QUESTION 1

You are a health physicist at a Tritium production facility. You have received a regulatory information bulletin concerning a tritium uptake at a similar facility. In response to this bulletin, you initiate a special round of airborne monitoring and urine sampling for tritium.

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Tritium Data:

ALI: 80,000 μCi

$T_{1/2}$: 12.3 years

Biological Data for Reference Man:

Volume of free water within the whole body: 43 l

Mass of Soft Tissues within the whole body: 65 kg

Daily water loss for Reference Man: 3 l/d

Daily urine loss for Reference Man: 1.4 l/d

POINTS

20 A. Describe two airborne monitoring techniques that you would consider using to measure airborne tritium concentrations. Give one advantage and one disadvantage for each discussed technique. **Number your responses. Only the first two techniques will be graded.**

20 B. A positive spot urine sample result of 500 dpm/ml is reported for a researcher who entered the reactor facility only once, 60 days prior to submitting the sample. Assuming reference man metabolism, estimate the initial tritium uptake. **Show all work.**

10 C. An individual has a single intake 1600 μCi of tritium. This individual also has 100 mrem of whole body external exposure for the year. **What is the individual's total effective dose equivalent for the year? What is the target organ?**

QUESTION 2

You are a consulting health physicist and have been asked to answer the following questions regarding ionization chambers, given the information below. Assume that the detectors are vented to the atmosphere.

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Ionization chamber description:
Chamber volume = 200 cm^3
Bias Voltage = 25 V

Conversions:
1eV = 1.6×10^{-12} erg
1 Ampere = 1 C/s
1 coulomb = 6.24×10^{18} electronic charges
1 R = 2.58×10^{-4} C/kg
$\rho_{AIR} = 1.29 \times 10^{-6}$ kg/cm^3 at STP

POINTS

20 A. Calculate the electron current (in Amperes) generated in the sensitive volume of the above ionization chamber when exposed to 100 mR/h (in air) of 1 MeV photons. Assume STP conditions and that all charge produced in the sensitive volume is collected (no recombination losses). **Show all work.**

20 B. Assuming all other variables remain unchanged, state the impact on the reading of this ionization chamber if it is:

1. calibrated in San Diego (elevation 120 feet) and used in Santa Fe (elevation 6,375 ft.) **Briefly explain your answer.**

2. calibrated at 25 degrees C and used at 0 degrees C. **Briefly explain your answer.**

10 C. If this instrument was calibrated in rad/h for photons in air, would a correction factor have to be applied to determine a gamma skin dose rate in rad/h? **Briefly explain your answer**

QUESTION 3

The following questions concern external dosimetry.

15 A. A worker works in a mixed radiation field which includes beta particles, gamma photons, alpha particles and thermal and mixed energy fast neutrons. The absorbed dose from external sources in the work environment was reported as 30 mrad beta, 70 mrad gamma, 90 mrad thermal neutron and 25 mrad mixed fast neutron. Calculate the ICRP 60 Equivalent Dose in mrem. **Show all work.**

5 B. A 26 year old worker had a lifetime dose of 32 rem. Compare this worker's lifetime dose to the recommendations of NCRP 91.

5 C. A radiation worker recorded the following doses over the past 4 years:

Year	Dose (rem)
1	1
2	3
3	4
4	2

According to ICRP 60, what is the maximum recommended dose for this worker in year 5?

Given the information in the following table, construct a dosimeter to measure the effective dose equivalent for each of the following workers specified in Parts D and E. Clearly state the number of the chips to be included in the dosimeter and limit the number of chips to a maximum of four. **Provide justification for your selections.**

Chip	Material	Thickness	Cover
1	^{7}LiF	0.38 cm	100 mg cm^{-2} copper and 200 mg cm^{-2} plastic
2	^{7}LiF	0.38 cm	1000 mg cm^{-2} plastic
3	^{7}LiF	0.15 cm	7 mg cm^{-2} mylar
4	^{6}LiF	0.38 cm	300 mg cm^{-2} plastic
5	^{7}LiF	0.38 cm	300 mg cm^{-2} plastic
6	^{6}LiF	0.38 cm	300 mg cm^{-2} plastic and Cd filter

10 D. A laboratory worker using a Pu/Be neutron source.

10 E. An X-ray Technologist

5 F. A portable meter (i.e. BF_3) could be used to determine the neutron dose equivalent to an individual with **(Match with the most appropriate statement)**:

1. knowledge of the neutron spectrum so that the proper RBE can be determined.
2. knowledge of the relationship between the neutron energy spectrum and the energy of the neutron calibration source, the ratio of gamma and neutron fluence rates, and the individual's stay-time.
3. the magnitude of the dose equivalent due to photons to be subtracted from the total dose equivalent (i.e., the meter is "zeroed") and application of a neutron energy correction.

4. knowledge of how the instrument responds to the spectrum as compared to the neutron calibration source as well as the individual's stay-time.
5. near laboratory conditions controlling temperature, humidity, neutron energy, and fluence rate.

QUESTION 4

You are a health physicist assigned to a research reactor. The reactor is equipped with a number of sample irradiation locations, including a pneumatic sample delivery system ("rabbit"). The reactor operators are performing extended activation runs with the reactor and would like to measure thermal neutron flux levels in the rabbit sample location using gold foil activation analysis. After inserting the sample into the reactor, the pneumatic system develops problems that do not allow retrieval of the sample. Six hours after insertion of the sample into the reactor, the rabbit problems are repaired and the sample is retrieved. The next morning (11 hours after being removed from the reactor), the sample is counted in a Na I (Tl) well detector with a multi-channel analyzer.

GIVEN

Rabbit transit time from reactor to rabbit portal = 2 s
Inner diameter of rabbit tube = 4 cm

Target foil (thin) is ^{197}Au with a mass of 25 mg
The thermal activation cross-section for ^{197}Au(n, ( )^{198}Au is 98.8 barns

^{198}Au $\quad$ $-: E_{max}= 961 keV abundance = 98.65%
($\quad$ 412 keV, abundance = 95.5%
half-life = 2.695 d

Ignore self-shielding in gold foil
Measured net photopeak counts = 827,410 in 1 minute
Na I (Tl) detector efficiency at 412 keV = 27.3%

POINTS

20 A. Using the <u>measured values for the sample</u>, what is the ^{198}Au activity, in Bq, when it was removed from the reactor? **Show all work.**

20 B. For this part only, assume the sample activity upon exiting the reactor is 3.5 mCi. Estimate the gamma dose rate, in mR/h, at 10 cm. **Show all work.**

10 C. If the gold foil target contains 1 x 10^{24} ^{197}Au atoms and the incident thermal neutron flux is 1 x 10^{11} n/cm^2-s, what is the saturation activity?

1. 9.88 x 10^{36} Bq
2. 9.88 x 10^{12} Bq
3. 10^{35} Bq
4. 10^{11} Bq
5. 98.8 Bq

QUESTION 5

You are the health physicist at a research facility and the staff has asked you to provide the following information regarding neutron detection.

POINTS

15 A. Identify the nuclear reaction which occurs in each of the following neutron detectors.

- $^{10}BF_3$ counter
- ^{6}Li counter
- ^{3}He counter.

15 B. Explain how to determine the flux and the average energy of an unknown neutron field using the Bonner sphere method with a $^{6}LiI(Eu)$ scintillator.

10 C. Explain the basis for neutron detection by the foil activation method. State one key advantage of this method when used for criticality dosimetry.

10 D. Fission chambers can be used for detection of either thermal or fast neutrons. Which uranium isotope (^{235}U or ^{238}U) provides for detection of thermal neutrons? **Briefly explain your answer.**

QUESTION 6

A calibration source was counted yielding the data shown below. Answer the following questions concerning radioactive counting and counting statistics:

GIVEN

Count Data	
C1	60 cpm
C2	55 cpm
C3	64 cpm
C4	69 cpm
C5	70 cpm
C6	63 cpm
mean	63.5 cpm
std. dev.	5.6 cpm

Cumulative Distribution of Chi-Square, χ^2

	Probability of a greater value					
Degrees of Freedom	**0.900**	**0.750**	**0.500**	**0.250**	**0.100**	**0.050**
1	0.02	0.10	0.45	1.32	2.71	3.84
2	0.21	0.58	1.39	2.77	4.61	5.99
3	0.58	1.21	2.37	4.11	6.25	7.81
4	1.06	1.92	3.36	5.39	7.78	9.49
5	1.61	2.67	4.35	6.63	9.24	11.07
6	2.20	3.45	5.35	7.84	10.64	12.59
7	2.83	4.25	6.35	9.04	12.02	14.07

POINTS

10 **A.** Define the terms "Type I" and "Type II" errors as they apply to the analysis of low-level radioactive samples.

5 **B.** What are "blank" samples and why are they used to determine instrument background?

10 **C.** A radioactive sample is counted yielding 500 counts (gross) in 10 minutes. The background of the counting system is 460 counts in 60 minutes. If the efficiency of the counting system is 15%, calculate the activity of the sample and the associated uncertainty. State any assumptions used in the calculation. **Show all work.**

15 **D.** Briefly describe the purpose of the χ^2 (Chi-square) test. Using the χ^2 table shown above, what is the implication if the χ^2 value is 4.01 and assuming 5 degrees of freedom?

10 **E.** Given the table above, calculate the χ^2 value for he given data.

QUESTION 7

You are the health physicist for a new research accelerator facility that has both primary and secondary beam areas, and your field measurements show that the average ambient fluxes, (per cm^2 per sec), in the control room are 3000 3-MeV photons, 500 thermal neutrons, and 800 fast neutrons. The control room is used by 10 people who on the average work 40 hours per week, 50 weeks per year in the control room. A 5-m by 20-m concrete shielding wall between the control room and the accelerator room is 2-m-thick. The accelerator operates constantly for 40 hours per week and is designed for a 20 year operating lifetime.

GIVEN

Conversion between particle fluence and effective dose,

Neutron Energy	Sv per n/cm^2
Thermal	2.3 x 10^{-12}
Fast	1.2 x 10^{-10}

Photon Energy, MeV	Sv per photon/cm^2
1	3.27 x 10^{-12}
3	8.2 x 10^{-12}
5	1.2 x 10^{-11}

and dose attenuation coefficients.

Particle	E, cm^{-1}
Thermal neutrons	0.25
Fast neutrons	0.08
3-MeV Gammas	0.08

Concrete cost: $500 per cubic meter
ALARA: $2000 cost per person-rem saving
POINTS

20 A Calculate the annual collective effective dose in the control room. **Show all work**

30 B Calculate the concrete shielding wall thickness required to reduce the effective dose rate in the control room from 100 mrem/hr to 1 mrem/hr. (Assume dose buildup factor = 1). **Show all work.**

20 C Assume a collective dose rate of 1000 person-rem/yr in the control room with the existing shielding wall. Is it cost-effective to increase the shielding wall thickness to reduce this to 1 person-rem per year? **Show all work.**

30 D List six events/conditions that could lead to unusual exposures either in the primary or in the secondary beam areas (provide explanation to support each event/condition). (5 points for each anwer. **Number your responses. Only the first six will be graded.**

QUESTION 8

The water in a pond is uniformly contaminated with ^{106}Ru. A raccoon has just moved into the contaminated area.

GIVEN

Constant water concentration of 250 pCi/l
Radiological half-life of ^{106}Ru is 1.02 y
^{106}Ru Decay: 0.039(max) β
^{106}Ru ingestion ALI: 200µCi
Raccoon parameters:
    body (fresh) weight: 8 kg
    water intake rate: 0.08 l/d per kg of raccoon body weight
    effective loss rate constant for ^{106}Ru, k_{eff}, (includes biological and radiological losses): 0.069/d
    mouse consumption rate: 0.002 kg of mouse/d per kg of raccoon body weight
    ^{106}Ru in body: 30% in soft tissue
        30% bone
        40% free
Mouse parameters
    20 g body (fresh) weight
    20 pCi body burden

POINTS

35 A. The raccoon lives at the pond for a period of 1 year. Assuming the raccoon's only source of water is the pond and that he eats his daily fill of mice, calculate the ^{106}Ru concentration in the raccoon at the end of the year. Show all work.

15 B. Calculate the steady state activity (pCi) of ^{106}Ru if the raccoon lives at the pond the rest of his life. Show all work.

30 C. A house located adjacent to the site uses a well which draws water from the pond. An adult consumes 2.2l/d for 1 year from the pond. Calculate the Effective Dose to the adult. How does this number compare to natural background. Show all work.

20 D. Calculate the biological half life of ^{106}Ru in raccoons.

QUESTION 9

A plutonium fire occurs in an inerted glove box as a result of air leakage into the glove box. The glove box contains 750 grams of nominally pure ^{239}Pu in the form of a fine powder and combustible solvents. The fire burns for 20 minutes immediately causing a breach of the integrity of the glove box and the smoke fills the surrounding room. Normal ventilation is automatically secured and emergency room ventilation starts due to the high airborne radioactivity in the room. The emergency ventilation is exhausted to the atmosphere via a single-stage high efficiency particulate air (HEPA) filter through a 10-meter high stack.

GIVEN

Room dimensions: 6 m x 6 m x 3 m
$T_{1/2}$ for ^{239}Pu- 24,100 y
Emergency ventilation flow: 7 m^3/min
HEPA collection efficiency: 99.95%
DAC for ^{239}Pu: 2 x 10^{-12} μCi/cc
Wind speed: 9 m/s for Stability Class A conditions.
Site Boundary Distance: 1,000 meters.
Graphs of σ_y and σ_z versus distance from "Meteorology and Atomic Energy, 1968."

$$c = \frac{Q'}{2p\, s_y s_z u} \exp\left(-\frac{y^2}{2 s_y^2}\right)\left[\exp\left(-\frac{(z-h)^2}{2 s_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2 s_z^2}\right)\right]$$

Where: Q' = release rate (Ci/s) u = mean wind speed (m/s) z = elevation (m) h = stack height (m)
χ = concentration (Ci/m^3) y = cross-wind distance (m)

POINTS

20 A. How many curies of ^{239}Pu are contained in the glove box prior to the fire? **Show all work.**

20 B. List five factors on which the occurrence of accidental criticality depend. **Number your responses. Only the first five will be graded.**

20 C. Assuming an initial concentration of 4 x 10^{-4} μCi/cc immediately after the fire ceases, how much time must elapse before the concentration in the room falls below 1 DAC?

40 D. Emergency ventilation is exhausted to the atmosphere via a single stage high efficiency particulate (HEPA) air filter through a 10-meter high stack. Assume a constant air concentration of 4 x 10^{-4} μCi/cc in the room. What is the air

concentration at ground level at the site boundary (on the plume centerline) for Class A stability conditions? **Show all work.**

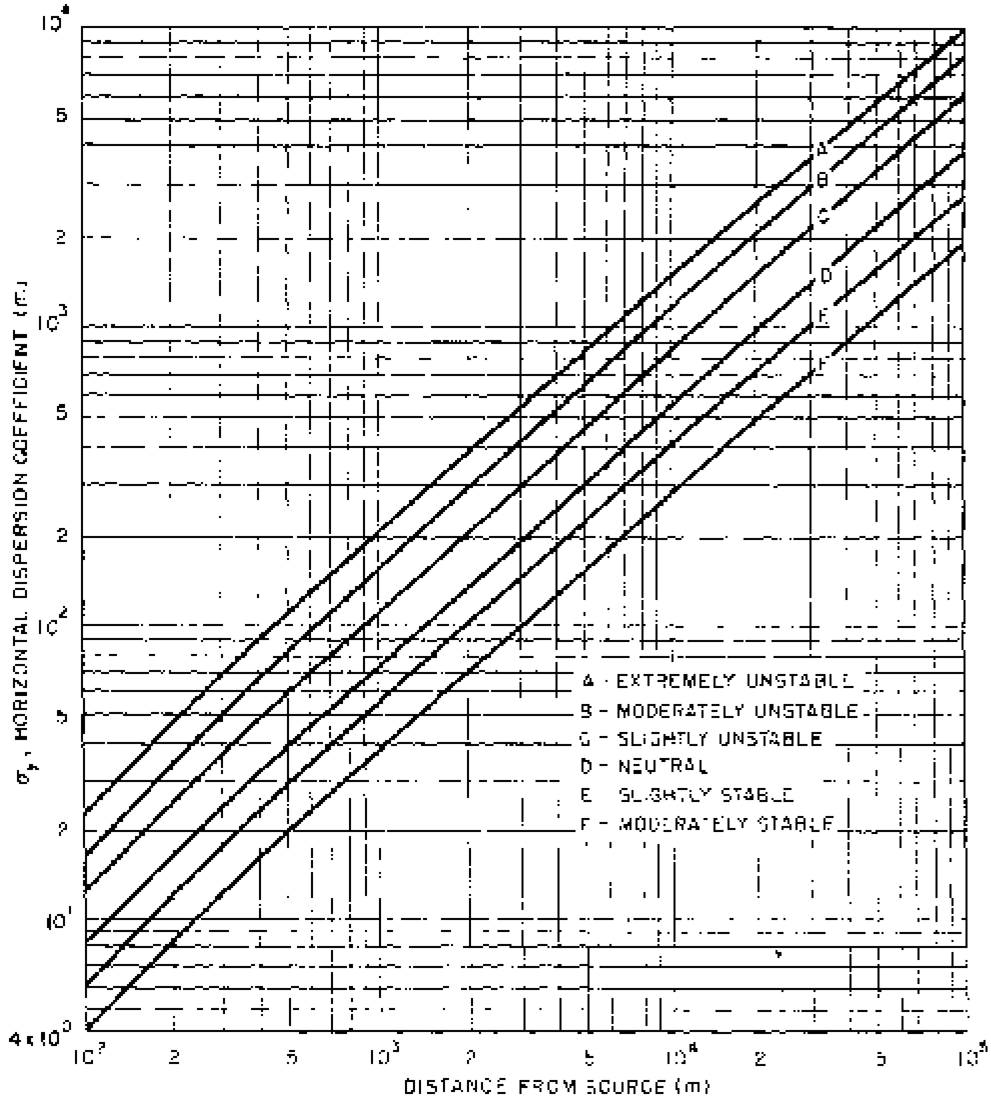

Figure A.2 Meteorology and Atomic Energy : y versus distance

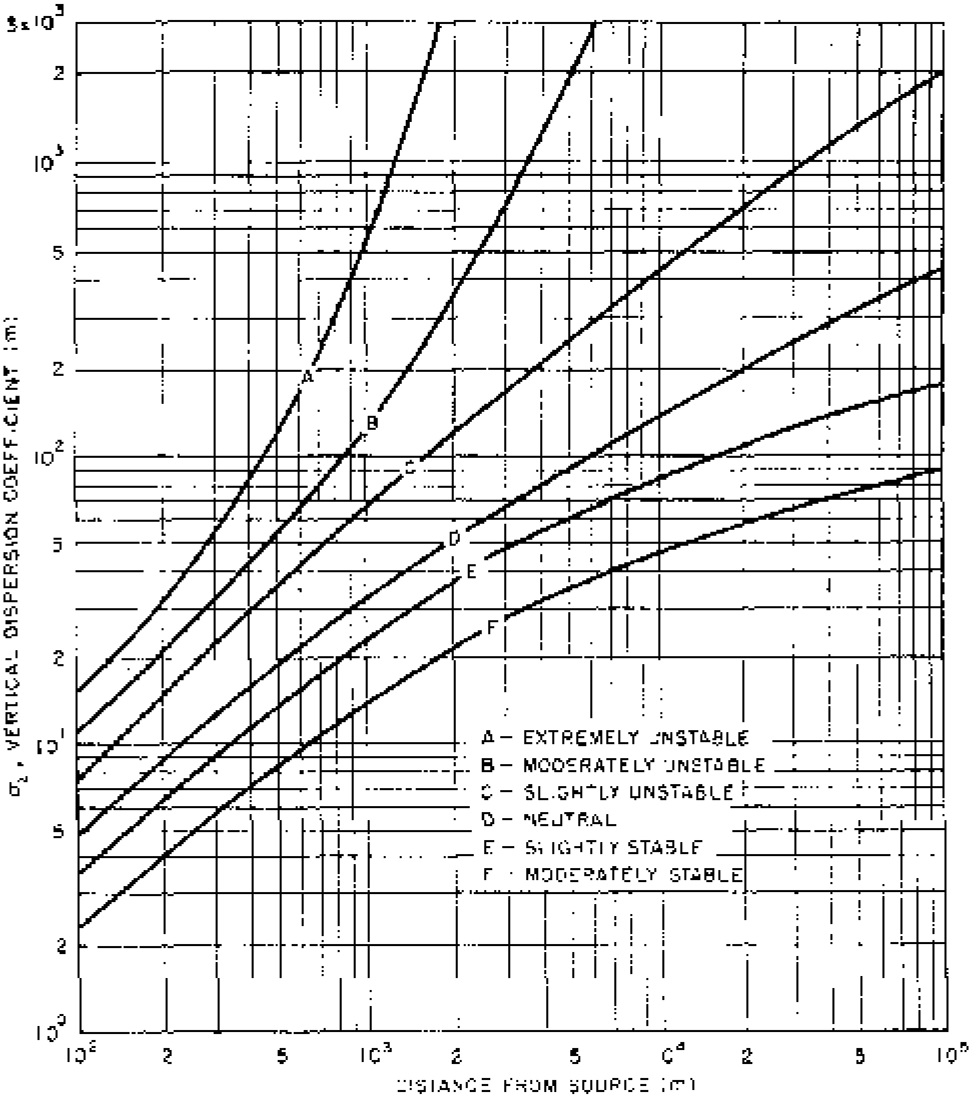

FIGURE A.3 METEOROLOGY AND ATOMIC ENERGY : Z VERSUS DISTANCE

QUESTION 10

An accidental airborne release of approximately 2 kg of “nominally pure” plutonium has occurred. The plume is predicted to drift offsite and pass over a nearby town. Assume that the material is released in a particulate form, is assigned to inhalation class ‘Y’, and has the isotopic mixture shown in the table below.

GIVEN

- The DCF for external exposure to plutonium is 2.8 x 10^{-3} rem/h per g/m^2
- The DCF for Pu inhalation (Class Y, 1 micron AMAD) = 330 rem/ µCi (alpha) inhaled
- The f_1 value for Class Y plutonium is 1.0 x 10^{-5}
- The breathing rate is 20 l/min
- The resuspension factor is 10^{-5} m^{-1}.

Isotope	Weight %	Specific Activity (Ci/g isotope)	Total Activity (Ci isotope/g Pu mix)	Major radiations				
				Alpha (MeV)	Beta (MeV)	Photon Energy (MeV)	Photon Yield (%)	Spontaneous Neutrons (n/g-s)
Pu-238	0.04	17.10	0.007	5.49	–	0.017 0.099 0.150 0.77	11 0.008 0.001 0.00005	2600
Pu-239	93.3	0.06	0.056	5.15	–	0.017 0.039 0.052 0.129 0.375 0.414 0.65 0.77	5 0.007 0.020 0.005 0.0012 0.0012 0.00008 0.00002	0.03
Pu-240	5.99	0.23	0.014	5.16	–	0.017 0.65	11 0.00002	1000
Pu-241	0.28	103.00	0.288	–	0.021	0.145	0.00016	–
Pu-242	0.04	0.004	0.000002	4.9	–	–	–	1700
Am-241	0.30	3.44	0.01	5.5	–	0.017 0.060 0.101 0.208 0.335 0.37 0.663 0.722	37 36 0.04 0.0006 0.0008 0.0004 0.0005 0.0003	1.10
Pu (mix)	100		0.09 (alpha Ci) 0.38 (total Ci)	4.9-5.5	0.021	0.06		62

POINTS

10 A. Assuming that the inital plume has passed, give **two** (2) actions which could most **significantly** reduce the dose to the downwind population during the first week following the accident. **Number your answers. Only the first two will be graded.**

20 B. The EPA recommends relocation of the general public based on a 1st year Protection Action Guide (PAG) of >2 rem TEDE. Assume the estimated dose received by residents who were outdoors during the initial plume passage ranges from 1.5 to 2 rem CEDE and the estimated additional dose these residents are likely to receive during the first year after the accident is 1.3 rem CEDE. Specify:

1. The meaning and intent of the PAGs, and

2. Your recommendations with respect to relocation of the population. **Justify your answer.**

20 C. To assess the offsite surface deposition of plutonium you equip field teams with portable hand-held thin-crystal sodium-iodide-based single channel analyzers. These monitors may be calibrated to detect either the 17 keV or the 60 keV photons emitted from material involved in this release. Given that the emission ratio of the 17 keV to 60 keV photons is approximately 2.5, answer the following:

1. State two advantages of each energy calibration?
2. State which photon energy you would recommend under the following two conditions. Why?

   a. Dry paved road surfaces.

   b. Agricultural field following an extended rain.

30 D. Calculate the internal dose from plutonium ground depositions for an individual who walks for one hour on soil contaminated at a level of 100 µCi /m^2. **Show all work, and state any assumptions.**

20 E. Applying default assumptions from the facility's emergency plan, you estimate that a radiological worker who responded to the accident received a total effective dose equivalent of 4.8 rem. Is further refinement of this dose estimate necessary? If so, what action would you take to refine the dose estimate?

QUESTION 11

A pharmaceutical representative has just completed a presentation on the merits of a new radiopharmaceutical for the study of the blood perfusion of heart muscle in patients with suspected or known coronary artery disease. The new radiopharmaceutical is labeled with ^{99m}Tc (trade name Tetrolite). The radiopharmaceutical that has been the standard in heart perfusion imaging for years is ^{201}Tl-Cl (trade name thallium). One of the selling points that the salesperson uses is the favorable dosimetry of Tetrolite relative to ^{201}Tl-Cl. After the presentation, your nuclear medicine manager asks you to explain why one can inject nearly 10 times more Tetrolite than thallium into the patient without increasing the patient's effective dose equivalent.

GIVEN

The protocol for the heart muscle blood perfusion studies are as follows:

> ^{201}Tl - Patient is physically stressed and 4 mCi ^{201}Tl-Cl is injected at peak stress. An image is made immediately following the end of stress. About 2 hours later an image is obtained representative of the rest condition. No additional ^{201}Tl-Cl is injected
>
> ^{99m}Tc-Tetrolite - Patient in rest condition is injected with 10 mCi of Tetrolite and one hour later a rest image is obtained. About 3 hours later, the patient is stressed physically and at peak stress, an additional 20 mCi is injected and an image representative of the patient's physical stress condition is obtained about 40 minutes later.

From the literature you discover that both radiopharmaceuticals distribute themselves uniformly throughout the body and that the half lives for biological elimination from the body are 10 days. The physical half life for ^{99m}Tc is 6 hours. The physical half life for ^{201}Tl is 73 hours.

Reference man weights 70 kg.

Assume that the distribution and kinetics of elimination of the two radiopharmaceuticals is about the same during both the rest and stress phase of the diagnostic protocol.

Energies and frequencies and Absorbed Fractions and absorption coefficient in air of major photons emitted from decay of ^{99m}Tc and ^{201}Tl; (Contributions of Auger and internal conversion electrons to patient dose are considered insignificant.)				
^{201}Tl				
Radiation Type	Energy (kev)	Frequency	Absorbed Fraction**	Absorption coefficient in air (cm^2/gm)
X-ray Kα1	68.9	0.27	0.47	0.0262
X-ray Kα2	70.8	0.465	0.47	0.0262
X-ray Kαβ	80.3	0.205	0.47	0.0236
^{99m}Tc				
Radiation Type	Energy (kev)	Frequency	Absorbed Fraction**	Absorption coefficient in air (cm^2/gm)
Gamma	140.5	0.891	0.36	0.0245
**The fraction of the energy of a photon originating in the whole body (the source organ) which is absorbed in the whole body (target organ). From Snyder et al., 1969, MIRD Pamphlet No. 5.				

POINTS

15 A. What are the three major factors which one would use to define the committed effective dose equivalent received by the patient who has been injected with either of these radiopharmaceuticals? **Number your responses. Only the first three will be graded.**

30 B. What are the RELATIVE contributions of each factor in determining the nearly 10-fold difference in effective dose equivalent per mCi between the thallium and Tetrolite radiopharmaceuticals? **Show all work.**

10 C. If the biological half life of ^{99m}Tc-Tetrolite in the gall bladder is 7 days, what is the effective half life for ^{99m}Tc in the gall bladder? **Show all work.**

20 D. The gamma camera used for production of a nuclear medicine image functions in much the same manner as a solid scintillation survey meter. Assume that the injection activities given for the protocols above result in 20 times more counts being acquired with ^{99m}Tc-Tetrolite than with ^{201}TlCl. What is the relative variability in the counts which are acquired using the two radiopharmaceuticals? (Variability is defined by the standard deviation of the number of counts divided by the number of counts.) **Show all work.**

25 E. What is the RELATIVE extremity dose to a nuclear medicine technician who is performing injections of the thallium and the Tetrolite for heart perfusion studies? The protocol is the same as that identified above. The injection process requires about 1 minute of syringe handling time for the thallium procedure and about 2 minutes of syringe handling time for the Tetrolite procedure.

QUESTION 12

Radioactive gases create health physics issues at both Pressurized Water Reactors (PWR's) and Boiling Water Reactors (BWR's).

POINTS

25 A. Given the following information, calculate the **alarm setpoint** to correspond to 60% of the maximum acceptable total release rate from a tank designed to store gaseous radioactive waste. **Show all work**.

Radionuclide Mixture:	^{85}Kr, ^{133}Xe, ^{135}Xe
Acceptable total release rate:	8.35×10^4 μCi/sec
Detector efficiency:	1.69×10^{-6} μCi/cm^3 per cpm
Detector background:	730 cpm
Effluent flow rate at release point:	6300 ft^3/m
Conversion factor:	2.83×10^4 cm^3/ft^3

15 B. What are three sources of radioactive gas in the reactor coolant system. **Number your responses; only the first 3 will be graded.**

15 C. Specify three mechanisms by which ^{3}H is produced in a PWR. **Number your responses; only the first 3 will be graded.**

10 D. Generally speaking, a BWR will have lower equilibrium concentrations of radioactive gases in the reactor coolant than a PWR, even though the fuel load and power history may be similar. Explain why this occurs.

9 E. The presence of hydrogen (H_2) in a radioactive gaseous waste system poses an explosive hazard. By what process is hydrogen produced in the reactor system?

10 F. Describe two methods used to prevent the hydrogen concentration from reaching explosive concentrations? **Number your responses; only the first two will be graded.**

16 G. The following questions pertain to a specific radionuclide in BWR.

1. Which radionuclide would be the source of the highest on-site external dose rate during reactor operation.
2. Where would the highest accessible dose rate likely occur?
3. Why is this radionuclide NOT a problem during reactor shutdown?
4. What is the production mechanism for this radionuclide?

QUESTION 13

A technician at your university was performing a cell wash at a sink inside a walk-in cooler. Approximately 45 cm away, a protein labeled with ^{125}I was being dialyzed. The technician observed the radioactive material sign on the dialysis material, became concerned and contacted, the chairperson of the Radiation Safety Committee (RSC). Because she was performing a procedure that did not involve radioactive material, she was not wearing dosimetry. The chairperson has asked you to investigate.

You learn that the protein labeling procedure was conducted two weeks ago with 370 MBq of ^{125}I. The labeling procedure has an efficiency of 45%. The technician was present in the work area for about 1.5 hours while the protein was being dialyzed.

GIVEN

Half-life of ^{125}I = 60.1 days.
Lead density: 11.35 g/cm^3
Mass attenuation coefficient of lead: 28.9 cm^2/g.
Gamma constant (Γ) for ^{125}I : 7.4×10^{-5} mSv/hr-MBq @ 1 meter.
^{125}I emits the following:

Emission	Energy (keV)	Intensity (%)
x-ray	27.2	39.7
x-ray	27.4	74.1
x-ray	31	25.7
gamma	35.5	6.7

POINTS

10 A. List two possible routes of exposure to the technician and how you would assess each. **Number your responses. Only the first two will be graded.**

50 B. Assume attenuation from the dialysis apparatus is negligible and the apparatus is a point source. Calculate the effective dose from external radiation to the technician. **Show all work**.

20 C. The technician has some lead foil that is 0.015 cm thick. Assume that the activity of the source is 200 MBq for this part. What is the dose rate at 45 cm if the lead is used? **Justify your answer and show all work.**

20 D. List two other corrective actions that could be taken to minimize dose to the technician (in addition to shielding the dialysis apparatus). **Number your responses. Only the first two will be graded.**

QUESTION 14

After using a diode laser pointer in lectures, a university professor received questions from students who are concerned about the safety of such devices. The professor decides to consult with you, the Radiation Safety Officer of the University. You have collected the relevant data and performed an analysis according to ANSI Z136.1-1993.

GIVEN The laser pointer: Wavelength (λ) = 660-680 nm
Output power (Φ) = 4.5 mW
Aperture diameter (a) = 0.2 cm
Beam divergence (ϕ) = 0.2 milliradians

Distance from the professor to students = 3 to 50 m
Time for human blinking (aversion time) = 0.25s
Maximum Permissible Exposure, MPE

$$MPE = \frac{1.8t^{3/4} x10^{-3}\ Jcm^{-2}}{t(s)}$$

(for exposure time t: $18 \times 10^{-6} < t < 10$ s)

$$\text{NOHD} = \left[\frac{1}{f}\right]\left\{\frac{4\Phi}{p\ (\text{MPE})} - a^2\right\}^{1/2}$$

POINTS

20 A. Calculate the emerging irradiance in mW/cm^2. **Show all work. State the answer which is most appropriate.**

a) 24 mW/cm^2
b) 36 mW/cm^2
c) 95 mW/cm^2
d) 143 mW/cm^2
e) 450 mW/cm^2

15 B. Calculate the MPE, in mW/cm^2, for intrabeam viewing. **Show all work. state the answer which is most appropriate.**

a) 0.64 mW/cm^2
b) 1.9 mW/cm^2
c) 2.5 mW/cm^2
d) 3.6 mW/cm^2
e) 2500 mW/cm^2

10 C. Define nominal occular hazard distance (NOHD).

20 D. Assuming a MPE value of 3.0 mW/cm^2. Calculate the NOHD for the laser pointer. **Show all work.** Does it include the lecture audience and why?

10 E. To which class of laser does this laser pointer belong? Justify your answer.

10 F. List two of the ANSI recommended safety precautions to the professor for this class of laser. **Number your responses. Only the first two will be graded.**

15 G. During your investigation you discovered that some professors are using older HeNe laser pointers. These are Class II devices operating with a power output of 0.5 mW. What is the basis for the difference in the hazard between the two lasers (diode and HeNe)?