COMPREHENSIVE EXAMINATION INSTRUCTIONS

Read these instructions carefully and follow them closely

1. Part 2 of this examination consists of two sections:
   - The first section (questions 1-6) consists of six fundamental questions. <u>All six will be graded.</u>
   - The second section (questions 7-14) consists of eight specialty questions. **<u>Answer any four.</u>** The proctor can accept only four answers from this section.

2. Questions 1-6 are each worth 50 points. Questions 7-14 are each worth 100 points. The maximum possible score is 700 points. The relative weight of each part of a question is given.

3. You have five hours to complete the examination.

4. On the <u>cover</u> sheet:
   a. <u>Print</u> your name;
   b. Write your identification number;
   c. Sign your name;
   d. When you have finished the exam, mark the questions you have answered.

5. On the <u>answer</u> sheet:
   a. Identify yourself with each sheet by writing your number (not your name) in the upper right corner. The graders can be objective when names do not appear.
   b. Write the question number in the upper left corner.
   c. When you have completed the answer to a question, go back and write beside the question number the number of pages in your answer: Page 1 of __, Page 2 of __, etc., so that the grader knows that all answer sheets are present.
   d. Write only on one side of the sheets.
   e. Begin each new question on a separate sheet.

6. This is a closed-book examination so no texts or reference materials are permitted. Standard slide rules may be used, but not the so-called "Health Physics" slide rules. Non-programmable electronic calculators are permissible. Only those programmable calculators which have previously been approved by the Board are allowed. <u>All calculators must be checked by the proctor prior to the start of the examination</u>.

7. If the information in a particular question appears to be inadequate, list any assumptions you make in developing your solution.

8. If you find you are running short of time, simply set up an outline showing clearly how you would complete the solution without working out the actual numerical answer. Appropriate partial credit will be given.

9. Return the completed cover sheet and your answer sheet to the proctor when you have completed the examination. You may keep the copy of the examination.

ABHP PART 2 EXAMINATION COVER SHEET

June 30, 1997

Name: ______________________________

Identification Number: ____________________

Signature: ____________________________

Mark (X) the questions you have answered and are submitting for grading:

1. X
2. X
3. X
4. X
5. X
6. X

7. __
8. __
9. __
10. __
11. __
12. __
13. __
14. __

Remember to indicate on each answer sheet your identification number, the question number, and the number of pages for each, e.g.,

ID #1859, Question 4, page 2 of 3

ID #1859, Question 6, page 1 of 1

Have you taken a certification preparation or refresher course prior to taking this examination?

□ Yes □ No

If so, what format was involved?

□ Intensive, one or two weeks □ Multi-week, one or two classes per week

QUESTION 1

You are the health physicist responsible for setting up an air-sampling system in the exhaust vent of a nuclear facility which emits both particulates and radioiodine.

POINTS

10 A. Define isokinetic sampling and discuss its significance in setting up the air-sampling system. What is the effect on the representative nature of the air sample if the system is anisokinetic?

10 B. Assuming anisokinetic sampling conditions, list two principle factors which contribute to the error relative to collection of a representative sample. **Number your responses. Only the first 2 will be graded.**

10 C. Sampling line losses can range widely (from zero to 100 percent). List five factors that lead to sample line losses. **Number your responses. Only the first 5 will be graded.**

10 D. If copper tubing is used for the sampling line in the air-sampling system you are setting up for particulates and radioiodines, what would be the effect on the air sample? Why?

10 E. Briefly describe the function of using a cascade impactor air sampler in the initial design of a sampling system that minimizes sampling line losses.

QUESTION 2

An inhalation incident involving airborne ^{60}Co and ^{131}I occurred at a radiochemistry laboratory. The worker immediately took a shower and changed clothes, then received a whole body count. Assume that the ^{60}Co was a class Y compound and the ^{131}I was class D. Apply ICRP 30 methodology to answer the following questions.

GIVEN:

^{60}Co data:

$T_{1/2}$ = 5.2 years
For inhalation class Y:
ALI_{stoch} = 30 μCi
Committed dose equivalent (CDE) in lungs: 3.4×10^{-7} Sv/Bq ($f_{N\text{-}P}$, $f_{T\text{-}B}$, f_P) = (0, 0, 100)
where: $f_{N\text{-}P}$, $f_{T\text{-}B}$, f_P are the fractional contributions of the CDE to the reference tissue from initial depositions in the nasal passages, tracheo-bronchial, and pulmonary regions, respectively.

Fraction of initial intake remaining in whole body as a function of inhaled particle size (in microns) and elapsed time:

Elapsed Time (days)	**Inhaled Particle Size: 1 μm**	**5 μm**	**10 μm**
0	0.63	0.91	1.00
1	0.57	0.80	0.87
5	0.18	0.10	0.09
10	0.14	0.06	0.04
15	0.13	0.05	0.04
20	0.12	0.05	0.03

ICRP 26 recommended weighting factors

Organ or tissue	**W_T**
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

Fraction of intake deposited in the lung compartments

AMAD	**DEPOSITION**			
(microns)	**D_{N-P}**	**D_{T-B}**	**D_P**	**SUM**
1	0.30	0.08	0.25	0.63
5	0.74	0.08	0.09	0.91
10	0.87	0.08	0.05	1.00

Correction for particle size:

$$\frac{H_{50}(AMAD)}{H_{50}(1\ \mu m)} = f_{N-P}\,\frac{D_{N-P}(AMAD)}{D_{N-P}(1\ \mu m)} + f_{T-B}\,\frac{D_{T-B}(AMAD)}{D_{T-B}(1\ \mu m)} + f_P\,\frac{D_P(AMAD)}{D_P(1\ \mu m)}$$

POINTS:

10 A. The ^{60}Co component of the whole body count result was 21 mCi. Assuming that the activity median aerodynamic diameter (AMAD) of the aerosol was 1 mm, estimate the intake, expressed in %ALI, based on the whole body count result. **Show all work.**

10 B. Calculate the committed effective dose equivalent (CEDE) for an inhalation intake of 25 mCi of 1 mm AMAD class Y^{60}Co. **Show all work.**

10 C. For this part only, assume that the CEDE due to ^{60}Co was 50 mrem. The worker had an ^{131}I intake that resulted in 600 mrem committed dose equivalent (CDE) to the thyroid. Assume that the thyroid is the only significantly irradiated organ or tissue. During the same monitoring period, the worker also received 250 mrem due to external radiation exposure from ^{60}Co. What is the total effective dose equivalent (TEDE) to the worker during the monitoring period? **Show all work.**

20 D. Another worker inhaled 30 mCi of class Y ^{60}Co. The AMAD was determined to be 10 mm. Calculate the committed dose equivalent (CDE) to the lungs. **Show all work.**

QUESTION 3

GIVEN:

The number of induced genetic defects (I) per generation for a given population is expressed as:

$\mathbf{I} = 0.05(Sd/D_g)$

where: S = spontaneous occurrence of defects in the population,
d = dose equivalent to an average exposed individual in the population,
D_g = genetic doubling dose equivalent (assume 250 mSv).

This assumes that both mother and father are exposed. **I** must be corrected by a factor of 1/2 if only one of the parents is exposed.

Relative risk (R) of genetic defects in a population is defined as: R= (S+I)/S
Dose and Dose Rate Effectiveness Factor for cancer induction (DDREF) = 2.0

POINTS

A. The linear-no-threshold model is most commonly used to describe dose response for induction of cancer by radiation.

10 1. Name two other models and describe (or draw) the shapes of their dose response curves. **Number your responses. Only the first 2 will be graded.**

5 2. What characteristic of the linear-no-threshold model makes it useful as a basis for radiation protection purposes? **Justify your answer.**

6 B. What will be the most likely effect from a 30 rem dose equivalent delivered to the fetus 3 days, 3 weeks, and 3 months after conception?

C. The following questions relate to genetic effects of radiation:

4 1. What does the term "genetic doubling dose" mean? What two types of studies were used to determine the genetic doubling dose?

10 2. What is the relative risk of genetic defects (per generation) caused by an average dose equivalent of 4 mSv to each individual in a population of 40,000 men?

D. The concept of collective dose is sometimes used in assessing the potential harm which low level radiation may cause in a large population.

5 1. In applying collective dose, the dose response is assumed to have what shape?

5 2. Several additional assumptions regarding the attributable risks, exposed population or exposure conditions must be made in order to properly estimate risk using the collective dose concept. Name **one** of the assumptions. **Only the first response will be graded.**

5 E. A population of 40,000 individuals was exposed, on average, to 4 mSv. Estimate the excess number of cancer deaths that might be expected in the remaining lifetime of this population. **List any assumptions.**

QUESTION 4

You are a health physicist using a commercial ionization chamber survey instrument to perform general area surveys in a highly contaminated area containing mixed fission products.

GIVEN:

The instrument has the following characteristics:

Volume = 200 cm3
Gas fill = ambient air
Sliding shield = 0.34 cm phenolic
Window = 7 mg/cm2 aluminized mylar
Walls = 0.16 cm phenolic (plastic)
Collection bias = 50 Volts

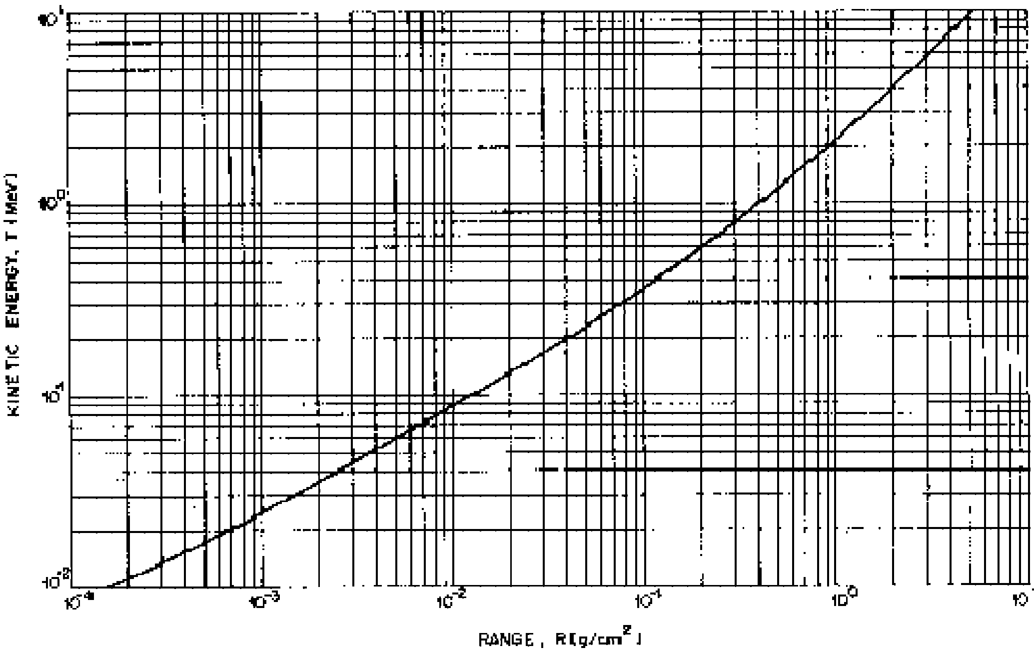
In addition, you have the following data:

	Density (g/cm^3)	Mass attention coefficient (γ) (cm^2/g) @ 0.5 MeV	@ 1.0 MeV
Phenolic	1.25	0.091	0.067
Air	1.29E-3	0.087	0.063

Thicknesses of Ionization Chamber Walls Required for Establishment of Electronic Equilibrium
(from ICRU #20)

Photon Energy (MeV)	Thickness (g/cm2)
0.02	0.0008
0.05	0.0042
0.1	0.014
0.2	0.044
0.5	0.17
1	0.43
2	0.96
5	2.5
10	4.9

1 erg = 6.2×10^{11} eV
w = 35 eV/ion pair
10^7 ergs = 1 Joule
1 amp = 6×10^{18} ions/sec



Beta Range-Energy Curve (from Radiological Health Handbook)

POINTS

10 A. Describe how this instrument can be used to determine the separate dose rates for betas and gammas in a mixed field.

15 B. List three of the parameters that affect the correction factor needed to convert the meter reading to actual beta dose rate. **Number your responses. Only the first 3 will be graded.**

15 C. 1. What is the maximum gamma ray energy for which full electronic equilibrium is established in the sliding shield?

2. What is the maximum energy beta particle that would be stopped by the sliding shield? **Do not use rules of thumb.**

D. Regarding electronic equilibrium:

5 1. Briefly explain the meaning of "electronic equilibrium."

5 2. What is the consequence if full electronic equilibrium is not established?

QUESTION 5

You are a health physicist at a manufacturing facility which produces depleted uranium plates. An employee of one of your customers has recently learned that the plates are radioactive and has expressed concern about her exposure. She has been working for three years in a warehouse where plates of depleted uranium are stacked on pallets forming an extended source. She has never worn any dosimetry. Her job duties involve visually inspecting the pallets and occasionally handling the plates. You have been asked to serve as a health physics consultant to your customer.

GIVEN:

Density of Air at STP: 0.001293 g/cm^3
Density of Water: 1.000 g/cm^3

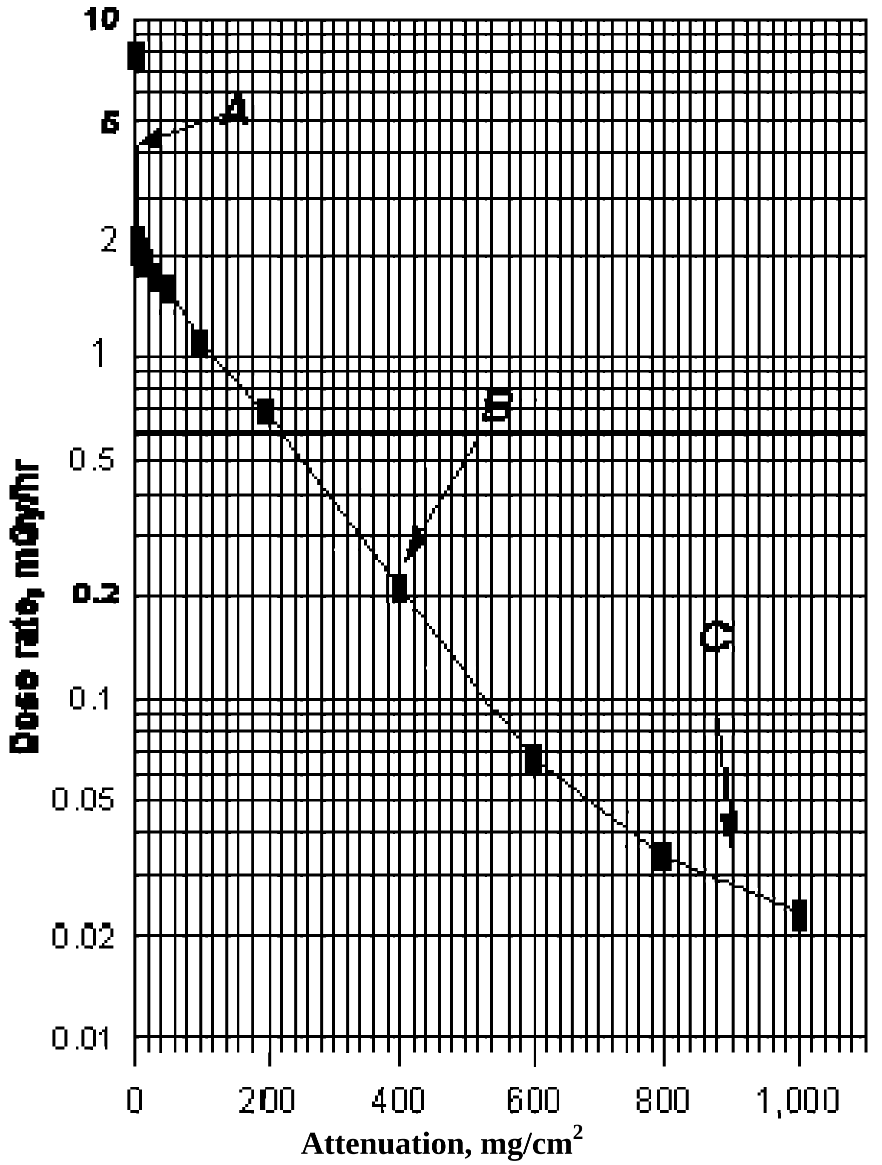
Specific Activity of depleted uranium: 3.6×10^{-7} Ci/g

Glove mass: 200 g
Glove total surface area: 400 cm^2

Attached graph of "Dose rate from an extended source of depleted uranium," applicable to materials of low atomic number

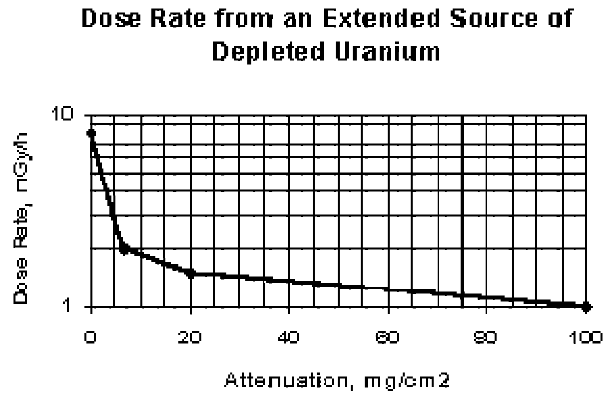
Emissions from depleted uranium (partial list) (MeV)			
	α	β	γ
U-238	4.1, 4.2	--	--
Th-234	--	0.1, 0.2	0.06, 0.09
Pa-234	--	2.3	0.8, 0.1
U-234	4.7, 4.8	--	--

Figure 1:
Dose rate from an extended source of depleted uranium



Source: Handbook of Safety Procedures for Processing Depleted Uranium, Army Material Command Handbook, No. AMCHDBK-385-1.1-89, Department of the Army, Washington, D.C.

Expansion of Figure 1 for Range of 0 to 100 mg/cm^2



POINTS:

10 A. Calculate the shallow dose rate to the skin of the hands when handling the plates with and without gloves. If the wearing of gloves does not effect work performance, would you advise adopting the wearing of gloves as a standard practice? **Show all work; justify your recommendation.**

10 B. Individuals walking through the warehouse maintain a distance of about one meter from the loaded pallets. Assuming that the loaded pallets essentially form a semi- infinite source relative to the individuals, what is the dose rate in air at a distance of 1.0 m from the pallets? **Show all work.**

10 C. Assuming that eye protection is not used and that visual inspection of the pallets is performed for 2.5 hours a day at an eye-to-source distance of 30 cm, calculate the annual eye dose equivalent. Was the annual eye dose equivalent limit exceeded? State this limit as part of your evidence. **State all assumptions; show all work.**

10 D. If you were the RSO for this warehouse facility, what radiological safety practices would you recommend be implemented? List five recommendations and provide a brief description for each. **Number your responses. Only the first 5 will be graded.**

10 E. The plot of dose rate versus mass density thickness (Figure 1) displays three distinct slopes within regions A, B, and C. Describe the physical and/or radiological processes that account for this.

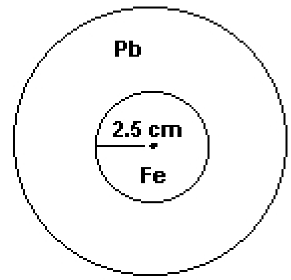
QUESTION 6

You are tasked with the design and fabrication of a spherical shield for a point source. The source currently has a 2.5 cm iron shield; your task is to add an outer lead shield. The configuration is shown below.

GIVEN

Isotope: ^{60}Co
Source Strength: Up to 15 Ci

$\Gamma_{Co60} = 1.32$ R-m^2/Ci-hr



source/shield configuration
(not to scale)

Pb linear attenuation coefficient for ^{60}Co = 0.679 cm^{-1}
Fe linear attenuation coefficient for ^{60}Co = 0.35 cm^{-1}

Buildup factors for a point source: Pb: $1 + (\mu x/3)$
Fe: $1 + \mu x$
where x is the thickness of the shield

POINTS

35 A. Neglecting the dose buildup effect, what is the minimum thickness of lead that must be added to the existing iron shield to reach a desired exposure rate of 2.5 mR/hr at the surface of the shield? **Show all work.**

15 B. For this part only, assume a total shield (lead + iron) thickness of 22 cm. Calculate the expected exposure rate on the outside surface of the shield if the exposure rate without buildup is 2.5 mR/hr. Assume the energy spectrum is not significantly degraded as it penetrates the iron shield. **Show all work.**

QUESTION 7

During an annual survey of a general purpose X-ray machine, the data in the table below were collected for machine output in mR as a function of kVp and the accompanying mAs and SID settings.

GIVEN:

Conditions and results of survey measurements:

- The X-ray beam was oriented vertically so that the central axis of the beam was normal to the patient table.
- The ionization chamber was located 4 inches above the table.
- The image receptor (cassette containing screen and film) was located in a stationary position 3 inches below the table.
- Source-to-Image Receptor Distance (SID): 34 inches
- mAs = 10

kVp	55	65	75	85	95	105	115	125
mR	58	81	112	145	183	223	264	305

Additional information:

Anterior-posterior (AP) abdominal exam: table top exam with SID of 40 inches
Posterior-anterior (PA) chest exam: horizontal beam with SID of 72 inches.

POINTS

15 A. For an AP abdominal exam on a standard patient, the technique settings are 75 kVp and 60 mAs. The standard patient abdominal thickness is assumed to be 10 inches. The screen-film speed is 250 and a 10:1 grid is used. What will the patient entrance skin exposure (ESE) be?

20 B. For a PA chest exam on the standard patient, technique settings of 115 kVp and 5 mAs are used. Assume the distance from the chest board surface to the cassette can is zero and the patient abdominal thickness is 10 inches. The screen-film speed is 250 and a 10:1 grid is used. What will the patient entrance skin exposure (ESE) be?

20 C. Recommend two procedural changes which could reduce the ESE for these procedures. State the effect each change would have on image quality. **Number your responses. Only the first 2 will be graded.**

10 D. A technologist stands about 1 meter from the patient during an AP abdominal exam and is not wearing a lead apron and is not behind a control room wall. What is the approximate exposure from scatter to the technologist from one exposure? Show how you derived this exposure value.

12 E. Provide three design features of the room containing the control panel that are required to minimize the technologist's dose during X-ray exposures. **Number your responses. Only the first 3 will be graded.**

8 F. An X-ray technologist performs only mammographic procedures in a large hospital X-ray department. In June, the technologist's monthly whole body film dosimeter read 80 mrem. Is this dose equivalent typical of the average monthly occupational dose one would expect of this radiation worker? **Explain your answer.**

15 G. Identify three design characteristics of a general purpose X-ray system and the associated image receptor system which are required to minimize patient dose. **Number your responses. Only the first 3 will be graded.**

QUESTION 8

An incident occurred when a ^{137}Cs source was accidentally processed in a metal smelter. Subsequent investigation revealed that this incident resulted in a release of ^{137}Cs from the smelter stack over an 8 hour period.

GIVEN

Maximum ^{137}Cs deposition on soil at 135 degrees and 2 km: D_s = 14,000 pCi/m^2
Meteorological Conditions:
Wind at 5 m/s from the NW
Pasquill Stability Class C.

Nominal deposition velocity: V_d = 0.002 m/s
Effective stack height: H = 40 m

Breathing rate: R = 0.8 m^3/h

Gaussian Plume dispersion equation for particles:

$$\chi(x,0,0) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-0.5\left(\frac{H^2}{\sigma_z^2}\right)\right]$$

where: χ (x,0,0) = ground level downwind concentration in air (pCi/m^3),
Q = release rate (pCi/s),
u = wind speed (m/s)

Charts of σ_y and σ_z attached

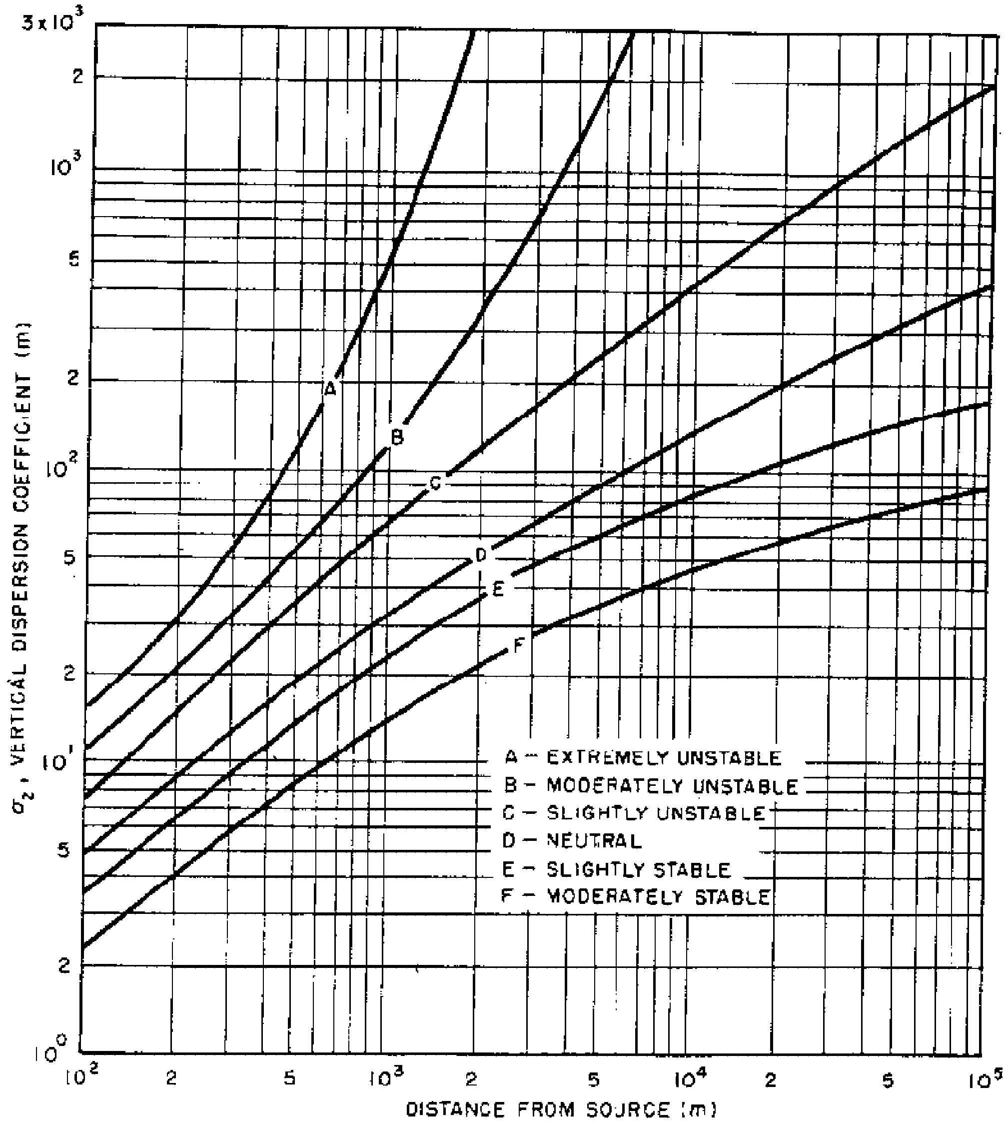


Fig. 3.11 — Vertical diffusion, σ_z, vs. downwind distance from source for Pasquill's turbulence types.

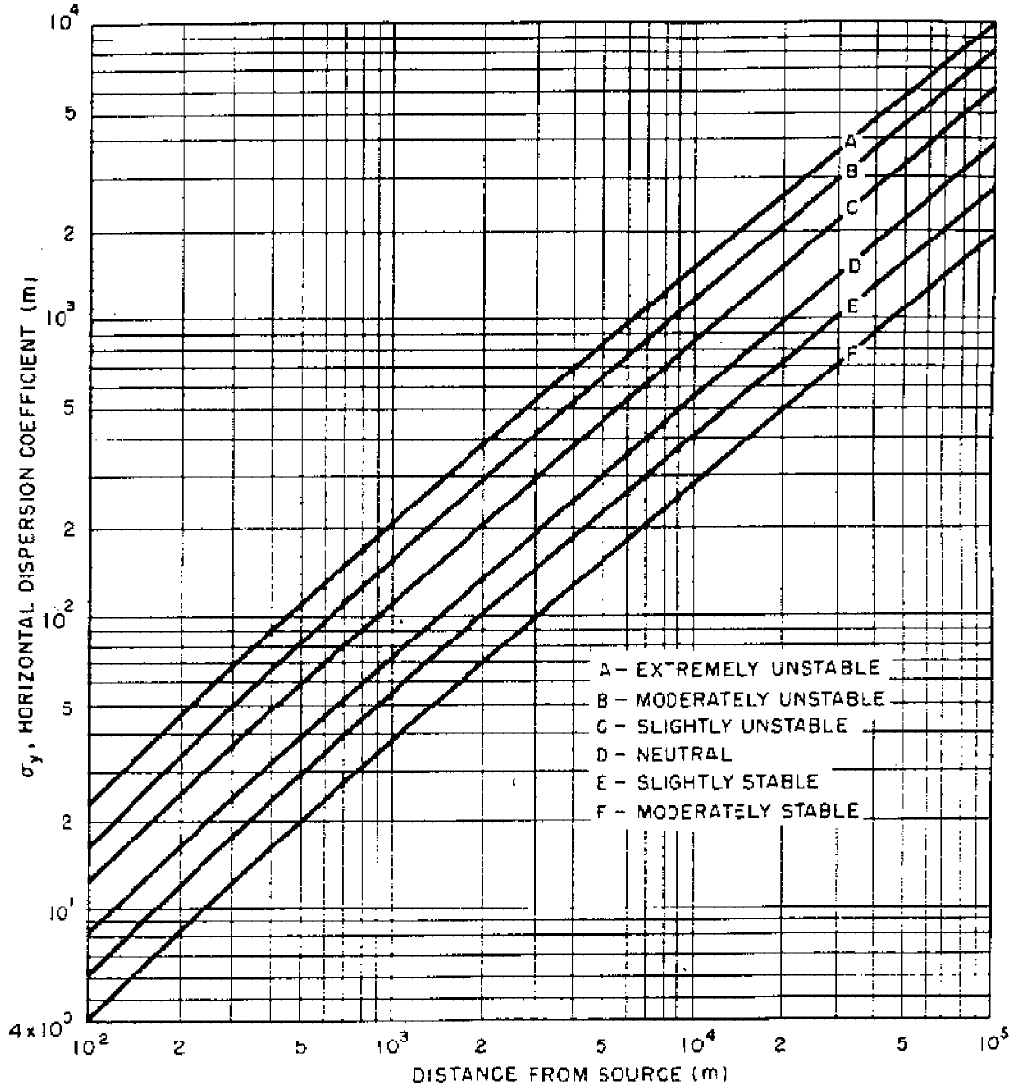


Fig. 3.10—Lateral diffusion, σ_y, vs. downwind distance from source for Pasquill's turbulence types.

POINTS

20 A. What is the inhalation intake to a person present at the given point of maximum ^{137}Cs deposition (2 km, 135 degrees) during the 8 hours that the release occurs? **Show all work.**

20 B. Assume that you calculated the 8-hour average air concentration at the soil sampling site to be 300 pCi/m^3. On that basis, how much ^{137}Cs was released from the stack? **Show all work.**

10 C. What additional information would you request in order to confirm the release scenario and reduce the uncertainty in the release estimate?

10 D. An analytical instrument is set up to count environmental samples taken as a result of this incident. List five tasks that should be routinely performed to assure the quality of the counting system. **Number your responses. Only the first 5 will be graded.**

E. A 100-minute background is run on the system in part D. Five 1-minute counts are performed on a NIST traceable standard. The sample is then counted for 50 minutes. **Show all work for each part below.**

Data:	Background Count:	123 counts	(100 minutes)
	Sample Count (gross):	225 counts	(50 minutes)

NIST Standard activity: 89570 ± 789 dpm
NIST Standard counts (gross): 9263, 9607, 9242, 9681, 9524 (1 minute each)

20 1. What is the counter efficiency and the error associated with this efficiency?

20 2. What is the sample activity and its associated error?

QUESTION 9

You are a health physicist at a 100 MeV particle accelerator. The $^{4}He^{+2}$ beam and thick target combination produces two primary products in the following reactions with equal cross sections:

$$X\,(^{4}He,n)A \qquad X(^{4}He,2n)B$$

GIVEN:

The radioactive reaction products A and B have the following properties:

A: $t_{½} = 1$ d	$\Gamma_A = 0.5$ R-m^2(Ci-h)$^{-1}$	$\rho_A = 7.8$ g/cm^3
B: $t_{½} = 5$ d	$\Gamma_B = 1.0$ R-m^2(Ci-h)$^{-1}$	$\rho_B = 3.3$ g/cm^3

1 mA = 6.2×10^{12} electrons/sec
1 e^- = 1.6×10^{-19} C
Cell Volume = 100 m^3
Cell Ventilation Rate = 7 m^3/sec

POINTS

A. From an initially cold target the 100 MeV $^{4}He^{+2}$ beam is applied and held at a steady state. What is the ratio of the exposure rate from the decay of A to the exposure rate from the decay of B at the following times? (Assume no attenuation between target and point of measurement.) **Show all work.**

10 1. After 1 day of operation.
10 2. After 2 months of operation
10 3. 2 days after shutdown, after operating for 2 months.

10 B. The 100 MeV $^{4}He^{+2}$ beam from this accelerator is pulsed with a duty factor of 10^{-3}. The peak electrical beam current intensity during the 1ms pulse is measured to be 1 mA. How many beam particles per second are available to interact with the target? **Show all work.**

30 C. Assume that the O_3 concentration in the cell achieves a steady state value of 10 ppm. Calculate the delay time after beam shutdown for the O_3 concentration to reach a safe level of 0.1 ppm. Assume that the mean life of O_3 is 2000 sec. **Show all work.**

D. What is the most likely problem each of the following instruments could experience when operating in the vicinity of the beam interaction area with the beam described in part B?

5 1. A Geiger-Mueller instrument.
5 2. A standard portable ion chamber instrument.

5 E. What half-life would you expect the neutron field in part A to die off with when the beam is turned off? **Explain your answer**

10 F. List 5 sources of industrial hazards associated with the operation of a facility such as this. **Number your responses. Only the first 5 will be graded**.

5 G. List 5 ionizing radiations that can be produced during the operation of this machine. **Number your responses. Only the first 5 will be graded.**

QUESTION 10

You have been tasked to investigate a urine bioassay sample that was collected upon termination of a worker. There were no radionuclides detected in his last routine urine sample. The worker had been assigned to process and prepare radioactive waste for shipment. Upon questioning, the worker acknowledged that a drum containing dry resin contaminated with ^{137}Cs vented some of its contents due to gas buildup while he was in the process of tightening the lid and he remained in the area for 30 minutes after it vented. The event occurred approximately 20 days prior to collection of the termination bioassay. The worker was not wearing respiratory protection during the waste preparation.

GIVEN:

The ventilation system in the waste preparation room delivers one room air change every 2 hours.

Reference Man breathing rate = 1.2 m^3/h

Sample collection time = 24 hr
Sample volume = 1500 mL
Analyzed portion of sample = 500 mL
^{137}Cs activity in analyzed portion = 0.43 mCi

The following is an excerpt from the cesium table in NUREG/CR-4884:

CLASS D AMAD = 1 MICRON HALFLIFE = 1.10E+04 DAYS CESIUM- 137

TIME AFTER SINGLE INTAKE	**FRACTION OF INITIAL INTAKE IN**	
DAYS	24-HOUR URINE	ACCUMULATED URINE
1.00E+00	1.35E-02	1.35E-02
2.00E+00	1.33E-02	2.68E-02
3.00E+00	1.10E-02	3.78E-02
4.00E+00	8.87E-03	4.67E-02
5.00E+00	7.16E-03	5.38E-02
6.00E+00	5.89E-03	5.97E-02
7.00E+00	4.97E-03	6.47E-02
8.00E+00	4.32E-03	6.90E-02
9.00E+00	3.85E-03	7.28E-02
1.00E+01	3.51E-03	7.63E-02
2.00E+01	2.59E-03	1.04E-01
3.00E+01	2.41E-03	1.29E-01
4.00E+01	2.26E-03	1.52E-01

POINTS

20 A. What is the estimated intake for the worker, in μCi? **Show all work.**

30 B. Assume the intake for the worker was 1.5 mCi. What is the estimated **initial** concentration of ^{137}Cs in air to which the worker was exposed? **Show all work.**

Your facility also processes naturally occurring uranium. Your duties require conformance to regulatory requirements pertaining to worker safety, including protection of workers from airborne radioactive materials and personnel contamination. Answer the following questions:

10 C. Naturally occurring uranium consists of ^{234}U, ^{235}U, and ^{238}U. By weight, the distribution is:

U-234	0.013 g/mole-total U	$T_{1/2}$ = 2.5E5 y
U-235	1.71 g/mole-total U	$T_{1/2}$ = 7.0E8 y
U-238	236.4 g/mole-total U	$T_{1/2}$ = 4.5E9 y

One μg of uranium typically has a total activity of 0.66 pCi. Assuming equilibrium conditions, approximately what percentages of the total activity can be attributed to ^{234}U, ^{235}U, and ^{238}U, respectively?

1. negligible, 0.7%, 99.3%
2. 65%, 10%, 25%
3. 49%, 2%, 49%
4. 33%, 33%, 33%
5. 99.3%, 0.7%, negligible

10 D. ANSI Z88.2, "Practices for Respiratory Protection," gives recommendations for the use of supplied breathing air. This manual references other standards and specifications from other organizations such as the Compressed Gas Association. Choose the best answer that agrees with the recommendations of ANSI Z88.2.

1. Grade D breathing air specifications should be considered as the limits for compressed air of deteriorating quality.
2. The oxygen content of supplied breathing air shall be a minimum of 19.0 percent by volume.
3. Compressed oxygen may be used in supplied air or open-circuit self contained breathing apparatus in which compressed air has previously been used.

4. 1 & 2.
5. 1 & 3.

20 E. 10 CFR Part 20 provides respiratory protection factors for standard types of approved respiratory protection devices as listed in items 1 through 4 below. Match the maximum allowable protection factors given in (a) through (d) to the given respiratory protection devices. Assume that the airborne hazard is radioactive particulate material.

1. Full facepiece, negative pressure mode, air-purifying respirator.	(a) 10
2. Full facepiece, pressure demand mode, self contained breathing apparatus (SCBA).	(b) 50
3. Half-mask facepiece, negative pressure mode, air-purifying respirator	(c) 1000
4. Half-mask facepiece, positive pressure mode, air-purifying respirator	(d) 10000

10 F. Describe one type of hand-held instrument routinely used for the detection of uranium contamination on personnel as they leave contaminated areas. Your description should include the types of radiation detected, any special constraints, and advantages or disadvantages of the instrument.

QUESTION 11

Indoor radon is believed by many to be a serious radiological protection problem. The questions below address various aspects of radon quantities, units, and measurements.

GIVEN:

Nuclide	Principal Radiations	Energies (MeV)	Half-life
^{222}Rn	α	5.5	3.82 day
^{218}Po	α	6.0	3.10 min
^{214}P	β,γ	1.0 max (β)	27 min
^{214}Bi	β,γ	3.3 max (β)	19.9 min
^{214}Po	α	7.7	164 μs
^{210}Pb	β	0.061 max	22.3 yrs

POINTS

5 A. Define the working level (WL).

20 B. If an atmosphere contains 600 Bq/m^3 of ^{218}Po, what is the working-level concentration due to the ^{218}Po? **Show all work.**

20 C. A person is exposed in his home to an average concentration of 0.02 WL for 14 hours per day for 30 weeks. What is his cumulative exposure in working-level months during this time? **Show all work.**

D. In various models, the dose delivered by radon/radon progeny to the lung depends on properties of both the inhaled aerosol and the physiology of the respiratory tract.

8 1. List 2 important Rn/Rn progeny aerosol properties.

12 2. List 3 important physiological characteristics of the respiratory tract.

5 E. The best estimate listed below for lung dose from exposure to radon progeny is:

1. 0.05 mrad/WLM
2. 0.5 mrad/WLM
3. 5 mrad/WLM
4. 50 mrad/WLM
5. 500 mrad/WLM.

F. Radon and radon progeny measurements can be categorized into three types: instantaneous (grab); integrated; and continuous.

15 1. Define each of the 3 types listed above.

15 2. Give one example of a method or instrument that exemplifies each type of measurement (list the type along with the corresponding method or instrument). Do not use manufacturer and model number; rather, specify each instrument generically.

QUESTION 12

You work for the large business conglomerate International Industrial Innovations (I^3). As part of their multi-disciplinary health and safety department, you are participating as a member of a team performing hazard assessments throughout the company. The team leader has asked you to look specifically at the non-ionizing radiation hazards present within several of the laboratories.

GIVEN:

In the biomedical research wing, a UV light box has just been installed. It is used to view and photograph electrophoresis gels stained with ethidium bromide and operates at a peak wavelength of 300 nm. This laboratory also uses a biological safety cabinet (BSC) containing a bulb with a peak wavelength of 280 nm. Gel manipulation requires about 20 minutes each day. Work in the BSC requires about 30 minutes each day; the bulb in this cabinet is left on at all times.

$h = 6.6262 \times 10^{-34}$ J-sec
1 J = 6.24×10^{12} MeV

Ultraviolet Radiation Exposure TLV and Spectral Weighting Function

Wavelength (nm)	TLV (mJ/cm^2)	TLV (mJ/cm^2)	Relative Spectral Effectiveness, S_λ
250	70	7.0	0.430
260	46	4.6	0.650
270	30	3.0	1.000
280	34	3.4	0.880
290	47	4.7	0.610
300	100	10	0.300
310	2000	200	0.015

POINTS

A. The manufacturer reports in its operating manual that the irradiance at 2 ft from the light box is 1 $\mu W/cm^2$ and at 6 inches from the BSC the level is 0.6 $\mu W/cm^2$.

15 1. Assuming the entire irradiance is at the peak wavelengths given, is the TLV exceeded?

5 2. Is the assumption of irradiance at the peak wavelength accurate? Justify your answer.

5 3. Briefly describe a better means of assessing the exposure to an individual working with this equipment.

10 B. What are the two biological tissues at risk from excessive UV light exposure? How would excessive exposure be manifest for each of these tissues, i.e., what symptom would be present in each case? **Number your responses. Only the first 2 will be graded.**

10 C. List two steps you would recommend to lower the exposure to UV light in this lab. **Number your responses. Only the first 2 will be graded.**

D. Another laboratory has acquired a surplus microwave transmitter that it intends to use for microwave health effect experiments. The device operates with the following parameters:

Frequency:	10 GHz
Peak power:	2000 W
Pulse width:	1 msec
Pulse rep rate:	200 pps
Antenna gain:	16 dB

Maximum horn antenna dimension: 0.2 m

4 1. List two precautions that could be followed to prevent harm to the technicians. **Number your responses. Only the first 2 will be graded.**

10 2. The device's horn antenna transmits into the room and the closest human access distance is 3 meters away. Assuming far-field conditions, calculate the maximum equivalent plane-wave free space power density at this distance in units of milliwatts per square centimeter. **Show all work.**

6 3. The staff are not permitted in the test room when the device is energized. However, on this day a lab worker ignores the warning sign on the door, enters the room, and remains inside for an estimated 2 minutes before leaving for the day. Measurements in the room indicate the lab worker was exposed to a free-space power density of 25 mW/cm^2. No levels could be detected outside the room. Was the lab worker exposed in excess of the ACGIH or ANSI microwave recommendations? **Show all work and justify your response by stating the appropriate exposure limit recommendations**.

E. The laboratory has purchased a microwave device used to cure a particular form of adhesive. The device operates at a frequency of 2400 MHz. Workers are concerned about possible health effects including cancer induction.

15 1. Can the radiation emitted by this source cause ionization and subsequent damage to DNA? **Justify your answer quantitatively.**

10 2. What is the primary effect of this type of radiation on tissue? Describe why it causes this effect.

10 F. The ALARA principle is generally applied to radiation exposure controls while most of the above hazards are limited by TLVs . What is the basis for the difference between these two concepts?

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QUESTION 13

You are a health physicist at a power reactor during a refueling outage.

GIVEN:

^{60}Co Information
Gamma emissions:
1.17 MeV @ 99.9%
1.33 MeV @ 100%
$\Gamma_{Co\text{-}60} = 3.7 \times 10^{-4}$ mSv/hr-MBq @ 1 m
$\mu_{Co\text{-}60}$ for lead = 0.679 cm^{-1}
$\mu_{Co\text{-}60}$ for H_2O = 0.0707 cm^{-1}
$\mu_{Co\text{-}60}$ for air = 7.75×10^{-1} cm^{-5}

^{137}Cs Information
Gamma emissions:
0.662 MeV @ 89.8%
$\mu_{en\ Cs\text{-}137}$ for H_2O = 0.0327 cm^{-1}
$\mu_{\ Cs\text{-}137}$ for H_2O = 0.0894 cm^{-1}

Additional Information:
1 MeV = 1.6×10^{-6} erg
Pb blanket specs: 31 cm x 62 cm x 2.5 cm, 10.4 kg
ρ_{Pb} = 11.4 g/cm^3

Exposure BuildUp Factors for a Point Source at 1 MeV

R(mfp)*	Water	Air	Lead
0.5	1.47	1.47	1.20
1	2.08	2.08	1.38
2	3.62	3.60	1.68
3	5.50	5.46	1.95
4	7.68	7.60	2.19
5	10.1	10.0	2.43
6	12.8	12.7	2.66
7	15.8	15.6	2.89
8	19.0	18.8	3.10
10	26.1	25.8	3.51
15	47.7	47.0	4.45
20	74.0	72.8	5.27

* mean free paths

POINTS

20 A. The dose rate from a small bucket of activated metal bearings in the fuel pool is 3 rad/hr at one meter underwater. Assume all activity in the bucket is due to ^{60}Co. Calculate the dose rate in the overhead crane cab 10 meters above the water surface directly above the bucket when the bucket is lifted above the water surface (i.e., the source-to-operator distance is 10 m). State any assumptions used in the calculation. **Show all work.**

30 B. The dose rate in air from a small sealed source containing ^{137}Cs is 100 mGy/hr at 30 cm. Calculate the activity of the source in Bq for the shipping documents. **Show all work.**

25 C. The dose rate from a long, thin-walled, 2.5 cm diameter pipe is 900 mrad/hr at one meter. Calculate the activity per unit length in the pipe. Assume all activity in the pipe is ^{60}Co which uniformly coats the pipe interior. State any assumptions used in the calculation. **Show all work.**

25 D. The dose equivalent rate at one meter from a small valve is 150 mrem/hr, due to ^{60}Co. Calculate the minimum layers of lead-wool blankets (PVC covered lead-wool used for shielding) needed to reduce the area around the valve to below the regulatory high radiation criteria. State the criteria for a high radiation area and any assumptions used in the calculation. **Show all work.**

QUESTION 14

The following questions relate to a university radiochemistry facility. A cyclotron produces large activities of radioactive gases with short half lives (^{11}C, ^{13}N, ^{15}O and ^{18}F). These nuclides are transported via a carrier gas through plastic tubing into a laboratory hood. Radiochemical processing occurs in a shielded reaction vessel in the hood. An accident occurred when a ceiling tile dislodged and knocked loose the gas line, allowing ^{15}O to be released at a constant rate into the laboratory room air.

GIVEN:

Assume instant and complete mixing of ^{15}O with room air.
Room ventilation occurs only through hood exhaust, and volume exhaust rate is 30 m^3/min.
Room size is 6 m x 6 m x 3 m

^{15}O release rate = 2.6 x 10^9 atoms/s
^{15}O half life = 12.2 s

POINTS:

10 A. Will room ventilation or radioactive decay be the dominant removal mechanism? **Justify your answer**

30 B. What is the room activity concentration of ^{15}O (in Bq/m^3) after 4 minutes of release? **Show all work.**

20 C. Flow was terminated after 6 minutes and the technician left the room. She is concerned because she calculated the room's ^{15}O concentration to be much greater than the DAC (4000 Bq/m^3 for submersion) at the time she exited. Give two reasons why exceeding this DAC does not necessarily mean that an overexposure to ^{15}O has occurred. **Number your responses. Only the first 2 will be graded.**

10 D. NRC licensed materials are also used in this laboratory and airborne radionuclide concentrations of these materials occasionally exceed the DAC inside the hood. The hood is posted with a sign bearing the radiation symbol and the words "CAUTION, AIRBORNE RADIOACTIVITY AREA". Is this posting necessary? **Justify your answer**.

10 E. What type of radiation do ^{11}C, ^{13}N, ^{15}O and ^{18}F emit?

10 F. Identify two health physics concerns which would result from the use of plastic transport lines for ^{11}C, ^{13}N, ^{15}O and ^{18}F. **Number your responses. Only the first 2 will be graded.**

10 G. Monitoring is being considered for the laboratory hood exhaust stack. Monitoring needs to be able to detect releases of these radionuclides (^{11}C, ^{13}N, ^{15}O and ^{18}F) and yet be rather insensitive to common activities of most other radioactive materials used in university research (^{3}H, ^{14}C, ^{32}P, and ^{125}I). Which of the following instrument and sampling combinations would be most appropriate?

1. NaI detectors with coincidence counting of flow-through sampler.

2. G-M tube counting of buildup on particulate filter sample.

3. Solid state silicon detector counting of buildup in charcoal cartridge sample.

4. Energy compensated G-M counting of flow through sampler.

5. Wide range ionization chamber monitoring of flow through sampler.