NPRE 402
Nuclear Power Engineering
Fall 2023

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

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=HSC7Lp1nvx8
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	8/21	8/28	**Reading assignment** **Preface** **Written Assignment** Write a paragraph about the "Fermi Paradox". Define the Megawatt, Gigawatt and Terawatt units of power. Access the internet to determine the latest available figure of total global **power** consumption. Use the Carl Sagan's formula to calculate our technological civilization's level on the Kardashev's cosmic scale. On the Kardashev Scale, identify the power needs in Watts for Type I, II and III civilizations. In how many years is our Earth expected to achieve a Type I status? What is the percentage share of nuclear energy in: a) The primary energy supply, b) Electrical energy generation? Define the Quad unit of energy in terms of BTUs and Joules. Use the "Sankey diagram" to calculate the end use efficiencies of the following energy sectors: 1. Residential, 2. Commercial, 3. Industrial, 4. Transportation.
2	8/23	8/30	**Reading assignment**

			Preface **Written Assignment** Draw a diagram and list the components of the envisioned Internet of Things (IoT) for a future energy system. Once built and operational, nuclear power plants become cash cows for their operators. Consider a 1,000 Mwe nuclear power plant costing about $5,000 per installed kWe of capacity. Calculate: 1. The capital cost of the plant in billions of dollars. 2. If it operates for 60 years at a capacity factor of 90 percent, the amount of electrical energy in kW.hr it would produce per year. 3. Sold to electrical consumers at a profit over expenses of 6 cents / kW.hr, the generated profit stream in $ million /year. 4. The total profit in $ billion over its projected 60 years of operation.
3	8/25	9/1	**Reading assignment** **1. First Human Made Reactor and Birth of Nuclear Age** **Written Assignment** 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. Compare the operating power levels of the following reactors: 1. CP1, Chicago pile 1 2. X-10 graphite reactor 3. Hanford piles 4. Typical Pressurized or Boiling Water power plant.
4	8/28	9/4	**Reading assignment** **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) Identify three elements that have a single naturally occurring isotope.
5	8/30	9/6	**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	9/1	9/8	**Reading Assignment** **4. Nuclear World** **Written Assignment** What do the following nuclear-related acronyms stand for? ICBM, ABM, MIRV, kT, MT, DU, HEU, NPT, MAD, TNT, SALT, UUV, UAV.
7	9/6	9/13	**Reading Assignment** **4. Nuclear World** **Written Assignment** The reported time for an ICBM to travel from the continental USA to its assigned target is about t = ½ hour. To cover the distance of 6,000 miles, calculate the speed of travel of the missile in miles / hour. What would the hypersonic Mach Number be? Hint: Use the speed of sound as 761.2 miles /hour. Read then write a one paragraph summary of the paper: Magdi Ragheb, "Restoring The Global Equatorial Ocean Current Using Nuclear Excavation," i-manager's Journal on Future Engineering & Technology, Vol. 5, No. 1, pp. 74-82, August-October, 2009. Read then write a one paragraph summary of the paper: Magdi Ragheb, "Lanchester Law, Shock and Awe Strategies," J. Def. Manag. 2015, 6:1, http://dx.doi.org/10.4172/2167-0374.1000137
8	9/8	9/15	**Reading Assignment** **4. Nuclear Processes, The Strong Force** **Written Assignment** Apply conservation of charge and nucleons to 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) Combine the two equations for the energy of a mass m and the energy of radiation with a frequency υ and a wavelength 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: $R = \frac{h}{c^2} = 7.365864 \times 10^{-48} \frac{erg.sec^3}{cm^2}$ is a constant of nature.
9	9/11	9/18	**Reading Assignment** 4. Nuclear Processes, The Strong Force **Written Assignment** Apply conservation of mass/energy to calculate the Q values the following binary reactions: 1. $_1D^2 + _1T^3 \rightarrow _0n^1 + ?$ (DT fusion reaction) 2. $_1D^2 + _1D^2 \rightarrow _1H1 + ?$ (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). Calculate the Q values or energy releases in MeV from the following nuclear fission reactions: 1. $_0n^1 + _{92}U^{235} \rightarrow 3\ _0n^1 + _{53}I^{137} + _{39}Y^{96}$ 2. $_0n^1 + _{92}U^{235} \rightarrow 3\ _0n^1 + _{54}Xe^{136} + _{38}Sr^{97}$ For the DT fusion reaction, use conservation of momentum to determine how is the kinetic energy release distributed among the two product nuclei?
10	9/13	9/20	**Reading Assignmeng** 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. 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.
11	9/15	9/22	**Reading Assignmeng** 1. Radioactive Transformations Theory, The Weak Force **Written Assignment** 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.

			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.
12	9/18	9/25	**Reading Assignment** 1. Radioactive Transformations Theory, The Weak Force 2. Food Preservation by Radiation **Written Assignment** In a possibly future matter/antimatter reactor, use the mass to energy equivalence relationship to calculate the energy release in ergs, Joules and MeV from the complete annihilation of: a. An electron/positron pair. b. An antiproton/proton pair. Consider the following masses: $m_{electron} = m_{positron} = 9.10956 \times 10^{-28}$ gram $m_{proton} = m_{antiproton} = 1.67261 \times 10^{-24}$ gram. Match the following radiological quantities to their respective equivalents: 1 Curie — 100 [ergs/gm] 1 Becquerel — 1[Joule/kg] 1 rad — 1 [trans/sec] 1 Gray — $3.7\text{x}10^{10}$[trans/sec] 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:

<table>
<tr><td></td><td></td><td></td><td>$_0n^1 + _{90}Th^{232} \rightarrow _{90}Th^?$
$_{90}Th^? \rightarrow _{-1}e^0 + _?\,?^?$
$_?\,?^? \rightarrow _{-1}e^0 + _?\,?^?$
$-------------$
$_0n^1 + _{90}Th^{232} \rightarrow 2\,_{-1}e^0 + _?\,?^?$

How many rads and Grays of radiation absorbed dose are needed for:
1. Pasteurization,
2. Sterilization,
of food and medical products?</td></tr>
<tr><td>13</td><td>9/20</td><td>9/27</td><td>Reading Assignment
3. Radioisotopes Power Production
Written Assignment
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 thermal power generation in [Watts(th) / gm].
For a 100 Watts(th) 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?
Use: 1 MeV/sec = 1.602×10^{-13} Watts, $A_v = 0.602 \times 10^{24}$ [nuclei/mole], 1 Curie = 3.7×10^{10} Bq</td></tr>
<tr><td>14</td><td>9/22</td><td>9/29</td><td>Reading Assignment
3. Terrestrial Radioactivity and Geothermal Energy
4. Biogenic and Abiogenic Petroleum
9. Gamma and X rays Detection
Written Assignment
Show a sketch of the electronic circuit of a Geiger-Mûller radiation detector.

Calculate the ratio of heat convection in rocks to that of incident solar radiation.
Compare the result to the ratio of energy available in photosynthesis, storage in plants, and fossil fuels to the incident solar radiation.
Discuss the implication concerning geothermal energy and bioenergy and fossil sources.

Write a paragraph on the Cassini spacecraft, using its radar system, discovering evidence for hydrocarbon lakes on the Titan’s moon of Saturn and the possibility of abiogenic petroleum.</td></tr>
<tr><td>15</td><td>9//25</td><td>10/2</td><td>Reading Assignment
5. Gamma Rays Interaction with Matter
Written Assignment
List the different processes of gamma rays’ interaction with matter

Compare the thicknesses of the following different materials that would attenuate a narrow beam of 1 MeV gamma-rays in “good geometry” with a build-up factor B of 2, to one billionth of its initial strength, given their linear attenuation coefficient in cm^{-1}:</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td><table>
<tr><th>Material</th><th>Density
[gm/cm^3]</th><th>Linear attenuation
coefficient, μ
at 1 MeV, [cm^{-1}]</th></tr>
<tr><td>Pb</td><td>11.3</td><td>0.771</td></tr>
<tr><td>H_2O</td><td>1</td><td>0.071</td></tr>
<tr><td>Concrete</td><td>2.35</td><td>0.149</td></tr>
</table></td></tr>
<tr><td>16</td><td>9/27</td><td>10/2</td><td>Reading Assignment
1. Nuclear Reactor Concepts and Thermodynamic Cycles
Written Assignment
List the principles governing energy conversion and extraction from the environment and their corollaries.

Construct a table comparing the Engineered Safety Features (ESFs) of the:
1. PWR
2. BWR
Reactor concepts.

What do the following acronyms stand for?
PWR
BWR
HTGR
LMFBR
GCFBR</td></tr>
<tr><td>17</td><td>9/29</td><td>10/2</td><td>Reading Assignment
1. Nuclear Reactor Concepts and Thermodynamic Cycles
Written Assignment
A Stirling cycle engine using a radioactive isotope for space power applications operates at a hot end temperature of 650 °C and rejects heat through a radiator to the vacuum of space with a cold end temperature at 120 °C.
Calculate its ideal Stirling cycle efficiency.

Assuming that heat rejection occurs at an ambient temperature of 20 degrees Celsius, for the average heat addition temperatures T_a given below, compare the Carnot cycle thermal efficiencies of the following reactor concepts:
1. PWR, 168 °C.
2. BWR, 164 °C.
3. HTGR, 205 °C.
4. LMFBR, 215 °C.</td></tr>
<tr><td></td><td></td><td>10/2</td><td>First midterm exam, during class period</td></tr>
<tr><td>18</td><td>10/4</td><td>10/11</td><td>Reading Assignment
2. Pressurized Water Reactors
Written Assignment
Construct a table comparing the main Technical Specifications (Tech Specs) of the PWR and the BWR concepts.

Once built and operational, nuclear power plants become cash cows for their operators. Consider a 1,000 MWe nuclear power plant costing about $5,000 per installed kWe of capacity.
Calculate:
1. The capital cost of the plant in billions of dollars.
2. If it operates for 60 years at a capacity factor of 90 percent, the amount of electrical</td></tr>
</table>

			energy in kW.hr it would produce per year. 3. Sold to electrical consumers at 5 cents / kW.hr, the generated income stream in $ million /year. 4. The total income stream in $ billion over 60 years of operation.
19	10/6	10/13	**Reading Assignment** 3. Boiling Water Reactors **Written Assignment** A Boiling Water Reactor (BWR) produces saturated steam at 1,000 psia. The steam passes through a turbine and is exhausted at 1 psia. The steam is condensed to a subcooling of 3°F and then pumped back to the reactor pressure. Compute the following parameters: a. Net work done per pound of fluid. b. Heat rejected per pound of fluid. c. Heat added by the reactor per pound of fluid. d. The turbine heat rate defined as: [(Heat rejected +Net turbine work)/Net turbine work] in units of [BTU/(kW.hr)] e. Overall Thermal efficiency. You may use the following data: From the ASME Steam Tables, saturated steam at 1,000 psia has an enthalpy of h = 1,192.9 [BTU/lbm]. At 1 psia pressure the fluid enthalpy from an isentropic expansion is 776 [BTU/lbm]. The isentropic pumping work is 2.96 [BTU/lbm]. The enthalpy of the liquid at 1 psia subcooled to 3 °F is 66.73 [BTU/lbm]. 1 [kW.hr] = 3,412 [BTU]
20	10/9	10/16	**Reading Assignment** 1. Energy Hydrogenation and Decarbonization **Written Assignment** As a reverse reaction to the electrolysis process, write the two half reactions describing the reverse reaction as the simple fuel cell concept. High Temperature Electrolysis (HTE) has a high efficiency $\eta_{electrolysis} > 0.90$. Calculate the efficiency of a hydrogen production system for a future transportation alternative for the cases of: 1. A nuclear system using the Steam Cycle with an overall thermal efficiency of 33.3 percent, 2. A nuclear system using the Brayton Gas Turbine Cycle with an overall thermal efficiency of 50 percent. Discuss the implication of this observation concerning future nuclear power plants designs.
21	10/11	10/18	**Reading Assignment** 1. Energy Hydrogenation and Decarbonization **Written Assignment** Compare the voltages generated by a single fuel cell element using hydrogen as an energy carrier when it is operated at: a. 20 °C, b. 100 °C. Use: n =2, $\Delta E = \frac{T\Delta S - \Delta H}{n.F}$, $\Delta S = -163.2\ J/K$, $\Delta H = -285{,}800\,J$, F (Faraday's constant) = 96,487 [Coulombs] or [Joules/Vol What is the implication concerning fuel cells operation?

			How many cells are needed for: 1. A 12 volt fuel cell generator 2. A 19 volt fuel cell generator
22	10/13	10/20	**Reading Assignment** 4. High Temperature Gas Cooled Reactor 5. Heavy Water Reactor **Written Assignment** For heat rejection at 20 degrees Celsius, compare the Carnot cycle efficiencies for an HTGR operating in the following modes: a) Process heat, b) Power generation, c) Hydrogen production. Compare the prices of electricity produced by: 1. CANDU reactor 2. Coal 3. Natural gas at capacity factors of: 1. 20 percent, 2. 80 percent.
23	10/16	10/23	**Reading Assignment** 6. Fourth Generation Reactor Concepts 7. Fast Breeder Reactors **Written Assignment** List the reactors concepts considered in the "Fourth Generation" initiative and their associated acronyms.
24	10/18	10/25	**Reading Assignment** 10. Isotopic Separation and Enrichment **Written Assignment** Identify the level of U^{235} enrichment of: 1. Natural uranium, 2. Enrichment level of Depleted Uranium, DU, 3. Level of enrichment for LWRs. List the two processes used in the production of Heavy Water.
25	10/20	10/27	**Reading Assignment** 10. Isotopic Separation and Enrichment **Written Assignment** An executive at an electrical utility company needs to order natural uranium fuel from a mine. The utility operates a single Heavy Water Reactor (HWR) 500 MWe power plant of the CANDU type using natural uranium and operating at an overall thermal efficiency of 1/3. What is the yearly amount of: a. U^{235} burned up by the reactor? b. U^{235} consumed by the reactor? c. Natural uranium fuel that the executive has to contract with the mine per year as feed to his nuclear unit? An executive at an electrical utility company needs to order uranium fuel from a mine. This utility operates a single 500 MWe PWR power plant operating at an overall thermal efficiency of 33.33 percent. The fuel needs to be enriched to the 5 w/o in U^{235}.

<table>
<tr><td></td><td></td><td></td><td>Consider that the enrichment plant generates tailings at the 0.2 w/o in U^{235} level. Calculate the yearly amount of natural uranium metal that the executive has to contract with the mine as feed to his nuclear unit.

Compare the results for the CANDU and the PWR designs.</td></tr>
<tr><td>26</td><td>10/23</td><td>10/30</td><td>Reading Assignment
10. Isotopic Separation and Enrichment
Written Assignment
List the methods used in the enrichment of the heavy-element isotopes.

Compare the ratio and the difference in the separation radii in the electromagnetic separation method (Calutron) for the separation of the ions of the isotopes and molecules of:
a) U^{235} and U^{238},
b) Li^6 and Li^7</td></tr>
<tr><td>27</td><td>10/25</td><td>11/1</td><td>Reading Assignment
8. Autonomous Battery Reactors
11. Traveling Wave Reactor
12. Modular Integral Compact Underground Reactor
13. Underwater Power Plants
14. Floating Nuclear Barges
Written Assignment
List the proposed “Small reactors” concepts and their associated power levels in Mwe.

List the main characteristics of the “Modular Integral Compact Reactor”</td></tr>
<tr><td>28</td><td>10/27</td><td>11/3</td><td>Reading Assignment
6. Natural Nuclear Reactors, The Oklo Phenomenon
Written Assignment
Write the four factors formula for the infinite medium multiplication factor and briefly describe its different components.</td></tr>
<tr><td>29</td><td>10/30</td><td>11/6</td><td>Reading Assignment
2. Ionizing Radiation Units and Standards
Written Assignment
Show in the table the corresponding units and their abbreviations of the following radiological quantities
<table>
<tr><th>Radiological quantity</th><th>Conventional System Unit</th><th>SI System Unit</th></tr>
<tr><td>Effective dose, dose equivalent</td><td></td><td></td></tr>
<tr><td>Absorbed dose</td><td></td><td></td></tr>
<tr><td>Exposure</td><td></td><td></td></tr>
<tr><td>Activity</td><td></td><td></td></tr>
</table>
Approximate overall annual dose equivalent to a person in the USA is: _______________.
The maximum allowable yearly dose equivalent for occupational exposure is: _________.
alara stands for: ________________________.
RBE stands for: ________________________</td></tr>
<tr><td>30</td><td>11/1</td><td>11/6</td><td>Reading Assignment
2. Ionizing Radiation Units and Standards
Written Assignment
ICRP stands for:________________________
aslap stands for:________________________

Standards for Limiting radiation effective doses:</td></tr>
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<table>
<tr><th>Category</th><th>Maximum yearly per capita effective dose
[cSv/(person.year)]
[rem/(person.year)]</th></tr>
<tr><td>Occupational workers</td><td></td></tr>
<tr><td>Members of the public</td><td></td></tr>
<tr><td>Whole population average (all sources other than medical)</td><td></td></tr>
</table>
The allowable effective dose is a cumulative figure that depends on age, thus over a lifetime the cumulative radiation effective dose to an occupational worker is:
$$\text{Effective Dose}_{\text{cumulative}} = \_\_\_\_\_\_\_\_\_\_ \left[\frac{\text{cSv}}{\text{person}}\right] \text{ or } \left[\frac{\text{rem}}{\text{person}}\right]$$
where N is the age of the exposed individual in years.
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<tr>
<td>31</td>
<td>11/3</td>
<td>11/6</td>
<td>
Reading Assignment
3. Nonionizing Radiation
Written Assignment
The Federal Communications Commission (FCC) and the Federal Drug Administration (FDA) regulate cell phones in the USA.
For nonionizing radiation, define the Specific Absorption Rate (SAR).
The FCC requires that all cell phones sold in the USA have an SAR of ________ [Watts/kg] or less.
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<td>11/6</td>
<td>Second midterm exam</td>
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<td>32</td>
<td>11/8</td>
<td>11/15</td>
<td>
Reading Assignment
1. Transport Theory
Written Assignment
List nine examples of physical processes governed by the Transport Equation.
Write the Integro-Differential form of the neutron Transport Equation.
List the approximations used in solving the neutron Transport Equation.
</td>
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<tr>
<td>33</td>
<td>11/10</td>
<td>11/17</td>
<td>
Reading Assignment
3. Neutron Cross Sections
Written Assignment
Access the Chart of the Nuclides for 2,200 m/sec or thermal neutrons, and determine the total microscopic cross sections for the following isotopes:
1. U^{235}
2. Pu^{239}
3. Be^{9}
4. C^{12}
Estimate their:

Number densities,
Total macroscopic cross-sections,
Total mean free paths.

Calculate the total cross sections and the mean free paths of thermal neutrons in the following moderators:
1. H_2O,
</td>
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</table>

			2. D_2O.
34	11/13	11/27	**Reading Assignment** 3. Neutron Cross Sections **Written Assignment** A stainless-steel composition is 69 w/o Fe, 17 w/o chromium, 12 w/o nickel and 2 w/o molybdenum. Calculate its absorption macroscopic cross section and its absorption mean free path for thermal neutrons. For a thermal neutron flux of 10^{10} neutrons / (cm^2.sec), estimate the neutron absorption rate density in the stainless steel.
35	11/15	11/27	**Reading Assignment** 5. Neutron Diffusion Theory **Written Assignment** Using the cartesian coordinate system, prove that the divergence of the gradient leads to the Laplacian operator in the leakage term of the neutron diffusion equation for a constant diffusion coefficient D: $\nabla.(-D\nabla\phi) = -D\nabla^2\phi$ Calculate the fluxes and the currents in the following situations: 1. At the center of a line of length 'ℓ' with two sources of strength S at each end. 2. An equilateral triangle of side length 'ℓ' at the center and at the midpoint of one side, where neutron sources of strengths S [neutrons/second] are placed at each one of the vertices. Carry out the calculations in a vacuum, using the inverse square law.
36	11/17	11/27	**Reading Assignment** 6. Neutron Diffusion in Nonmultiplying Media **Written Assignment** Using the exponential attenuation law, calculate the thickness of a neutron shield that would attenuate a beam of neutrons by a factor of one million. Use: $\Sigma_t = 0.1 cm^{-1}$ Using the exponential attenuation law, calculate the e-folding distance or the thickness of a shield that would attenuate a beam of neutrons by a factor equal to the base of the natural logarithm (e = 2.718). Use: $\Sigma_t = 0.1 cm^{-1}$
37	11/27	12/4	**Reading Assignment** 6. Neutron Diffusion in Nonmultiplying Media **Written Assignment** Calculate the flux and the current in the following situation: At the center of a line of length 200 cm with two sources of strength S= 10^6 neutrons/sec at each end. Carry on the calculations in a diffusing medium with a diffusion coefficient D = 1 cm and a diffusion length L = 10 cm. Note: Fick's law applies in the case of a diffusing medium.
38	11/29	12/6	**Reading Assignment** 7. One-Group Reactor Theory **Written Assignment** Consider a bare un-reflected spherical fast reactor of pure fissile material. a) By equating the geometrical buckling to the material buckling, using the one group diffusion theory, and ignoring the extrapolation length, derive expressions for: 1) The critical radius, 2) The critical volume,

			3) The critical mass. b) Calculate these values for a U^{235} spherical fast reactor with: microscopic transport cross section = 8.246 barns, microscopic absorption cross section = 2.844 barns, density = 18.75 [gm/cm^3] product of average number of neutrons released in fission (ν) and the microscopic fission cross section = 5.297 neutrons.barn. Note that the diffusion coefficient (D) is equal to 1/3 the transport mean free path. c) Compare your result to the actual critical mass of the Godiva fast critical experiment composed of 93.9 percent enriched U^{235} where $M_{critical}$= 48.8 kgs.
39	12/1	12/6	**Reading Assignment** **9. Multidimensional Reactor Systems in Diffusion Theory**

Written Assignment

Consider a bare homogenous cylindrical core with material composition typical of a modern Pressurized Water Reactor (PWR) operating at full power conditions. The reactor contains a concentration of 2.21 ppb of natural boron as boric acid dissolved in the coolant water and is fueled with UO_2 at 2.78 percent enrichment in U^{235}.

The macroscopic cross sections for the materials composing this core are as shown in Table 1.

Based on thermal design considerations, the core height is fixed at 370 centimeters.

Table 1: Macroscopic Cross sections for a PWR core.

ement/Isotope	Transport cross section, [cm^{-1}] Σ_{tr}	Absorption cross section, [cm^{-1}] Σ_a	Product of averag number of neutron released in fissior and fission cross section, [neutron cm^{-1}] $\nu\Sigma_f$
H	1.79×10^{-2}	8.08×10^{-3}	-
O	7.16×10^{-3}	4.90×10^{-6}	-
Zr	2.91×10^{-3}	7.01×10^{-4}	-
Fe	9.46×10^{-4}	3.99×10^{-3}	-
U^{235}	3.08×10^{-4}	9.24×10^{-2}	1.45×10^{-1}
U^{238}	6.95×10^{-3}	1.39×10^{-2}	1.20×10^{-2}
B^{10}	8.77×10^{-6}	3.41×10^{-2}	-

Based on thermal design considerations, the core height is fixed at 370 centimeters.

Hints: $B^2_{g,cylinder} = \left(\frac{2.405}{R}\right)^2 + \left(\frac{\pi}{H}\right)^2$, $D = \frac{1}{3}\lambda_{tr} = \frac{1}{3}\frac{1}{\Sigma_{tr}}$, $k_\infty = \eta\varepsilon pf$,

$L^2 = \frac{D}{\Sigma_a}$, $B^2_m = \frac{k_\infty - 1}{L^2}$

			Calculate the following parameters that are characteristic of a PWR core using the one-group diffusion theory model, **ignoring the extrapolation distance**, and using the fast fission factor ε and resonance escape probability p as unity: 1. Infinite medium multiplication factor, k_∞ . 2. Diffusion coefficient, D. 3. Diffusion area, L^2 and diffusion length, L. 4. Material buckling, B_m^2 . 5. Axial geometrical buckling, B_z^2 . 6. Radial geometrical buckling, B_r^2 . 7. Critical radius, R_c. 8. Critical core volume in cubic meters, V_c
40	12/4	12/6	**Reading Assignment** **Written Assignment**
41	12/6	12/15	**Reading Assignment** **Written Assignment**
	12/15	Final exam	Final Exam 7:00-10:00 pm

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.