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

Problem 1. Overall Neutron Balance, k_{eff}, Conversion Ratio, Etc. (15 points)

A normalized neutron balance for an experimental fast system containing U238 and Pu239 is given below:

Leakage	0.065	
U238 capture	0.257	
U238 fission	0.097	
Pu239 capture	0.030	
Pu239 fission	0.251	
Other losses	0.300	(includes control)
Total	1.000	

also U238 $\nu = 2.60$
Pu239 $\nu = 2.98$

a. Is this system critical, subcritical, or supercritical?

b. Is this system a plutonium breeder or burner?

Explain your logic and show the calculations used to support your answers!

Problem 2. UMLRR Control Blades: Densities, Cross Sections, Etc. (20 points)

Part A:

The UMass-Lowell research reactor (UMLRR) has recently installed a new control blade within the facility. The new material is a metal matrix composite (MMC) of boron carbide (B_4C) and aluminum (Al). The industrial name for the material is BORTEC (or sometimes it is called BORALCAN). The manufacturer specifications for the material are as follows:

$$\rho_{MMC} = \frac{2.685 \text{ g MMC}}{\text{cm}^3} \qquad \frac{\text{g B}_4\text{C}}{\text{g MMC}} = 0.206 \qquad \frac{\text{g B}}{\text{g B}_4\text{C}} = 0.76 \qquad \frac{\text{g B10}}{\text{g B}} = 0.181$$

With these specifications, calculate the atom densities of B-10, carbon, and aluminum for this material.

Use the following molecular weights in your calculations, as needed (units of g/gmole):

$M_{B10} = 10.01$, $M_{B11} = 11.01$, $M_{Cnat} = 12.01$, and $M_{Al} = 26.98$

Part B:

The new UMLRR control blade simply consists of a 0.375 inch (0.9525 cm) thick slab of BORTEC and a reasonable set of average total cross sections for thermal neutrons for the materials involved are:

$\sigma_{B10} = 3840$ b, $\sigma_{Cnat} = 5.58$ b, and $\sigma_{Al} = 1.85$ b

With this information, perform the following analyses:

a. Estimate the thermal macroscopic total cross section for the new BORTEC control blade.

b. Estimate the probability that a thermal neutron can pass through the control blade without a collision.

c. If a collision occurs, what is the probability that the interaction is with a B-10 atom?

Problem 3. Q-value Calculations (15 points)

Compute the Q-value for the following reactions (see selected set of mass data at end of exam):

a. n,α reaction in O-16

b. β^+ decay in Na-22

Problem 4. Gold Activation Analysis (15 points)

A small 0.12 g gold sample (pure Au197) is placed in an experimental location in a research reactor where the average neutron flux is 5×10^{11} n/cm^2-s. The properly averaged capture cross section for Au197 is approximately 85 b. The sample is irradiated for 4 hr after which it is removed from the neutron field. During the irradiation, radioactive Au198 is produced at a constant rate via neutron capture in Au197 (that is, the flux is constant and the amount of Au197 does not change significantly during the irradiation interval). The half-life of Au198 is about 2.7 days and its neutron absorption cross section is small.

Based on the above description, estimate the activity (in curies) of the gold sample at the following times:

a. immediately upon removal from the reactor and

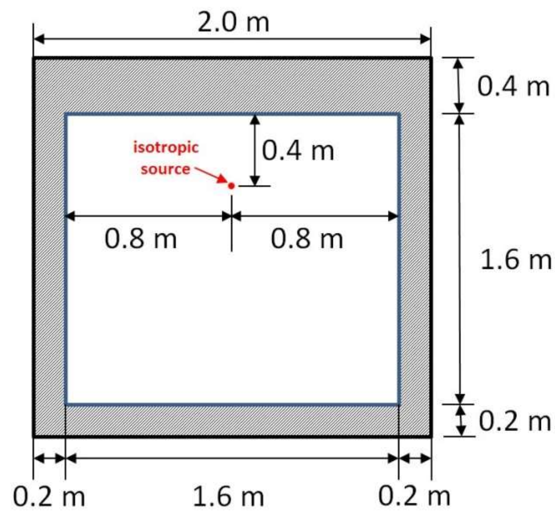
b. 72 hrs after removal from the reactor.

Explain your solution logic and support your results with a set of formal calculations/analyses.

Note: This is an application-oriented problem. As such, I am NOT asking for a formal derivation of the needed equations. Thus, if you know the equations to use (you should) or you have them on your Useful Information sheet, then you can just apply the appropriate relationships as needed. If, however, the equations are not readily available, then derive them -- since this is also a straightforward process. Either way, I am interested in your overall understanding of the activation analysis procedure, and your ability to estimate the activity of an irradiated sample during irradiation and after removal from a known neutron field.

Problem 5. Radiation Protection -- Distance and Shielding (15 points)

A small isotropic neutron source that emits 2×10^6 neutrons/second is contained in a tall air-filled concrete bunker. The top view of the usual storage geometry is shown in the sketch. The drawing is not to scale but the source location and bunker geometry are clearly identified with the dimensions given. The neutrons are emitted at high energy and a suitably averaged macroscopic cross section for concrete at high energy is $0.12\ cm^{-1}$. Note also that, at high energies, air can be considered as essentially a vacuum for neutron transport over distances of a few meters.



For this system, the goal is determine the flux magnitude and the location where the maximum uncollided flux (neutrons/cm^2-s) would be observed on the outer surface of the concrete container.

Clearly state any assumptions needed for your analysis and be sure to explain the logic used to identify where the maximum uncollided flux will occur.

Problem 6. Miscellaneous Stuff (20 points)

Part A:

List five (5) design or operational characteristics that are quite different between typical PWR and BWR designs.

Part B:

At a particular position, the particle flux is measured to be $2\times10^{12}\ cm^{-2}s^{-1}$.

a. If the particles are 1.2 MeV photons, what is the photon density (photons/cm^3) at this point?

b. If the particles are thermal neutrons (E = 0.0253 eV), what is the neutron density (neutrons/cm^3) at this location?

Part C:

The first resonance in the cross sections for Fe56 occurs at about 1 keV. The capture cross section at 100 eV is 0.038 b and the scattering cross section at this energy is roughly 11.7 b. Based on these facts and your understanding of the typical behavior of $\sigma(E)$, estimate σ_c, σ_s, and σ_t at 0.1 eV. State any assumptions.

Part D:

Identify several desirable properties of a neutron moderator (from a neutronics viewpoint). What single parameter is usually used to quantify many of these properties? Explain why this is used.

Some Useful Information for Use on (closed-book) Exams (from Shultis & Faw)

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 1 Ci = 3.7×10^{10} decays/sec

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