Georgia Institute of Technology

The George W. Woodruff School of Mechanical Engineering
Nuclear & Radiological Engineering/Medical Physics Program

Ph.D. Qualifier Exam

Spring Semester 2009

_______________ Your ID Code

Radiation Detection & Protection (Day 3)

Instructions

1. Use a separate page for each answer sheet (no front to back answers).
2. The question number should be shown on each answer sheet.
3. ANSWER 4 OF 6 QUESTIONS ONLY.
4. Staple your question sheet to your answer sheets and turn in.

NRE/MP Radiation Detection & Protection

Answer 4 of the following questions.

1. Describe two different systems (including the detector type and the associated electronics) that can both be used to measure neutron and gamma events separately in a mixed field of neutrons and gamma-rays, and describe the pros and cons of each system.
2. You are to determine the half-life and activity of a very weak ^{116m}In sample based on two consecutive 1-hr measurements with a GM counter. Given that the two measurement results are 1000 counts and 475 counts, respectively, and that the detection efficiency of the GM counter is 40% (i.e. it measures 40 counts per 100 disintegrations of ^{116m}In atoms),

   a. calculate the half-life and the standard deviation (or error) associated with it.
   b. calculate the initial activity (in dpm) and the associated error of the sample.

   Note: you may ignore the background count.
3. A narrow beam containing 10^{20} photons at 6 MeV impinges perpendicularly on a layer of lead 12 mm thick, having a density of 11.3 g/cm^3. See attachment A for necessary data.

   a. How many interactions of each type (i.e., photoelectric, Compton, and pair) occur in the lead?
   b. How much energy is transferred to charged particles due to pair production interactions in a) above?

ATTACHMENT A

Note: Perform a linear interpolation of the table values if necessary.

Photon interaction cross section data for Pb

(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
	Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
MeV	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g
1.000E+00	2.99E-03	4.99E-02	1.81E-02	0.00E+00	0.00E+00	7.10E-02	6.80E-02
1.022E+00	2.87E-03	4.94E-02	1.73E-02	0.00E+00	0.00E+00	6.96E-02	6.68E-02
1.250E+00	1.93E-03	4.48E-02	1.17E-02	3.78E-04	0.00E+00	5.88E-02	5.68E-02
1.500E+00	1.35E-03	4.07E-02	8.32E-03	1.81E-03	0.00E+00	5.22E-02	5.09E-02
2.000E+00	7.63E-04	3.48E-02	5.03E-03	5.45E-03	0.00E+00	4.61E-02	4.53E-02
2.044E+00	7.30E-04	3.44E-02	4.85E-03	5.77E-03	0.00E+00	4.58E-02	4.50E-02
3.000E+00	3.41E-04	2.74E-02	2.63E-03	1.19E-02	9.59E-06	4.23E-02	4.20E-02
4.000E+00	1.92E-04	2.29E-02	1.72E-03	1.71E-02	3.91E-05	4.20E-02	4.18E-02
5.000E+00	1.23E-04	1.98E-02	1.26E-03	2.15E-02	7.77E-05	4.27E-02	4.26E-02
6.000E+00	8.54E-05	1.75E-02	9.89E-04	2.52E-02	1.19E-04	4.39E-02	4.38E-02
7.000E+00	6.28E-05	1.57E-02	8.10E-04	2.85E-02	1.60E-04	4.53E-02	4.52E-02
8.000E+00	4.81E-05	1.43E-02	6.84E-04	3.15E-02	2.00E-04	4.67E-02	4.67E-02
9.000E+00	3.80E-05	1.32E-02	5.91E-04	3.42E-02	2.38E-04	4.82E-02	4.82E-02
1.000E+01	3.08E-05	1.22E-02	5.20E-04	3.67E-02	2.74E-04	4.97E-02	4.97E-02

In the following table, 1st column → $h\nu$; 2nd column → $_e\sigma$; 3rd column → $_e\sigma_{sc}$; 4th column → $_e\sigma_{tr}$

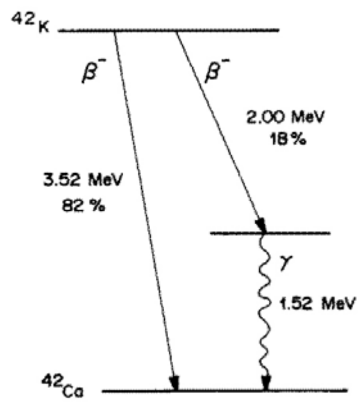
APPENDIX D.1 Klein–Nishina Interaction Cross Sections for Free Electrons[a]

$h\nu$ (keV)	$_e\sigma$ (cm^2/e)	$_e\sigma_s$ (cm^2/e)	$_e\sigma_{tr}$ (cm^2/e)
1.0	0.6627 −24	0.6614 −24	0.1291 −26
1.5	0.6614 −24	0.6594 −24	0.1929 −26
2.0	0.6601 −24	0.6575 −24	0.2561 −26
3.0	0.6576 −24	0.6537 −24	0.3811 −26
4.0	0.6550 −24	0.6500 −24	0.5041 −26
5.0	0.6525 −24	0.6463 −24	0.6251 −26
6.0	0.6501 −24	0.6426 −24	0.7441 −26
8.0	0.6452 −24	0.6355 −24	0.9766 −26
10.0	0.6405 −24	0.6285 −24	0.1202 −25
15.0	0.6290 −24	0.6116 −24	0.1735 −25
20.0	0.6180 −24	0.5957 −24	0.2228 −25
30.0	0.5975 −24	0.5664 −24	0.3109 −25
40.0	0.5787 −24	0.5400 −24	0.3871 −25
50.0	0.5615 −24	0.5162 −24	0.4532 −25
60.0	0.5456 −24	0.4945 −24	0.5109 −25
80.0	0.5173 −24	0.4567 −24	0.6059 −25
100.0	0.4927 −24	0.4247 −24	0.6800 −25
150.0	0.4436 −24	0.3631 −24	0.8054 −25
200.0	0.4065 −24	0.3185 −24	0.8794 −25
300.0	0.3535 −24	0.2581 −24	0.9531 −25
400.0	0.3167 −24	0.2186 −24	0.9805 −25
500.0	0.2892 −24	0.1905 −24	0.9871 −25
600.0	0.2675 −24	0.1692 −24	0.9831 −25
662.0	0.2561 −24	0.1584 −24	0.9775 −25
800.0	0.2350 −24	0.1389 −24	0.9602 −25
(MeV)			
1.0	0.2112 −24	0.1183 −24	0.9294 −25
1.25	0.1888 −24	0.9997 −25	0.8885 −25
1.5	0.1716 −24	0.8670 −25	0.8488 −25
2.0	0.1464 −24	0.6867 −25	0.7769 −25
3.0	0.1151 −24	0.4865 −25	0.6644 −25
4.0	0.9597 −25	0.3772 −25	0.5825 −25
5.0	0.8287 −25	0.3083 −25	0.5204 −25
6.0	0.7323 −25	0.2607 −25	0.4716 −25
8.0	0.5988 −25	0.1993 −25	0.3995 −25
10.0	0.5099 −25	0.1613 −25	0.3485 −25
15.0	0.3771 −25	0.1094 −25	0.2678 −25
20.0	0.3025 −25	0.8271 −26	0.2198 −25
30.0	0.2200 −25	0.5563 −26	0.1644 −25
40.0	0.1746 −25	0.4191 −26	0.1327 −25
50.0	0.1457 −25	0.3362 −26	0.1121 −25
60.0	0.1254 −25	0.2807 −26	0.9736 −26
80.0	0.9882 −26	0.2110 −26	0.7772 −26
100.0	0.8199 −26	0.1690 −26	0.6508 −26

[a] Table provided by Patrick D. Higgins, personal communication, 1986.

4. A 10-Ci point isotropic source of ^{42}K is located behind a lead shield with the thickness of 13 cm. Without a shield, the exposure rate at 1 m from the source is known to be 1.37 R h^{-1}. What will be the exposure rate at 1 m from the same source with a lead shield in place?

   Note: 1 Ci = 3.7×10^{10} Bq, ρ_{Pb} = 11.3 g/cm^3. See attachment B tables for buildup factors and photon attenuation coefficients. You may neglect β-particles for this problem.



ATTACHMENT B

TABLE 15.1. Dose Buildup Factors *B* for a Point Isotropic Source

		Number of Relaxation Lengths, μx						
Material	MeV	1	2	4	7	10	15	2
Water	0.5	2.52	5.14	14.3	38.8	77.6	178	334
	1.0	2.13	3.71	7.68	16.2	27.1	50.4	82
	2.0	1.83	2.77	4.88	8.46	12.4	19.5	27
	3.0	1.69	2.42	3.91	6.23	8.63	12.8	17
	4.0	1.58	2.17	3.34	5.13	6.94	9.97	12
	6.0	1.46	1.91	2.76	3.99	5.18	7.09	8.
	8.0	1.38	1.74	2.40	3.34	4.25	5.66	6.
	10.0	1.33	1.63	2.19	2.97	3.72	4.90	5.
Aluminum	0.5	2.37	4.24	9.47	21.5	38.9	80.8	141
	1.0	2.02	3.31	6.57	13.1	21.2	37.9	58.
	2.0	1.75	2.61	4.62	8.05	11.9	18.7	26.
	3.0	1.64	2.32	3.78	6.14	8.65	13.0	17.
	4.0	1.53	2.08	3.22	5.01	6.88	10.1	13.
	6.0	1.42	1.85	2.70	4.06	5.49	7.97	10.
	8.0	1.34	1.68	2.37	3.45	4.58	6.56	8.
	10.0	1.28	1.55	2.12	3.01	3.96	5.63	7.
Iron	0.5	1.98	3.09	5.98	11.7	19.2	35.4	55.
	1.0	1.87	2.89	5.39	10.2	16.2	28.3	42.
	2.0	1.76	2.43	4.13	7.25	10.9	17.6	25.
	3.0	1.55	2.15	3.51	5.85	8.51	13.5	19.
	4.0	1.45	1.94	3.03	4.91	7.11	11.2	16.
	6.0	1.34	1.72	2.58	4.14	6.02	9.89	14.
	8.0	1.27	1.56	2.23	3.49	5.07	8.50	13.
	10.0	1.20	1.42	1.95	2.99	4.35	7.54	12.
Lead	0.5	1.24	1.42	1.69	2.00	2.27	2.65	2.
	1.0	1.37	1.69	2.26	3.02	3.74	4.81	5.
	2.0	1.39	1.76	2.51	3.66	4.84	6.87	9.
	3.0	1.34	1.68	2.43	2.75	5.30	8.44	12.
	4.0	1.27	1.56	2.25	3.61	5.44	9.80	16.
	6.0	1.18	1.40	1.97	3.34	5.69	13.8	32.
	8.0	1.14	1.30	1.74	2.89	5.07	14.1	44.
	10.0	1.11	1.23	1.58	2.52	4.34	12.5	39.
Uranium	0.5	1.17	1.30	1.48	1.67	1.85	2.08	—
	1.0	1.31	1.56	1.98	2.50	2.97	3.67	—
	2.0	1.33	1.64	2.23	3.09	3.95	5.36	6.
	3.0	1.29	1.58	2.21	3.27	4.51	6.97	9.
	4.0	1.24	1.50	2.09	3.21	4.66	8.01	12.
	6.0	1.16	1.36	1.85	2.96	4.80	10.8	23.
	8.0	1.12	1.27	1.66	2.61	4.36	11.2	28.
	10.0	1.09	1.20	1.51	2.26	3.78	10.5	28.

Source: Tables 15.1 and 15.2 are from U.S. Public Health Service, *Radiological Health Handbc* Publ. No. 2016, Bureau of Radiological Health, Rockville, Md. (1970). For concrete, use aver of values for Al and Fe.

5. A 600-MeV parallel alpha beam impinges on a person. Assume the person is 30 cm thick, semi-infinite slab of striated muscle (1 g/cm^3). The incident intensity of the beam is 10^6 alpha particles per second per cm^2. Data for alphas in striated muscle are attached.
   a. What is the absorbed dose rate (Gy/s) at a depth of 8 cm in the person.
   b. Does the thickness of the "person" exceed the range of the alpha particle?
   c. Assuming that the maximum of the Bragg peak occurs at the maximum stopping power or LET, at what depth in the phantom does it occur?

ALPHA DATA FROM ICRU REPORT 49

ALPHA PARTICLES IN MUSCLE, STRIATED (ICRU)

ENERGY	STOPPING POWER			CSDA	DETOUR
	ELECTRONIC	NUCLEAR	TOTAL	RANGE	FACTOR
MeV	MeV cm2/g	MeV cm2/g	MeV cm2/g	g/cm2	
0.001	1.047E+02	2.226E+02	3.273E+02	3.302E-06	0.5172
0.0015	1.294E+02	2.029E+02	3.324E+02	4.814E-06	0.5335
0.002	1.505E+02	1.868E+02	3.372E+02	6.308E-06	0.5482
0.0025	1.692E+02	1.734E+02	3.426E+02	7.779E-06	0.5612
0.003	1.862E+02	1.622E+02	3.484E+02	9.227E-06	0.5730
0.004	2.165E+02	1.444E+02	3.609E+02	1.205E-05	0.5935
0.005	2.434E+02	1.307E+02	3.741E+02	1.477E-05	0.6109
0.006	2.679E+02	1.198E+02	3.877E+02	1.740E-05	0.6261
0.007	2.905E+02	1.108E+02	4.013E+02	1.993E-05	0.6395
0.008	3.117E+02	1.033E+02	4.150E+02	2.238E-05	0.6514
0.009	3.316E+02	9.690E+01	4.285E+02	2.475E-05	0.6622
0.010	3.505E+02	9.136E+01	4.419E+02	2.705E-05	0.6720
0.0125	3.942E+02	8.026E+01	4.745E+02	3.251E-05	0.6931
0.015	4.339E+02	7.186E+01	5.058E+02	3.761E-05	0.7105
0.0175	4.706E+02	6.525E+01	5.358E+02	4.241E-05	0.7252
0.020	5.049E+02	5.988E+01	5.647E+02	4.695E-05	0.7378
0.0225	5.372E+02	5.543E+01	5.926E+02	5.127E-05	0.7488
0.025	5.678E+02	5.166E+01	6.194E+02	5.540E-05	0.7586
0.0275	5.969E+02	4.843E+01	6.454E+02	5.935E-05	0.7672
0.030	6.249E+02	4.562E+01	6.705E+02	6.315E-05	0.7751
0.035	6.775E+02	4.097E+01	7.185E+02	7.035E-05	0.7886
0.040	7.267E+02	3.727E+01	7.639E+02	7.710E-05	0.7999
0.045	7.728E+02	3.424E+01	8.071E+02	8.346E-05	0.8096
0.050	8.165E+02	3.171E+01	8.482E+02	8.951E-05	0.8180
0.055	8.581E+02	2.956E+01	8.877E+02	9.527E-05	0.8254
0.060	8.978E+02	2.771E+01	9.255E+02	1.008E-04	0.8320
0.065	9.358E+02	2.610E+01	9.619E+02	1.061E-04	0.8379
0.070	9.723E+02	2.469E+01	9.970E+02	1.112E-04	0.8432
0.075	1.007E+03	2.343E+01	1.031E+03	1.161E-04	0.8481
0.080	1.041E+03	2.231E+01	1.064E+03	1.209E-04	0.8525
0.085	1.074E+03	2.130E+01	1.096E+03	1.255E-04	0.8565
0.090	1.106E+03	2.038E+01	1.126E+03	1.300E-04	0.8603
0.095	1.137E+03	1.955E+01	1.156E+03	1.344E-04	0.8637
0.100	1.167E+03	1.879E+01	1.185E+03	1.387E-04	0.8670
0.125	1.304E+03	1.578E+01	1.320E+03	1.586E-04	0.8803
0.150	1.425E+03	1.366E+01	1.439E+03	1.768E-04	0.8904
0.175	1.532E+03	1.208E+01	1.544E+03	1.935E-04	0.8983
0.200	1.629E+03	1.085E+01	1.640E+03	2.092E-04	0.9048
0.225	1.715E+03	9.859E+00	1.725E+03	2.241E-04	0.9103
0.250	1.793E+03	9.048E+00	1.802E+03	2.382E-04	0.9149
0.275	1.863E+03	8.370E+00	1.871E+03	2.519E-04	0.9190
0.30	1.925E+03	7.793E+00	1.933E+03	2.650E-04	0.9225
0.35	2.032E+03	6.862E+00	2.039E+03	2.902E-04	0.9286
0.40	2.116E+03	6.142E+00	2.122E+03	3.142E-04	0.9335
0.45	2.181E+03	5.568E+00	2.187E+03	3.374E-04	0.9377
0.50	2.230E+03	5.098E+00	2.235E+03	3.600E-04	0.9413
0.55	2.265E+03	4.706E+00	2.270E+03	3.821E-04	0.9445
0.60	2.289E+03	4.374E+00	2.293E+03	4.041E-04	0.9473
0.65	2.302E+03	4.088E+00	2.306E+03	4.258E-04	0.9498
0.70	2.306E+03	3.839E+00	2.310E+03	4.474E-04	0.9520
0.75	2.304E+03	3.621E+00	2.307E+03	4.691E-04	0.9541
0.80	2.295E+03	3.428E+00	2.299E+03	4.908E-04	0.9560
0.85	2.282E+03	3.256E+00	2.285E+03	5.126E-04	0.9578
0.90	2.264E+03	3.101E+00	2.267E+03	5.346E-04	0.9594
0.95	2.244E+03	2.961E+00	2.246E+03	5.567E-04	0.9609
1.00	2.220E+03	2.834E+00	2.223E+03	5.791E-04	0.9623
1.25	2.063E+03	2.340E+00	2.065E+03	6.956E-04	0.9683
1.50	1.894E+03	2.000E+00	1.896E+03	8.219E-04	0.9730
1.75	1.742E+03	1.750E+00	1.744E+03	9.595E-04	0.9766
2.00	1.611E+03	1.558E+00	1.612E+03	1.109E-03	0.9796
2.25	1.498E+03	1.407E+00	1.500E+03	1.270E-03	0.9821
2.50	1.401E+03	1.283E+00	1.403E+03	1.442E-03	0.9841
2.75	1.318E+03	1.180E+00	1.319E+03	1.626E-03	0.9858
3.0	1.244E+03	1.094E+00	1.246E+03	1.821E-03	0.9872
3.5	1.123E+03	9.553E-01	1.123E+03	2.245E-03	0.9895
4.0	1.025E+03	8.493E-01	1.026E+03	2.711E-03	0.9911

ENERGY	STOPPING POWER			CSDA	DETOUR
	ELECTRONIC	NUCLEAR	TOTAL	RANGE	FACTOR
MeV	MeV cm2/g	MeV cm2/g	MeV cm2/g	g/cm2	
4.5	9.445E+02	7.654E-01	9.453E+02	3.219E-03	0.9924
5.0	8.772E+02	6.973E-01	8.779E+02	3.768E-03	0.9934
5.5	8.199E+02	6.408E-01	8.206E+02	4.358E-03	0.9942
6.0	7.706E+02	5.932E-01	7.712E+02	4.987E-03	0.9949
6.5	7.273E+02	5.524E-01	7.279E+02	5.655E-03	0.9954
7.0	6.892E+02	5.171E-01	6.897E+02	6.361E-03	0.9958
7.5	6.553E+02	4.862E-01	6.558E+02	7.104E-03	0.9962
8.0	6.250E+02	4.590E-01	6.255E+02	7.885E-03	0.9965
8.5	5.977E+02	4.348E-01	5.981E+02	8.703E-03	0.9968
9.0	5.729E+02	4.131E-01	5.733E+02	9.557E-03	0.9970
9.5	5.504E+02	3.936E-01	5.508E+02	1.045E-02	0.9972
10.0	5.297E+02	3.759E-01	5.301E+02	1.137E-02	0.9974
12.5	4.478E+02	3.075E-01	4.481E+02	1.652E-02	0.9980
15.0	3.896E+02	2.608E-01	3.898E+02	2.252E-02	0.9984
17.5	3.459E+02	2.268E-01	3.461E+02	2.934E-02	0.9987
20.0	3.118E+02	2.009E-01	3.120E+02	3.696E-02	0.9988
22.5	2.844E+02	1.804E-01	2.846E+02	4.536E-02	0.9990
25.0	2.618E+02	1.638E-01	2.619E+02	5.453E-02	0.9990
27.5	2.428E+02	1.501E-01	2.429E+02	6.444E-02	0.9991
30.0	2.265E+02	1.386E-01	2.267E+02	7.511E-02	0.9992
35.0	2.003E+02	1.202E-01	2.005E+02	9.861E-02	0.9993
40.0	1.800E+02	1.063E-01	1.801E+02	1.250E-01	0.9993
45.0	1.637E+02	9.527E-02	1.638E+02	1.541E-01	0.9994
50.0	1.504E+02	8.637E-02	1.505E+02	1.860E-01	0.9994
55.0	1.392E+02	7.902E-02	1.393E+02	2.206E-01	0.9994
60.0	1.298E+02	7.283E-02	1.298E+02	2.578E-01	0.9994
65.0	1.216E+02	6.755E-02	1.217E+02	2.976E-01	0.9995
70.0	1.145E+02	6.300E-02	1.146E+02	3.399E-01	0.9995
75.0	1.083E+02	5.903E-02	1.083E+02	3.848E-01	0.9995
80.0	1.027E+02	5.553E-02	1.028E+02	4.322E-01	0.9995
85.0	9.781E+01	5.244E-02	9.786E+01	4.821E-01	0.9995
90.0	9.337E+01	4.968E-02	9.342E+01	5.344E-01	0.9995
95.0	8.936E+01	4.720E-02	8.941E+01	5.891E-01	0.9995
100.0	8.572E+01	4.496E-02	8.576E+01	6.463E-01	0.9995
125.0	7.154E+01	3.635E-02	7.158E+01	9.669E-01	0.9996
150.0	6.176E+01	3.051E-02	6.179E+01	1.344E+00	0.9996
175.0	5.458E+01	2.629E-02	5.461E+01	1.775E+00	0.9996
200.0	4.908E+01	2.310E-02	4.910E+01	2.259E+00	0.9996
225.0	4.471E+01	2.061E-02	4.473E+01	2.793E+00	0.9996
250.0	4.116E+01	1.861E-02	4.118E+01	3.376E+00	0.9996
275.0	3.822E+01	1.696E-02	3.824E+01	4.007E+00	0.9996
300.0	3.574E+01	1.557E-02	3.575E+01	4.683E+00	0.9996
350.0	3.177E+01	1.339E-02	3.179E+01	6.170E+00	0.9996
400.0	2.875E+01	1.174E-02	2.876E+01	7.826E+00	0.9996
450.0	2.636E+01	1.046E-02	2.637E+01	9.644E+00	0.9996
500.0	2.442E+01	9.423E-03	2.443E+01	1.162E+01	0.9997
550.0	2.283E+01	8.578E-03	2.283E+01	1.373E+01	0.9997
600.0	2.148E+01	7.873E-03	2.149E+01	1.599E+01	0.9997
650.0	2.034E+01	7.274E-03	2.034E+01	1.839E+01	0.9997
700.0	1.935E+01	6.758E-03	1.935E+01	2.091E+01	0.9997
750.0	1.849E+01	6.310E-03	1.849E+01	2.355E+01	0.9997
800.0	1.773E+01	5.917E-03	1.774E+01	2.631E+01	0.9997
850.0	1.706E+01	5.570E-03	1.706E+01	2.919E+01	0.9997
900.0	1.646E+01	5.262E-03	1.647E+01	3.217E+01	0.9997
950.0	1.592E+01	4.987E-03	1.593E+01	3.526E+01	0.9997
1000.0	1.544E+01	4.740E-03	1.545E+01	3.845E+01	0.9997

6. The air concentration of Cs-138, the short-lived particulate progeny of Xe-138, is found at a research reactor be in the air at a concentration of 400 Bq/cm^3.

   a. Air is sampled through a particulate filter at a flow rate of 3.5 liters/minute (1 liter – 1000 cm^3). The collection efficiency of the filter is 90%. Starting with a fresh filter, what quantity of activity remains on the filter at the end of a 33-minute sampling period?
   b. What activity of Cs-138 would be present on the filter at equilibrium? Assume the air concentration is always the same.
   c. If the filter is used to sample until the equilibrium amount of Cs-138 attached to it and then immediately (no decay before it is loaded into the detector) counted for 10 minutes with a GM counter that has a 10% absolute detection efficiency, how many total counts are observed?

   Half-life of Cs-138 = 33 minutes.