ENGY.3310 Fundamentals of Nuclear Science and Engineering
Exam #1 Spring 2016

Problem 1. PWR Plant Layout and Components (15 points)

a. Sketch the key components and the energy flow paths associated with the power conversion systems within a typical pressurized water reactor (PWR). Be sure to label the key system components…

b. Briefly describe the purpose and basic operation of a pressurizer within a PWR plant. What two devices/components within the pressurizer are used to control the system pressure? Explain briefly…

Problem 2. Fuel Consumption in a Nuclear Reactor (15 points)

Consider a 1250 MWe PWR that has an overall thermal conversion efficiency of 33.5% and a 0.92 operational capacity factor. If the average capture-to-fission ratio in the reactor core is 0.21, estimate how much fissionable material (in kg) is consumed per year.

Note: Assume that the average molecular weight of the fuel in 235.8 g/gmole (i.e. the fissile material is primarily a combination of U235 and Pu239).

Problem 3. Overall Neutron Balance, k_{eff}, Power Level Adjustments, Etc. (20 points)

a. Define the terms ***multiplication factor*** and ***reactivity***. Now, using these concepts, describe briefly how the power level of a critical reactor can be adjusted. For specificity within your discussion, assume that we desire to go from steady operation at 100% power to steady operation at 80% of full power. Be as explicit as possible in your overall discussions…

b. Measurements on an experimental thermal reactor show that, for every 100 neutrons emitted from fission, 10 escape while slowing down, 7 neutrons are absorbed within the reactor while slowing down, and 8 escape after having slowed down to thermal energies. Of those neutrons absorbed at thermal energies, 64.6% are absorbed in fissile material.

   What is the multiplication factor of the reactor at the time these observations are made?

   Note: The values of η and ν for the reactor fuel are 2.07 and 2.42, respectively.

Problem 4. B-10 Atom Density within Borated Aluminum (15 points)

In the United States, the sole supplier of boron-aluminum alloys is Eagle Picher. Because of the low solubility of boron in aluminum, the boron used is usually enriched with the B-10 isotope so that adequate reactivity control can be achieved in a variety of spent fuel storage applications.

One particular Eagle Picher product includes aluminum boride (AlB_2) dispersed in an aluminum matrix, with the following properties (where the "mix" refers to the solid mixture of AlB_2 and Al which is usually denoted as AlB_2-Al):

$\rho_{mix} = 2.81$ g/cm^3 with 5.88 w/o AlB_2 with the boron enriched to 95 w/o.

Using the molecular weights given below, compute the B-10 atom density for this neutron poison material.

$M_{B\text{-}10} = 10.01$ $M_{B\text{-}11} = 11.01$ $M_{Al} = 26.98$

Problem 5. Chart of Nuclides, Stability, Mass-Energy Equivalency, etc. (15 points)

a. What is the average kinetic energy of a neutron emitted in the fission process? **Note:** If you do not know the answer here, assume some reasonable value so that you can continue with the remaining parts of this problem.

b. What is the total energy in MeV of the neutron described in Part a?

c. What is the effective mass in amu of the neutron described in Part a?

d. Assume that a photon has the same energy as the kinetic energy of the neutron described in Part a. What is the photon's effective mass in amu?

e. Sketch the line of stability on a plot of proton number, Z, versus neutron number, N (i.e. a rough Chart of the Nuclides). Also show the Z = N line for reference. Using your chart, identify the regions where β^-, β^+ or EC, and α decay occur.

Problem 6. Binary Reactions, Q Values, and Binding Energy Calculations (20 points)

a. The external neutron source in the UMLRR contains a combination of Am241 and Be9. The americium alpha decays and the interaction of the α-particle with the beryllium emits neutrons to provide the initial neutron source needed to initiate the chain reaction.

   This problem wants you to write the complete reaction equation for the α,n reaction in Be9 and to compute the Q value for this reaction. Assume that the reaction product is in its ground state.

b. What is the proton separation energy for Be9? That is, what is the minimum energy needed to remove a single proton from a Be9 atom?

c. Define the term ***mass defect*** and explain the basic concept behind this term. How is this related to the concept of ***binding energy***? Now, based on your discussion, compute the binding energy per nucleon, BE/A, for the Be9 isotope.

Some Useful Information for Use on (closed-book) Exams

Constant	Symbol	Value (with alternate units in some cases)	
Speed of light (in vacuum)	c	$2.997\,924\,58 \times 10^{8}$ ms^{-1}	
Electron charge	e	$1.602\,176\,53 \times 10^{-19}$ C	
Atomic mass unit	u	$1.660\,538\,9 \times 10^{-27}$ kg	931.494 043 MeV/c^2
Electron rest mass	m_e	$9.109\,382\,6 \times 10^{-31}$ kg	0.510 998 92 MeV/c^2
			$5.485\,799\,09 \times 10^{-4}$ u
Proton rest mass	m_p	$1.672\,621\,7 \times 10^{-27}$ kg	938.272 03 MeV/c^2
			1.007 276 466 9 u
Neutron rest mass	m_n	$1.674\,927\,3 \times 10^{-27}$ kg	939.565 36 MeV/c^2
			1.008 664 915 6 u
Hydrogen atom rest mass	$M({}^1_1H)$	$1.673\,532\,6 \times 10^{-27}$ kg	1.007 825 032 2 u
Planck's constant	h	$6.626\,069\,3 \times 10^{-34}$ J s	$4.135\,6674 \times 10^{-15}$ eV s
Avogadro's constant	N_A	$6.022\,141\,5 \times 10^{23}$ mol^{-1}	
Boltzmann constant	k	$1.380\,650\,5 \times 10^{-23}$ J K^{-1}	8.617343×10^{-5} eV K^{-1}
Ideal gas constant (STP)	R	8.314 472 J mol K^{-1}	
Electric constant	ε_o	$8.854\,187\,817 \times 10^{-12}$ F m^{-1}	

Conversion Factors

1 MeV = 1.602×10^{-13} J

κ = average recoverable energy per fission = 200 MeV/fission

Table B.1. Atomic mass tables

N	Z	A	El	Atomic Mass (μu)	N	Z	A	El	Atomic Mass (μu)	N	Z	A	El	Atomic Mass (μu)
1	0	1	n	1 008664.9233	10	5	15	B	15 031097	13	10		Ne	22 994467.34
0	1		H	1 007825.0321	9	6		C	15 010599.3	12	11		Na	22 989769.67
1	1	2	H	2 014101.7780	8	7		N	15 000108.8984	11	12		Mg	22 994124.9
2	1	3	H	3 016049.2675	7	8		O	15 003065.4	10	13		Al	23 007265
1	2		He	3 016029.3097	6	9		F	15 018010	9	14		Si	23 025520
3	1	4	H	4 027830	11	5	16	B	16 039810	17	7	24	N	24 050500
2	2		He	4 002603.2497	10	6		C	16 014701	16	8		O	24 020370
1	3		Li	4 027180	9	7		N	16 006101.4	15	9		F	24 008100
4	1	5	H	5 039540	8	8		O	15 994914.6221	14	10		Ne	23 993615
3	2		He	5 012220	7	9		F	16 011466	13	11		Na	23 990963.33
2	3		Li	5 012540	6	10		Ne	16 025757	12	12		Mg	23 985041.90
1	4		Be	5 040790	12	5	17	B	17 046930	11	13		Al	23 999941
5	1	6	H	6 044940	11	6		C	17 022584	10	14		Si	24 011546
4	2		He	6 018888.1	10	7		N	17 008450	9	15		P	24 034350
3	3		Li	6 015122.3	9	8		O	16 999131.50	17	8	25	O	25 029140
2	4		Be	6 019726	8	9		F	17 002095.24	16	9		F	25 012090
5	2	7	He	7 028030	7	10		Ne	17 017700	15	10		Ne	24 997790
4	3		Li	7 016004.0	13	5	18	B	18 056170	14	11		Na	24 989954.4
3	4		Be	7 016929.2	12	6		C	18 026760	13	12		Mg	24 985837.02
2	5		B	7 029920	11	7		N	18 014082	12	13		Al	24 990428.6
6	2	8	He	8 033922	10	8		O	17 999160.4	11	14		Si	25 004107
5	3		Li	8 022486.7	9	9		F	18 000937.7	10	15		P	25 020260
4	4		Be	8 005305.09	8	10		Ne	18 005697.1	18	8	26	O	26 037750
3	5		B	8 024606.7	7	11		Na	18 027180	17	9		F	26 019630
2	6		C	8 037675	14	5	19	B	19 063730	16	10		Ne	26 000460
7	2	9	He	9 043820	13	6		C	19 035250	15	11		Na	25 992590
6	3		Li	9 026789.1	12	7		N	19 017027	14	12		Mg	25 982593.04
5	4		Be	9 012182.1	11	8		O	19 003579	13	13		Al	25 986891.66
4	5		B	9 013328.8	10	9		F	18 998403.20	12	14		Si	25 992330
3	6		C	9 031040.1	9	10		Ne	19 001879.8	11	15		P	26 011780
8	2	10	He	10 052400	8	11		Na	19 013879	10	16		S	26 027880
7	3		Li	10 035481	14	6	20	C	20 040320	18	9	27	F	27 026890
6	4		Be	10 013533.7	13	7		N	20 023370	17	10		Ne	27 007620
5	5		B	10 012937.0	12	8		O	20 004076.2	16	11		Na	26 994010
4	6		C	10 016853.1	11	9		F	19 999981.32	15	12		Mg	26 984340.74
3	7		N	10 042620	10	10		Ne	19 992440.1759	14	13		Al	26 981538.44
8	3	11	Li	11 043796	9	11		Na	20 007348	13	14		Si	26 986704.76
7	4		Be	11 021658	8	12		Mg	20 018863	12	15		P	26 999190
6	5		B	11 009305.5	15	6	21	C	21 049340	11	16		S	27 018800
5	6		C	11 011433.8	14	7		N	21 027090	19	9	28	F	28 035670
4	7		N	11 026800	13	8		O	21 008655	18	10		Ne	28 012110
9	3	12	Li	12 053780	12	9		F	20 999948.9	17	11		Na	27 998890
8	4		Be	12 026921	11	10		Ne	20 993846.74	16	12		Mg	27 983876.7
7	5		B	12 014352.1	10	11		Na	20 997655.1	15	13		Al	27 981910.18
6	6		C	12 000000.0	9	12		Mg	21 011714	14	14		Si	27 976926.5327
5	7		N	12 018613.2	8	13		Al	21 028040	13	15		P	27 992312
4	8		O	12 034405	16	6	22	C	22 056450	12	16		S	28 004370
9	4	13	Be	13 036130	15	7		N	22 034440	11	17		Cl	28 028510
8	5		B	13 017780.3	14	8		O	22 009970	20	9	29	F	29 043260
7	6		C	13 003354.8378	13	9		F	22 002999	19	10		Ne	29 019350
6	7		N	13 005738.58	12	10		Ne	21 991385.51	18	11		Na	29 002810
5	8		O	13 024810	11	11		Na	21 994436.8	17	12		Mg	28 988550
10	4	14	Be	14 042820	10	12		Mg	21 999574.1	16	13		Al	28 980444.8
9	5		B	14 025404	9	13		Al	22 019520	15	14		Si	28 976494.72
8	6		C	14 003241.988	8	14		Si	22 034530	14	15		P	28 981801.4
7	7		N	14 003074.0052	16	7	23	N	23 040510	13	16		S	28 996610
6	8		O	14 008595.29	15	8		O	23 015690	12	17		Cl	29 014110
5	9		F	14 036080	14	9		F	23 003570	20	10	30	Ne	30 023870