RESERVE DESK

Health Physics Ph.D. Qualifier Exam
Fall Quarter 1997

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GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1997

Environmental Radiation Protection Ph.D. Qualifying Exam
EXAM AREA

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

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

Please **print** your name here.

The Exam Committee will get a copy of this exam and will not be notified whose paper it is until it is graded.

Code #________________

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff School of Mechanical Engineering

Health Physics

Ph.D. Qualifiers Exam

Fall Quarter, 1997

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.

Code #________________

HP.3.1 A fuel rod can be represented as a line source for some shielding applications. The gamma ray source strength of a spent fuel rod is distributed in the following functional form $S_o \sim \sin\left(\frac{\pi y}{h}\right)$ where the variables are as given below.

a. What is the properly normalized cumulative distribution function that would be used to sample the gamma ray emission on the line source in a Monte Carlo simulation?

b. In a particular application, the gammas emitted at the upper end of the fuel rod are more important for solving the shielding problem of interest. Being a good Monte Carlo simulator, you decide to sample the emission location using the function $f(y) = e^{\alpha y}$, where $\alpha > 0$, instead of the actual source distribution to guarantee adequate sampling of the spatial region of importance.

(1) What is the cumulative probability function that must now be sampled?

(2) What must you do to ensure that the game is still fair, i.e. that you have not changed the mean score of the quantity of interest? Be as quantitative as possible.

c. In another situation, the ends of the fuel rod are important source regions. You decide to use the following biased unnormalized source distribution to sample gamma-ray emission:

$$f(y) = \begin{cases} \left(\frac{h}{2} - x\right) & x \le \frac{h}{2} \\ 2\left(x - \frac{h}{2}\right) & x > \frac{h}{2} \end{cases}$$

How would you sample this distribution and adjust the particle weights?

Code #____________

HP.3.2 A graphite-moderated reactor is cooled by passing 680,000 kg air per hour through the core. The mean temperature in the core is 300°C, and the thermal neutron flux is 5×10^{13} neutrons/cm^2/sec.

A. If the air spends an average of 10 sec in the reactor core, what is the rate of production of ^{41}A?

B. If the stack through which the air is discharged is 90 meters high and has an orifice diameter of 2 meters; and the temperature of the effluent air is 170°C with an exit velocity of 6.2 m/sec , while the ambient temperature is 30°C on a sunny day and if the mean wind velocity is 2 m/sec, at what distance from the stack will the ground level concentration of ^{41}A be a maximum?

C. What will be the value of this maximum concentration (in Bq/m^3)?

Data:

1. The radiological half life of ^{41}A is 1.83 hr.
2. The thermal neutron cross section for ^{40}A is 0.61 barns at 20°C.
3. The natural abundance of ^{40}A is 99.6%.
4. The air contains 0.94% of ^{40}A, 79% of N_2, 21% of O_2, and 0.03% of CO_2. (% is by volume).
5. $$\chi = \frac{Q}{2\pi \sigma_y \sigma_z u}\left(e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \right)\left[e^{-\frac{1}{2}\left(\frac{h-z}{\sigma_z}\right)^2} + e^{-\frac{1}{2}\left(\frac{h+z}{\sigma_z}\right)^2} \right]$$
6. The effective stack height is

$$h = h_s + d\left(\frac{\upsilon}{\mu}\right)^{1.4}\left(1 + \frac{\Delta T}{T}\right)$$

where

h_s = actual stack height (m)
d = stack outlet diameter (m)
υ = exit velocity of gas (m/sec)
μ = mean wind velocity (m/sec)
ΔT = difference between ambient and effluent gas temperatures
T = absolute temperature of effluent gas

7. Pasquill's categories of atmospheric stability
8. Dispersion coefficient curves (σ_y and σ_z)

(3 sheets attached)

ATMOSPHERIC STABILITY AND DISPERSION COEFFICIENTS

The most common method to classify atmospheric stability is that of Pasquill:

Table 3.1 Pasquill's Categories of Atmospheric Stability

A: Extremely unstable conditions
B: Moderately unstable conditions
C: Slightly unstable conditions
D: Neutral conditions*
E: Slightly stable conditions
F: Moderately stable conditions

Surface sind speed, m/sec	Daytime Sunlight			(Night time) Thin overcast or ≥ 4/8 cloudiness†	≤ 3/8 cloudiness
	Strong	Moderate	Slight		
<2	A	A–B	B		
2	A–B	B	C	E	F
4	B	B–C	C	D	E
6	C	C–D	D	D	D
>6	C	D	D	D	D

*Applicable to heavy overcast, day or night.
†The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon which is covered by clouds. (Manual of Surface Observations [WBAN], Circular N [7th ed.], paragraph 1210, U.S. Government Printing Office, Washington, July 1960.) (From W. F. Hilsmeier and F. A. Gifford, Jr. *Graphs for Estimating Atmospheric Dispersion*. Report ORO-545, Oak Ridge National Laboratory.

DISPERSION COEFFICIENTS (σ_y AND σ_z)

σ_y and σ_z are quantitative measures of how much the plume has spread out in the horizontal and vertical directions. They are dependent on the downwind distance from the source (x) and atmospheric stability.

σ_y = the horizontal distance on either side of the plume centerline that contains 68% of the plume's activity.

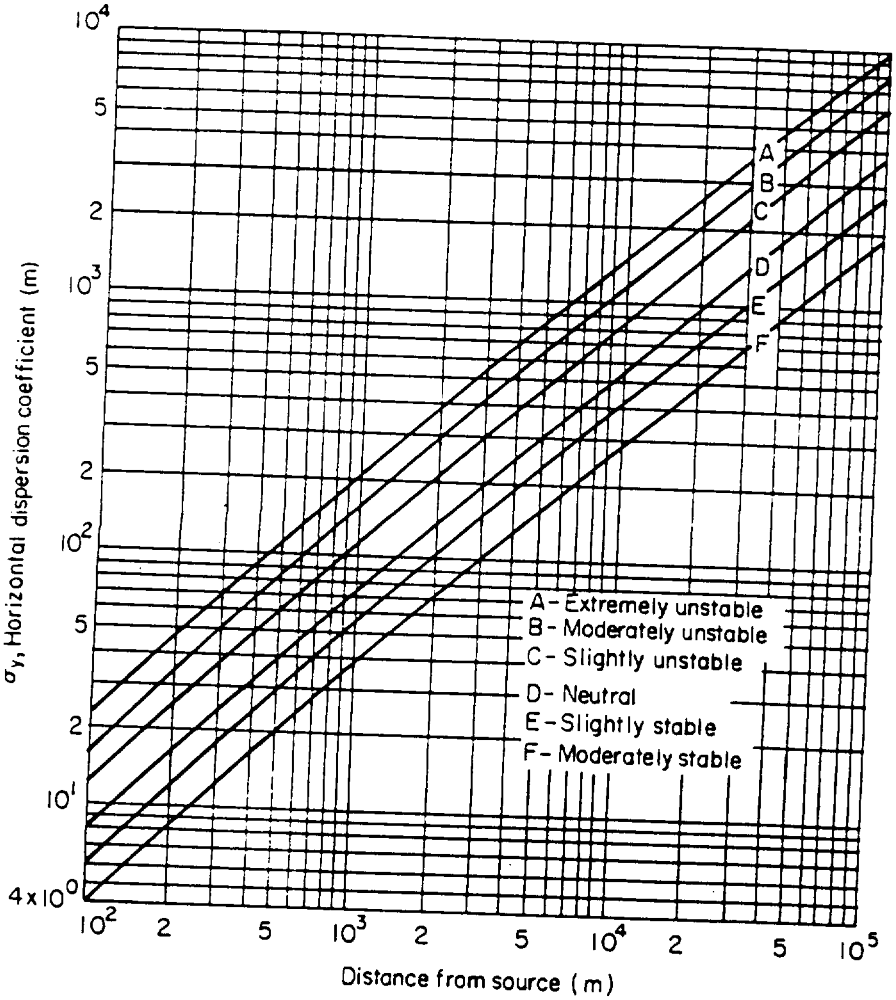

Fig. 3.5 Lateral diffusion (σ_y) vs. downwind distance from source for various turbulence types. (From Gifford, 1968.)

σ_z = the vertical distance on either side of the plume centerline that contains 68% of the plume's activity.

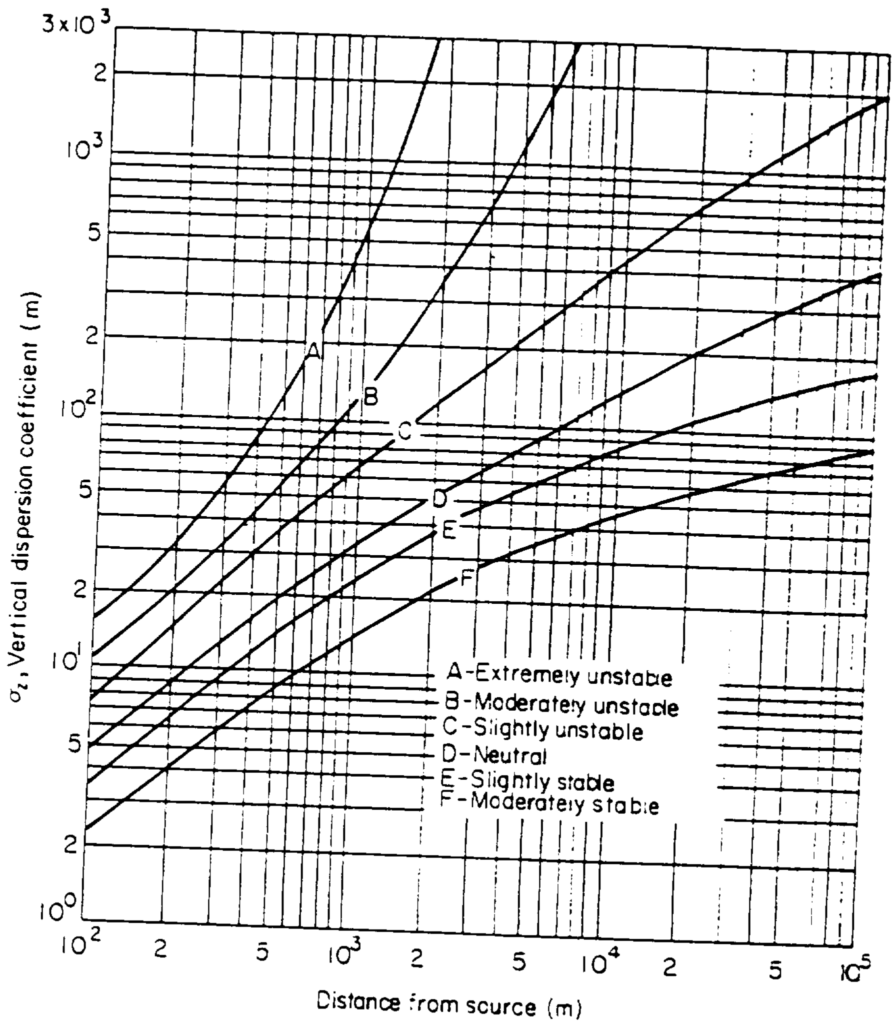

Fig. 3.6 Vertical diffusion (δ_z) vs. downwind distance from source for various turbulence types. (From Gifford, 1968.)

Code #________________

HP.3.3 Hot cell facilities may have a zinc bromide ($ZnBr_2$) solution viewing window. Necessary properties related to the zinc bromide solution and other materials are given below.

a. An experiment to be placed in a hot cell requires an absorbed dose rate of 10 kGy/hr in silicon at 30 cm from a Co-60 source. What is the activity of the Co-60 source in Bq required to deliver this dose?

b. If the viewing window is 2 meters from the Co-60 source, how thick must the window be to reduce the contact dose on its outer surface to 0.1 mGy/hr?

c. How does this thickness compare with the required thickness of the concrete shielding walls of the hot cell assuming that the nearest wall is 2 meters from the source?

Assume that the buildup factor for all materials can be represented by the following equation for all the materials:

$$B(\mu X) = 1 + 1.15\mu x\, e^{.026\mu x}$$

Data:

Zinc Bromide

$A_{zn} = 65.39$ amu
$A_{br} = 79.904$ amu
$\rho\,(ZnBr_2) = 2.5\ g/cm^3$

$$\left(\frac{\mu}{\rho}\right)^{H_2O}_{1.25\,MeV} = 6.413\,(10^{-3})\frac{m^2}{kg}\ ;\left(\frac{\mu}{\rho}\right)^{Zn}_{1.25\,MeV} = 5.389\,(10^{-3})\frac{m^2}{kg}$$

$$\left(\frac{\mu}{\rho}\right)^{Br}_{1.25\,MeV} = 5.189\,(10^{-3})\,m^2/kg$$

Silicon:

$$\left(\frac{\mu en}{\rho}\right)^{S_i}_{1.25\,MeV} = 2.654\,(10^{-3})\,m^2/kg$$

$$\left(\frac{\mu}{\rho}\right)^{S_i}_{1.25\,MeV} = 5.772\,(10^{-3})\,m^2/kg$$

Components of Solution	Weight Percent
$ZnBr_2$	60%
H_2O	40%

Concrete: $\rho = 2.35\ g/cm^3$

$$(\mu/\rho)_{1.25\,MeV} = 5.789\,(10^{-3})\,m^2/kg$$

Code #_______________

HP.3.4 A chemist accidentally inhaled a ^{14}C tagged organic solvent that is readily absorbed from the lungs. The solvent is known to concentrate in the liver, and to be detoxified there. The part of the solvent that is eliminated from the body before deposition in the liver leaves in the urine; the detoxification products are eliminated from the liver into the G.I. tract and into the urinary tract: 75% is eliminated in the feces and 25% is eliminated in the urine. Following the accident, 24 hour urine samples were collected, over a 2-week period, and the following data were obtained:

Days:

post-accident:	1	2	3	4	5	6	8	10	12	14
μCi/sample:	5.3	3.1	2.1	1.5	1.05	0.97	0.65	0.55	0.40	0.33

a. How much activity was absorbed during the accident?

b. What was the total dose to the body during the 13 weeks after inhalation?

c. What was the dose to the liver during the 13 weeks after inhalation?

Data:

1. ^{14}C emits β-particles (yield rate of 100%) with maximum energy of 156.5 keV.
2. The body weight of the chemist is 70 kg.
3. The liver weight of the chemist is 1,800 g.
4. Graph paper

Code #_______________

HP.3.5 Ten kg of uranium-bearing ore containing 10% by weight of U_3O_8, is left in an unventilated storeroom. The dimensions of the room are 10' x 15' x 8' high.

a. What is the rate of production of radon?

1. in microcuries per minute, and
2. in cm^3 per minute, at NTP

b. Assuming that all the radon that is produced escapes into the room, plot the radon concentration versus time for a 4-week period after bringing the uranium ore into the storeroom. What is the concentration of ^{218}Po at four weeks?

c. If the room is ventilated by a system that turns over the air 6 times per hour, plot the radon concentration versus time for a 1-week period after bringing the uranium ore into the room. Write the equation for the radon buildup curve, using the appropriate numerical values for the parameters.

Data:

1. Decay chain of radon.
2. Graphic paper

(1 sheet attachment plus 3 sheets of each type graph paper)

NATIONAL
12-182
U.S.A.

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Semi-Logarithmic
2 Cycles x 10 to the inch

NATIONAL
12-182

10 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1

Semi-Logarithmic
ycles x 10 to the inch

TABLE 4.3. Uranium Series (4*n* + 2)

Nuclide	Half-life	Energy, MeV		
		Alpha[a]	Beta	Gamma, photons/trans.[b]
$^{238}_{92}U$	4.51×10^9 years	4.18		
$^{234}_{90}Th$ (UX_1)	24.10 days		0.193, 0.103	0.092 (0.04)
				0.063 (0.03)
$^{234m}_{91}Pa$ (UX_2)	1.175 min		2.31	1.0 (0.015)
				0.76 (0.0063), I.T.
$^{234}_{91}Pa$ (UZ)	6.66 h		0.5	Many weak
$^{234}_{92}U$ (UII)	2.48×10^5 years	4.763		
$^{230}_{90}Th$ (I_0)	8.0×10^4 years	4.685		0.068 (0.0059)
$^{226}_{88}Ra$	1,622 years	4.777		
$^{222}_{86}Em$ (Rn)	3.825 days	5.486		0.51 (very weak)
$^{218}_{84}Po$ (RaA)	3.05 min	5.998 (99.978%)[c]	Energy not known (0.022%)[c]	
$^{218}_{85}At$ (RaA′)	2 s	6.63 (99.9%)[c]	Energy not known (0.1%)[c]	0.186 (0.030)
$^{218}_{86}Em$ (RaA″)	0.019 s	7.127		
$^{214}_{82}Pb$ (RaB)	26.8 min		0.65	0.352 (0.036)
				0.295 (0.020)
				0.242 (0.07)
$^{214}_{83}Bi$ (RaC)	19.7 min	5.505 (0.04%)[c]	1.65, 3.7 (99.96%)[c]	0.609 (0.295)
				1.12 (0.131)
$^{214}_{84}Po$ (RaC′)	1.64×10^{-4} s	7.680		
$^{210}_{81}Tl$ (RaC″)	1.32 min		1.96	2.36 (1)
				0.783 (1)
				0.297 (1)
$^{210}_{82}Pb$ (RaD)	19.4 years		0.017	0.0467 (0.045)
$^{210}_{83}Bi$ (RaE)	5.00 days		1.17	
$^{210}_{84}Po$ (RaF)	138.40 days	5.298		0.802 (0.000012)
$^{206}_{82}Pb$ (RaG)	Stable			

[a]Only the highest-energy alpha is given. Complete information on alpha energies may be obtained from Sullivan's *Trilinear Chart of Nuclides*, Government Printing Office, Washington, D.C., 1957.

[b]Only the most prominent gamma photons are listed. For the complete gamma-ray information, consult T. P. KOHMAN: Natural radioactivity, in H. Blatz (ed.): *Radiation Hygiene Handbook*. McGraw-Hill, New York, 1959, pp. 6–13. With permission.

[c]Indicates branching. The percentage enclosed in the parentheses gives the proportional decay by the indicated mode

NATIONAL
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Semi-Logarithmic
Cycles x 10 to the inch

NATIONAL
12-282

20 Squares to the Inch

NATIONAL
12-282

20 Squares to the Inch

NATIONAL
12-282

20 Squares to the Inch

Code #________________

HP.3.6 As you arrive for work one day at a plutonium processing facility, you learn of an exposure incident which occurred during the previous shift. While working in a process area, an employee heard a hissing sound coming from a nearby glove-box, but did not pay immediate attention to it. The worker reports that about one minute after he first heard the hiss, the continuous air monitor (CAM) in the room alarmed. He walked over to examine the CAM and observed that the count rate meter was pegged. He then walked over to the hissing glove-box, noticed that extensive rupture of process vessels within the box had occurred, material was spread throughout the internals of the box, and that one of the gloves had been ruptured. He estimated an additional 20 seconds elapsed between the time the CAM alarmed and he left the room. He did not put on his respirator during any of the this time. When the on-duty health physics technician arrived, he determined that the worker was contaminated (hair, face, clothing) and a positive indication of alpha contamination was found on a nasal smear. Using the data provided, perform an exposure assessment of this incident:

a. Estimate the annual (first year) dose equivalent to the (1) lung, (2) red bone marrow, (3) bone surfaces, and (4) liver of this worker. Assume the CAM data represents the average concentration to which the worker was exposed during the incident prior to leaving the room.

b. Calculate the annual effective dose equivalent (first year) assuming the organs identified in (a) above are the only important target organs for internal plutonium exposure and that any external gamma exposure during this incident was negligible.

c. What are the relevant ICRP stochastic and nonstochastic exposure limits appropriate for this circumstance? Was either limit exceeded?

d. What additional follow-up would you recommend to assess more accurately the dose to this worker?

Data:

1. Activity fractions of nuclides in Mixture
   ^{238}Pu: 1.2×10^{-2}
   ^{239}Pu: 1.4×10^{-1}
   ^{240}Pu: 3.1×10^{-2}
   ^{241}Pu: 8.1×10^{-1}
   ^{241}Am: 1.5×10^{-3}

2. CAM data resulted in concentration estimate = 2×10^{-5} μCi mL^{-1} (alpha plus beta)

3. Assume 1 μm AMAD.

4. Assume breathing rate of worker = 20 L min^{-1}

Code #________________

HP.3.6. (Continued)

5. Inhalation Dose, First Year, 1 μm AMAD Solubility Class as Indicated (Sv Bq^{-1} Intake)

Inhalation Dose, First Year, 1 μ AMAD, Solubility Class as Indicated (Sv Bq^{-1} Intake)				
Nuclide	**Lung**	**Liver**	**Bone Surface**	**Red Marrow**
Pu-238 (Y)	7 E-5	9.7 E-7	3.5 E-6	3 E-7
Pu-239 (Y)	6.7 E-5	9.2 E-7	3.5 E-6	2.7 E-7
Pu-240 (Y)	6.7 E-5	9.2 E-7	3.5 E-6	2.7 E-7
Pu-241 (Y)	7 E-9	1.1 E-9	3.8 E-9	2.7 E-10
Am-241 (W)	1.8 E-5	1.5 E-6	5.4 E-5	4.3 E-6

6.

Weighting Factors	
Tissue	**WT**
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder (5 highest other organs)	0.30

Code #________________

HP.3.7 A 200 ft. concrete stack contaminated with an estimated 100 Ci of tritium is scheduled for demolition. The stack has a 10′5" inner diameter at the base and tapers to 5′ at the top of the stack. The stack wall is 1′6" thick at the base and 6" thick at the top. The total weight of the stack is 487 tons. A demolition expert has estimated that 5.4 lbs of contaminated dust will become airborne as a result of toppling the stack with explosives. She also estimates that another 282.5 lbs of contaminated dust will be released over a week due to further demolition of the stack with a jackhammer.

a. Make an estimate of the maximum inhalation Committed Effective Dose Equivalent to a worker on this project. A statement of your assumptions is crucial.

b. What preventive measures might you take to reduce exposure?

Information you might want to use:

Average site wind speed - 4 m/s

CEDE Dose factor for ^{3}H Inhalation = 1.73×10^{-11} Sv/Bq

454g ≡ 1 lb

Light Activity Breathing Rate = 25 liters/minute

Code #________________

HP.3.8 Cleanup standards for radioactively-contaminated ecosystems can be developed using concepts in the field of radioecology. Explain how one might determine the threshold level of surface soil contamination that might warrant soil removal, based on risk to (1) human health and (2) the vitality of plant and animal populations.