COMPREHENSIVE EXAM INSTRUCTIONS

READ THESE INSTRUCTIONS CAREFULLY AND FOLLOW THEM CLOSELY

1. Part II of this examination consists of two sections:
   - The first section (questions 1–6) consists of six fundamental questions. All six will be graded.
   - The second section (questions 7–14) consists of eight specialty questions. Answer any four. 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 in which to complete the examination.
4. On the cover sheet:
   a. Print your name.
   b. Write your identification number.
   c. Sign your name.
   d. When you have finished the examination, mark the questions you have answered.
5. On the answer sheets:
   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 answers sheets are present.
   d. Write on only 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 been previously approved by the Board are allowed. All calculators must be checked by the proctor prior to the start of the examination.
7. If the information given 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 sheets to the proctor when you have completed the examination. You may keep the copy of the examination.

ABHP PART II EXAMINATION COVER SHEET

July 24, 1995

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, which format was involved?
☐ Intensive, one or two weeks
☐ Multi-week, one or two classes per week?

QUESTION 1

You are the health physicist in a proton accelerator facility and wish to determine the proton beam intensity (number of protons per beam pulse) using a carbon activation technique. You expose a carbon disk to a proton beam with a cross sectional area less than the area of the disk (that is, the entire proton beam impinges on the disk).

GIVEN:

- The carbon disk has a thickness of 0.2 cm.
- The ^{12}C atom density is 9.3×10^{22} atoms cm^{-3}.
- The cross section for $^{12}C(p,pn)^{11}C$ is 25 mb.
- ^{11}C is a pure positron emitter (100%) with a half-life of 20.4 min.
- The efficiency of the NaI gamma spectrometer counting system is 0.15 counts for every disintegration of ^{11}C in the graphite disk.

POINTS

20 A. The carbon disk is counted using a NaI spectrometer in the laboratory for 30 min. The total number of counts is 2300. What is the ^{11}C activity in the disk at the beginning of the counting period? **Show all work.**

5 B. The transfer time from the accelerator to the counting room is 10 min. **For this part only, assume** that the activity in the disk at the beginning of the counting period is 2000 dpm. What is the activity at the end of the irradiation period? **Show all work.**

25 C. The proton beam is operated at 4 pulses per min. The disk is exposed in the beam for 40 min. **For this part only, assume** that the ^{11}C activity in the disk at the end of the irradiation time is 5000 dpm. Calculate the number of protons per pulse. **Show all work.**

QUESTION 2

You are the RSO for a radiochemical laboratory. An individual performs the following two experiments during a single calendar year. The first experiment is completed during an 80-h period and uses ^{14}C in the form of a stable radio-labeled protein. The material is continuously released to the air of the laboratory resulting in an average airborne concentration of 2.0×10^{-6} μCi mL^{-1}. The second experiment is performed in a separate room. The individual uses a sealed ^{93}Tc source that has an activity at the beginning of the experiment of 70.0 mCi. The source is on a laboratory bench that keeps the worker 2 m from the source. These are the worker's only occupational exposures to radioactive material during the calendar year.

GIVEN:

			Table 1 Occupational values		Table 2 Effluent concentrations	
			Col. 2	Col. 3	Col. 1	Col. 2
			Inhalation			
Atomic No.	Radionuclide	Class	ALI (μCi)	DAC (μCi mL^{-1})	Air (μCi mL^{-1})	Water (μCi mL^{-1})
6	Carbon-14	Monoxide	2×10^{6}	7×10^{-4}	2×10^{-6}	—
		Dioxide	2×10^{5}	9×10^{-5}	3×10^{-7}	—
		Compounds	2×10^{3}	1×10^{-6}	3×10^{-9}	3×10^{-5}

^{93}Tc half-life = 2.75 h

^{93}Tc specific gamma-ray constant = 6.11×10^{-7} rem m^{2} (μCi h)$^{-1}$

POINTS

15 A. If the annual internal dose is administratively restricted to one-tenth of the annual occupational limit, what would be the maximum average airborne concentration to which the individual could be exposed?

15 B. What would be the committed effective dose equivalent to the individual performing the experiment due to the exposure to airborne radioactive material?

15 C. If the second experiment takes 8 h to complete, what is the unshielded deep dose equivalent to the individual? **You must account for ^{93}Tc decay during the 8-h period. Show all calculations.**

5 D. Calculate the total effective dose equivalent to the individual after completion of both experiments (or explain how to calculate it).

QUESTION 3

You are studying the interactions of ^{137}Cs gamma photons entering a Pb slab in a normal direction. Assume that the distance between successive interactions is equal to the mean free path.

GIVEN:

Photon energy (keV)	Compton interaction atomic attenuation coefficient (10^{-24} cm^2 atom^{-1})	Photoelectric interaction atomic attenuation coefficient (10^{-24} cm^2 atom^{-1})	Average energy transferred (keV)	Average energy absorbed (keV)
300	27.77	100.5	191	185
400	25.22	48.33	247	239
500	23.21	27.93	298	286
662	20.68	14.59	376	360

Pb atomic weight	207.2 g mole^{-1}
Pb density	11.36 g cm^{-3}

Compton scattering energy E':

$$E' = \frac{E_0}{1 + \frac{E_0 (1 - \cos\theta)}{m_e c^2}}$$

POINTS

15 A. What is the average distance below the surface at which the photon experiences its first interaction with a Pb atom? **Show all work.**

15 B. If the first interaction is a Compton interaction and results in the average energy transfer, what is the approximate probability that the next interaction will be a photoelectric interaction? **Show all work.**

15 C. If the Compton scatter angle following an interaction is 41°, what is the energy of the scattered photon and of the Compton electron? **Show all work.**

5 D. Interactions between the photons and the Pb slab results in a transfer of energy to electrons. Less than 100 percent of the transferred energy is absorbed in the Pb slab. Describe the process most responsible for the “lost” energy.

QUESTION 4

You are using an air-sample counting system at your facility to measure ^{239}Pu in air.

GIVEN:

Counting system specifications:

Detector type	Silicon surface barrier
Electronics	Single-channel analyzer
Window	5.2 ± 0.5 MeV
Source-to-detector distance	5 cm
Detector active diameter	3 cm

Measurement results:

	Background	Sample
Counts	750	3210 (gross)
Counting time (s)	1800	600

^{239}Pu:

Half-life = 24,065 y
Decay mode = α

Radiation	y(i) $(Bq\text{-}s)^{-1}$	E(i) (MeV)	y(i) × E(i) (MeV)
α 44	0.107	5.105	0.545
α recoil	0.107	0.08695	0.00929
α 46	0.152	5.143	0.783
α recoil	0.1052	0.0876	0.0133
α 47	0.738	5.156	3.80
α recoil	0.738	0.08781	0.0648
α 48	0.00121	5.156	0.00624
α recoil	0.00121	0.0878	0.000106

[From ICRP Pub 38, *Radionuclide Transformations*, Pergamon Press, New York, 1983]

POINTS

15 A. Assume an air sample yielded the given measurement results. Calculate the ^{239}Pu activity on the sample and its associated standard deviation. Assume an absolute efficiency of 35 percent **for this part only.**

10 B. What is the relationship between intrinsic and absolute efficiency?

10 C. Now assume a 0.4-μCi ^{239}Pu point source yielded the given measurement results. Calculate the intrinsic efficiency of the detector. A good, substantiated approximation is acceptable. **State any assumptions you make.**

10 D. The vacuum system in the detector has failed. What is the maximum allowable sample-to-detector distance? You may use rules-of-thumb. **Show all work.**

5 E. What other operating parameter must be adjusted in order to operate the instrument properly at atmospheric pressure?

QUESTION 5

You are a health physicist at a radiochemical laboratory. You have determined the concentration of ^{137}Cs in milk samples using a proportional counter and chemical processing. Assume a normal distribution for variation of background in the counter.

GIVEN:

^{137}Cs concentration in the raw milk sample	40 pCi L^{-1}
Sample volume	0.5 L
Sample count time	60 min
Background count time	60 min
Background count rate	28 cpm
Background count rate standard deviation (σ_{bkg})	4 cpm
Lower limit of detection (L_D)	4.66 σ_{bkg}
Counter efficiency	35%
Chemical recovery	90%

POINTS

15 A. You determine that the relative standard deviation in the gross count rate is 12 percent. What are the net count rate and its standard deviation? **Show all work and state assumptions.**

10 B. Evaluate the suitability of the counting system for achieving L_D = 5 pCi L^{-1}. **Show all work.**

15 C. How does the variation in background for the proportional counter compare with that expected if the only source of variability was the probabilistic nature of radioactive decay? State two factors that could contribute to the difference. **Number your responses. Only the first two responses will be graded.**

D. While preparing the next sample you notice that the background count rate has decreased to 12 cpm.

4 1. Explain why this is or is not a significant change.

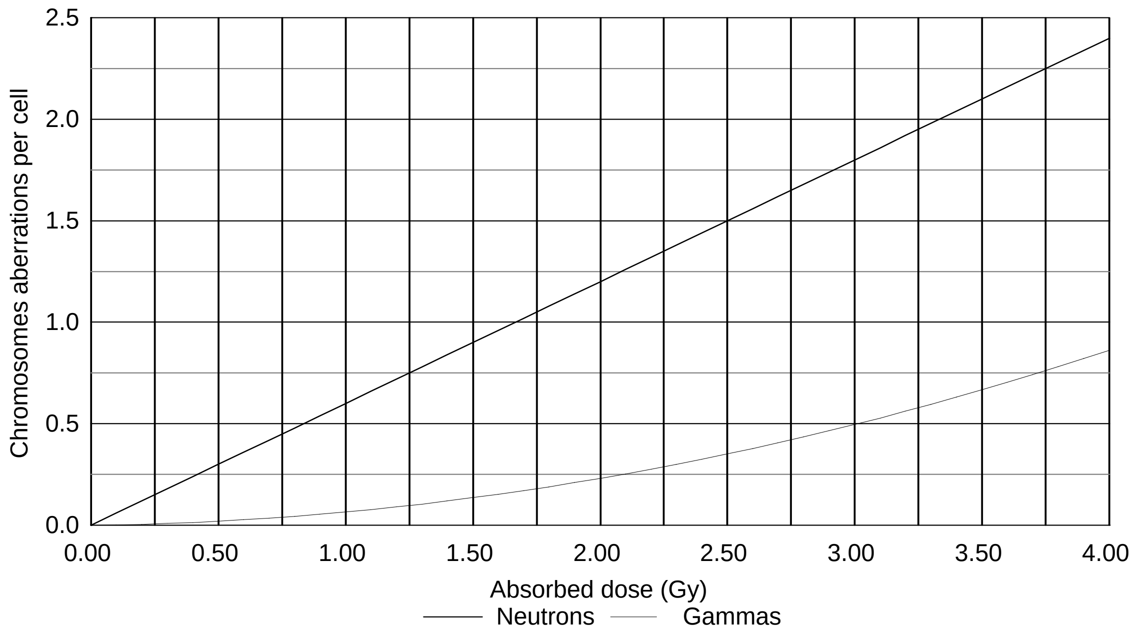
6 2. State two possible reasons for the change. **Number your responses. Only the first two responses will be graded.**

QUESTION 6

Dose response curves for chromosome aberrations in human lymphocytes exposed to ^{60}Co gamma rays and to fission spectrum neutrons are given in the figure below.

GIVEN:

Chromosome Aberrations in Human Lymphocytes*



$D \equiv$ absorbed dose in grays
For neutrons: Number of chromosome aberrations per cell = $0.60\ D$
For gammas: Number of chromosome aberrations per cell = $0.0157\ D + 0.05\ D^2$

* From ICRU Report No. 40.

POINTS

15 A. What is the primary mode of interaction for the following radiations in tissue?

1. Fast neutrons.
2. Thermal neutrons.
3. ^{60}Co gamma rays.

10 B. What property of the neutrons and gammas accounts for the difference in shape of the two curves above?

10 C. What is the RBE for neutrons for an effect of 0.5 chromosome aberrations per cell?

10 D. What is the maximum value of the RBE for chromosome aberrations for neutrons based on the information provided above?

5 E. What value should be used for the quality factor *Q* for neutrons with unspecified energies? Provide the basis (source) for your answer.

QUESTION 7

You are a health physicist at an accelerator facility. You base your radiation safety recommendations on National Council on Radiation Protection and Measurements (NCRP) Report No. 51, *Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities.*

GIVEN:

Electron beam energy	100 MeV
Density of air (NTP)	0.001205 g cm^{-3}
Chamber dimensions	6 m × 8 m × 2.5 m
Collision mass stopping power for 10-MeV electrons in air	1.98 MeV $\text{cm}^2\ \text{g}^{-1}$
Distance traversed in air by electron beam	2 m

Ozone production in electron-beam facilities:

$$C_{O_3} = 3.25\,\frac{S_{\text{coll}} I \chi t}{V}$$

where

C_{O_3} is the ozone concentration in ppm,
S_{coll} is the collision stopping power of electrons in air in keV cm^{-1},
I is the electron beam current in mA,
χ is the distance traversed in air by the electron beam in cm,
t is the irradiation time in s, and
V is the volume of the irradiation chamber in liters.

$$B_x \geq 1.67 \times 10^{-5}\left(\frac{\dot{H}_m d^2}{\dot{D}_0 T}\right)$$

where

B_x is the shielding transmission ratio,
$\dot{H}_m$ is the maximum permissible dose equivalent rate in mrem h^{-1},[†]
d is the distance between the source and the reference point in m,
$\dot{D}_0$ is the absorbed dose index rate in rad $\text{m}^2\ \text{min}^{-1}$,[†]
T is the area occupancy factor, and
1.67×10^{-5} is a constant that depends on the units being used.

[†] The definitions for $\dot{H}_m$ and $\dot{D}_0$ were mistakenly switched on the original examination.

From Appendix E-1, NCRP Report No. 51:

$$\dot{D}_0 I^{-1} = 4.7 \times 10^4 \text{ rads m}^2 \text{ mA}^{-1} \text{ min}^{-1} \text{ (forward direction)}$$

From Appendix E-8, NCRP Report No. 51:

Broad-Beam Transmission through Concrete of X-rays Produced by 0.5-176 MeV Electrons

Slab thickness (cm)	Transmission
100	2.2×10^{-3}
75	1.0×10^{-2}
50	4.7×10^{-2}
25	1.7×10^{-2}

POINTS

15 A. You are inspecting the accelerator facility before it begins its initial operation. According to NCRP Report No. 51, what is an interlock and where should interlocks be installed?

15 B. Upon inspection of the beam dump, you find that the depth of the cavity is greater than the diameter of the aperture. Is this acceptable? Describe why or why not.

20 C. List four kinds of radiation produced as a consequence of an interaction between a particle beam and the material it strikes in an accelerator. Describe the method of production of each. **Number your responses. Only the first four responses will be graded.**

30 D. A scattering experiment produces an X-ray beam using a 1-cm diameter, 10-MeV electron beam incident on a thick W target. The experimenter will be behind a 75-cm thick concrete shield at a point in the controlled area that is on the beam-line and 10 m from the target. The dose rate is limited to 2.5 mrem h^{-1} at the experimenter's location. Calculate the peak current value for the beam. **Show all work.**

20 E. Using information given above and a beam current of 0.05 mA, calculate the concentration (ppm) of O_3 in the irradiation chamber following 2 h of continuous operation. Assume a ventilation rate of 2 m^3 min^{-1} and an O_3 molecule mean life of 50 min. **Show all work.**

QUESTION 8

You choose environmental dosimeters randomly from a field batch that you exposed to a standard source. You wish to determine their performance against the requirements of ANSI N545-1975. You exposed them to ^{137}Cs in a fixture designed for assurance of electronic equilibrium at a dose equivalent rate of 5 mrem h^{-1}. You allow one week to elapse between exposure and readout so that lower-energy components of the thermoluminescent glow curve can fade and minimize their contributions to the thermoluminescent response.

GIVEN:

Delivered dose equivalent H = 7.2 mrem

Dosimeter response statistics:

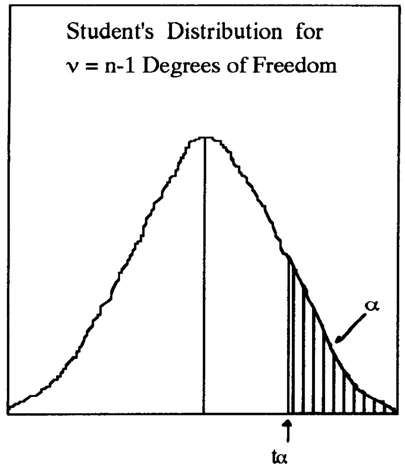
Sample mean	6.0 mrem
Sample standard deviation	0.9 mrem
Number of dosimeters in sample	5

Percentile values (t_α) for Student's *t* distribution with ν degrees of freedom

ν	$t_{0.10}$	$t_{0.05}$	$t_{0.025}$
1	3.08	6.31	12.71
2	1.89	2.92	4.303
3	1.64	2.35	3.182
4	1.53	2.13	2.776
5	1.48	2.02	2.571
10	1.37	1.81	2.228
20	1.33	1.73	2.086
30	1.31	1.7	2.042
60	1.3	1.67	2
∞	1.28	1.65	1.96

The Student's *t* statistic is given by:

$$t = \frac{(\overline{x} - \mu)\sqrt{n}}{s}$$



POINTS

25 A. Show by calculation whether the measurement results agree with the known exposure to within 10 percent at the 95 percent confidence level, as required by the standard.

15 B. List three potential sources of TLD measurement error (in addition to the response uncertainty evaluated in Part A) when the dosimeters are placed in the field. **Number your responses. Only the first three responses will be graded.**

30 C. State and discuss three considerations for siting, storing, or transporting environmental dosimeters for field measurements. **Number your responses. Only the first three responses will be graded.**

D. If you were to measure natural background radiation on a coral atoll in the Pacific Ocean near the equator, would you expect the radiation levels from the following sources to be lower, higher, or about the same as for the continental United States? Briefly explain each answer.

8 1. Cosmic rays

8 2. Primordial radionuclides and their progeny (except radon)

7 3. Radon and its progeny

7 4. Cosmogenic radionuclides

QUESTION 9

You are a health physicist at a 1000 MWe power reactor. The reactor runs for 300 d at 100 percent power after an initial core load.

GIVEN:

Thermal efficiency	34%
Fission yield for ^{137}Cs	0.0622
Energy released per ^{235}U fission	190 MeV
^{137}Cs ALI (based on stochastic effects)	162 μCi
^{137}Cs specific gamma-ray constant	0.33 R m^2 Ci^{-1} h^{-1}
^{137}Cs half-life	30.18 y
^{90}Sr DAC	8×10^{-9} μCi mL^{-1}

$$\int \frac{x\,dx}{x^2 + a^2} = \tfrac{1}{2} \ln(x^2 + a^2) + \text{constant}$$

POINTS

30 A. Calculate the ^{137}Cs activity in the reactor core at the time of shutdown. **Show all work.**

30 B. The core is reprocessed after a decay period of 5 y. One of the steps during reprocessing is dissolution of the fission products in acid. Some of this acid solution is spilled on a concrete floor over a 1-m diameter circular area. The exposure rate measured 1 m above the center of the spill is 500 mR h^{-1} using a gamma-sensitive ionization chamber instrument. Calculate the activity present on the floor. Assume that ^{137}Cs only is responsible for the measured exposure rate. **Show all work. Do not use rules of thumb.**

C. Some of the spilled solution soaks into the floor and dries. The surface of the concrete is to be removed by scabbing (pneumatic chipping). The worker doing the scabbing wore a personal breathing-zone (lapel) air sampler. The air sampler's flow rate was 2,000 mL min^{-1}. The count rate for the filter from this air sampler at the end of the job was 3700 cpm as measured by a GM-type counter with an efficiency of 0.2 for ^{137}Cs. Assume that the gamma efficiency was zero. Assume the light activity breathing rate is 20 L min^{-1}. Calculate the following (**show all work**):

15 1. The resulting airborne intake *in units of DAC-h* assuming that ^{137}Cs is the only radionuclide present.

15 2. The committed effective dose equivalent (CEDE) from this inhalation assuming ^{137}Cs is the only radionuclide present.

10 D. You plan to reassess the airborne exposure assuming that ^{90}Sr is present as well as ^{137}Cs. List two assumptions that you would use to determine the inhalation exposure using the breathing zone air sampler with only the information given above. **Number your responses. Only the first two responses will be graded.**

QUESTION 10

You are a hospital RSO. A cardiologist performs cardiac catheterization procedures at several hospitals in your area. You know that the cardiologist performs about 10 cineradiography and 10 fluoroscopy procedures per week. For the purposes of this problem, all x-ray projections are vertical. The table on which the patient is located is at the level of the cardiologist's navel. The cardiologist wears a shielding apron with a lead equivalence of 0.5 mm. The cardiologist does not wear eye protection. The cardiologist wears a TLD on his collar.

GIVEN:

- The horizontal distance from the center of the fluoroscopic field to the cardiologist's abdomen is 0.5 m.
- The horizontal distance from the center of the cineradiographic field to the cardiologist's abdomen is 1.0 m.
- The distance between the cardiologist's abdomen and head is 0.6 m.
- The density of Pb is 11.3 g cm^{-3}.
- The mass attenuation coefficient for Pb is 10.0 cm^2 g^{-1} at the cineradiography effective beam energy of 45 keV and 4.86 cm^2 g^{-1} at the fluoroscopy effective beam energy of 60 keV.
- The average "on-time" per cineradiographic session is a total of 60 s. Tube current during cineradiographic procedures is 100 mA. Entrance skin exposure for cineradiographic procedures is 10.0 mrad mAs^{-1}.
- The average "on-time" per fluoroscopic procedure is 10 min. Tube current during fluoroscopic procedures is 2 mA. Entrance skin exposure for fluoroscopic procedures is 12.5 mrad mAs^{-1}.
- Source-to-skin distance is 0.6 m for both procedures
- The circular field of view has an area of 63.6 in^2.

Ratio of scatter exposure at 1 m to incident exposure on a patient for a 400 cm^2 field of view

Angle (°)	Cineradiography	Fluoroscopy
45	0.0003	0.00065
60	0.0003	0.00065
90	0.0004	0.0008
120	0.0009	0.0013
135	0.0011	0.0016

Annual TLD Results

1,000 mg cm^{-2}	8.7 rem
300 mg cm^{-2}	9.5 rem
7 mg cm^{-2}	17.6 rem

POINTS

25 A. Calculate the estimated annual dose equivalent to the cardiologist's abdomen. **Show all work and state all assumptions.**

25 B. Calculate the estimated annual dose equivalent to the cardiologist's whole body. **Show all work and state all assumptions.**

C. The following questions are about occupational dose limits.

10 1. What are the relevant Federal occupational dose limits and where are they found?

10 2. Compare the cardiologist's annual dose equivalent as given by the annual TLD results with the relevant limits.

D. A regulatory inspector conducts an inspection of the hospital and raises concerns about the accuracy in assessments of exposures and incorporation of ALARA measures.

15 1. List or describe five recommendations for reducing the cardiologist's annual dose equivalent. **Number your responses. Only the first five responses will be graded.**

15 2. Suggest five ways to improve the measurement of the cardiologist's dose equivalent. **Number your responses. Only the first five responses will be graded.**

QUESTION 11

You are responsible for emergency environmental assessment and dose projection at a boiling water reactor. An instantaneous release of gaseous ^{131}I into the dry-well occurs due to the lifting of a relief valve. The dry-well leaks directly to the environment for 1 min after which the stand-by gas treatment (SBGT) system becomes operational. Ten percent of the continuing dry-well leakage bypasses the gas treatment system and is discharged to the environment. The release is terminated at 2 h. The control room HVAC supply is equipped with intake and recirculation filters for radioiodine.

GIVEN:

^{131}I half-life	8.040 d
^{131}I activity released to the dry-well	1.00 Ci
Leakage rate from dry-well to environment	0.5% d^{-1}
Bypass leakage fraction to the environment	10%
Efficiency of the SBGT for radioiodines	99%
Control room thyroid iodine protection factor	1,000
χ/Q at exclusion area boundary	2×10^{-4} s m^{-3}
χ/Q outside the control room	4×10^{-4} s m^{-3}
^{131}I committed dose equivalent for the thyroid	1.48×10^{6} rem Ci^{-1}
Adult breathing rate	3.47×10^{-4} m^3 s^{-1}

POINTS

25 A. Calculate the activity released to the environment from the dry-well during the one-minute period before the gas treatment system became operational. **Show all work.**

35 B. Calculate the activity released to the environment during the filtered-release period. **Show all work.**

C. Assuming a total of 10 mCi of ^{131}I is released to the atmosphere:

10 1. Calculate the thyroid committed dose equivalent for an individual at the exclusion area boundary for the entire release period. **Show all work.**

10 2. Calculate the thyroid committed dose equivalent for a control room operator assuming exposure for the entire release period. **Show all work.**

D. The following questions are about protective action recommendations:

10 1. Discuss two protective action recommendations and their associated dose trigger points that responsible off-site agencies should consider for protection of the public during the early phase of an incident involving a large airborne fission product release. **Number your responses. Only the first two responses will be graded.**

10 2. Discuss two factors that should be considered in applying these protective action recommendations. **Number your responses. Only the first two responses will be graded.**

QUESTION 12

You are the health physicist at a 1000 MWe pressurized water reactor that has shut down for a refueling and maintenance outage

GIVEN:

Derived air concentrations (DACs) and inhalation classes for selected radionuclides

Nuclide	Class	DAC (μCi mL^{-1})
^{58}Co	Y	3×10^{-7}
^{60}Co	Y	1×10^{-8}
^{137}Cs	D	6×10^{-8}
^{54}Mn	W	3×10^{-7}
^{51}Cr	Y	8×10^{-6}
^{59}Fe	W	2×10^{-7}

^{60}Co ALI (inhalation class Y)	30 μCi
Air flow rate	30 cfm
Air sample collection time	10 min
Count time	1 min
Counter efficiency	0.32 c d^{-1}
Total counts on air filter	4500 (beta)

POINTS

25 A. In preparation for removing a man-way cover from a steam generator, you collect an air sample in the surrounding tent. All the radionuclides in the above table are known to contribute to the airborne activity. Assume the most conservative DAC. Calculate the airborne concentration in terms of fraction of DAC. **Show all work.**

10 B. Procedures call for the generator to be depressurized prior to opening but, as the workers were loosening the man-way cover bolts, a vapor spray was released. They were not wearing respirators and all immediately left the tent. The worker closest to the cover required extensive decontamination. Which of the following might be used for effective decontamination after soap and water? **Justify your answer.**

1. Detergent.
2. Diethylenetriaminepentaacetate (DTPA).
3. Nitrile triacetic acid (NTA).
4. Potassium permanganate.
5. Sodium iodide.

25 C. No breathing-zone concentration data are available for the most highly contaminated individual. However, a whole-body count was performed after decontamination was complete approximately 3 h after the intake. The measured ^{60}Co activity was 110 nCi. Assume that the material was inhaled and that it has a solubility class of Y. About 63 percent of the intake is expected to remain in the body shortly after the incident. Calculate the dose due to this intake. **Show all work.**

15 D. Seventy-two hours later a follow-up body count is performed on the worker in Part C. The activity remaining is only 8 nCi. Assume that there was no external contamination at the time of the first body count. What can account for this reduction?

25 E. An isotopic measurement is performed on an air sample after the incident. The ^{60}Co concentration is 9.8×10^{-8} μCi mL^{-1} and the ^{51}Cr concentration is 7.2×10^{-5} μCi mL^{-1}. A worker wearing a full-face, negative-pressure respirator (PF = 50) will spend 3 h in the environment. What is the total number of DAC-h to be assigned to the worker? **Show all work.**

QUESTION 13

You are the health physicist at a university with a research reactor. You note that ^{41}Ar is produced in this reactor by activation of natural Ar dissolved in the pool water and in air-filled voids near the core. Some experimenters also produce it intentionally for use as a tracer.

GIVEN:

Reactor room volume	2,000 m^3
Reactor building outside cross-sectional area	100 m^2
Reactor building roof height	15 m
Reactor room ventilation fan flow-rate	1.4 $m^3\ s^{-1}$
Wind speed	1 $m\ s^{-1}$

^{41}Ar data:

Half-life	1.83 h
Beta emission	0.9917 β $decay^{-1}$, E_{max} = 1.198 MeV 0.0078 β $decay^{-1}$, E_{max} = 2.492 MeV
Gamma emission	0.9917 γ $decay^{-1}$, E = 1.293 MeV
DAC	1×10^5 Bq m^{-3}
Effluent limit (unrestricted area)	400 Bq m^{-3}

POINTS

A. The valve on a pressure cylinder containing 3.7×10^{10} Bq of ^{41}Ar fails during a transfer. All of the ^{41}Ar is released to the reactor room. The reactor room ventilation fan exhausts at the building roof level. It operates during and after the event. The ^{41}Ar mixes uniformly with the air in the reactor building immediately after the release.

35 1. What effective dose equivalent would a person staying in the reactor room for 1 h after release receive? **Show all work.**

35 2. The outside of the reactor building at ground level is an unrestricted area. This ground level release represents what fraction of the annual unrestricted area effluent limit? **Show all work.**

30 B. You collect a 0.01-m^3 sample of air from the reactor bay in a gas cylinder. You place it on a NaI gamma detector and count for 50 min. A total of 25,000 counts accumulate in the region of interest for the 1.293-MeV photo-peak. The background count rate for the region of interest is 120 cpm. What is the true count rate for the 1.293-MeV gamma rays in the region of interest *at the beginning of the counting period*? **Show all work. Do not use approximations.**

QUESTION 14

As the only health physicist on-site, you are surveying a circular-aperture, parabolic-dish, microwave radar.

GIVEN:

Dish diameter, *D*	10 m
Operating frequency	3,000 MHz
Peak power	1 MW
Antenna gain	20 dB
Duty factor	0.001
Far-field distance	$\frac{0.6\,D^2}{\lambda}$
Near-field distance	$\frac{0.25\,D^2}{\lambda}$

The 1992 ANSI standard for power density at 3,000 MHz is 10 mW cm^{-2} for controlled environments and 2 mW cm^{-2} for uncontrolled environments.

POINTS

15 A. What is the major effect on the human body from exposure to microwave radiation? List four factors affecting the extent of injury. **Number your responses. Only the first four responses will be graded.**

20 B. List five items of information you need to perform the hazard evaluation. **Number your responses. Only the first five responses will be graded.**

C. Answer the following questions.

5 1. What is the average power that the antenna radiates?

5 2. What are the near- and far-field distances?

5 3. What are the relationships of the power density and distance in the near and far fields?

5 4. What is the significance of near and far fields with respect to power density measurements?

5 5. What is the maximum power density at the near field?

20 D. Is an individual who works at about 300 m along the beam axis overexposed according to the 1992 ANSI standard? **Justify your answer.**[†]

10 E. You install a fence at 250 m around the installation. Is it possible for anyone outside that fence to exceed the 1992 ANSI standard for continuous exposure? **Justify your answer.**[†]

10 F. Some time after the survey, the worker complained about being overexposed to microwave radiation. You plan to investigate the allegation. List two steps you will take. **Number your responses. Only the first two responses will be graded.**

[†] The statement, "Justify your answer," was mistakenly left out of the original examination.