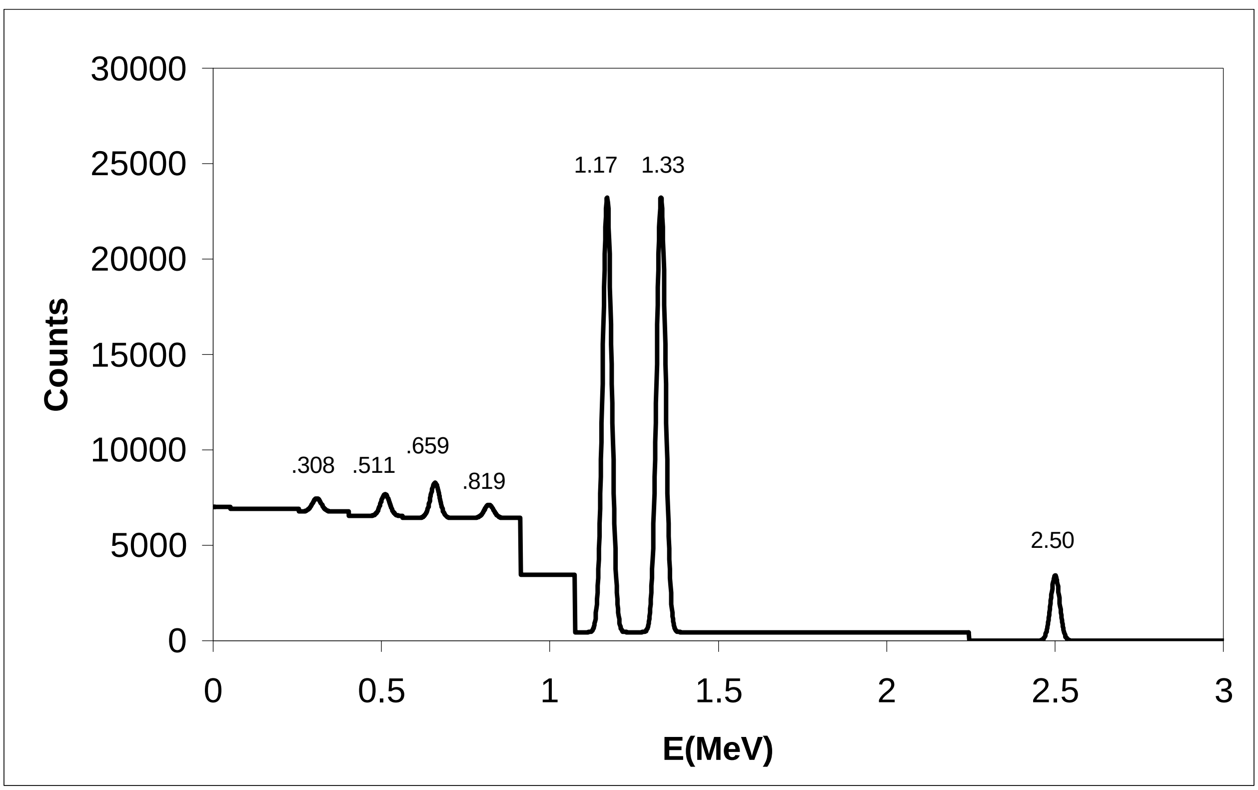
QUESTION 1

You are a health physicist at a nuclear power plant. During a routine "frisk" survey of a worker exiting a controlled area, a "hot particle" is discovered. As an initial estimate of the potential dose rate from this particle, a technician removed the particle using a piece of tape and then measured the contact dose rate using an ion chamber with the end window open. Following that initial measurement, the particle was taken to the gamma spectroscopy lab for analysis on a high resolution germanium detector.

GIVEN

- Specifications for air filled ionization chamber vented to atmosphere:
  - Detector volume 220 cm^3
  - Chamber window 7 mg cm^{-2}
  - Beta shield 1,000 mg cm^{-2}
- The ionization chamber was calibrated using a gamma-only source.
- Gamma spectrum analysis showing the following peaks:



POINTS

STATE ALL ASSUMPTIONS

4 A. When calculating the dose from a hot particle, what skin area and tissue depth is generally assumed for the purpose of estimating the skin dose?

12 B. Is a dose measured by an ion chamber the “true” skin dose? State 3 reasons why or why not. **Number your responses. Only the first three answers will be graded.**

28 C. The gamma spectrum reveals that the activity of this particular hot particle is due primarily to ^{60}Co. Given the seven peak energies shown on the spectrum graph above, identify the most likely origin of each of the seven peaks and describe the mechanism that causes each peak.

6 D. What three follow up actions would you take in the work area upon discovery of this hot particle? **Number your responses. Only the first three answers will be graded.**

QUESTION 2

A radiobiology student comes to your office and asks for your assistance in studying for the final exam. Answer the following questions in such a way that the student has a good chance of doing well on the exam.

POINTS

STATE ALL ASSUMPTIONS

12 A. Identify and describe two general mechanisms by which radiation can damage a critical target in a cell. In your discussion identify which mechanism is usually dominant with high-LET radiation. **Number your responses. Only the first two will be graded.**

9 B. Name three (3) general types of biological effects of ionizing radiation that are taken into consideration in the derivation of dose limits for radiation workers. **Number your responses. Only the first three will be graded.**

15 C. List five (5) deterministic effects resulting from exposure to acute, high dose rate ionizing radiation. **Number your responses. Only the first five will be graded.**

5 D. What is the relationship between RBE and LET for low LET radiation (up to 100 keV/ m)?

9 E. Rank the following forms of radiation in order of **increasing** RBE. (use 1 = low, 3 = high)

_____ 5 MeV protons
_____ Fission-spectrum neutrons
_____ 20 keV x-rays

QUESTION 3

A 2” diameter hot liquid waste line carries 10 L min^{-1} ^{131}I waste, at a concentration of 50 μCi L^{-1}, through a closed room 3 m wide x 2 m deep x 3 m high to a shielded ion exchange unit in an adjacent laboratory. The ventilation rate in the closed room is 5 m^3 min^{-1}. A supervisor who looks through the viewing port of the shielded door sees that a valve in the line is leaking at a rate of 10 drops per minute. (The volume of each drop is 0.05 mL, the drops evaporate immediately, and the iodine is immediately dispersed uniformly into the room air.) Another supervisor estimates that a single mechanic can repair the valve in 1 hour.

GIVEN

- $C = \frac{G}{Q}\left(1 - e^{-\frac{Q}{V} \times t}\right)$

  where

  G is the release rate,
  Q is the ventilation rate, and
  V is the volume.
- Non-stochastic (thyroid) DAC for ^{131}I = 2 x 10^{-8} μCi mL^{-1}
- $T_{1/2}$ (^{131}I) = 8.05 d
- w_T (thyroid) = 0.03

POINTS

STATE ALL ASSUMPTIONS

10 A. 1) At what rate is ^{131}I being introduced into the atmosphere of the room? **Show all calculations.**

2) If conditions remain the same, what is the maximum concentration that airborne ^{131}I in the room could reach? **Show all calculations.**

10 B. What is the air turnover rate in the room, assuming complete, instantaneous mixing? **Show all calculations.**

10 C. Assume that the air turnover rate is 0.1 min^{-1}. How long will it take before the atmospheric ^{131}I concentration is reduced to 1% of its value after the leak has been stopped? **Show all calculations.**

10 D. Assume that the room concentration is 8 x 10^{-9} μCi mL^{-1}. What would be the mechanic's committed effective dose equivalent (CEDE) if he spends 1 hour in the room without respiratory protection (according to current US regulations per 10CFR20 and 10CFR835) with the room ventilation turned off for the duration? Assume that contributions to the CEDE from other organs is negligible. **Show all calculations.**

10 E. Based on the situation initially described above, what are two actions that you would recommend be taken prior to allowing the mechanic to enter the room? **Number your responses. Only the first two will be graded. Justify each answer.**

QUESTION 4

You are the project health physicist decommissioning a hot cell that manufactured thermoelectric generators from ^{90}Sr, with strontium nitrate being converted to strontium titanate. Most of the radioactivity is in steel tubing in the hot cell and only strontium nitrate has been found so far. All external surfaces within the hot cell and the adjacent isolation room also have high levels of removable and fixed surface contamination.

GIVEN

- ICRP-30 model
- The stochastic inhalation ALI for Class D ^{90}Sr = 20 μCi
- The non-stochastic inhalation ALI (Bone Surfaces) for Class D ^{90}Sr = 20 μCi
- The stochastic inhalation ALI for Class Y ^{90}Sr = 4 μCi
- Strontium nitrate is Class D and strontium titanate is Class Y.
- Counting efficiency of GM instrument with a pancake probe for ^{90}Sr on an air filter paper = 25%
- Air flow of a high volume air sampler = 4.0 L min^{-1}
- Reference Man breathing rate (light activity) = 20 L min^{-1}
- From NUREG/CR 4884, the fraction of any initial intake of Class D ^{90}Sr in a 24-hour urine void beginning directly after intake = 0.0857

POINTS

STATE ALL ASSUMPTIONS

15 A. A worker in the isolation room may have been exposed to airborne ^{90}Sr. Identify two (2) qualitative measures you can take to see if the individual was exposed. **Number your responses. Only the first two will be graded.** Identify three (3) quantitative analyses you can do to estimate exposure. **Number your responses. Only the first three will be graded.**

15 B. Assume that the worker was exposed to strontium nitrate and that a 24 hour urine void taken directly after the exposure has a ^{90}Sr activity of 2.62 μCi. What is the estimated committed effective dose equivalent (CEDE) to the individual? **State all assumptions and show all calculations.** List the two (2) primary reasons why a dose estimate that was based on a urine sample collected immediately after the exposure would not be accurate. **Number your responses. Only the first two will be graded. Explain your answer.**

15 C. During robotic dismantling activities a continuous air monitor alarms in the hot cell because of an inadvertent release of source material. A 5-minute high volume air sample from the isolation room reads 10^3 cpm on the GM instrument with a pancake probe. What is the DAC level in the isolation room? **Show all calculations.** Workers are wearing full-face respirators with a respiratory protection factor of 50. Based on the potential internal dose, will you allow work to continue in the isolation room? **Justify your answer.**

5 D. For the situation in part C, you discover that ^{90}Sr is in the form of strontium titanate. How would this information change the internal dose estimated in part C above? It is not necessary to repeat the calculation. Describe qualitatively what the result will be.

QUESTION 5

You are a health physicist working at a nuclear power station. You are assigned the task of calculating potential dose rates from systems scheduled for maintenance during an upcoming outage to enable pre-staging of temporary shielding materials.

GIVEN

- The sample coupon originally weighed 5 grams
- The sample was 100% ^{59}Co
- The dimensions of the sample are 1 cm x 3 cm x 0.2 cm
- The ^{59}Co (n,γ) ^{60}Co thermal neutron activation cross section is 37 barns
- Average thermal neutron fluence rate in the reactor is 1 x 10^{10} n cm^{-2} sec^{-1}
- Average fast neutron fluence rate is 4 x 10^{10} n cm^{-2} sec^{-1}
- ^{60}Co has a half-life of 5.27 years
- The specific gamma-ray exposure constant, Γ, for ^{60}Co is 1.3 R m^{2} Ci^{-1} hr^{-1}

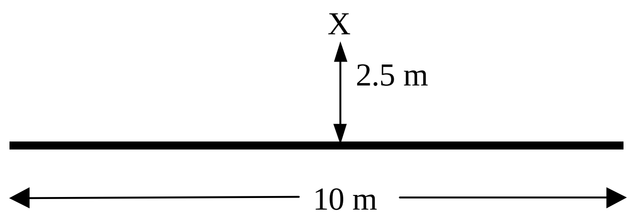
POINTS

STATE ALL ASSUMPTIONS

20 A. Nine months ago, a sample coupon was removed from the reactor vessel. Plant records indicate that the sample had been in the reactor since initial start-up for a length of 22 effective full power years. What is the activity in the sample coupon currently? **State all assumptions and show all calculations.**

10 B. Assume that the activity of the coupon is 0.75 Ci. What is the exposure rate, in R hr^{-1}, that can be expected at a point 3 meters from the coupon? **State all assumptions and show all calculations.**

20 C. A worker will have to stand at a point 'X' that is 2.5 m away from the mid-point of a 0.5-cm diameter sample line that is 10 m long (See below). The interior of the line is uniformly contaminated with 4 Ci of ^{60}Co. What is the exposure rate at the point 'X', where the worker is standing? Neglect self-shielding in the pipe. **State all assumptions and show all calculations.**



QUESTION 6

A worker at a facility where ^{131}I materials are manufactured appears to have a positive result for ^{131}I in a spot urine sample. The chemical form of the ^{131}I is NaI. The sample was taken late in the day, after the majority of the day was spent working with ^{131}I. No air sample results are available for this case.

GIVEN

- From external thyroid counting, the following data are obtained:

Time Post Intake (d)	Thyroid Activity (kBq)	IRF*
1	250	0.133
7	230	0.0995
10	130	0.0751

* Intake Retention Fraction for Inhalation of Class D ^{131}I – fraction of intake expected to be in the thyroid this time post-intake. NOTE: Radioactive decay is accounted for in these values.

- For inhalation of class D ^{131}I, the dose conversion factor for thyroid is 2.9×10^{-7} Sv Bq^{-1}
- Approximately 75% of ^{131}I as NaI is excreted from the body in the urine in 1-2 days with an effective halftime of about 6 hours. The remaining 25% of ^{131}I will be trapped in the subject's thyroid, reaching a maximum about 24 hours post-intake, and be excreted with an effective half-time of about 7 days
- 10CFR20 Organ Dose Weighting Factor, w_T, for the thyroid is 0.03

POINTS

STATE ALL ASSUMPTIONS

20 A. Given that you can choose *in vivo* or *in vitro* methods of analysis to perform bioassay, describe and discuss the optimal approach for this case. In your discussion list two advantages and two disadvantages for *in vitro* and for *in vivo* methods of analysis as related to this case. **Justify your answer. Number your responses. Only the first two advantages and the first two disadvantages for *in vitro* and for *in vivo* methods will be graded.**

10 B. How might your approach to bioassay change as time goes by, given the metabolic model for iodine? **Explain your answer.**

10 C. Based on the thyroid counting data given, what is your best estimate of the subject's intake? **Show all calculations.**

10 D. Assume that the intake was 5 MBq. What is the committed dose equivalent (CDE) to thyroid for this intake? What is the committed effective dose equivalent (CEDE) for this intake? Assume that organs other than the thyroid make a negligible contribution to the CEDE. Have any regulatory limits been exceeded? **State all assumptions and show all calculations.**

QUESTION 7

As RSO at a university with a vivarium, you receive a call at 1:05 PM saying that there has been a spill of radiopharmaceutical containing ^{99m}Tc in one of the rooms. An inexperienced technician tells you that a large dog had been injected with 5 mCi of the compound at noon (12:00 PM). The animal urinated on the floor at 1:00 PM and the technician observed a reading of 20 mR hr^{-1} when using a G-M instrument held at waist level above the spill.

GIVEN

- Assume the technician's waist level is about 1 m above the ground
- The area of the puddle is 0.25 m^2
- The specific gamma-ray exposure constant for ^{99m}Tc = 0.06 R m^2 hr^{-1} Ci^{-1}
- ^{99m}Tc half life = 6.02 hr $E_{beta}(max)$ = 0.002 MeV E_{gamma} = 0.141 MeV
- ^{99}Tc half life = 213,000 yr $E_{beta}(max)$ = 0.293 MeV   no gamma
- The University's license sets the limit for free release of contaminated areas as
  - 1000 dpm/100 cm^2 removable (average),
  - 5000 dpm/100 cm^2 fixed plus removable, and
  - Not to exceed 15,000 dpm / 100 cm^2 total contamination in any location when averaged over 1 square meter.

POINTS

STATE ALL ASSUMPTIONS

15 A. When you asked the technician about the instrument he used to measure radiation levels, he showed you a Geiger-Mueller instrument with a "pancake" probe. Is this detector suitable for measuring radiation exposure rate in this instance? Give two reasons why this detector is or is not acceptable for measuring radiation exposure rate in this instance. **Number your responses. Only the first two will be graded.**

20 B. Calculate the exposure rate at 1 meter above the spill at 1:00 PM. Assume that all activity is voided in the first urination. **State all assumptions and show all calculations.**

20 C. List five precautions necessary to begin cleaning up this spill. **Number your responses. Only the first five will be graded.**

30 D. Because the floor is composed of individual tiles, it is not possible to fully decontaminate the room. After two hours of steady work, the highest total contamination levels are 150,000-dpm/100 cm^2 and average total contamination levels are about 75,000 dpm/100 cm^2, with removable contamination levels of up to 10,000 dpm/100 cm^2. The vivarium director informs you that the room must be in use by noon tomorrow because of some time-critical research. Can it be released immediately? Can it be released by noon tomorrow? **Justify your answers.**

15 E. After 7 days you survey the spill site with a GM “pancake” detector and you detect no activity.

1) Show by calculation why you did not detect ^{99m}Tc activity. **Show all calculations.**

2) ^{99m}Tc decays into ^{99}Tc. Show that ^{99}Tc would not be detectable either. **Show all calculations.**

QUESTION 8

An unconscious woman was brought into the Emergency Room, bleeding and with broken bones, following a motor vehicle accident. When first admitted, the Computed Tomography (CT) scanner was down and a "trauma" series of diagnostic x-rays was taken, after which fluoroscopy was required as part of an effort to investigate for internal injuries. When the woman awakened, she informed her physician she just found out she is pregnant and that she thinks the date of conception was about 1 month ago.

GIVEN

- The trauma series of diagnostic x-rays include one each of the head/neck, chest, abdomen, pelvis, and lumbar spine. Assume all x-ray projections are anterior-posterior (AP).
- Four minutes of fluoroscopy time at 2 mA was logged for abdominal procedures.
- For the machine parameters on file for the machines in use, fetal dose is determined to be 45% of the entrance skin exposure to the mother.
- Radiological information is summarized in the following table:

Procedure	**Entrance Skin Exposure (ESE) (C/kg)**
Chest	0.07×10^{-4}
Pelvic	0.79×10^{-4}
Head/neck	1.14×10^{-4}
Abdomen	1.08×10^{-4}
Lumbar spine	1.40×10^{-4}
Thoracic spine	1.33×10^{-4}
Cervical spine	0.39×10^{-4}

- Fluoroscopy Entrance Skin Exposure (ESE) = 1.7 R/mA-min

POINTS

STATE ALL ASSUMPTIONS

30 A. Calculate the radiation dose to the fetus using the above information. You need not calculate radiation dose from every procedure if you can justify omitting the calculations. **State all assumptions and show all calculations.**

15 B. Assume that the radiation dose calculated in part A was 3.5 rad. What three pieces of advice (based on NCRP 54: "Medical Radiation Exposure of Pregnant and Potentially Pregnant Women") would you give the woman's OB/GYN regarding terminating the pregnancy or letting it proceed? **Number your responses. Only the first three will be graded. Justify your answer.**

15 C. What are three pieces of information necessary to determine the risk of injury to the fetus from this incident? **Number your responses. Only the first three will be graded.**

25 D. During subsequent communication with the woman's physician you are informed that she appeared to have skin burns. List five reasonable explanations as to why this could occur. **Number your responses. Only the first five will be graded.**

15 E. List five machine parameters that will affect fetal radiation exposure from CT, x-ray, or fluoroscopy. **Number your responses. Only the first five will be graded.**

QUESTION 9

You are the designated laser safety officer (LSO) for an outdoor military battlefield tactics range, which has controlled air space in order to exclude commercial or private aviation from the area. A variety of military aircraft, ground troops, and mechanized equipment utilize the range. In addition to conventional weapons, a multitude of lasers are actively employed in the training. They may be operated for long exposure duration during field operations. For all potential exposures, purposeful staring into a laser beam is neither intended nor anticipated.

GIVEN

Maximum Permissible Exposure for Direct Ocular Exposure Intra-beam Viewing from a Laser Beam [From ANSI Z136.1 (1993)]

Wavelength (micrometers)	Exposure Duration (seconds)	Maximum Permissible Exposure	
		$(J * cm^{-2})$	$(W * cm^{-2})$
0.4 to 0.7	10^{-9} to 18×10^{-6}	0.5×10^{-6}	
0.4 to 0.7	18×10^{-6} to 10	$1.8\ t^{3/4} \times 10^{-3}$	
0.4 to 0.55	10 to 10^{4}	10×10^{-3}	
0.55 to 0.7	10 to T_1	$1.8\ t^{3/4} \times 10^{-3}$	
0.55 to 0.7	T_1 to 10^{4}	$10\ C_B \times 10^{-3}$	
0.4 to 0.7	10^{4} to 3×10^{4}		$C_B \times 10^{-6}$
0.7 to 1.05	10^{-9} to 18×10^{-6}	$0.5\ C_A \times 10^{-6}$	
0.7 to 1.05	18×10^{-6} to 10^{3}	$1.8\ C_A\ t^{3/4} \times 10^{-3}$	
0.7 to 1.05	10^{3} to 3×10^{4}		$320\ C_A \times 10^{-6}$
1.05 to 1.4	10^{-9} to 50×10^{-6}	$5\ C_C \times 10^{-6}$	
1.05 to 1.4	50×10^{-6} to 10^{3}	$9.0\ C_C\ t^{3/4} \times 10^{-3}$	
1.05 to 1.4	10^{3} to 3×10^{4}		$1.6\ C_C \times 10^{-3}$

Limiting Aperture Diameter: 0.7 cm

Correction Factors:

$T_1 = 10 \times 10^{20(\lambda-0.55)}$	0.55 to 0.7 μm	$C_A = 1.0$	0.4 to 0.7 μm
$C_B = 1.00$	4 to 0.55 μm	$C_A = 10^{2(\lambda-0.7)}$	0.7 to 1.05 μm
$C_B = 10^{15(\lambda-0.55)}$	0.55 to 0.7 μm	$C_A = 5.0$	1.05 to 1.4 μm
$C_C = 1.0$	1.05 to 1.15 μm	$C_C = 10^{18(\lambda-1.15)}$	1.15 to 1.2 μm
$C_C = 8.0$	1.2 to 1.4 μm		

Maximum Permissible Exposure for Skin Exposure to a Laser Beam [From ANSI Z136.1 (1993)]

Wavelength (micrometers)	Exposure Duration (seconds)	Maximum Permissible Exposure	
		($J * cm^{-2}$)	($W * cm^{-2}$)
0.4 to 1.4	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$	
0.4 to 1.4	10^{-7} to 10	$1.1\ C_A \times t^{1/4}$	
0.4 to 1.4	10 to 3×10^4		$0.2\ C_A$

C_A is defined above
Limiting Aperture Diameter: 0.35 cm

POINTS

STATE ALL ASSUMPTIONS

15 A. For a laser with the following specifications, calculate an appropriate MPE. Justify selection of exposure duration (T_{max}) used for the MPE calculation. **Show all calculations.**

Wavelength = 1.06 μm
Energy/Pulse = 1.0 J
Pulse Repetition Frequency = 0.5 Hz
Pulse Width = 25×10^{-9} s
Beam Width (Laser Exit-1/e) = 0.9 cm
Divergence = 1 mrad (1/e)
Beam is Diverging

10 B. For the laser with specifications given in (A) and an MPE of 7×10^{-6} J cm^{-2}, determine the nominal ocular hazard distance (NOHD). **Show all calculations.**

40 C. For the two continuous-wave (CW) lasers with parameters listed in the table below, determine the organs at risk for biological damage from unprotected exposure at 1) the exit port and 2) 2 kilometers (km). Justify selection of exposure duration (T_{max}) for MPE calculations. **Show all calculations.**

Laser Type	Power (Watts)	Beam Diameter (1/e)		λ (μm)	Irradiance ($W * cm^2$)		Divergence (1/e) radians
		Exit (cm)	@ 2 km (cm)		Exit	@ 2 km	
Argon	0.1	8	21	0.515	2.0×10^{-3}	2.9×10^{-4}	65×10^{-6}
GaAs	0.02	0.8	200.8	0.905	0.04	6.3×10^{-7}	1.0×10^{-3}

10 D. For the two lasers listed in Part C, what additional hazards exist from use of the lasers on this range? Assume that aircraft, equipment, or personnel are within 2 km of the lasers' exit ports and long exposure duration may be used. List only the two most important additional hazards. If the hazard is exclusive to just one of the lasers, state such. **Justify your answer. Number your responses. Only the first two will be graded.**

25 E. For the lasers of emission wavelength listed in the left column select the tissue(s) with significant energy absorption from the list in the right column. **Select only one answer per laser wavelength. Selections from the right column may be used more than once.**

Wavelength (μm)	**Tissues with Significant Energy Absorption**
1. 1.3 ______	A. Retina & Cornea
2. 5.0 ______	B. Skin & Retina
3. 0.28 ______	C. Skin & Cornea
4. 0.5 ______	D. Skin, Retina, Cornea, & Lens
5. 0.36 ______	E. Skin & Lens

QUESTION 10

You are a health physicist at a nuclear power plant. The plant is shutting down for refueling shortly. The plant manager asks you to assess some of the expected radiological conditions during the shutdown.

GIVEN

Reactor coolant system (RCS) data (average data for 90 days prior to shutdown):

• Reactor coolant volume	= 60,000 gal
• Reactor coolant ^{131}I concentration	= 0.01 μCi mL^{-1}
• Reactor coolant ^{133}Xe concentration	= 10 μCi mL^{-1}
• RCS leak rate to containment atmosphere	= 0.5 gal min^{-1}
• Reactor coolant cleanup rate	= 100 gal min^{-1}
• Reactor coolant cleanup efficiency	= 90 %
• Containment ^{131}I concentration	= 8 x 10^{-9} μCi cm^{-3}

Containment data:

• Containment free air volume	= 2 x 10^{6} ft^{3} or 6 x 10^{10} cm^{3}
• Containment atmosphere pressure reduction ventilation rate	= 2000 ft^{3} min^{-1}
• Containment atmosphere charcoal filters cleanup flow rate	= 15,000 ft^{3} min^{-1}
• Containment atmosphere charcoal filter efficiency	= 95%
• Ambient containment radiation level	= 5 mrem h^{-1}

Additional data:

• 1 gal	= 3800 cm^{3}
• Half-life of ^{131}I	= 8 d
• Half-life of ^{58}Co	= 71 d
• DAC for ^{131}I	= 2 x 10^{-8} μCi cm^{-3}
• Specific gamma-ray exposure constant for ^{58}Co, ,	= 5.5 (R cm^{2} mCi^{-1} hr^{-1})
• w_T (thyroid)	= 0.03

POINTS

STATE ALL ASSUMPTIONS

25 A. List five considerations when estimating the ^{131}I airborne concentration in containment 24 hours after shutdown. **Number your responses. Only the first five will be graded.**

20 B. Determine the committed dose equivalent (CDE) to the worker's thyroid from a 10-hour exposure to an ^{131}I containment atmosphere of 8×10^{-9} $\mu Ci\ cm^{-3}$. The worker did not use respiratory protection. **State all assumptions and show all calculations.** Also determine the worker's committed effective dose equivalent (CEDE). **State all assumptions and show all calculations.**

20 C. List four factors that should be considered in the pre-job analysis for a containment entry after shutdown in order to keep the worker's total effective dose equivalent ALARA. **Number your responses. Only the first four will be graded.**

25 D. The plant manager considers H_2O_2 treatment of the RCS. H_2O_2 will be added at Mode 5 initiation and will increase the level of soluble ^{58}Co in the RCS. The solubilized ^{58}Co is removed by the RCS demineralizers. You expect the level of ^{58}Co in the RCS to increase to 1 $\mu Ci\ ml^{-1}$ as a result.

1) State three methods for reducing the RCS ^{58}Co cleanup time. **Number your responses. Only the first three responses will be graded.**

2) State two benefits of adding H_2O_2 to the RCS at the onset of a refueling**. Number your responses. Only the first two responses will be graded.**

10 E. Given an exposure rate of 0.25 mR hr^{-1} at 2 meters away on the center line of a 2 m long pipe containing uniform concentration of ^{58}Co, calculate the total activity contained in the pipe. **State all assumptions and show all calculations.**

QUESTION 11

You are the Radiation Safety Officer (RSO) at a large fuel reprocessing facility. The facility includes a tank used to process highly enriched uranium. During a batch processing operation, a technician violates the plant's operating procedures, which leads to a critical geometry in the tank. The technician is standing behind a 30-cm thick, polyethylene shield, and is 3 meters from the center of the tank.

GIVEN

- 1.0×10^{16} fissions occur during the criticality incident
- Each fission event produces three (3) neutrons and eight (8) gamma rays
- Density of polyethylene shield is 1.5 g cm^{-3}
- Dose conversion factor for 2.5 MeV neutrons is 2.0 mrem hr^{-1} per 20 neutrons cm^{-2} sec^{-1}
- Gamma exposure rate conversion factor is 6.0×10^{5} gamma rays cm^{-2} sec^{-1} per 1 R hr^{-1}
- Mean neutron and gamma energies are 2.5 MeV and 1.0 MeV, respectively
- Neutron dose attenuation factor for 2.5 MeV neutrons through 30 cm of polyethylene is 0.005
- Mass attenuation coefficient for polyethylene for a fission gamma spectrum is 0.073 cm^{2} g^{-1}
- The dimensions of the tank are 45 cm by 45 cm
- The quality factor for 2.5 MeV neutrons is 10
- The quality factor for 1.0 MeV gamma rays is 1.0
- 0.95 rad = 1 R

POINTS

STATE ALL ASSUMPTIONS

50 A. What is the neutron dose equivalent in rem received by the technician during the criticality incident? **Show all calculations.** What is the gamma dose equivalent in rem received by the technician during the same incident? **Show all calculations.**

30 B. The facility criticality monitor is a γ-response instrument with an alarm set point of 500 mR hr^{-1}. If, during a short transient, the detector response corresponds to 1/3500 of the actual gamma exposure rate, what is the maximum distance over which the device will be effective in signaling an unshielded, 1-msec criticality incident with 1.0×10^{16} fissions? **Neglect air absorption. Assume that an incident with 1.0×10^{15} fissions results in a gamma exposure of 2.0 R at 2 meters. Show all calculations.**

20 C. List four (4) factors that affect criticality. **Number your responses. Only the first four will be graded.**

QUESTION 12

The water-cooled beam stop for the electron accelerator at your facility was designed for 0.5 to 5.0 GeV electron energies and beam currents no greater than 200 A. By design, 10% of the beam power is absorbed in the cooling water, and the rest is absorbed into the beam stop itself. Assume that the circulation rate of the water results in a well-mixed system. The entire water capacity of the system is 6000 liters. The beam energy is 2.0 GeV, and the average current is 100 A.

GIVEN

Radionuclides produced in water:

Radionuclide	Saturation Activity	Half-life	Principal Emission
^{15}O	330 GBq/kW in water	123 seconds	Positron
^{13}N	3.7 GBq/kW in water	9.96 minutes	Positron
^{11}C	15 GBq/kW in water	20.34 minutes	Positron
^{7}Be	1.5 GBq/kW in water	53.6 days	Gamma
^{3}H	7.4 GBq/kW in water	12.3 years	Beta

POINTS

STATE ALL ASSUMPTIONS

30 A. Starting with new water and assuming that only the given radionuclides are produced, what is the activity concentration in the water:

1) after 30 days of constant beam time?
2) after running for 30 days and then being shut down for 7 days?

Show all calculations.

10 B. Assume that activation varies linearly with power. If you increase the energy of the accelerator to 4.5 GeV and decrease the current to 50 microamps, by what factor would the specific activity change? **Show all calculations.**

30 C. The accelerator will be shut down for a major upgrade that will take six months to complete. You would like to reduce the radiological content of the water to as low as reasonably achievable during the upgrade. You decide that you would like to release a portion of the water each day to the sanitary sewer under an existing disposal permit. Due to limitations on the system, you cannot reduce the water volume in the cooling system to less than 90% capacity (5400 L) at any time. List six (6) factors that your would consider in planning this release. **Number your responses. Only the first six will be graded.**

30 D. You discover that 20 liters of water has leaked into the cooling water building and cooling water is still leaking. Entry into the building by personnel will be required to stop the leak and clean up the spill. State two (2) factors you would take into consideration for each of the following radiological aspects of the operation:

1) Personal Protective Equipment (PPE)
2) External Dosimetry
3) Internal Dosimetry
4) Radiation Monitoring for Dose/Exposure
5) Analysis of Samples

Number your responses. Only the first two for each item will be graded.

QUESTION 13

You are the project health physicist at an industrial site that used uranium ore in an extraction process. Several buildings and the surrounding grounds are lightly contaminated with natural U (U-nat). These buildings and the grounds must be remediated and surveyed for unrestricted release. On a small portion of Building B-7 there is a maximum reading on an alpha scintillation probe of 100 cpm with the detector in a fixed position.

GIVEN

- The surface activity derived concentration guideline level (DCGL) for U-nat is 500 dpm per 100 cm^2, assuming that no more than 10% of the activity is removable.
- The response of your alpha scintillation probe for U-nat is 20%.
- The surface area of your alpha scintillation probe is 50 cm^2.
- The surface emission abundance of alphas from a concrete block is 50%.
- The alpha scintillation probe has a background of 2 cpm.

POINTS

STATE ALL ASSUMPTIONS

10	A.	What are two (2) critical factors one must consider in evaluating equipment or property to determine whether it meets the release criteria for license termination or unrestricted release of equipment or property? **Number your responses. Only the first two will be graded.**
15	B.	Explain what a DCGL is and how is it determined. Does the predicted land use or reuse of structures affect the DCGL determination? **Justify your answer.**
35	C.	What is the activity associated with this location at Building B-7? . **Show all work**. Can you release Building B-7 without further decontamination? **Justify your answer.**
20	D.	In scanning surface soils for gross gamma activity explain four factors that must be considered in converting field instrument readings to a specific DCGL. **Number your responses. Only the first four will be graded.**
20	E.	Describe 5 pathways by which radioactivity in soil can contribute to human dose. **Number your responses. Only the first five will be graded.** What are two (2) parameters that are important to know when conducting a dose assessment? Explain why each is important. **Number your responses. Only the first two will be graded. Justify your answer.**

QUESTION 14

A molecular biologist works with ^{125}I in the form of sodium iodide. He has recently begun experiments involving the iodination of thyroid hormones and their subsequent metabolism in rats. His laboratory technicians will perform a series of three procedures over a week: iodination, animal sacrifice and tissue preparation, and low-pressure liquid chromatography (LPLC). Each procedure is performed in a separate room in the laboratory and the iodination is done in a fume hood. You place air samplers in each of the rooms and collect a sample for the duration of each procedure.

GIVEN

- Half-life of ^{125}I = 60.14 days
- Exhaust Rate in Room #3 = 15 $m^3\ min^{-1}$
- Air sample filter efficiency = 95 %
- Volume of Room #3 = 60 m^3
- CEDE per unit intake of ^{125}I = 6.53×10^{-9} Sv Bq^{-1}

Air Sampler Data

Room No.	Sampling rate (L min^{-1})	Description of Procedure	Duration of Procedure (hours)	^{125}I Filter Activity (MBq)
1	20	iodination	5	0.56
2	15	animal sacrifice	2	0.15
3	30	LPLC	6	1.76

Organ	Committed Dose Equivalent per Unit Intake (Sv Bq^{-1})
Gonad	1.84×10^{-11}
Breast	9.25×10^{-11}
Lung	1.19×10^{-10}
R Marrow	4.41×10^{-11}
B Surface	4.27×10^{-11}
Thyroid	2.16×10^{-7}
Remainder	3.33×10^{-11}

^{125}I	Occupational ALI (MBq)	Occupational DAC (MBq m^{-3})
Stochastic	4	0.002
Non-stochastic	2	0.001

POINTS

STATE ALL ASSUMPTIONS

15 A. Calculate the average airborne iodine concentration in each room. **Show all work.**

15 B. If one of the technicians was exposed to a room air concentration of 0.192 MBq m^{-3} for a three-hour procedure, have any dose limits been exceeded? **Justify your answer.**

20 C. One of the laboratory technicians is a declared pregnant worker. Three weeks after a procedure, she showed a decay-corrected intake of 0.27 MBq, with minimal deep dose equivalent. Based on this information, calculate the CDE and the CEDE and determine if the NCRP's fetal dose recommendation for the entire pregnancy was exceeded. **Justify your answer.**

20 D. List four (4) radiological controls that could be established to reduce personnel exposures during the procedures. **Number your responses. Only the first four will be graded.**

30 E. An air conditioning repairman enters Room #3 for the final 1 hour of the chromatography procedure and stays in the room for an additional 2 hrs. The repairman is an unmonitored member of the general public. How many DAC-hrs was he exposed to and did this exceed the limits for a member of the public? For this problem, assume the air concentration in Room #3 during the chromatography procedure to be 0.10 MBq m^{-3}. **Show all work**.