NPRE 402
Nuclear Power Engineering
Spring 2018

Number	Date Assigned	Due Date	Description
1	1/17	1/24	1. Define the Quad unit of energy in terms of BTUs and Joules. 2. List the components of the envisioned Internet of Things (IoT) for a future energy system. 3. On the Kardashev Scale, identify the power needs in Watts for Type I, II and III civilizations. What is the current position of human civilization on that scale? In how many years is humanity expected to achieve a Type I status? 4. Using the Sankey diagram, estimate the overall conversion efficiency of the primary sources of energy into useful energy services in the USA. What is the percentage share of nuclear energy in: a) The primary energy supply, b) Electrical energy generation?
2	1/19	1/26	1. Calculate the speed in [m/s] of a kT moderated "thermal neutron" with an energy of 0.025 eV. 2. Calculate the speed of a fission unmoderated "fast neutron" with an energy of 2.0 MeV. 3. Calculate the speed of a fusion unmoderated "fast neutron" with an energy of 14.06 MeV. Consider the kinetic energy as non-relativistic; $E=\frac{1}{2}mv^2$.
3	1/22	1/29	Apply conservation of charge and of nucleons to balance the following fissile breeding reactions with uranium: ${}_0n^1 + {}_{92}U^{238} \rightarrow {}_{92}U^?$ ${}_{92}U^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ ${}_?{?}^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ ${}_?{?}^? \rightarrow {}_2He^4 + {}_?{?}^?$ ------------------ ${}_0n^1 + {}_{92}U^{238} \rightarrow 2\,{}_{-1}e^0 + {}_2He^4 + {}_?{?}^?$
4	1/24	1/31	The yield from the Hiroshima U^{235} gun-barrel device was 12.5 kT of TNT equivalent, and the yield from the Nagasaki Pu^{239} implosion device was 22 kT of TNT. Assuming that one critical mass of lead reflected U^{235} Oralloy at about 30 kgs, and one critical mass of Pu^{239} at about 10 kgs were used to generate these yields, compare the energy release efficiencies of the two devices as the fraction or percentage of the fissile material converted into energy in the case of the gun barrel versus the implosion process. Access the Table of the Nuclides data warehouse and data-mine for the following information about the naturally occurring isotopes of the given elements of interest in nuclear power generation: a) Natural abundances in atomic percent (a/o), b) Atomic mass in atomic mass units (amu). 1. Uranium, 2. Thorium,

<table>
<tr><td></td><td></td><td></td><td>3. Lithium,
4. Carbon,
5. Hydrogen,
6. Lead,
7. Beryllium,
8. Boron,
9. Cadmium,
10. Sodium.</td></tr>
<tr><td>5</td><td>1/26</td><td>2/2</td><td>Balance the following nuclear reactions occurring in thermonuclear devices.
Tritium breeding from lithium:
$ {}_0n^1 + {}_3Li^6 \rightarrow {}_1T^3 + ? $
$ {}_0n^1 + {}_3Li^7 \rightarrow {}_0n^1 + {}_1T^3 + ? $
$ \overline{\hspace{6cm}} $
$ {}_0n^1 + {}_3Li^6 + {}_3Li^7 \rightarrow ? + ? $
Deuterium and tritium fusion:
$ {}_1\mathrm{D}^2 + {}_1\mathrm{T}^3 \rightarrow ?(3.52\ \mathrm{MeV}) + ?(14.06\ \mathrm{MeV}) + 17.58\ \mathrm{MeV} $</td></tr>
<tr><td>6</td><td>1/29</td><td>2/5</td><td>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.
Fill out the following table describing the energy partition of energy release in a single fission reaction;
<table>
<tr><th>Distribution of Fission Energy</th><th>Energy (MeV)</th><th>Fraction, [percent]</th></tr>
<tr><td>Kinetic energy of fission fragments</td><td></td><td></td></tr>
<tr><td>Prompt gamma rays energy</td><td></td><td></td></tr>
<tr><td>Kinetic energy of fission neutrons</td><td></td><td></td></tr>
<tr><td>Beta particles from fission products</td><td></td><td></td></tr>
<tr><td>Delayed gamma rays from fission products</td><td></td><td></td></tr>
<tr><td>Antineutrinos from the fission products</td><td></td><td></td></tr>
<tr><td>Gammas from radiative capture in structure</td><td></td><td></td></tr>
<tr><td></td><td>_____</td><td>_____</td></tr>
<tr><td>Energy release per fission event</td><td></td><td></td></tr>
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<tr><td>7</td><td>1/31</td><td>2/7</td><td>1. Use Avogadro’s law to calculate the number of atoms N_0 in 1 gm of the Radium^{226} isotope. Obtain the half-life of Radium^{226} from the Chart of the Nuclides and estimate its decay constant.
Calculate the activity in Becquerels and in Curies of 1 gm of the isotope Radium^{226}.
Discuss the relationship to the “Curie” unit of “activity.”

2. Radon^{222} as a daughter in the decay chain of uranium^{238} is gaseous at room temperature. It is an inert or noble gas that does not interact chemically in the body. However it decays into Pb^{210} which attaches itself to vegetation such as tobacco leaves as a solid and subsequently decays into Po^{210} which emits an energetic alpha particle with 5.3 MeV of energy. The inhalation of these two isotopes in the particulate matter of cigarettes smoke delivers to the average smoker a radiation dose equivalent or dose equivalent of 8 rems (radiation equivalent man) per year to the basal cells of the bronchial tissue in the lungs. The “cancer dose” is the total radiation dose that if spread through a population would cause one additional cancer death and is considered to be approximately 2,000 rems. Calculate the ensuing radiological risk in cancer deaths per year in a population of one million smokers.</td></tr>
<tr><td>8</td><td>2/2</td><td>2/9</td><td>1. Draw a diagram of the Geiger-Mueller radiation detection device.</td></tr>
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			2. Accessing the chart of the nuclides, generate the decay chain of U^{235} and identify its end stable decay product. 3. The naturally occurring isotope K^{40} is widely spread in the environment. In fact, the average concentration of potassium in the crustal rocks is 27 [g/kg] and in the oceans is 380 [mg/liter]. K^{40} occurs in plants and animals, has a half-life of 1.3 billion years and an abundance of 0.0119 percent. Potassium's concentration in humans is 1.7 [g/kg]. In urine, potassium's concentration is 1.5 [g/liter]. a) Calculate the specific activity of K^{40} in Becquerels per gram and in Curies/gm of K^{40}. b) Calculate the specific activity of K^{40} in Becquerels per gram and in Curies per gm of overall potassium. c) Calculate the activity of K^{40} in Becquerels and in Curies in the human body for an average weight of 70 kgs. d) Calculate the specific activity of K^{40} in urine in [Bq/liter].
9	2/5	2/12	1. Apply conservation of charge and of nucleons to balance the following "fissile breeding" reaction, ignoring the antineutrinos: $_0n^1 + {}_{90}Th^{232} \rightarrow {}_{90}Th^?$ $_{90}Th^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ $_?{?}^? \rightarrow {}_{-1}e^0 + {}_?{?}^?$ $-------------$ $_0n^1 + {}_{90}Th^{232} \rightarrow 2\,{}_{-1}e^0 + {}_?{?}^?$ 2. 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 present. The methodology is designated as: "Carbon Dating." 1. Write down the nuclear reaction leading to the formation of C^{14}. 2. 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 / minute]. Estimate the approximate age of the wood, if it is assumed that the current equilibrium *specific activity* of C^{14} in carbon has been approximately constant at 13.56 [disintegrations / (minute . gram)].
10	2/7	2/14	The isotope $_{81}Thallium^{204}$ has a half-life of 3.78 years. It decays through beta decay to $_{82}Pb^{204}$ with a branching ratio of 97.1 percent with a 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. 1. Calculate its total specific activity in [Becquerels / gm]. 2. Calculate its total specific activity in [Curies / gm]. 3. Calculate the specific power generation in thermal [Watts(th) / gm]. 4. For a 100 Watts of thermal power in a Radioisotope Heating Unit (RHU) power generator, how many grams of $_{81}Thallium^{204}$ are needed? 5. After 3.78 years of operation, what would its power become?

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<td>2/16</td>
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1. Write down the units and the 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>Activity</td><td></td><td></td></tr>
<tr><td>Absorbed dose</td><td></td><td></td></tr>
</table>

2. The isotope $_{38}Strontium^{90}$ is a pure beta emitter without gamma rays emissions. This makes particularly suitable for radio isotopic power generation. Its half-life is 29 years and its beta disintegration energy is 0.546 MeV. We can initially ignore its $_{39}Y^{90}$daughter product.
1. Calculate its specific activity in Becquerels per gram and Curies per gram.
2. Calculate its specific thermal power generation in Watts(th) / gm.
3. For a 100 Watts of thermal power in a radio isotopic power generator, how many grams of $_{38}Sr^{90}$ are needed?
4. After 29 years of operation, what would its power become?
Use: 1 Curie=$3.7x10^{10}$ Bq, 1 MeV/sec=$1.602x10^{-13}$ Watts, $A_v=0.602x10^{24}$.
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a) What is the radiation dose in rads and Grays in food preservation for:
1. Sterilization,
2. Pasteurization.
b) 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, bioenergy and fossil sources.
c) Consider the 99.92 percent of the time emission of the 2.5 MeV photon from the radioactive decay of the Co^{60} isotope. Calculate the activity of 1 kilogram of Co^{60}, then estimate the ensuing dose rate, assuming the photons are all absorbed in the material in units of rad/hr and Gray/hr.
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A unifying universal energy-mass-radiation equivalence relationship is:
$E = mc^2 = h\nu = h\frac{c}{\lambda}$. This unifies mass and electromagnetic radiation through the relationship: $m = \frac{h\nu}{c^2} = \frac{1}{\lambda c}$. We can consequently write that: $m = R\nu = R\frac{c}{\lambda}$, where $R = \frac{h}{c^2}$.
The equation suggests that when radiation reaches extremely high frequencies (ν) or very short wave lengths (λ) it is expected to exhibit mass properties.
Estimate the value of the universal constant R in the SI system of units.

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.
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<td>2/23</td>
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i) List the effects that solar storms and Coronal Mass Ejections (CMEs) can have on power and communications infrastructures. What effects can they have on:
1. Nuclear Power plants’ operations?
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			2. The North American Power Grid? ii) Briefly describe the expected effects of a High Altitude Nuclear Electromagnetic Pulse (HEMP) on the existing electrical power supply.
15	2/19	2/26	Balance the following nuclear reactions: 1. $_1T^3 + _1T^3 + \rightarrow 2\,_0n^1 + ?$ (neutron multiplier reaction) 2. $_0n^1 + _5B^{10} \rightarrow _2He^4 + ?$ (neutron absorption reaction) 3. $_0n^1 + _{92}U^{235} \rightarrow 3\ _0n^1 + _{54}Xe^{136} + ?$ (fission reaction) Balance, calculate the Q-values then use conservation of momentum and energy to estimate the energy release partitioning in the following binary 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). Balance then calculate the Q-value to estimate the energy release in the following fission nuclear reaction: 1. $_0n^1 + _{92}U^{235} \rightarrow 3\ _0n^1 + _{53}I^{137} + ?$ (fission reaction)
16	2/21	2/26	
17	2/23	2/26	

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned.

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.