NPRE 402
Nuclear Power Engineering

Fall 2018

Number	Date Assigned	Due Date	Description
1	8/27	9/5	The “Kardashev Scale” is a hypothetical measurement of a civilization’s level of technological achievement. It was suggested by Russian astronomer Nikolai Kardashev in 1964. 1. List the different types of power usage level in Watts. 2. Where humanity is currently placed on the Kardashev’s scale? Construct a diagram showing the different components of the future smart electrical grid from the perspective of the vision of the Internet of Things (IoT).
2	8/29	9/5	Access the Table of the Nuclides data warehouse and mine for the following data for 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, 3. Lithium, 4. Carbon, 5. Hydrogen, 6. Lead, 7. Calcium, 8. Beryllium, 9. Boron, 10. Sodium.
3	8/31	9/7	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 (kT) neutrons at 0.025 eV.
4	9/5	9/12	Apply conservation of charge and of nucleons to balance the following two “fissile breeding” reactions, ignoring the antineutrinos:

			$_0n^1 + {}_{92}U^{238} \rightarrow {}_{92}U^?$ $_{92}U^? \rightarrow {}_{-1}e^0 + {}_??^?$ $_??^? \rightarrow {}_{-1}e^0 + {}_??^?$ $-----------------$ $_0n^1 + {}_{92}U^{238} \rightarrow 2\,{}_{-1}e^0 + {}_??^?$ $_0n^1 + {}_{90}Th^{232} \rightarrow {}_{90}Th^?$ $_{90}Th^? \rightarrow {}_{-1}e^0 + {}_??^?$ $_??^? \rightarrow {}_{-1}e^0 + {}_??^?$ $-----------------$ $_0n^1 + {}_{90}Th^{232} \rightarrow 2\,{}_{-1}e^0 + {}_??^?$
5	9/7	9/14	If a single fission reaction produces about 200 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. Consider 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 atom.
6	9/10	9/17	Apply conservation of nucleons and of charge to balance 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). 5. $_0n^1 + {}_3Li^6 + \rightarrow ?+?$ (thermal neutron tritium breeding reaction) 6. $_0n^1 + {}_3Li^7 + \rightarrow {}_0n^1 + ?+?$ (fast neutron tritium breeding reaction)
7	9/12	9/19	What do the following nuclear-related acronyms stand for? ICBM, ABM, MIRV, kT, MT, DU, HEU, NPT, MAD, TNT, SALT, UUV, UAV.

8	9/14	9/21	a. Prove that the two forms of the law of radioactive decay are equivalent. b. Access the chart of the nuclides and obtain the half-lives for the following isotopes: 1. Tritium: $_1T^3$ 2. U^{235} 3. Pu^{239} 4. C^{14} 5. K^{40} c. Complete the following nuclear reactions occurring when radioactive materials such as radium are placed in a sealed container of air. Small amounts of hydrogen, which does not exist in ordinary air, would appear. $_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + ?$ $? + {}_7N^{14} \rightarrow {}_1H^1 + ?$ $\overline{}$ $_{88}Ra^{226} + {}_7N^{14} \rightarrow {}_1H^1 + ? + ?$ d. 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	9/17	9/24	a) 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. b) 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]. i) Calculate the specific activity of K^{40} in Becquerels per gram and in Curies/gm of K^{40}. ii) Calculate the specific activity of K^{40} in Becquerels per gram and in Curies per gm of overall potassium. ii) Calculate the specific activity of K^{40} in the human body in [Bq/kg]. iii) Calculate the activity density of K^{40} in urine in [Bq/liter]. c) Draw a simple diagram of the electronic circuit of a Geiger-Müller tube radiation detector.
10	9/19	9/26	Radon^{222} as a daughter in the decay chain of uranium is gaseous at room temperature. It is an inert or noble gas that does not interact chemically in the human 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 lung's bronchial tissue. 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 units of cancer deaths per year in a population of one million smokers.
11	9/21	9/28	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 3.7×10^{10}[trans/sec] 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	9/24	10/1	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 overall 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 a thermal power generation of 200 Watts(th) what is the needed weight of this isotope in grams? 4. For an electrical power of 200 Watts(e) what would be the weight needed for this generator in grams and in ounces? 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}.
13	9/26	10/3	Apply conservation of 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. ${}_0n^1 + {}_{92}U^{235} \rightarrow 3\,{}_0n^1 + {}_{54}Xe^{136} + {}_{38}Sr^{97}$ 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: $R = \frac{h}{c^2} = 7.365864 \times 10^{-48} \frac{\text{erg.sec}^3}{\text{cm}^2}$ is a constant of nature.
14	9/28	10/3	Apply conservation of momentum and energy to calculate the the kinetic energies of the product nuclei from 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 energy release in MeV in the annihilation process of a positron and an electron. List the principles governing energy conversion processes and heir corollaries.
15	10/1	10/3	What do the following acronyms stand for? LWR PWR BWR LMFBR HTGR List the Engineered Safety Features(ESFs) of the following reactor designs: PWR, BWR
16	10/5	10/12	A Stirling cycle engine using a radioactive isotope for space power applications operates at a hot end temperature of 650 ^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.
17	10/8	10/15	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 (Pressurized Water Reactor), 168 ^oC. 2. BWR (Boiling Water Reactor), 164 ^oC. 3. CANDU (Canadian Deuterium Uranium), 141 ^oC. 4. HTGR (High Temperature Gas-cooled Reacror), 205 ^oC. 5. LMFBR (Liquid Metal Fast Breeder Reactor), 215 ^oC.
18	10/10	10/17	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 ^oF and then pumped back to the reactor pressure. Compute the following cycle parameters: a. Net work 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=1192.9 [BTU/lb_m] At 1 psia pressure the fluid enthalpy from an isentropic expansion is 776 [BTU/lb_m] The isentropic pumping work is 2.96 [BTU/lb_m] The enthalpy of the liquid at 1 psia subcooled to 3 ^oF is 66.73 [BTU/lb_m] 1 [kW.hr] = 3412 [BTU]
19	10//12	10/19	Fill up the values of the hydrogen to carbon ratio in the following table.

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<table>
<tr><th>Fuel</th><th>Hydrogen to Carbon ratio, (H/C)</th></tr>
<tr><td>Wood</td><td></td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Oil</td><td></td></tr>
<tr><td>Light sweet crude oil, $(CH_{1.5})_n$</td><td></td></tr>
<tr><td>Heavy sour crude oil, $(CH_{0.8})_n$</td><td></td></tr>
<tr><td>Clean transport fuel, $(CH_2)_n$</td><td></td></tr>
<tr><td>Cetane, $C_{16}H_{34}$</td><td></td></tr>
<tr><td>Hexane, C_6H_{14}</td><td></td></tr>
<tr><td>Propane, C_3H_8</td><td></td></tr>
<tr><td>Methane, CH_4</td><td></td></tr>
<tr><td>Methanol, methyl alcohol, CH_3OH</td><td></td></tr>
<tr><td>Ethanol, ethyl alcohol, C_2H_5OH</td><td></td></tr>
<tr><td>Hydrogen</td><td></td></tr>
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For heat rejection at 20 degrees Celsius, compare the Carnot cycle efficiencies for an HTGR operating in the following modes:
a) Process heat,
b) Electrical power generation,
c) Hydrogen production.
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<td>10/15</td>
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Compare the voltages generated by a single fuel cell element using hydrogen as an energy carrier when it is operated at:
a. 20 ^oC,
b. 100 ^oC.
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/Volt].

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 60 percent.
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<td>10/17</td>
<td>10/24</td>
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a) List the reactors concepts considered in the "Fourth Generation" initiative and their associated acronyms.

b) 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.
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<td>10/19</td>
<td>10/26</td>
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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.
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			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.
23	10/22	10/29	Identify the level of U^{235} enrichment in: 1. Natural uranium, 2. LWR: BWR and PWR, reactor fuel, 3. Depleted uranium discharge from enrichment plant, 4. Burnt-out discharged reactor fuel.
24	10/24	10/31	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) 1.000 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?
25	10/26	11/2	An executive at an electrical utility company needs to order uranium fuel from a mine. This utility operates a single 1,000 MWe PWR power plant operating at an overall thermal efficiency of 1/3. The fuel needs to be enriched to the 3 w/o in U^{235}. 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 natural uranium fuel needs in the case of the PWR design to the CANDU design.
26	10/29	11/2	1. List the known methods for the separation and enrichment of the heavy isotopes of uranium. 2. Compare the *ratios* in the separation radii in the electromagnetic separation method (Calutron) for the separation of the ions of the isotopes: a) U^{235} and U^{238} for fission applications, b) Li^6 and Li^7 for fusion applications.
27	10/31	11/2	Write the mathematical expression for the general form of the neutron transport equation: {Time rate of change of n} = {Change due to leakage through surface S} + {Change due to collisions} + {Sources} 1. In terms of the neutron density $n(\underline{r},\underline{v},t)$, 2. In terms of the neutron flux, $\varphi(\underline{r}, t) = \int v\, n(\underline{r},\underline{v},t) d^3v$. 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: 1. Number densities, 2. Total macroscopic cross-sections, Total mean free paths. A neutron beam of 10^{10} [neutrons / (cm^2.sec)] intensity interacts with a material with a macroscopic total cross section of 0.5 cm^{-1}. Calculate the ensuing reaction rate density.

28	11/5	11/12	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: $\nabla.(-D\nabla\phi) = -D\nabla^2\phi$
29	11/7	11/14	Through direct substitution prove that the different general forms given for the solution of the Simple Harmonic Oscillator in its forms: a) $\ddot{x}(t) = -\omega^2 x(t)$, b) $\ddot{x}(t) = +\omega^2 x(t)$ do indeed satisfy the underlying differential equations. A beam of neutrons falls on a slab of a shielding material whose mean free path is 1 cm. Using the exponential attenuation law, ignoring the buildup factor, calculate the thickness of a shield that would attenuate a beam of neutrons by a factor of: a) One million times (10^{-6}). b) One billion times (10^{-9}). Calculate the flux and the current in vacuum at the center of a line of length ‘L’ with two sources of strength S at each end.
30	11/9	11/16	Calculate the fluxes and the currents in the following geometries, in a diffusing medium with a diffusion coefficient D and diffusion length L: 1. At the center of a line of length ‘x’ with two sources of strength S at each end. 2. A square of edge length ‘a’ at the center and at the midpoint of one edge, where neutron sources of strengths S [neutrons/second] are placed at each one of the vertices. Hint: Consider that the neutron flux is a scalar quantity, whereas the neutron current is a vector quantity following Fick’s law.
31	11/12	11/26	Consider a bare unreflected 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. 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.
32	11/14	11/26	Repeat the calculations in the previous problem for a Pu^{239} spherical reactor with: microscopic transport cross section = 6.8 barns microscopic radiative capture cross section = 0.26 barns density = 19.74 [gm/cm^3] average number of neutrons released per fission ν = 2.98 microscopic fission cross section = 1.85 barns Compare your result to the actual critical mass of the Jezebel Experiment composed of pure Pu^{239} where $M_{critical}$= 20.53 kgs.
33	11/16	11/28	Three fission reactor designs in the shape of: a) A sphere, b) A cube, c) A finite height cylinder, The height to diameter ratio of the cylinder is (H/D) = 1,

have the following parameters:
Diffusion coefficient D = 9.21 [cm],
Overall macroscopic absorption cross section: Σ_a = 0.153 [cm^{-1}],
Fuel macroscopic absorption cross section: $\Sigma_{a\,F}$ = 0.140 [cm^{-1}],
$\nu\Sigma_f$ = 0.157[neutrons.cm^{-1}],
$\varepsilon = p \approx 1.$
Density: ρ = 5 [gm/cm^3]
Calculate the following reactor parameters for the three reactor geometries using the one-group diffusion theory and ignoring the extrapolation lengths:

1. Infinite medium multiplication factor, k_∞ ,
2. Diffusion length, L,
3. Material buckling, B_m^2 ,

By equating the material buckling to the geometric buckling, calculate:
i). The critical dimensions for each geometry: critical radius, R_c, critical height H_c, and critical side length a_c,
ii). The critical masses, M_c, in kgs and metric tonnes for each geometry,
iii). Compare the critical masses for the three reactor configurations and discuss the results.

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.

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 average number of neutrons released in fission 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.

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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^2_m.
5. Axial geometrical buckling, B^2_z.
6. Radial geometrical buckling, B^2_r.
7. Critical radius, R_c.
8. Critical core volume in cubic meters, V_c.

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1. List the processes of gamma rays interaction with matter.

2. A radiation shield is used to attenuate a gamma rays beam of initial intensity $I_0=10^{10}$ [photons/(cm^2.sec)].
If the shield is made of lead with a total attenuation coefficient at 1 MeV of μ_t = 0.771 cm^{-1}, what would be the thickness of the shield for attenuating the gamma rays beam's intensity by a factor of 1 million, considering an exponential attenuation of the beam, and a buildup factor of B = 5?

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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 of 2 to one millionth of its initial strength, given their linear attenuation coefficients in cm^{-1}:

<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>1.0</td><td>0.071</td></tr>
<tr><td>Concrete</td><td>2.35</td><td>0.149</td></tr>
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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:

Effective Dose$_{cumulative}$ = ___________ $\left[\frac{\text{cSv}}{\text{person}}\right]$ or $\left[\frac{\text{rem}}{\text{person}}\right]$

where N is the age of the exposed individual in years.

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>
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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: _______________________

The Standards for Limiting radiation effective doses are:
<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>
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<td>37</td>
<td>12/3</td>
<td>12/10</td>
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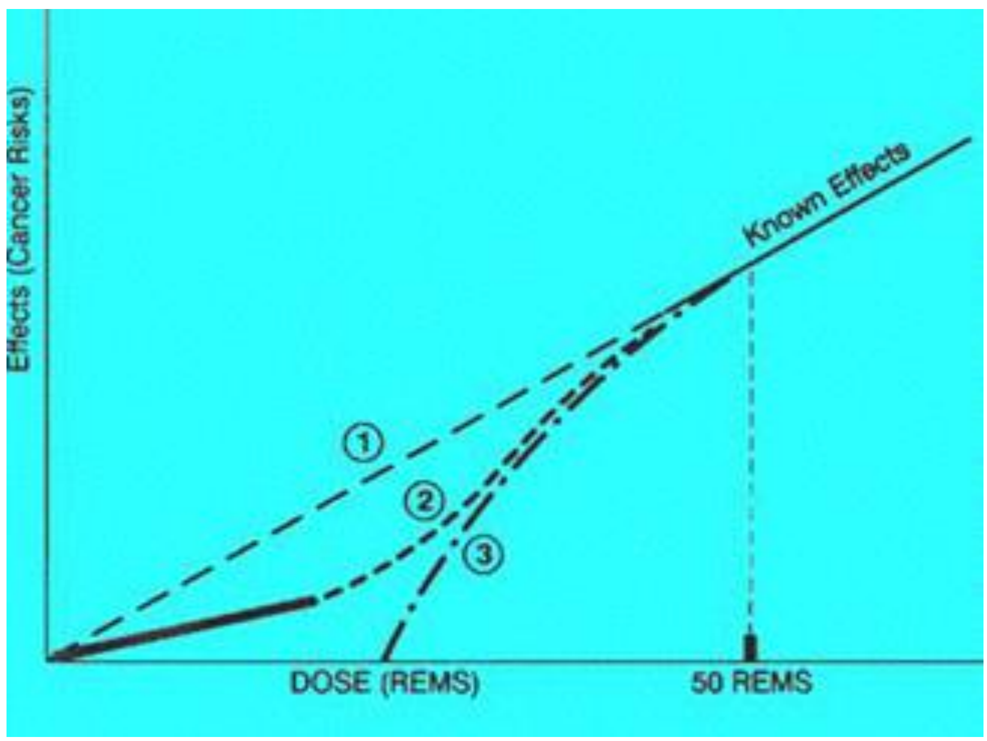
For nonionizing radiation define the Specific Absorption Rate (SAR).
The Federal Communications Commission (FCC) and the Federal Drug Administration (FDA) regulate cell phones in the USA. The FCC requires that all cell phones sold in the USA have an SAR of ________ [Watts/kg] or less.



On the diagram for the dose effect curves for nuclear radiation dose, identify:
a) the curve describing the threshold hypothesis,
b) the curve describing the Linear No Threshold (LNT) relationship,
c) the curve describing the radiation hormesis concept.
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<td>12/5</td>
<td>12/12</td>
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For a practically unlimited supply of deuterium from water at a deuterium to hydrogen ratio of D/H = 160 ppm in the world oceans, one can envision the use of the catalyzed DD reaction in the fusion island.
For plasma kinetic reactions temperatures below 50 keV, the DHe^3 reaction is not significant and the energy release would be 43.23 - 18.34 = 24.89 with each of the five deuterons
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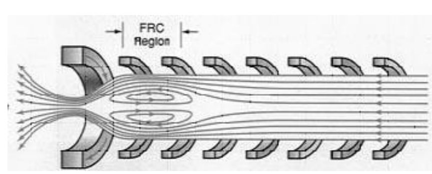
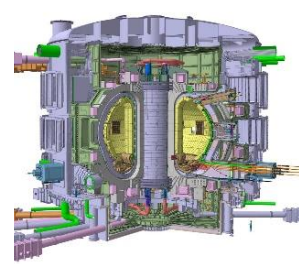
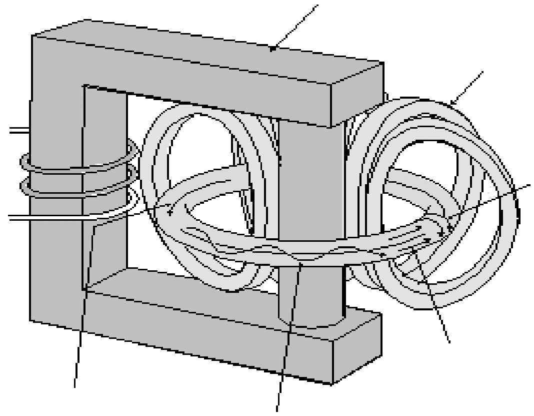
			contributing an energy release of 24.89/5 = 4.978 MeV in the semi-catalyzed DD fusion reaction: $_1D^2 + {_1D^2} \rightarrow ?(1.01) + {_1H^1}(3.03) + 4.04\ MeV$ $_1D^2 + {_1D^2} \rightarrow ?(0.82) + {_0n^1}(2.45) + 3.27\ MeV$ $_1D^2 + {_1T^3} \rightarrow ?(3.52) + {_0n^1}(14.06)\ +\ 17.58\ MeV$ ____ $5\,{_1D^2} \rightarrow ? + ? + ? + 2\,{_0n^1} + 24.89 MeV$ In this case, there would be no need to breed tritium from lithium. Write the two reactions that would breed tritium from the lithium isotopes in the DT fusion cycle. Write the reaction that would be suitable for future space fusion rocket propulsion.
39	12/7	12/12	Enunciate the statement of, and briefly explain the “Lawson Criterion.” A cylindrical inertial confinement fusion pellet of initial density ρ_0 [gm/cm^3] is imploded by an array of laser beams. Calculate the resultant density for: a. A reduction of the initial radius r_0 by a factor of 2. b. A reduction in the initial radius r_0 by a factor of 10. Recalculate the values for a spherical pellet. Calculate the attainable density of metallic uranium with a density of $\rho = 18.9\ [gm/cm^3]$ included in a hybrid fusion-fission pellet if it is imploded by a laser driver in cylindrical and in spherical geometry to: a) One half its initial radius b) One tenth its initial radius.
40	12/10	12/12	Identify by name the types of the magnetic confinement fusion devices shown in the diagrams  What is the type of fusion device shown in the diagram? ______________________________ Identify on the diagram the following components: Transformer core. Toroidal field magnet coils.

			Toroidal magnetic field. Poloidal plasma current. Poloidal magnetic field. Resultant magnetic field. 

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.