GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1995

Health Physics - Day One
EXAM AREA

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Name

-- **Please sign your name on the back of this page** --

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

Health Physics

Ph.D. Qualifiers Exam

Fall Quarter, 1995

Day 1

Instructions

1. Complete 6 of the 8 questions.
2. Place your identifying code letter on the top right corner of each page of your question and answer sheets.
3. Use a separate page for each answer sheet (no front to back answers).
4. The question number should be shown on each answer sheet.
5. Staple your question sheet to your answer sheets and turn in.

HP.I.1. Refer to the following beta decay process:

$$n \dashrightarrow p^{+} + \beta^{-} + \bar{\nu}$$

The rest masses of neutron, proton, and β^{-} are 939.6, 938.3, and 0.511 MeV/c^2, respectively. Assume that the initial kinetic energy of the neutron is zero, and that the $\bar{\nu}$ carries no energy, calculate the kinetic energies associated with p^{+} and β^{-}. The energy and momentum relationship for electron or positron is given by: $(cp)^2 = E^2 - (m_0c^2)^2$, where p is the momentum and c is the speed of light.

HP.I.2. The "liquid drop" model is used to derive an expression for the expected mass of a nuclide with given numbers of protons (Z) and neutrons (N). Using this model, give the semi-empirical mass equation in symbolic form as a function of A, Z, and N.

Briefly describe the basis for each term in the resulting equation.

HP.I.3. A very thin (<10 μm) ^{115}In foil was irradiated in a nuclear reactor for 2 hours, and then taken out and measured with a GM counter for 1 hour.

Given:

1. The detection efficiency of the counter for measuring ^{116m}In decays is 5%,
2. The background count is negligible,
3. The total counts accumulated in 1 hour is 10,000,
4. The half life of ^{116m}In is 54 minutes, and
5. The averaged macroscopic absorption cross section of ^{115}In for thermal neutrons is 7.5 cm^{-1}.

Estimate:

a. the initial (i.e. when the counter started counting) activity of the ^{116m}In, and

b. the thermal neutron flux (in neutrons/cm^2-sec) in the reactor during irradiation.

Note: Please carefully include the counting statistics in your calculation.

HP.I.4 An 1-MeV photon fully deposits its energy in a HPGe detector connected to the circuit shown in Fig. a below. Assume that the current output of the event from the HPGe detector is uniformly distributed in a 50-ns period (see Fig. b below).

Given: $C_f = 10$ pF and $R_f = 1.0 \times 10^7$ ohms.

Calculate the peak preamplifier output voltage, and sketch the time-dependent preamplifier output.

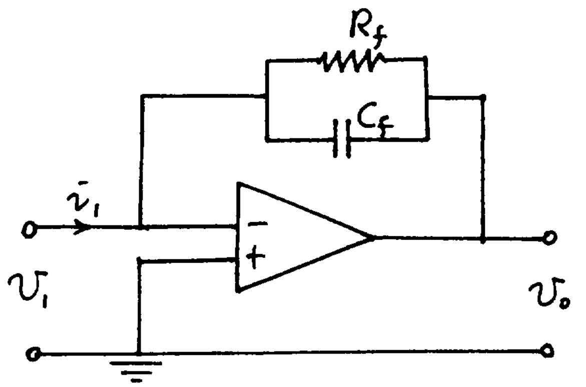

Fig. a

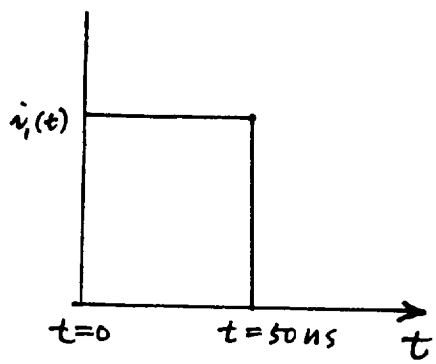

Fig. b

HP.I.5. The energy resolution of a spectrometry detector is usually proportional to the fractional deviation of the electric charge (i.e. σ_Q/Q) collected at the preamplier. Discuss the major properties of a detector that affect σ_Q/Q for a proportional counter, a NaI(Tl) scintillator, and a HPGe detector, respectively, and then assign the figure of merit (FOM) of the energy resolution for each detector accordingly. (Note: you must be as quantitative as possible)

HP.I.6. On the basis of the semi-empirical mass equation, discuss the observation that odd A nuclides have only one stable isobar, whereas even A nuclide can have more than one stable isobar.

HP.I.7. Describe how Bonner-Sphere technique is used to measure a neutron spectrum. (Note: you must include mathematical expression in your description)

HP.I.8. Can a G-M counter be used as an accurate dosimeter in an unknown gamma field? Why?

8

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1995

Health Physics - Day 2
EXAM AREA

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Assigned Number **(DO NOT SIGN YOUR NAME)**

-- Please sign your name on the back of this page --

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

Health Physics

Ph.D. Qualifiers Exam

Fall Quarter, 1995

Day 2

Instructions

1. Complete 6 of the 8 questions.
2. Place your identifying code letter on the top right corner of each page of your question and answer sheets.
3. Use a separate page for each answer sheet (no front to back answers).
4. The question number should be shown on each answer sheet.
5. Staple your question sheet to your answer sheets and turn in.

HP.II.1. A particulate air sample is to be used in estimating Kr-88 concentrations in a PWR containment building. The filter paper is counted for a 30-minute period to detect the Rb-88 beta particles. The Kr-88 source input has been continuous and the Kr-88 concentration unchanged for 2 days. Assume that the collection of the Kr-88 on the filter paper is negligible.

Given:

Kr-88 → Rb-88 + β^-

Kr-88 half-life = 2.84 hr

Rb-88 half-life = 17.7 minutes

Net counts in 30 minutes = 1.50×10^5 counts

Beta efficiency = 0.1 counts/disintegration

Transit time = 10 minutes (time from the air sampler being turned off to the start of the count)

Air sample time = 30 minutes

Sample flow rate = 30 liters/min

Filter retention = 100%

a. What is the Rb-88 filter activity at the beginning of the counting interval (μCi)?

b. What is the Rb-88 activity concentration?

c. What is the Kr-88 activity concentration?

HP.II.2. In an essay, discuss the generation and biochemical effects of radiation-induced free radicals.

HP.II.3. An immunology researcher is very anxious to know the radiation dose received by tumor cells during ^{131}I labeling process and a 4-day period post-labeling. Technical details are as follows:

a. 37 KBq (1 μCi) ^{131}I is added to 1 million cells suspended in 5 ml fluid in a test tube, then incubated for 5 hours.

b. After incubation, cells are washed three times after which cells are counted. Labeled fraction of ^{131}I on cells is determined to be 2.4 Kbq.

c. Entire lot of labeled cells are then suspended in a very small volume (0.1 ml) of fluid which is drawn up into a syringe and injected as a "clump" into one subcutaneous site on a mouse.

d. It is assumed that, once in-vivo, the cells stay relatively packed together and do not disperse.

e. Mouse undergoes whole body counting immediately and at certain time intervals post injection.

f. As the cells die and breakdown, radioiodine is released and excreted very rapidly via the urinary tract. 50% of iodine on injected cells is usually excreted within 24 hours. The clearance rate of radioiodine from the mouse is an index of cell death.

g. The mouse is terminated 4 days after post injection.

h. ^{131}I has a half life of 8 days, and it emits 1 beta particle (with an average energy of 180 keV), and 0.8 gamma photon (with an energy of 364 keV) per disintegration.

i. The relevant data for electrons and gamma rays are available on **Attachment A.**

Estimate:

1. The absorbed dose these cells would have received during the 5-hour labeling process with 37 Kbq ^{131}I, and

2. The absorbed dose to the labeled cells that survive the 4-day in-vivo period.

Attachment A for Problem HP.II.3. and HP.II.6.

Stopping powers for electrons

Air (Dry)

ENERGY MeV	STOPPING POWER COLLISION MeV cm²/g	STOPPING POWER RADIATIVE MeV cm²/g	TOTAL MeV cm²/g	CSDA RANGE g/cm²	RADIATION YIELD	DENS. EFF. CORR. (DELTA)
0.0100	1.975E+01	3.897E-03	1.976E+01	2.883E-04	1.082E-04	0.0
0.0125	1.663E+01	3.921E-03	1.663E+01	4.269E-04	1.299E-04	0.0
0.0150	1.445E+01	3.937E-03	1.445E+01	5.886E-04	1.506E-04	0.0
0.0175	1.283E+01	3.946E-03	1.283E+01	7.726E-04	1.706E-04	0.0
0.0200	1.157E+01	3.954E-03	1.158E+01	9.781E-04	1.898E-04	0.0
0.0250	9.753E+00	3.966E-03	9.757E+00	1.451E-03	2.267E-04	0.0
0.0300	8.492E+00	3.976E-03	8.496E+00	2.001E-03	2.618E-04	0.0
0.0350	7.563E+00	3.986E-03	7.567E+00	2.626E-03	2.955E-04	0.0
0.0400	6.848E+00	3.998E-03	6.852E+00	3.322E-03	3.280E-04	0.0
0.0450	6.281E+00	4.011E-03	6.285E+00	4.085E-03	3.594E-04	0.0
0.0500	5.819E+00	4.025E-03	5.823E+00	4.912E-03	3.900E-04	0.0
0.0550	5.435E+00	4.040E-03	5.439E+00	5.801E-03	4.197E-04	0.0
0.0600	5.111E+00	4.057E-03	5.115E+00	6.750E-03	4.488E-04	0.0
0.0700	4.593E+00	4.093E-03	4.597E+00	8.817E-03	5.049E-04	0.0
0.0800	4.198E+00	4.133E-03	4.202E+00	1.110E-02	5.590E-04	0.0
0.0900	3.886E+00	4.175E-03	3.890E+00	1.357E-02	6.112E-04	0.0
0.1000	3.633E+00	4.222E-03	3.637E+00	1.623E-02	6.618E-04	0.0
0.1250	3.172E+00	4.348E-03	3.177E+00	2.362E-02	7.826E-04	0.0
0.1500	2.861E+00	4.485E-03	2.865E+00	3.193E-02	8.968E-04	0.0
0.1750	2.637E+00	4.633E-03	2.642E+00	4.103E-02	1.006E-03	0.0
0.2000	2.470E+00	4.789E-03	2.474E+00	5.082E-02	1.111E-03	0.0
0.2500	2.236E+00	5.126E-03	2.242E+00	7.212E-02	1.311E-03	0.0
0.3000	2.084E+00	5.495E-03	2.089E+00	9.527E-02	1.502E-03	0.0
0.3500	1.978E+00	5.890E-03	1.984E+00	1.199E-01	1.688E-03	0.0
0.4000	1.902E+00	6.311E-03	1.908E+00	1.456E-01	1.869E-03	0.0
0.4500	1.845E+00	6.757E-03	1.852E+00	1.722E-01	2.048E-03	0.0
0.5000	1.802E+00	7.223E-03	1.809E+00	1.995E-01	2.225E-03	0.0
0.5500	1.769E+00	7.708E-03	1.776E+00	2.274E-01	2.401E-03	0.0
0.6000	1.743E+00	8.210E-03	1.751E+00	2.558E-01	2.577E-03	0.0
0.7000	1.706E+00	9.258E-03	1.715E+00	3.135E-01	2.929E-03	0.0
0.8000	1.683E+00	1.036E-02	1.694E+00	3.722E-01	3.283E-03	0.0
0.9000	1.669E+00	1.151E-02	1.681E+00	4.315E-01	3.638E-03	0.0
1.0000	1.661E+00	1.271E-02	1.674E+00	4.912E-01	3.997E-03	0.0
1.2500	1.655E+00	1.588E-02	1.671E+00	6.408E-01	4.906E-03	0.0
1.5000	1.661E+00	1.927E-02	1.680E+00	7.900E-01	5.836E-03	0.0
1.7500	1.672E+00	2.284E-02	1.694E+00	9.382E-01	6.784E-03	0.0
2.0000	1.684E+00	2.656E-02	1.711E+00	1.085E+00	7.748E-03	0.0
2.5000	1.712E+00	3.437E-02	1.747E+00	1.374E+00	9.716E-03	0.0
3.0000	1.740E+00	4.260E-02	1.783E+00	1.658E+00	1.173E-02	0.0
3.5000	1.766E+00	5.113E-02	1.817E+00	1.935E+00	1.377E-02	0.0
4.0000	1.790E+00	5.999E-02	1.850E+00	2.208E+00	1.583E-02	0.0
4.5000	1.812E+00	6.908E-02	1.882E+00	2.476E+00	1.792E-02	0.0
5.0000	1.833E+00	7.838E-02	1.911E+00	2.740E+00	2.001E-02	0.0
5.5000	1.852E+00	8.787E-02	1.940E+00	2.999E+00	2.211E-02	0.0
6.0000	1.870E+00	9.754E-02	1.968E+00	3.255E+00	2.422E-02	0.0
7.0000	1.902E+00	1.173E-01	2.020E+00	3.757E+00	2.845E-02	0.0
8.0000	1.931E+00	1.376E-01	2.068E+00	4.246E+00	3.269E-02	0.0
9.0000	1.956E+00	1.584E-01	2.115E+00	4.724E+00	3.692E-02	0.0
10.0000	1.979E+00	1.795E-01	2.159E+00	5.192E+00	4.113E-02	0.0
12.5000	2.029E+00	2.337E-01	2.262E+00	6.323E+00	5.156E-02	0.0
15.0000	2.069E+00	2.895E-01	2.359E+00	7.405E+00	6.181E-02	0.0
17.5000	2.104E+00	3.464E-01	2.451E+00	8.444E+00	7.185E-02	0.0
20.0000	2.134E+00	4.042E-01	2.539E+00	9.446E+00	8.167E-02	0.0
25.0000	2.185E+00	5.219E-01	2.707E+00	1.135E+01	1.006E-01	0.0
30.0000	2.226E+00	6.417E-01	2.868E+00	1.315E+01	1.186E-01	7.636E-03
35.0000	2.257E+00	7.630E-01	3.020E+00	1.485E+01	1.357E-01	5.984E-02
40.0000	2.282E+00	8.855E-01	3.167E+00	1.646E+01	1.520E-01	1.378E-01
45.0000	2.302E+00	1.009E+00	3.311E+00	1.801E+01	1.676E-01	2.266E-01
50.0000	2.319E+00	1.133E+00	3.452E+00	1.948E+01	1.825E-01	3.192E-01
55.0000	2.334E+00	1.258E+00	3.592E+00	2.090E+01	1.968E-01	4.120E-01
60.0000	2.347E+00	1.384E+00	3.731E+00	2.227E+01	2.104E-01	5.029E-01
70.0000	2.369E+00	1.637E+00	4.006E+00	2.486E+01	2.361E-01	6.762E-01
80.0000	2.387E+00	1.892E+00	4.279E+00	2.727E+01	2.598E-01	8.365E-01
90.0000	2.403E+00	2.148E+00	4.551E+00	2.954E+01	2.818E-01	9.842E-01

Water (Liquid)

ENERGY MeV	STOPPING POWER COLLISION MeV cm²/g	STOPPING POWER RADIATIVE MeV cm²/g	TOTAL MeV cm²/g	CSDA RANGE g/cm²	RADIATION YIELD	DEN[illegible] C[illegible] (D[illegible]
0.0100	2.256E+01	3.898E-03	2.257E+01	2.515E-04	9.408E-05	0.0
0.0125	1.897E+01	3.927E-03	1.898E+01	3.728E-04	1.133E-04	0.0
0.0150	1.647E+01	3.944E-03	1.647E+01	5.147E-04	1.316E-04	0.0
0.0175	1.461E+01	3.955E-03	1.461E+01	6.761E-04	1.492E-04	0.0
0.0200	1.317E+01	3.963E-03	1.318E+01	8.566E-04	1.663E-04	0.0
0.0250	1.109E+01	3.974E-03	1.110E+01	1.272E-03	1.990E-04	0.0
0.0300	9.653E+00	3.984E-03	9.657E+00	1.756E-03	2.301E-04	0.0
0.0350	8.592E+00	3.994E-03	8.596E+00	2.306E-03	2.599E-04	0.0
0.0400	7.777E+00	4.005E-03	7.781E+00	2.919E-03	2.886E-04	0.0
0.0450	7.130E+00	4.018E-03	7.134E+00	3.591E-03	3.165E-04	0.0
0.0500	6.603E+00	4.031E-03	6.607E+00	4.320E-03	3.435E-04	0.0
0.0550	6.166E+00	4.046E-03	6.170E+00	5.103E-03	3.698E-04	0.0
0.0600	5.797E+00	4.062E-03	5.801E+00	5.940E-03	3.955E-04	0.0
0.0700	5.207E+00	4.098E-03	5.211E+00	7.762E-03	4.452E-04	0.0
0.0800	4.757E+00	4.138E-03	4.762E+00	9.773E-03	4.931E-04	0.0
0.0900	4.402E+00	4.181E-03	4.407E+00	1.196E-02	5.393E-04	0.0
0.1000	4.115E+00	4.228E-03	4.120E+00	1.431E-02	5.841E-04	0.0
0.1250	3.591E+00	4.355E-03	3.596E+00	2.083E-02	6.912E-04	0.0
0.1500	3.238E+00	4.494E-03	3.242E+00	2.817E-02	7.926E-04	0.0
0.1750	2.984E+00	4.643E-03	2.988E+00	3.622E-02	8.894E-04	0.0
0.2000	2.793E+00	4.801E-03	2.798E+00	4.487E-02	9.826E-04	0.0
0.2500	2.528E+00	5.141E-03	2.533E+00	6.372E-02	1.161E-03	0.0
0.3000	2.355E+00	5.514E-03	2.360E+00	8.421E-02	1.331E-03	0.0
0.3500	2.235E+00	5.913E-03	2.241E+00	1.060E-01	1.496E-03	0.0
0.4000	2.148E+00	6.339E-03	2.154E+00	1.288E-01	1.658E-03	0.0
0.4500	2.083E+00	6.787E-03	2.090E+00	1.523E-01	1.818E-03	0.0
0.5000	2.034E+00	7.257E-03	2.041E+00	1.766E-01	1.976E-03	0.0
0.5500	1.995E+00	7.747E-03	2.003E+00	2.013E-01	2.134E-03	[illegible]
0.6000	1.963E+00	8.254E-03	1.972E+00	2.263E-01	2.292E-03	[illegible]
0.7000	1.917E+00	9.312E-03	1.926E+00	2.778E-01	2.608E-03	[illegible]
0.8000	1.886E+00	1.043E-02	1.896E+00	3.302E-01	2.928E-03	[illegible]
0.9000	1.864E+00	1.159E-02	1.876E+00	3.832E-01	3.251E-03	[illegible]
1.0000	1.849E+00	1.280E-02	1.862E+00	4.367E-01	3.579E-03	2.4[illegible]
1.2500	1.829E+00	1.600E-02	1.845E+00	5.717E-01	4.416E-03	3.9[illegible]
1.5000	1.822E+00	1.942E-02	1.841E+00	7.075E-01	5.281E-03	[illegible]
1.7500	1.821E+00	2.303E-02	1.844E+00	8.432E-01	6.171E-03	[illegible]
2.0000	1.824E+00	2.678E-02	1.850E+00	9.785E-01	7.085E-03	[illegible]
2.5000	1.834E+00	3.468E-02	1.868E+00	1.247E+00	8.969E-03	[illegible]
3.0000	1.846E+00	4.299E-02	1.889E+00	1.514E+00	1.092E-02	[illegible]
3.5000	1.858E+00	5.164E-02	1.910E+00	1.777E+00	1.291E-02	[illegible]
4.0000	1.870E+00	6.058E-02	1.931E+00	2.037E+00	1.495E-02	[illegible]
4.5000	1.882E+00	6.976E-02	1.951E+00	2.295E+00	1.702E-02	[illegible]
5.0000	1.892E+00	7.917E-02	1.971E+00	2.550E+00	1.911E-02	[illegible]
5.5000	1.902E+00	8.876E-02	1.991E+00	2.802E+00	2.123E-02	[illegible]
6.0000	1.911E+00	9.854E-02	2.010E+00	3.052E+00	2.336E-02	[illegible]
7.0000	1.928E+00	1.185E-01	2.047E+00	3.545E+00	2.766E-02	[illegible]
8.0000	1.943E+00	1.391E-01	2.082E+00	4.030E+00	3.200E-02	[illegible]
9.0000	1.956E+00	1.601E-01	2.116E+00	4.506E+00	3.636E-02	[illegible]
10.0000	1.968E+00	1.814E-01	2.149E+00	4.975E+00	4.072E-02	[illegible]
12.5000	1.993E+00	2.362E-01	2.230E+00	6.117E+00	5.163E-02	[illegible]
15.0000	2.014E+00	2.926E-01	2.306E+00	7.219E+00	6.243E-02	[illegible]
17.5000	2.031E+00	3.501E-01	2.381E+00	8.286E+00	7.309E-02	[illegible]
20.0000	2.046E+00	4.086E-01	2.454E+00	9.320E+00	8.355E-02	[illegible]
25.0000	2.070E+00	5.277E-01	2.598E+00	1.130E+01	1.039E-01	[illegible]
30.0000	2.089E+00	6.489E-01	2.738E+00	1.317E+01	1.233E-01	[illegible]
35.0000	2.105E+00	7.716E-01	2.876E+00	1.496E+01	1.418E-01	[illegible]
40.0000	2.118E+00	8.955E-01	3.013E+00	1.665E+01	1.594E-01	5.3[illegible]
45.0000	2.129E+00	1.021E+00	3.150E+00	1.828E+01	1.762E-01	5.5[illegible]
50.0000	2.139E+00	1.146E+00	3.286E+00	1.983E+01	1.923E-01	5.7[illegible]
55.0000	2.148E+00	1.273E+00	3.421E+00	2.132E+01	2.076E-01	5.9[illegible]
60.0000	2.156E+00	1.400E+00	3.556E+00	2.276E+01	2.222E-01	6.[illegible]
70.0000	2.170E+00	1.656E+00	3.827E+00	2.547E+01	2.496E-01	6.3[illegible]
80.0000	2.182E+00	1.914E+00	4.096E+00	2.799E+01	2.747E-01	6.6[illegible]
90.0000	2.193E+00	2.173E+00	4.366E+00	3.035E+01	2.978E-01	6.8[illegible]

μ/ρ, μ_{tr}/ρ, and μ_{en}/ρ for gamma photons

Photon Energy (MeV)	Air (cm²/g)			Water			ICRU Compact Bone (cm²/g)			ICRU Striated Muscle		
	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ
0.01	5.04	4.61	4.61	5.21	4.79	4.79	20.3	19.2	19.2	5.30	4.87	4.87
0.015	1.56	1.27	1.27	1.60	1.28	1.28	6.32	5.84	5.84	1.64	1.32	1.32
0.02	0.758	0.511	0.511	0.778	0.512	0.512	2.79	2.46	2.46	0.796	0.533	0.533
0.03	0.350	0.148	0.148	0.371	0.149	0.149	0.962	0.720	0.720	0.375	0.154	0.154
0.04	0.248	0.0668	0.0668	0.267	0.0677	0.0677	0.511	0.304	0.304	0.267	0.0701	0.0701
0.05	0.206	0.0406	0.0406	0.225	0.0418	0.0418	0.346	0.161	0.161	0.224	0.0431	0.0431
0.06	0.187	0.0305	0.0305	0.205	0.0320	0.0320	0.273	0.0998	0.0998	0.204	0.0328	0.0328
0.08	0.167	0.0243	0.0243	0.185	0.0262	0.0262	0.209	0.0537	0.0537	0.183	0.0264	0.0264
0.10	0.155	0.0234	0.0234	0.171	0.0256	0.0256	0.181	0.0387	0.0387	0.170	0.0256	0.0256
0.15	0.136	0.0250	0.0250	0.151	0.0277	0.0277	0.150	0.0305	0.0305	0.150	0.0275	0.0275
0.2	0.124	0.0268	0.0268	0.137	0.0297	0.0297	0.133	0.0301	0.0301	0.136	0.0294	0.0294
0.3	0.107	0.0287	0.0287	0.119	0.0319	0.0319	0.114	0.0310	0.0310	0.118	0.0317	0.0317
0.4	0.0954	0.0295	0.0295	0.106	0.0328	0.0328	0.102	0.0315	0.0315	0.105	0.0325	0.0325
0.5	0.0868	0.0297	0.0296	0.0966	0.0330	0.0330	0.0926	0.0317	0.0317	0.0958	0.0328	0.0328
0.6	0.0804	0.0296	0.0295	0.0894	0.0329	0.0329	0.0856	0.0315	0.0314	0.0886	0.0326	0.0325
0.8	0.0706	0.0289	0.0289	0.0785	0.0321	0.0321	0.0751	0.0307	0.0306	0.0778	0.0318	0.0318
1.0	0.0635	0.0280	0.0278	0.0706	0.0311	0.0309	0.0675	0.0297	0.0295	0.0699	0.0308	0.0306
1.5	0.0517	0.0256	0.0254	0.0575	0.0284	0.0282	0.0549	0.0272	0.0270	0.0570	0.0282	0.0280
2	0.0444	0.0236	0.0234	0.0493	0.0262	0.0260	0.0472	0.0251	0.0249	0.0489	0.0259	0.0257
3	0.0358	0.0207	0.0205	0.0396	0.0229	0.0227	0.0382	0.0221	0.0219	0.0392	0.0227	0.0225
4	0.0308	0.0189	0.0186	0.0340	0.0209	0.0206	0.0331	0.0204	0.0200	0.0337	0.0207	0.0204
5	0.0276	0.0178	0.0174	0.0303	0.0195	0.0191	0.0297	0.0192	0.0187	0.0300	0.0193	0.0189
6	0.0252	0.0168	0.0164	0.0277	0.0185	0.0180	0.0274	0.0184	0.0178	0.0274	0.0183	0.0178
8	0.0223	0.0157	0.0152	0.0243	0.0170	0.0166	0.0244	0.0173	0.0167	0.0240	0.0169	0.0164
10	0.0205	0.0151	0.0145	0.0222	0.0162	0.0157	0.0226	0.0168	0.0159	0.0219	0.0160	0.0155

HP.II.4. A person stands on the ground within an infinite cloud of radioactive gas that emits a 1.0-MeV gamma ray at a concentration of 0.15 MBq/m^3. The mass energy absorption coefficient of the gamma ray in air is 0.0028 m^2/kg and the density of air is 1.29 kg/m^3. Calculate the tissue dose rate to the person in Gy/hr.

HP.II.5. A linear accelerator (LINAC) bombards a tritium target with a 25-μA beam of 2.5-MeV protons. This produces 1.2-MeV neutrons via the T (p,n) reaction.

Data

Production rate = 1.8×10^{-6} neutrons/proton
6.24×10^{18} protons/amp-sec
Neutron removal cross section for concrete = 0.08 cm^{-1}
Dose equivalent rate = 3.5×10^{-8} rem cm^{-2} $neutron^{-1}$

a. Calculate the neutron dose equivalent at a point 40 cm away from the target along the beam centerline. State all assumptions.

b. An operator is located 4.0 meters from the target and is shielded by a 50-cm-thick concrete wall. Compared to the dose equivalent rate calculated in 3.a above, the dose equivalent rate at the operator's console will be reduced by what factor?

c. Which of the following instruments would have good sensitivity to neutrons while providing the best discrimination against gammas? Briefly explain your answer.

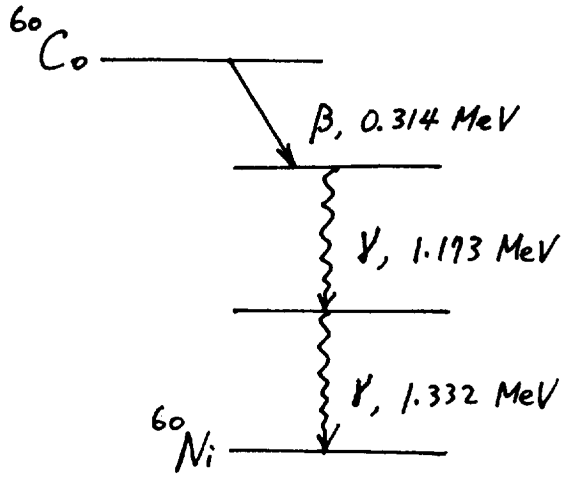
1. BF_3 proportional counter in a polyethylene moderator.
2. Geiger-Müller (GM) tube at greater than 2 atmospheres in a polyethylene moderator.
3. Silver-wrapped GM tube inserted in a polyethylene moderator.
4. LiI (Eu) scintillator inserted in a polyethylene moderator.
5. Cadmium-wrapped LiI(Eu) scintillator.

d. Which of the following statements best describes the neutron distribution as viewed in the laboratory coordinate system? Why?

1. Isotropic fluence rate, but energy peaked in the forward direction.
2. Isotropic energy distribution, but fluence rate peaked in the forward direction.
3. Both energy and fluence rate peaked in the forward direction.
4. Energy and fluence rate are peaked at 90° to the incident proton beam.
5. Fluence rate peaked at 90° to the incident proton beam, isotropic energy distribution.

HP.II.6. Use the first principles to estimate the exposure rate (in roentgen/hr) at 30 cm from a 1-Ci point source of ^{60}Co. The relevant data are available in **Attachment A & B.**

Attachment B for Problem HP.II.6.



Cobalt-60 decay scheme

- Air density at 1 atm and room temperature $= 1.293 \times 10^{-3}$ g/cm^3
- 1 roentgen $= 2.58 \times 10^{-4}$ Coul/kg of air
- $W_{air} = 33.8$ eV/ion pair

HP.II.7. A radionuclide with a half-life of 10 days is ingested by a radiation worker in drinking water consumed at the daily rate of 2L. Of the ingested radionuclide, 30% goes to organ A and 70% is directly excreted with negligible exposure to the GI tract. Organ A has a weighting factor for stochastic effects of 0.12 and a biological turnover for the radionuclide of 0.040 per day. The drinking water concentration is 1500 Bq/L and the ALI is 3.6 MBq.

1. Calculate the equilibrium activity in organ A, in MBq.

2. Calculate the dose equivalent to organ A, in mSv/yr.

HP.II.8. An annual plant seed germinates in the Spring. The plant matures in the Summer and sets seed and dies in the Fall. In an essay, discuss the effects of ionizing radiation on the various stages of the plant's life cycle.

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1995

Health Physics - Day 3

EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

-- Please sign your name on the back of this page --

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

Health Physics

Ph.D. Qualifiers Exam

Fall Quarter, 1995

Day 3

Instructions

1. Complete 6 of the 8 questions.
2. Place your identifying code letter on the top right corner of each page of your question and answer sheets.
3. Use a separate page for each answer sheet (no front to back answers).
4. The question number should be shown on each answer sheet.
5. Staple your question sheet to your answer sheets and turn in.

HP.III.1. A farm with a 4-year-old child is located 1 km from a nuclear power reactor. The child consumes 330 liters of fresh milk and 26 kilograms of fresh leafy vegetables per year from the family cow and the family garden, respectively. Calculate the annual release of I-131 ($T_{1/2}$= 8.05 d) which will result in a 15 mrem/year thyroid dose.

Data:

The annual-average atmospheric dispersion faction (χ/Q) is 4(10^{-6}) sec/m^3.

The deposition velocity is 0.01 m/s and the effective half-life for weathering loss is 14 days for both forage and vegetables.

The fraction of daily iodine cow intake via grass consumption transferred to milk is 6(10^{-3}) days/liter. The family cow consumes 50 kg/day of grass from a field whose yield is 0.75 kg/m^2. The vegetable yield is 2 kg/m^2. The retention factor for both is 1.0.

The child's breathing rate may be assumed to be 2700 m^3/y and the child spends 50% of the time on the farm.

The I-131 thyroid committed dose equivalent factors are for 5.43(10^{-3}) mrem/pCi for ingestion, 4.16(10^{-3}) mrem/pCi for inhalation. The whole body dose equivalent rate from I-131 deposited onto the ground is 2.80(10^{-9}) mrem/hr per pCi/m^2.

HP.III.2. You are a health physicist at a nuclear utility operating a single pressurized water reactor. The utility has assigned you the responsibilities of the Radiological Control Manager (RCM) at the off-site Emergency Operations Facility (EOF) during a declared emergency in which a radioactive release to the environment is possible.

Data

Letdown radiation monitor reading* (primary reactor coolant system activity):	7.3×10^2 µCi/cm^3
Blowdown radiation monitor reading* (secondary system activity):	2.4 µCi/cm^3
Steam generator "A" radiation monitor reading:	42 mR/hr
Iodine partitioning factor (liquid to gas)	0.015
Atmospheric relief valve flow rate:	1.4×10^7 cm^3/sec
Containment Pressure:	5.0 psig and increasing
Wind Speed:	15 mph
Pasquill stability class:	E
I-131 dose conversion factor:	(77.2 rem/sec)/ µCi/cm^3
1 mile = 1609.36 m	

Steam Generator "A" Blowdown Sample Isotopic Results		**Pasquill Class E Atmospheric Dispersion Factors**	
Radionuclide	Concentration µCi/cm^3	Distance (miles)	$\chi u/Q$ (1/m^2)
I-131	6.3×10^{-1}	1	1.57×10^{-2}
Xe-133	9.1×10^{-1}	2	2.69×10^{-3}
Xe-135	9.3×10^{-1}	5	1.56×10^{-3}
Cs-134	7.6×10^{-1}	10	6.19×10^{-4}
Cs-137	1.4×10^{-1}		

a. List the three fission product barriers that protect the public from a release of radioactivity.

b. Based on the data provided, what is the status of the fission product barriers?

c. At this time, a release has not occurred, but you have been asked to provide an assessment of off-site doses. Assuming the release would occur through the atmospheric release valve, off the main steam line, what is the projected thyroid dose rate 2.0 miles downwind from the facility?

d. A small town with a population of 2500 is located 2.7 miles downwind from the plant. If an atmospheric relief value were opened for 15 minutes and then closed, what Protective Action Recommendations would you make?

---

* Readings are normally in the pCi/cm^3 range.

HP.III.3. A 3-ℓ milk sample is analyzed for I-131 (half-life 8.0 d) by radiochemical separation and beta-particle counting. The following information is provided.

Gross count:	210 count
Counting time:	50 min
Interval since collection:	11.1 d
Background count rate:	1.5 count/min
Counting efficiency of standard I-131:	37%
Iodine carries added (as AgI):	18.0 mg
Iodine carrier recovered as AgI:	14.5 mg

a. Calculate the I-131 activity at sample collection, in pCi/L.

b. Propose and describe at least one alternative analytical procedure.

HP.III.4. a. Estimate the SEE (T←S)(specific effective energy) for Ce-141 if the source and target organs are both the liver.

b. Calculate the annual limit on intake (ALI) and the derived air concentration (DAC) for Ce-141. The route of entry is by inhalation and the material is Class Y.

DATA

a. See attached tables.

b. mass of liver = 1,800 grams.

Data Set for Problem HP.III.4.

Fraction *AF* of Photon Energy Released in Source Organ and Absorbed in Target Organ, Based on ICRP Publication 23.

Source = Target

SOURCE	PHOTON ENERGY (MeV) 0.010	0.015	0.020	0.030	0.050	0.100
Bladder[a]	3.83E−02[c]	6.31E−02	6.45E−02	4.43E−01	2.02E−02	1.15E−02
Stomach[a]	4.82E−02	1.14E−01	1.34E−01	1.03E−01	4.92E−02	2.82E−02
Small intestine[a]	7.70E−01	6.87E−01	5.82E−01	3.86E−01	1.94E−01	1.18E−01
Upper large intestine[a]	7.59E−02	1.67E−01	1.80E−01	1.16E−01	5.45E−02	3.18E−02
Lower large intestine[a]	8.53E−02	1.81E−01	1.86E−01	1.12E−01	4.75E−02	2.82E−02
Kidneys	9.32E−01	7.78E−01	5.79E−01	2.93E−01	1.12E−01	6.67E−02
Liver	9.75E−01	9.02E−01	8.06E−01	5.40E−01	2.76E−01	1.66E−01
Lungs	8.16E−01	6.57E−01	4.71E−01	2.30E−01	8.98E−02	5.04E−02
Other tissue (muscle)	8.72E−01	8.19E−01	7.33E−01	5.54E−01	3.44E−01	2.45E−01
Ovaries	8.01E−01	4.89E−01	2.70E−01	9.51E−02	2.96E−02	1.84E−02
Pancreas	8.86E−01	6.57E−01	4.31E−01	1.91E−01	6.63E−02	3.93E−02
Bone surface[b]	9.90E−01	9.42E−01	8.84E−01	7.18E−01	4.31E−01	1.90E−01
Red marrow[b]	1.41E−01	1.35E−01	1.26E−01	1.03E−01	6.15E−02	2.72E−02
Skin	5.80E−01	2.91E−01	1.58E−01	6.34E−02	2.28E−02	1.51E−02
Spleen	9.47E−01	8.11E−01	6.25E−01	3.24E−01	1.26E−01	7.33E−02
Testes	9.02E−01	6.90E−01	4.56E−01	1.98E−01	6.57E−02	3.97E−02
Thyroid	8.41E−01	5.74E−01	3.55E−01	1.45E−01	4.74E−02	2.82E−02
Total body	9.93E−01	9.65E−01	9.23E−01	7.97E−01	5.68E−01	3.78E−01

SOURCE	PHOTON ENERGY (MeV) 0.200	0.500	1.000	1.500	2.000	4.000
Bladder[a]	1.11E−02	1.15E−02	1.00E−02	9.34E−03	8.88E−03	7.08E−03
Stomach[a]	2.67E−02	2.69E−02	2.48E−02	2.22E−02	2.12E−02	1.73E−02
Small intestine[a]	1.11E−01	1.11E−01	9.95E−02	9.43E−02	8.56E−02	7.16E−02
Upper large intestine[a]	3.07E−02	3.07E−02	2.91E−02	2.59E−02	2.47E−02	1.95E−02
Lower large intestine[a]	2.78E−02	2.83E−02	2.59E−02	2.43E−02	2.22E−02	1.73E−02
Kidneys	6.79E−02	7.16E−02	6.42E−02	6.08E−02	5.48E−02	4.63E−02
Liver	1.60E−01	1.61E−01	1.47E−01	1.36E−01	1.25E−01	1.02E−01
Lungs	5.00E−02	5.00E−02	4.55E−02	4.32E−02	3.92E−02	3.08E−02
Other tissue (muscle)	2.42E−01	2.52E−01	2.41E−01	2.24E−01	2.10E−01	1.76E−01
Ovaries	2.05E−02	2.17E−02	2.00E−02	1.89E−02	1.75E−02	1.42E−02
Pancreas	4.15E−02	4.40E−02	4.06E−02	3.82E−02	3.45E−02	2.76E−02
Bone surface[b]	1.35E−01	1.25E−01	1.17E−01	1.06E−01	9.86E−02	8.18E−02
Red marrow[b]	1.94E−02	1.79E−02	1.67E−02	1.52E−02	1.41E−02	1.17E−02
Skin	1.71E−02	1.96E−02	1.96E−02	1.81E−02	1.70E−02	1.35E−02
Spleen	7.52E−02	7.81E−02	7.13E−02	6.56E−02	6.18E−02	4.75E−02
Testes	4.34E−02	4.56E−02	4.30E−02	3.86E−02	3.64E−02	2.84E−02
Thyroid	3.04E−02	3.25E−02	3.02E−02	2.84E−02	2.57E−02	2.06E−02
Total body	3.46E−01	3.47E−01	3.30E−01	3.08E−01	2.91E−01	2.43E−01

(Continued)

12.74 d

ctive Daughter		Half Life
a (100.0%)		40.27 h

al Beta Particles

. (%)	E_{avg} (keV)	E_{max} (keV)
4.60	136.5	453.9
9.82	176.6	567.4
3.80	305.6	872.4
8.86	339.6	991.2
2.92	356.9	1005.0
'decay	276.3	

al Conversion and Auger Electrons

. (%)	E (keV)
0.82	12.7
2.57	13.9
3.82	23.7
5.62	24.1
2.45	24.5
2.80	28.8
3.45	30.0
1.48	123.7
/decay	36.5 *

pal Gamma and X Rays

. (%)	E (keV)
1.22	13.9
13.78	30.0
1.01	33.4
6.21	162.6
4.30	304.9
3.15	423.7
1.93	437.6
24.39	537.3
/decay	182.7

40.272 h

pal Beta Particles

. (%)	E_{avg} (keV)	E_{max} (keV)
11.12	440.8	1238.2
5.71	443.2	1243.9
5.61	465.0	1295.7
44.87	487.1	1347.7
5.11	514.4	1411.8
20.83	629.2	1676.5
4.81	845.8	2163.5
'/decay	525.8	

more ...

^{140}La (continued)

Principal Conversion and Auger Electrons

keV/decay 9.33 *

Principal Gamma and X Rays

Freq. (%)	E (keV)
1.05	34.7
20.74	328.8
2.99	432.5
45.94	487.0
4.41	751.8
23.64	815.8
5.59	867.8
2.68	919.6
7.05	925.2
95.40	1596.5
3.43	2521.7
keV/decay	2315.9

^{141}Ce   32.50 d

Principal Beta Particles

Freq. (%)	E_{avg} (keV)	E_{max} (keV)
70.20	130.0	435.9
29.80	181.1	581.3
keV/decay	145.2	

Principal Conversion and Auger Electrons

Freq. (%)	E (keV)
18.71	103.5
2.35	138.6
keV/decay	25.5 *

Principal Gamma and X Rays

Freq. (%)	E (keV)
4.86	35.6
8.87	36.0
1.76	40.7
48.20	145.4
keV/decay	76.5

^{144}Ce   284.3 d

Radioactive Daughter	Ha
^{144}Pr (98.6%)	17.

Principal Beta Particles

Freq. (%)	E_{avg} (keV)	E_{m}
19.58	49.4	
4.60	65.3	
75.82	90.2	
keV/decay	81.1	

Principal Conversion and Auger Elec

Freq. (%)	E (keV)
3.48	38.1
5.33	91.5
keV/decay	11.1 *

Principal Gamma and X Rays

Freq. (%)	E (keV)
2.96	35.6
5.40	36.0
1.07	40.7
1.64	80.1
10.80	133.5
keV/decay	20.7 *

^{144}Pr   17.28 min

Principal Beta Particles

Freq. (%)	E_{avg} (keV)	E_{max}
1.08	266.9	81
1.17	894.7	230
97.74	1221.7	299
keV/decay	1207.5	

Principal Conversion and Auger Electr

keV/decay 0.056 *

Principal Gamma and X Rays

Freq. (%)	E (keV)
1.48	696.5
keV/decay	31.9 *

$$^{141}_{58}Ce(32.501d) \xrightarrow{\beta^-} {}^{141}_{59}Pr(stable)$$

SPECIFIC EFFECTIVE ENERGY (MeV PER GRAM PER TRANSFORMATION) OF CE-141

TARGETS	SOURCES: LUNGS	ULI CONTENT	LLI CONTENT	LIVER	SPLEEN
LUNGS	1.8E-04	7.1E-08	2.1E-08	7.6E-07	6.7E-07
ULI WALL	6.0E-08	4.0E-04	1.3E-06	7.2E-07	4.0E-07
LLI WALL	2.0E-08	9.4E-07	6.5E-04	6.1E-08	1.7E-07
LIVER	7.3E-07	7.3E-07	6.8E-08		2.7E-07
SPLEEN	6.8E-07	4.0E-07	2.2E-07	2.5E-07	9.9E-04

NUMBER OF NUCLEAR TRANSFORMATIONS OVER 50 YEARS
IN SOURCE ORGANS OR TISSUES PER UNIT INTAKE OF ACTIVITY
(TRANSFORMATIONS/Bq) OF CE-141

ORGAN	ORAL f_1=3.E-04	INHALATION CLASS W f_1=3.E-04	INHALATION CLASS Y f_1=3.E-04
LUNGS		4.0E 05	6.0E 05
ULI CONTENT	4.6E 04	2.0E 04	2.2E 04
LLI CONTENT	8.3E 04	3.7E 04	4.0E 04
LIVER	7.1E 02	2.1E 05	1.1E 04
SPLEEN	6.0E 01	1.7E 04	9.5E 02

HP.III.5. a. State 3 principles that are the basis for control by DOT of the safe shipment of radioactive material packages by commercial transport.

b. Define TI

c. What is the maximum external dose equivalent rate limit for the following:

1. White I
2. Yellow II

HP.III.6. A nuclear facility discharges airborne radionuclides at levels estimated to result in exposure rates due to gamma ray emission of about 10 mR/yr at certain nearby locations.

a. Show the calculations (equations and factors) that led to this estimated exposure rate.

b. Propose a study project that checks this estimate by direct measurement, indicating suitable radiation detection instruments, and discuss the reliability of measurements and sources of error.

HP.III.7. Consider a two-story house 20 x 20 m in size with walls 8 m high (includes both stories) and a basement 3 m deep. The basement floor and walls are made of concrete 30 cm thick, and the outside walls of the house are brick 10 cm thick. Plaster that is 1 cm thick lines all walls and the ceilings.

a. Estimate the number of Bq of K-40, Ra-226 and Th-232 in the structural materials of the house?

Building Material	Density (g/cm^3)	Specific Activity Range (pCi/g) K-40	Ra-226	Th-232
Brick	1.4 - 2.5	16 - 20	1.4 - 2.6	1.0 - 3.4
Concrete	2.25 - 2.4	7 - 19	0.9 - 2.0	0.9 - 2.3
Plaster	1.54	<2 - 10	0.09 - 0.6	<0.4 - 2.0
Granite	2.6 - 2.76	28 - 40	2.4 - 3	2.3 - 4.5
Limestone /Marble	1.87 - 2.76 /2.47 - 2.86	about 1	< 0.5	< 0.5

b. For soil with a density of 1.6 g/cm^3, Federal Guidance Report #12 gives the external effective dose equivalent factors conversion factors shown in the table below in Sv-m^3 per Bq-sec for K-40, Ra-226, and Th-232 uniformly distributed in contaminated soil. These dose conversion factors were computed assuming that the contaminated soil was laterally infinite. Use these dose conversion factors to estimate the external effective dose equivalent to a person sitting in the center of the house neglecting any attenuation by interior walls and floors. Justify this as a suitable approximation if you believe it is.

Depth of Soil (cm)	K-40	Ra-226	Th-232
5	2.78E-17	1.32E-19	5.04E-21
15	8.16E-18	1.88E-19	5.54E-21
infinite	9.33E-18	1.94E-19	5.55E-21

HP.III.8. Various agencies have developed standards governing conditions that are "acceptable" for workers employed in various U.S.A. industries. With that fact in mind, answer the following questions pertaining to those standards:

1. Name the government agency/agencies that has/have the most generally accepted standards.

2. What is/are the name/names given the standards?

3. Discuss the standards that were the specific focus of Biology 4416. This discussion should include (but not necessarily be limited to):

   a. their definition

   b. the physical basis of the standard

   c. conditions that must be known for accurate sampling

   d. correct type(s) of samples taken