22.55 Principles of Radiation Interactions Name:____________________
Spring 2004
Professor Coderre
Exam 1
March 12, 2004

You have 1.5 hours to complete this exam.
This exam is closed book.
Please show all work on the attached sheets.

Supplemental information (equations, Turner Table 5.3) is attached at the back.

This exam consists of 7 questions worth a total of 100 points.
The point values for each question are indicated in parentheses next to the question number.

1. (10 points)
a) What is the oxygen effect?
b) Why is this thought to be important in radiation therapy?
c) How does the Oxygen Enhancement Ratio (OER) vary with LET? Draw a diagram if it will help explain your answer.

2. (10 points)
Short answers.

a) A cell attempts to repair a site with relatively minor base damage but in the process actually creates much more serious, perhaps lethal, damage. Does this make sense? Explain.

b) Why must DNA damage assays based on the fraction of activity released into a gel use radiation doses as high as 900 Gy?

3. (20 points)

A spherical cell nucleus, 4 μm in diameter, is traversed at its thickest point by a single galactic cosmic ray: an iron particle ($^{56}_{26}Fe$) with energy 1.96 GeV and LET 951 keV/μm.

a) Calculate the dose, in Gy, to the entire nucleus. State any assumptions you make.
b) If the G value for OH radical production is 0.25, how many OH radicals are produced in the nucleus?

4. (15 points)

a) To what energies would you need to accelerate ${}^{12}_{6}C$ and ${}^{238}_{92}U$ ions in order for them to each have the same penumbra radius as a 240 MeV neon ion (${}^{20}_{10}Ne$)?

b) Estimate the range in water of each of these 3 ions.

5. (10 points)
A 10 gram tumor is treated with a total dose of 60 Gy of photons. The fractionated treatment (30 daily fractions of 2 Gy each) results in an effective survival curve that has no shoulder and a D_0 of 3.1 Gy. Assume that 1 gram of tumor contains 10^9 tumor cells. How many tumor cells survive this treatment?

6. (20 points)
An unknown organism (from Mars) has invaded the NASA radiation biology facility at Brookhaven National laboratory. Experimenters there irradiate the organism with various particle beams and measure the survival, generating the following data. From these results estimate the size of this organism.

Particle	***Charge (z)***	***LET (keV/μm)***	***D_0 (Gy)***
^{1}H	1	10	1.6×10^6
^{4}He	2	65	1.5×10^6
^{12}C	6	250	2.0×10^6
^{20}Ne	10	850	1.7×10^6
^{40}Ar	18	2000	3.5×10^6

7. (15 points)
Your mission is to determine the energy of a beam of photons. Using an ionization chamber to measure intensity and a series of 1 mm aluminum plates, you determine that 17 of these 1 mm aluminum plates reduces the intensity of the beam to 50% (i.e., half value layer is 1.7 cm of aluminum; aluminum MW = 27 grams/mole; density = 2.7 g/cm^3).
a) What is the energy of this beam?
b) What is the atomic cross section of aluminum for this energy photon?

Supplemental Material (you do not need all of this)

1 eV = 1.602 x 10^{-19} J
proton mass = 1.0073 AMU = 938.27 MeV = 1.6726 x 10^{-27} kg
neutron mass = 1.0087 AMU = 939.57 MeV = 1.6749 x 10^{-27} kg
electron mass = 0.00054858 AMU = 0.511 MeV = 9.1094 x 10^{-31} kg

penumbra radius, r_p

$$r_p = 0.768\,E - 1.925\sqrt{E}\ + 1.257\ \mathit{microns}$$

where E =MeV/nucleon.

core radius, r_c

$$r_c = 0.0116\ \beta$$

Energy densities, $\boldsymbol{\rho}$, for the core and the penumbra:

$$\rho_c = \frac{LET_\infty / 2}{\pi\, r_c^2} + \frac{LET_\infty / 2}{2\pi\, r_c^2 \ln(\sqrt{e}\cdot r_p / r_c)}$$

$$\rho_p = \frac{LET_\infty / 2}{2\pi\, r_c^2 \ln(\sqrt{e}\cdot r_p / r_c)}$$

Stopping power:

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

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

$\ln I_{ev} = 4.312$
n = 3.34 x 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.

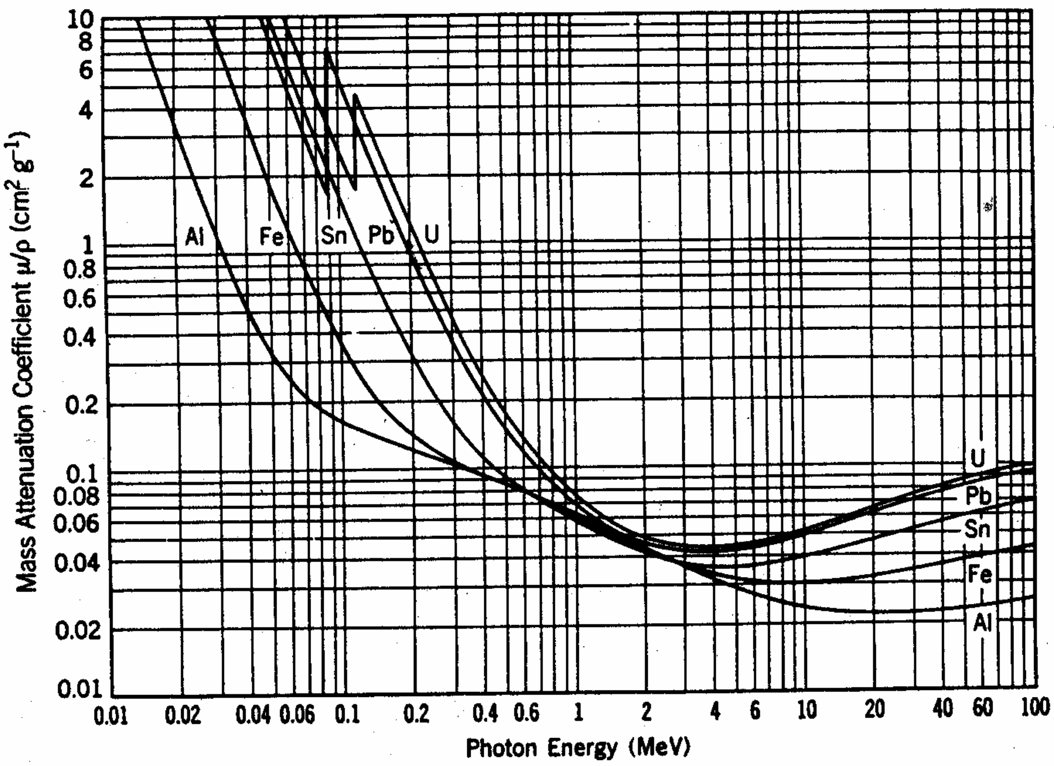

FIGURE 8.8. Mass attenuation coefficients for various elements. [Reprinted with permission from K. Z. Morgan and J. E. Turner, eds., *Principles of Radiation Protection*, Wiley, New York (1967). Copyright 1967 by John Wiley & Sons.]