1. Within 1 year. 2. Within 12.33 years. 3. Within 24.66 years.
12	9/19	9/26	**Reading Assignment** **3. Radioisotopes Power Production** **Written Assignment** A space probe needs a radioisotope power generator to generate electrical power for its equipment in the darkness of space away from the sun. The thermal to electrical conversion efficiency is 40 percent. 1. The isotope Pu^{238}, an alpha emitter is used in space applications and can produce the needed electrical energy. Calculate the specific activity of this isotope. 2. Calculate the specific power of this isotope. 3. For an electrical power of 100 Watts(e) what would be the weight needed for this generator in grams? Access the Table of the Nuclides and mine for the data concerning the half-lives, and the energy emitted in the alpha radioactive decay of Pu^{238}. The isotope $_{81}$Thallium^{204} has a half-life of 3.78 years and can be used as a nanotechnology and Micro Electro Mechanical Systems (MEMS) power source device. It decays through beta emission into $_{82}Pb^{204}$ with a branching ratio of 97.1 percent with an average decay energy of 0.764 MeV. It also decays through electron capture to $_{80}Hg^{204}$ with a branching ratio of 2.9 percent with a decay energy of 0.347 MeV. Calculate the average energy release per decay event in [MeV/disintegration] Calculate its total specific activity in [Becquerels / gm]. Calculate its total specific activity in [Curies / gm]. Calculate the specific power generation in [Watts(th) / gm]. For a 100 Watts of thermal power in a Radioisotope Heating Unit (RHU) power generator, how many grams of $_{81}$Thallium^{204} are needed? After 3.78 years of operation, what would its power become?

<table>
<tr><td></td><td></td><td></td><td>Use: 1 MeV/sec = 1.602×10^{-13} Watts, $A_v = 0.602\times10^{24}$ [nuclei/mole], 1 Curie = 3.7×10^{10} Bq.</td></tr>
<tr><td>13</td><td>9/21</td><td>9/28</td><td>Reading Assignment
2. Food Preservation by Radiation
Written Assignment
List two radioactive isotopes used in food preservation together with their half-lives.

What are the radiation doses needed for food products':
1. Pasteurization,
2. Sterilization.

List the chemicals currently used in the "fumigation" of stored grain supplies.

For the following radiological quantities, fill out the table showing the corresponding units and their abbreviations.
<table>
<tr><td>Radiological quantity</td><td>Conventional System Unit</td><td>SI System Unit</td></tr>
<tr><td>Absorbed dose</td><td></td><td></td></tr>
<tr><td>Activity</td><td></td><td></td></tr>
</table></td></tr>
<tr><td>14</td><td>9/23</td><td>9/30</td><td>Reading Assignment
5. Gamma Rays Interaction with Matter
Written Assignment
List the different processes of gamma rays interaction with matter.

Use the gamma-rays exponential attenuation law:
$I(x) = I_0 B(\mu x, E_\gamma).e^{-\mu(E_\gamma).x}$
to design a gamma-rays radiation shield made out of Pb with a linear attenuation coefficient $\mu = 0.771\,[cm^{-1}]$ that would attenuate a narrow beam of 1 MeV gamma-rays with a build-up factor of B = 2 to one thousandth (10^{-3}) of its initial strength.

Combine the two equations for the energy of a mass m and the energy of radiation with a frequency υ and a wave length λ:
$E = mc^2\,[ergs]$

$E = h\nu = h\frac{c}{\lambda}$
to deduce the equation that establishes the equivalence of mass and radiation:
$m = R\nu$

where: $R = \frac{h}{c^2} = 7.365864\times10^{-48}\,\frac{\text{erg.sec}^3}{\text{cm}^2}$ is a constant of nature.</td></tr>
<tr><td>15</td><td>9/26</td><td>9/30</td><td>Reading Assignment
1. Nuclear Reactor Concepts and Thermodynamic Cycles
Written Assignment
List the principles and their corollaries governing the processes of energy conversion and extraction from the environment.

What do the following acronyms stand for:
1. PWR
2. BWR
3. HTGR
4. LMFBR

Construct a table comparing the Engineered Safety Features (ESFs) of the:
1. PWR
2. BWR</td></tr>
</table>

			reactor concepts.
16	9/28	9/30	**Reading Assignment** **1. [Nuclear Reactor Concepts and Thermodynamic Cycles]** **Question Written Assignment** Assuming that heat rejection occurs at an ambient temperature of 20 degrees Celsius, estimate the Carnot cycle thermal efficiency of a PWR (Pressurized Water Reactor) operating at an average heat addition temperatures T_a of 168 ^oC. A Stirling Cycle engine using a radioactive isotope for space power applications operates at a hot end temperature of 600 ^oC and rejects heat through a radiator to the vacuum of space with a cold end temperature at 120 ^oC. Calculate its ideal Stirling cycle efficiency. Hint: Stirling cycle efficiency can be equal to Carnot cycle efficiency under ideal regeneration. List the gases that could be used as coolants in HTGR applications. List three alternatives in dissociating gases nuclear reactor applications.
		9/30	First Midterm exam. During class period.
17	10/3	10/10	

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned.
They need to be submitted earlier when tests are scheduled.
The first five minutes of the class period will be devoted for turning in, and returning graded assignments.
Late assignments will be assigned only a partial grade. Please try to submit them on time since once the assignments are graded and returned to the class, late assignments cannot be accepted any more.
If you are having difficulties with an assignment, you are encouraged to seek help from the teaching assistants (TAs) during their office hours. Questions may be e-mailed to the TA's, but face-to-face interaction is more beneficial.
Although you are encouraged to consult with each other if you are having difficulties, you are kindly expected to submit work that shows your individual effort. Please do not submit a copy of another person's work as your own. Copies of other people's assignments are not conducive to learning, and are unacceptable.
For further information, please read the detailed assignments guidelines.