22.01 Introduction to Ionizing Radiation Name:____________________
Fall 2003
Professor Coderre
Quiz # 2
October 27, 2003

You have 50 minutes to complete this quiz.
This quiz is closed book.
Please show all work on the attached sheets.

Supplemental information is attached for some of the problems.

This quiz consists of 4 questions worth a total of 100 points.

The point values for each question are indicated in parentheses next to the question number.

1. (25 points)
Stopping Power. High-energy carbon ions are used in radiation therapy.
(A) What is the stopping power (-dE/dx) of 200 MeV/nucleon carbon ions in water?
(B) What is the range of these ions in water?
Assume that the carbon is fully stripped of electrons (+6 charge).
Given:

$$-\frac{dE}{dx} = \frac{5.08\,x10^{-31}\,z^2 n}{\beta^2}[F(\beta) - \ln I_{ev}] \quad \text{MeV cm}^{-1}$$

where, $F(\beta) = \ln\frac{1.02\,x10^6\,\beta^2}{1-\beta^2} - \beta^2$

and
$\ln I_{ev}$ for water = 4.312
$n = 3.34 \times 10^{29}$ electrons/m^3

TABLE 5.3. Mass Stopping Power $-dE/\rho dx$ and Range R_p for Protons in Water

Kinetic Energy (MeV)	β^2	$-dE/\rho dx$ (MeV cm^2 g^{-1})	R_p (g cm^{-2})
0.01	.000021	500.	3×10^{-5}
0.04	.000085	860.	6×10^{-5}
0.05	.000107	910.	7×10^{-5}
0.08	.000171	920.	9×10^{-5}
0.10	.000213	910.	1×10^{-4}
0.50	.001065	428.	8×10^{-4}
1.00	.002129	270.	0.002
2.00	.004252	162.	0.007
4.00	.008476	95.4	0.023
6.00	.01267	69.3	0.047
8.00	.01685	55.0	0.079
10.0	.02099	45.9	0.118
12.0	.02511	39.5	0.168
14.0	.02920	34.9	0.217
16.0	.03327	31.3	0.280
18.0	.03731	28.5	0.342
20.0	.04133	26.1	0.418
25.0	.05126	21.8	0.623
30.0	.06104	18.7	0.864
35.0	.07066	16.5	1.14
40.0	.08014	14.9	1.46
45.0	.08948	13.5	1.80
50.0	.09867	12.4	2.18
60.0	.1166	10.8	3.03
70.0	.1341	9.55	4.00
80.0	.1510	8.62	5.08
90.0	.1675	7.88	6.27
100.	.1834	7.28	7.57
150.	.2568	5.44	15.5
200.	.3207	4.49	25.5
300.	.4260	3.52	50.6
400.	.5086	3.02	80.9
500.	.5746	2.74	115.
600.	.6281	2.55	152.
700.	.6721	2.42	192.
800.	.7088	2.33	234.
900.	.7396	2.26	277.
1000.	.7658	2.21	321.
2000.	.8981	2.05	795.
4000.	.9639	2.09	1780.

2. (25 points)
Neutron Activation. A gold foil weighing 3.500 mg is irradiated with thermal neutrons for exactly 10 minutes. Forty-eight hours after the end of the irradiation, the foil is placed in a gamma spectrometer with 100% counting efficiency and an activity of 2750 Bq is recorded.
(A) What was the thermal neutron flux (neutrons/cm^2/sec) to which the foil was exposed?
(B) What would be the saturation activity of this gold foil when exposed to this neutron flux?

Given:
^{197}Au (100% abundance)
thermal neutron capture cross section, σ = 98.8 barns
$^{197}Au + n \rightarrow {}^{198}Au$
^{198}Au t½ = 2.7 days

$$A = \lambda N = \Phi \sigma N_T (1 - e^{-\lambda t})$$

3. (25 points)

A narrow beam of 25 MeV photons passes through 20 cm of concrete ($\rho = 2.35$ g/cm^3), 100 cm of air ($\rho = 1.29 \times 10^{-3}$ g/cm^3) and then through 0.5 cm of lead ($\rho = 11.4$ g/cm^3). The original fluence rate of the beam was 2×10^{10} photons/cm^2/sec.

(A) What is the fluence rate of photons in the beam that passes through the concrete without interaction?

(B) What is the fluence rate of photons in the beam emerging from the lead without interaction?

(C) What secondary, long-range radiation might be produced in the lead?

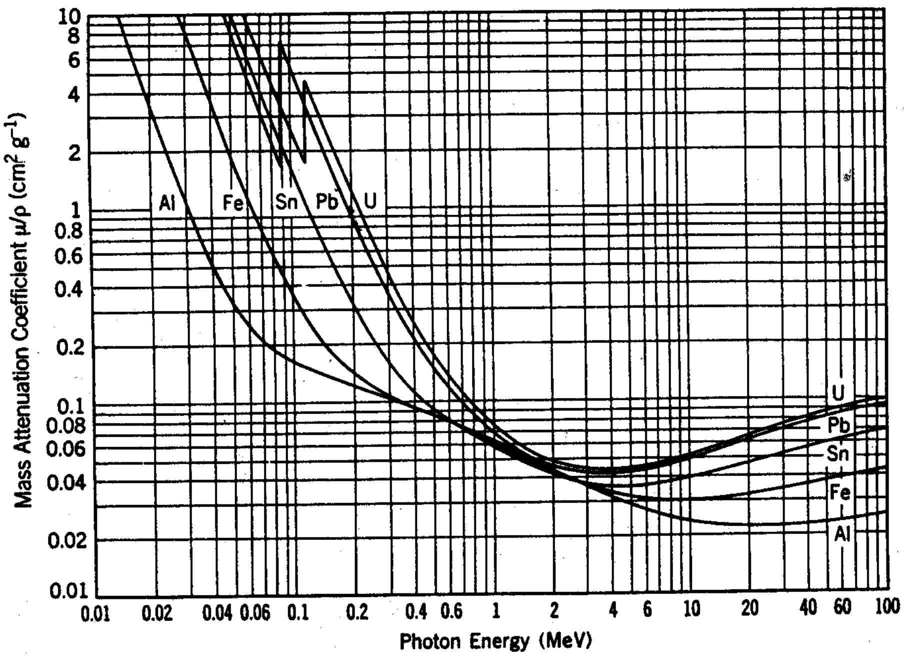

FIGURE 8.8. Mass attenuation coefficients for various elements. [Reprinted with permission from K. Z. Morgan and J. E. Turner, eds., *Principles of Radiation Protection*, Wiley, New York (1967). Copyright 1967 by John Wiley & Sons.]

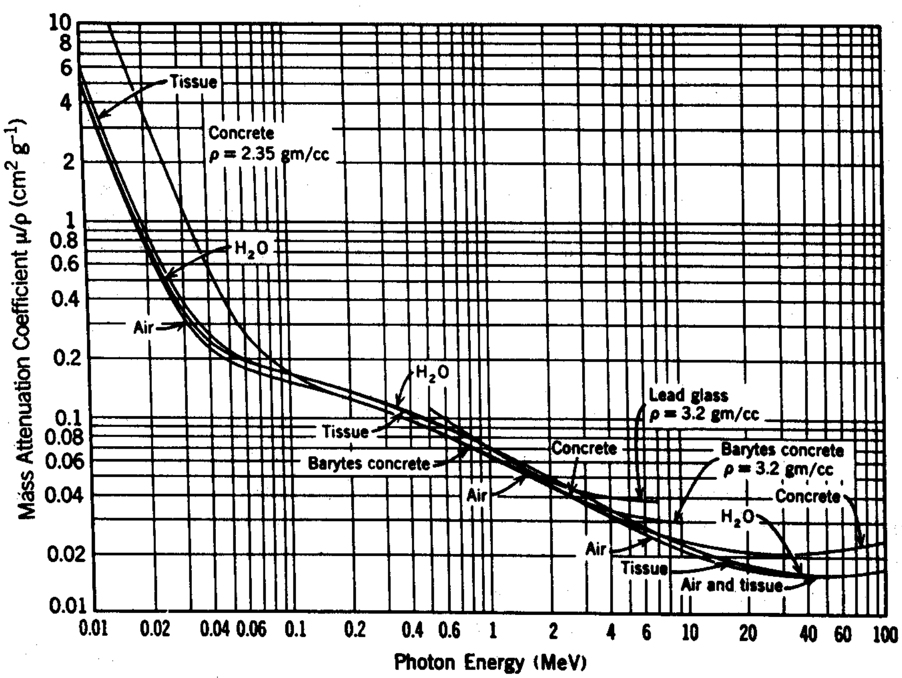

FIGURE 8.9. Mass attenuation coefficients for various materials. [Reprinted with permission from K. Z. Morgan and J. E. Turner, eds., *Principles of Radiation Protection*, Wiley, New York (1967). Copyright 1967 by John Wiley & Sons.]

4. (25 points)
A narrow beam of 100 MeV neutrons, with a fluence of 10^5 n/cm^2/sec, is normally incident on an aluminum [$^{27}_{13}Al$] plate. The elastic scattering cross section of aluminum for 100 MeV neutrons is 0.95 barns. The density of aluminum is 2.7 g/cm^3.

(A) How thick must the aluminum plate be in order to reduce the number of unscattered neutrons emerging from the plate by three orders of magnitude?
(B) How much would this plate attenuate a narrow beam of 100 MeV **photons**?