GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

HEALTH PHYSICS

Ph.D. Qualifiers Exam - Fall Quarter 1996

ENVIRONMENTAL RADIATION PROTECTION

EXAM AREA

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

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

Code #______________
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Health Physics

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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.III.1. A welder at a nuclear power plant spends six hours one day welding in a steam generator. The major sources of radiation are ^{60}Co and ^{54}Mn from crud. Seven days after performing the work, the welder received a whole body count which showed the presence of 3 μCi of ^{60}Co and 10 μCi of ^{54}Mn in the pulmonary region. A second count taken 21 days after the first showed 2.9 μCi of ^{60}Co and 7.1 μCi of ^{54}Mn remaining in the pulmonary region. Using the ICRP model, determine the clearance class and calculate the total intake (considered to be a single intake) of ^{60}Co and ^{54}Mn. Assume a particle size of 1 μm.

SEE ATTACHED - 1 SHEET

Data:

i) Half life of ^{60}Co = 5.2 year
ii) Half life of ^{54}Mn = 303 days
iii) See attached diagram of clearance model

ICRP 30 Metabolic Models

Region	Compartment	Class D T day	Class D F	Class W T day	Class W F	Class Y T day	Class Y F
N-P	a	0.01	0.5	0.01	0.1	0.01	0.01
(D_{N-P} = 0.30)	b	0.01	0.5	0.40	0.9	0.40	0.99
T-B	c	0.01	0.95	0.01	0.5	0.01	0.01
(D_{T-B} = 0.08)	d	0.2	0.05	0.2	0.5	0.2	0.99
	e	0.5	0.8	50	0.15	500	0.05
P	f	n.a.	n.a.	1.0	0.4	1.0	0.4
(D_P = 0.25)	g	n.a.	n.a.	50	0.4	500	0.4
	h	0.5	0.2	50	0.05	500	0.15
L	i	0.5	1.0	50	1.0	1 000	0.9
	j	n.a.	n.a.	n.a.	n.a.	∞	0.1

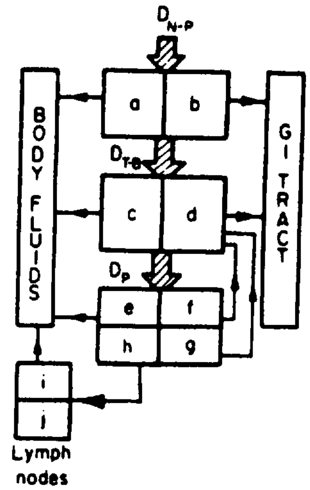

Fig. 5.2. Mathematical model used to describe clearance from the respiratory system. The values for the removal half-times, T_{a-i} and compartmental fractions, F_{a-i} are given in the tabular portion of the figure for each of the three classes of retained materials. The values given for D_{N-P}, D_{T-B} and D_P (left column) are the regional depositions for an aerosol with an AMAD of 1 μm. The schematic drawing identifies the various clearance pathways from compartments a–i in the four respiratory regions, N-P, T-B, P and L.

n.a. = not applicable.

HP III.1

HP.III.2. a. Thermoluminescent dosimeters, a high-pressure ionization chamber, a G-M survey meter, and a NaI(Tℓ) survey instrument are available for environmental measurements of the natural gamma-ray background. Discuss the advantages and disadvantages of each.

b. Past experience suggests that radioactive Ar-41 discharged from a stack at the Georgia Tech reactor will expose persons just outside the fence to an air dose rate of 6 microrad per hour. How can the dose rate be calculated from release rate measurements? How can environmental measurements be performed? (Ar-41 decays with a 1.8-hr half-life and emits 1.2-MeV maximum beta particles and 1.29-MeV gamma rays.)

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HP.III.3. A human health risk analysis is to be conducted to evaluate a land purchase for use as grazing lands and for feed production for dairy herds. This land was previously held in fee simple, fully owned rather than leased, by several petroleum companies. As part of pre-purchase disclosures, the owners have revealed that scale and sludge from petroleum operations containing NORM (Naturally Occurring Radioactive Materials) have been spread and mixed into the soil with disk harrows. The following information applies to this question:

(1) The NORM is in the form of radium/strontium sulfate, is very insoluble, and tightly binds radon in the crystal structure.
(2) It is stated in the contract that nowhere does the radium in soil exceed 10 pCi/g.
(3) The wells on site that will be used for stock watering contain ≤ 5 pCi/L radium contamination.
(4) Both beef and dairy animals will be fed 50% site-grown pasture grass and 50% site-grown dry feeds.
(5) Transfer factors are as shown below

TRANSFER	TRANSFER FACTOR
Soil to Dry Forage	1E-2pCi/kg of dry forage per pCi/kg of dry soil
Soil to Pasture Grass	2E-2 pCi/kg of dry grass per pCi/kg of dry soil
Feed to Meat (Feed is Pasture Grass plus Dry Forage)	The fraction of the nuclide ingested daily that is found in muscle or edible tissue is 5E-4 d/kg
Feed to Milk	The fraction of the nuclide ingested daily that is secreted in one liter of milk is 4E-4 d/L
Water to Meat	Use the same factor that is used for feed to meet
Water to Milk	Use the same factor that is used for feed to milk

(6) A dairy cow consumes 60 liters of water and 50 kg of all kinds of feed per day.
(7) A beef animal consumes 50 liters of water and 60 kg of all kinds of feed per day.
(8) Best estimates for food consumption by a human being is
- 306 liters of dairy products per year
- 86 kg of beef products per year
- 2 liters of local well water per day,

(A) If an individual whose sole source of dairy products and meat is the beef and dairy herds in question, and who gets all of his drinking water from the site, identify all the possible contaminant migration and transport pathways that will lead to the exposure of the

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individual to the NORM. (B) Based on the pathways identified in Part (A), calculate the maximum annual intake of radium by this individual.

HP.III.4. Calculate the annual limit on intake (ALI) for ^{41}Ca. Consider that only the bone receives significant doses. The route of entry is by ingestion.

SEE ATTACHED - 3 SHEETS

Data:

i) Half life of $^{41}Ca = 1.4 \times 10^5$ year

ii) ^{41}K (stable) $\leftarrow$ ^{41}Ca

iii) Electrons: E = 0.0030 MeV, yield rate = 0.770
γ and x-ray: E= 0.0033 MeV, yield rate = 0.123

iv) Source organ transformations in 50 years:
Cortical bone = 1.78×10^8 per Bq transferred to body fluids
Trabecular bone = 6.26×10^7 per Bq transferred to body fluids

v) Weighting factor for bone surface = 0.03
Weighting factor for red marrow = 0.12

vi) attached absorption fraction table taken from ICRP bone model.

vii) attached SPECIFIC absorption fraction (fraction per unit mass) table taken from ICRP 23.

viii) $f_1 = 0.3$ for Calcium

ix) mass of bone surface = 120 gram

x) mass of red marrow = 1,500 gram

ICRP 30 Metabolic Models

Recommended absorbed fractions for dosimetry of radionuclides in bone (ICRP 30)

		Class of radionuclide (see Section 7.2)				
Source organ	Target organ	α emitter uniform in volume	α emitter on bone surfaces	β emitter uniform in volume	β emitter on bone surfaces $\bar{E}_\beta \geq 0.2$ MeV	β emitter on bone surfaces $\bar{E}_\beta < 0.2$ MeV
Trabecular bone	Bone surfaces (BS)	0.025	0.25	0.025	0.025	0.25
Cortical bone	Bone surfaces (BS)	0.01	0.25	0.015	0.015	0.25
Trabecular bone	Red bone marrow (RM)	0.05	0.5	0.35	0.5	0.5
Cortical bone	Red bone marrow (RM)	0.0	0.0	0.0	0.0	0.0

HP.III.4 #1

Specific Absorbed Fraction of Photon Energy (*Continued*)

Target	Energy (MeV) 0.010	0.015	0.020	0.030	0.050	0.100
Source in Skeleton (suggested for Cancellous Bone, Cortical Bone, Red Marrow, and Yellow Marrow)						
Bladder wall	2.27E—11*	3.40E—11†	2.00E—08†	2.96E—07	1.51E—06	2.12E—06
Stomach wall	1.45E—07*	2.18E—07*	2.90E—07	1.06E—06	1.73E—06	2.11E—06
Small intestine plus contents	1.52E—07*	2.28E—07	5.01E—07	1.69E—06	3.09E—06	2.81E—06
Upper large intestine wall	2.12E—07*	3.17E—07	6.44E—07	1.38E—06	2.57E—06	2.56E—06
Lower large intestine wall	6.48E—07*	9.71E—07	1.84E—06	3.46E—06	4.10E—06	3.97E—06
Kidneys	3.02E—07*	4.54E—07*	6.05E—07	1.81E—06	3.26E—06	3.01E—06
Liver	1.24E—07*	1.87E—07	4.79E—07	1.67E—06	2.37E—06	2.55E—06
Lungs	1.69E—07*	2.54E—07	1.04E—06	3.20E—06	4.42E—06	3.63E—06
"Other tissues" (suggested for muscle)	3.85E—07⊗	9.43E—07⊗	1.63E—06⊗	3.06E—06⊗	3.82E—06⊗	3.66E—06⊗
Ovaries	2.12E—08*	3.18E—08†	9.03E—07†	3.85E—06†	3.20E—06	2.81E—06
Pancreas	3.91E—07*	5.87E—07*	7.83E—07†	1.39E—06	3.22E—06	2.78E—06
Skeleton (suggested for total endosteal cells)	9.34E—05	8.97E—05	8.42E—05	6.84E—05	4.10E—05	1.81E—05
Red marrow	9.42E—05	8.85E—05	8.31E—05	6.45E—05	3.77E—05	1.65E—05
Skin	4.95E—07	1.18E—06	1.85E—06	2.27E—06	2.40E—06	2.35E—06
Spleen	6.52E—07*	9.78E—07*	1.30E—06*	1.96E—06	2.76E—06	2.09E—06
Testes	1.81E—11*	2.71E—11†	2.22E—08†	8.29E—07†	1.73E—06	2.59E—06
Thymus	2.85E—07*	4.27E—07*	5.69E—07†	7.64E—07	1.87E—06	2.19E—06
Thyroid	1.32E—07*	1.98E—07*	2.64E—07†	1.94E—06†	2.91E—06	2.76E—06
Uterus	9.28E—11*	1.39E—10†	4.96E—08†	1.23E—06	1.63E—06	2.11E—06
Total body	1.43E—05	1.42E—05	1.40E—05	1.28E—05	9.31E—06	5.73E—06

HP.II.4 #2

Uterus	9.28E—11	1.39E—10†	4.96E—08†	1.25E—06	1.65E—06	2.1[illegible]E—06
Total body	1.43E—05	1.42E—05	1.40E—05	1.28E—05	9.31E—[illegible]	5.73E—06

Target	Energy (MeV)					
	0.200	0.500	1.000	1.500	2.000	4.000
Bladder wall	1.68E—06	2.28E—06	1.37E—06	2.56E—06	1.87E—06	1.94E—06
Stomach wall	2.07E—06	2.02E—06	1.76E—06	1.90E—06	1.72E—06	1.48E—06
Small intestine plus contents	2.73E—06	2.77E—06	2.79E—06	2.36E—06	2.35E—06	1.98E—06
Upper large intestine wall	2.67E—06	2.40E—06	2.61E—06	2.33E—06	2.32E—06	1.77E—06
Lower large intestine wall	3.82E—06	3.24E—06	3.58E—06	3.03E—06	2.72E—06	2.54E—06
Kidneys	3.29E—06	3.12E—06	4.02E—06	3.16E—06	2.43E—06	2.32E—06
Liver	2.39E—06	2.44E—06	2.41E—06	2.30E—06	2.50E—06	2.05E—06
Lungs	3.50E—06	3.38E—06	3.29E—06	3.03E—06	3.09E—06	2.30E—06
"Other tissues" (suggested for muscle)	3.74E—06⊗	3.82E—06⊗	3.67E—06⊗	3.54E—06⊗	3.33E—06⊗	2.83E—06⊗
Ovaries	2.46E—06	3.75E—06	3.16E—06†	2.79E—06†	2.75E—06†	2.22E—06†
Pancreas	3.90E—06	3.11E—06	3.29E—06	3.71E—06	3.50E—06	1.59E—06
Skeleton (suggested for total endosteal cells)	1.29E—05	1.19E—05	1.11E—05	1.01E—05	9.39E—06	7.79E—06
Red marrow	1.15E—05	1.06E—05	1.01E—05	9.19E—06	8.37E—06	7.06E—06
Skin	2.63E—06	3.00E—06	2.87E—06	2.85E—06	2.62E—06	2.46E—06
Spleen	2.32E—06	2.90E—06	2.96E—06	2.02E—06	2.17E—06	1.23E—06
Testes	2.23E—06	1.98E—06	2.24E—06	2.37E—06	3.88E—06	2.13E—06
Thymus	1.65E—06	2.64E—06	2.84E—06	1.41E—06	2.17E—06†	2.78E—06
Thyroid	3.31E—06	3.86E—06	1.60E—06	3.82E—06	1.82E—07	1.91E—06†
Uterus	2.24E—06	1.97E—06	3.15E—06	1.98E—06	1.57E—06	1.65E—06
Total body	5.01E—06	4.93E—06	4.70E—06	4.43E—06	4.16E—06	3.50E—06

* Extrapolation from higher energy.
† Build-up factor method.
Source: From ICRP Report No. 23, *Report of the Task Group on Reference Man*, Pergamon Press, Oxford, England, 1975. By permission.

HP.III.4 #3

HP.III.5. Describe the role played by the various advisory and/or regulatory agencies/organizations in the establishment of radiation protection standards in the United States. Be specific and describe the inter-dependencies which exist between certain of these organizations. Also describe the general differences between the Federal Rules 10 CFR 20 and 10 CFR 835 (such as to whom they apply, what guidance documents each are based on, and which regulatory agency is responsible for enforcement of each).

Using current regulations, explain why the following situation is correct:

A radiation worker with a cumulative Total Effective Dose Equivalent of 3.875 rem through 1994 receives an external dose equivalent of 0.250 rem in 1995, and another 0.150 rem in 1996. In late 1995, that worker receives an intake of radionuclides for which the effective dose equivalent through the remainder of the year is 0.750 rem. During 1996, another 0.250 rem effective dose equivalent is received from the same intake. Further bioassay analyses indicate no further contribution from that intake in subsequent years. Through 1995, that worker's cumulative Total Effective Dose Equivalent is 5.125 rem. Through 1996, that worker's cumulative Total Effective Dose Equivalent is 5.275 rem.

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HP.III.6. a. I-131 in milk can be measured by proportional counter, beta-gamma coincidence system, and a photon detector with spectral analysis. Describe the three procedures, beginning with a 1-liter sample, through counting and the concentration calculation.

b. How does one determine whether a method is sufficiently sensitive to detect 1 pCi/L? Identify the information needed and show the calculational approach.

HP.III7. A detached single-family home with full basement that has a free-space volume of 100 m^3 needs radon mitigation. A one-year alpha track measurement was performed in this house and the result shows an average radon concentration of 25 pCi/liter. The SF_6 tracer measurements have determined that outside air infiltrates the home at an average rate of 0.2 air changes per hour. Use the following data to answer the questions below:

Half life for Rn-222 = 3.8 days
Number of persons in the household = 5
Occupancy factor = 0.7
Daily water usage per person = 200 liters
Fraction of radon released from water usage = 0.7
Tracheobronchial dose conversion factor = 0.7 rad/WLM
ICRP organ weighting factor for the tracheobronchial (TB) region of the lung = 0.06

(A) Assuming that radon is removed only by outside air infiltration, estimate the annual average radon source strength or entry rate into the structure in units of pCi of Rn-222 per hour?

(B) Radon measurements of the household water supply indicate an Rn-222 concentration of 2000 pCi per liter of water. Could the water supply alone account for the elevated radon levels in the home?

(C) The radon progeny equilibrium factor for the home was determined to be 0.30 (unitless). Estimate the average potential alpha-energy air concentration in units of working level for this home.

(D) Calculate the annual effective dose equivalent for a member of this household if the indoor radon concentration is 0.1 WL.

(E) Assuming that the radon contribution from building materials used in constructing the home is negligible and that the household water is in insignificant source, what is the likely source of the elevated indoor radon? Name and briefly describe three mitigation techniques that you might recommend to reduce the home's radon levels.

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HP.III.8. Permissible noise levels in the work place are specified under U.S. Federal Law. DISCUSS:

a. The **DETAILED** anatomy of the part of the human body that processes this "noise" information.

b. The two (2) **MAJOR** types of loss of response that can result from occupational exposure to unacceptable levels of "noise".

c. What effect does each of the situations identified above [i.e., #b] have on the organ described [in #a, above]? (I.E., how does "noise" change it from its normal state?)

d. What is the maximum effectiveness, in dBA, of "noise" protective devices? Why can't they be made 100% effective?