QUESTION 1.

The following questions concern gas-filled detectors.

GIVEN:

air density = 1.29 kg/m^3 at STP
1 torr = 1 mm Hg at 0°C

POINTS:

10 A. Consider two cylindrical gas ionization chambers, A and B. The chamber of detector A has the dimensions 0.5 cm in diameter and 5 cm in height. Detector B has the dimensions 1.0 cm in diameter and 5 cm in height. Both detectors have the same chamber wall material and thickness, fill gas and chamber pressure. If detector A shows an output current of 1.0×10^{-10} A when placed in an isotropic gamma field, what theoretical response should be given by detector B when placed in the same field? Neglect detector end effects.

1. 2.5×10^{-11} A
2. 4.0×10^{-10} A
3. 2.0×10^{-10} A
4. 5.0×10^{-11} A
5. 1.0×10^{-10} A

10 B. The gas fill pressure in detector A is 7600 torr and the detector sensitivity is 1.2×10^{-10} A h R^{-1}. What would the detector sensitivity be if the gas fill pressure was increased to 11,400 torr? **Show All Work.**

20 C. Assuming a chamber air pressure of 7600 torr, a chamber volume of 100 cm^3, and a temperature of 20°C, calculate the exposure rate in R h^{-1} for the an air-equivalent wall ion chamber if the saturated ion current is 9×10^{-14} A. **Show All Work.**

10 D. An ambient-pressure air ion chamber is calibrated at 7000 feet altitude in New Mexico at 20°C, 591.6 torr air pressure to read correctly under those conditions. What exposure will it indicate in a 100 mR/h field at sea level in the Marshall Islands at 36°C, 760.0 torr air pressure?

1. 74 mR/h
2. 82 mR/h
3. 100 mR/h
4. 122 mR/h
5. 136 mR/h

QUESTION 2.

A radionuclide has the properties shown below. It is your job as the lead health physicist to design a spherical lead shield to safely store this radionuclide.

GIVEN

Half-life:		5 h	
Radiations:	Beta	E_{max}	= 1.00 MeV
	Gamma	E	= 2.00 MeV, 100% abundance
Deep Dose Equivalent Conversion Factor		DDECF	= 11.15 rem cm^2/mCi h
Density of Lead		ρ	= 11.34 g/cm^3

Photon Mass Attenuation Coefficient (cm^2/g)

Energy	Air	Tissue	Lead
2.00	0.0445	0.0489	0.0455

Photon Point-Source Buildup Factors for Lead

Energy (MeV)	Relaxation Lengths (μx) 1	2	4	7	10	15	20
2.00	1.39	1.76	2.51	3.66	4.84	6.87	9.00

POINTS

20 A. Calculate the unshielded deep dose equivalent to a hypothetical person standing 2 meters from the source for 8 hours if the initial source activity is 150 Ci.

20 B. Assume that the unshielded deep dose equivalent is 725 rem in 8 hours. Calculate the shield thickness necessary to limit total integrated dose to a value between 75 and 100 mrem for an 8-hour exposure.

10 C. List **two** factors which should be considered when shielding beta particles from a source that emits both beta and gamma radiation. Discuss your answers. **Number your answers. Only the first 2 numbered answers will be graded.**

10 E. A small package containing TLDs (being shipped for processing) is centered among the four packages containing radioactive materials. The TLD package is positioned 50 cm from the surface of each of these packages and left in place for 6 hours. The TLD package is separated from the generator packages by cartons of styrofoam pellets. What dose equivalent do the TLDs receive? **<u>State all assumptions. Your score depends on how realistic your assumptions are.</u>**

5 F. What provision do commercial dosimetry vendors make to compensate for the transit dose described above and obtain valid dosimetry results?

10 G. If the generator package is returned to the manufacturer for disposal and recycling exactly 2 weeks after it was initially labeled, what will the TI be for the return package?

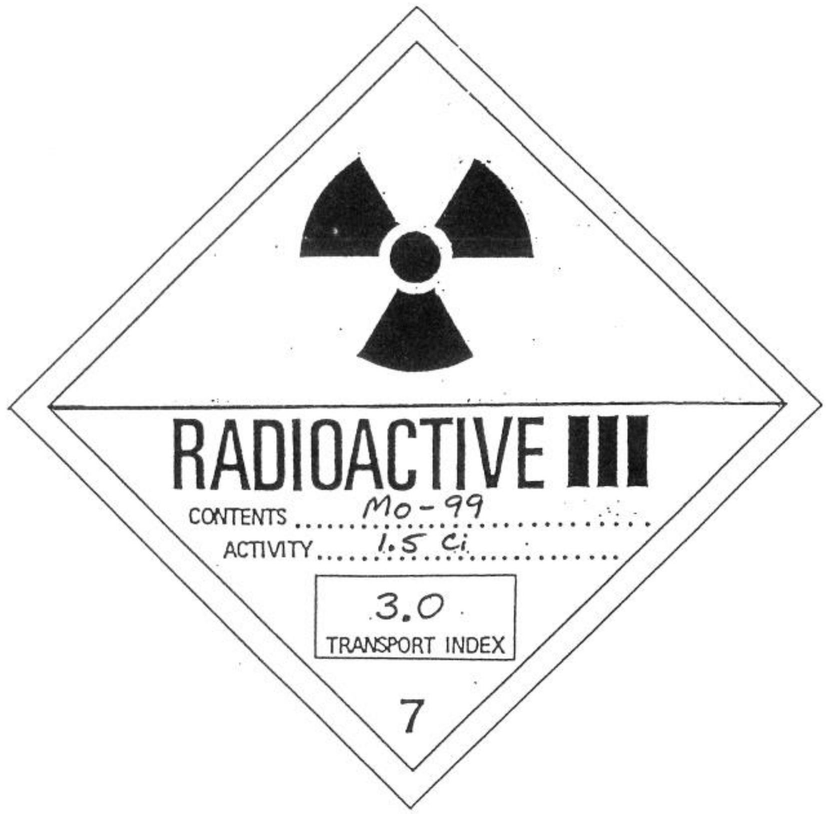
5 H. A ^{99}Mo-^{99m}Tc generator package (not the one specified previously) has a surface dose equivalent rate of 15 mrem/hr and a TI of 2.0. What label is required and why?

QUESTION 3.

GIVEN

A radiopharmaceutical firm packages its ^{99}Mo-^{99m}Tc generators within a 5 cm thick lead shield within a 60 × 60 × 60 cm carton, so that the activity is in the center of the carton. Each package bears the label shown.

The half-life of ^{99}Mo is 67 hours. The half-life of ^{99m}Tc is 6.0 hours.



POINTS:

5 A. What is the maximum dose equivalent rate at 1 meter from the surface of one of these packages? **Specify units.**

5 B. Calculate the maximum dose equivalent rate at the surface of one of these packages. **State your assumptions.**

5 C. Is the package legal for shipment on passenger aircraft in the USA? **Explain.**

5 D. A total of four (4) such packages comprise a shipment in the cargo hold of a commercial airliner. What is the Transport Index (TI) of the shipment?

QUESTION 4.

Most active, slow neutron detectors are based on nuclear reactions that result in the emission and detection of one or more charged particles, e.g. alpha, proton or fission product. More specifically, these reactions have the general form:

$$\textit{Target Nucleus} + {}^{1}_{0}n \rightarrow \begin{cases} \textit{recoil nucleus} \\ \textit{proton} \\ \alpha \textit{ particle} \\ \textit{fission fragment} \end{cases}$$

POINTS

10 A. Give **two** nuclear reaction equations that may be used in gas-filled, slow neutron detection systems. Provide the target nucleus and products and include all atomic mass and number information. Energies (Q-values) for the products are not required. **Number your responses. Only the first 2 answers will be graded.**

10 B. List **five** desirable characteristics of gas-filled, slow neutron detectors. **Number your responses. Only the first 5 answers will be graded.**

20 C. Define and discuss the phenomenon known as the "wall effect" as it pertains to active slow neutron gas-filled detection systems. Give **two** design methods by which the "wall effect" can be minimized or reduced. **Number your responses. Only the first 2 answers will be graded.**

10 D. In a 20-inch cylindrical BF_3 gas-filled detector, the microscopic cross section for thermal neutrons is 3840 barns. What is the microscopic cross section for 2.5 eV neutrons in this detector? **State all assumptions and show all work!**

QUESTION 5.

You are responsible for setting up a personnel dosimetry system using a variety of types of thermoluminescent dosimeters (TLDs). You will be providing dosimetry services for customers who need personnel monitoring devices for beta, photon and neutron dosimetry. Answer the following questions pertaining to TLD personnel dosimetry.

GIVEN

$Li_2B_4O_7$:Cu	$Z_{eff} = 7.4$
LiF	$Z_{eff} = 8.2$
$CaSO_4$:Tm	$Z_{eff} = 15.3$
CaF_2:Mn	$Z_{eff} = 16.3$
$CaSO_4$	$Z_{eff} = 15.3$

POINTS

5 A. Which of the following TLD phosphors exhibits an energy response most similar to that of tissue?

1. $CaSO_4$:Tm
2. LiF
3. $Li_2B_4O_7$:Cu
4. CaF_2:Mn
5. $CaSO_4$

20 B. You must design a TLD badge to measure shallow dose equivalent from ^{45}Ca radiation (pure β $E_{max} = 0.257$ MeV, no γ; $T_{1/2} = 163$ d). The dosimeter will consist of a single phosphor and filter. Describe the following design features that you would use in your dosimeter:

- phosphor characteristics
- phosphor thickness
- filtration type
- filtration thickness

5 C. The neutron dosimeter you are using is calibrated relative to moderated ^{252}Cf. How will this dosimeter respond to a bare ^{252}Cf source of the same fluence?

1. It will respond the **same** to bare ^{252}Cf and moderated ^{252}Cf.
2. It will **under-respond** to bare ^{252}Cf.
3. It will **over-respond** to bare ^{252}Cf.
4. Unable to determine without knowledge of filters over phosphors.
5. Unable to determine due to phosphor thickness effects.

5 D. Which of the following reactions is most commonly used for TLD monitoring of thermal neutrons?

1. $^{6}Li(n,\alpha)^{3}H$
2. $^{6}Li(n,\gamma)^{7}Li$
3. $^{19}F(n,p)^{19}O$
4. $^{40}Ca(n,\alpha)^{37}Ar$
5. $^{169}Tm(n,\gamma)^{170}Tm$

15 E. You must design a TLD badge to measure the shallow **and** deep dose equivalents from photon radiation of different energies. The badge must provide information on the quality of photon radiation in the energy range from 10 keV to 200 keV. Describe the following design features that you would use in your dosimeter and explain why you chose the design:

- phosphor characteristics
- phosphor thickness
- filtration type
- filtration thickness

QUESTION 6.

An individual was working in a room 5 ft wide, 10 ft long and 10 ft high. Powdered Thorium-232 was located in a fume hood. Suddenly the hood malfunctioned and a reverse draft blew the powder into the room. The individual was wearing a lapel air sampler which was collecting air at the rate of 2 liters min^{-1}. After the incident occurred, the individual remained in the room for approximately 1 minute. Upon realizing what had happened, he exited the room.

The lapel air sampler was activated 10 minutes prior to the incident and was turned off immediately after the individual exited the room. On previous occasions, when similar work was being done in the room with the hood operating properly, the lapel air sampler never registered any ^{232}Th.

When this filter was analyzed, it was found to contain 14 nCi of ^{232}Th.

The breathing rate of the individual is assumed to be the same as that for Reference Man under light activity conditions. **Please state all assumptions in your calculations.**

GIVEN: Reference: ICRP 26 and 30

Parameter	^{232}Th (class W)
Specific Activity (Ci/gm)	1.1E-7
Stochastic ALI (μCi)	3E-3
Non-Stochastic ALI (μCi)	1E-3 (bone surface)
DAC (μCi/ml)	5E-13

POINTS:

10 A. Assuming no ingestion, what is the committed effective dose equivalent (CEDE) received by the individual?

10 B. Compare the short term health effects expected for an individual who instantaneously receives a 300 rad whole body absorbed dose and an individual who receives a 300-rem committed effective dose equivalent from a ^{232}Th intake.

10 C. Calculate the 50-year committed dose equivalent to bone surfaces in the case of an individual with a committed effective dose equivalent of 300 rem from a ^{232}Th intake.

10 D. Assume that the individual who had the thorium intake described in the question scenario was **not** wearing a lapel sampler. No other air sampling information is available. List **two** procedures that are commonly used to estimate radionuclide intakes and discuss their applicability to this situation. **Number your responses. Only the first two numbered responses will be graded.**

10 E. In the absence of any other information concerning the exposure of an individual who instantaneously receives a 300 rad whole body absorbed dose (that is, no dosimeter and individual cannot specify duration of exposure or distance from the source), you must estimate the magnitude of the dose that he received. List **two** methods that could be used to estimate the magnitude of the dose that was received and explain your answers. **Number your responses. Only the first two numbered responses will be graded.**

QUESTION 7.

You have been hired by a large agricultural concern to evaluate a land purchase for use as grazing lands and for feed production for dairy herds. This land was previously held in fee simple, fully owned rather than leased, by several petroleum companies. As part of pre-purchase disclosures, the owners have revealed that scale and sludge from petroleum operations containing NORM (Naturally Occurring Radioactive Materials) have been spread and mixed into the soil with disk harrows.

GIVEN

The NORM is in the form of radium/strontium sulfate, is very insoluble, and tightly binds radon in the crystal structure.

It is stated in the contract that nowhere does the radium in soil exceed 10 pCi/g.

The wells on site that will be used for stock watering contain ≤5 pCi/L radium contamination.

Both beef and dairy animals will be fed 50% site-grown pasture grass and 50% site-grown dry feeds.

Transfer factors are as shown below.

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

A dairy cow consumes 60 liters of water and 50 kilograms of all kinds of feed per day.

A beef animal consumes 50 liters of water and 60 kilograms of all kinds of feed per day.

Best estimates for food consumption by a human being is
- 306 liters of dairy products per year;
- 86 kilograms of beef products per year;
- 2 liters of local well water per day.

ALIs by ingestion for radium (all compounds) are 2 μCi (bone surfaces) and 5 μCi (stochastic effects).

POINTS

75 A. For each pathway in the above scenario, calculate the maximum annual intake of radium by an individual whose sole source of dairy products and meat is the beef and dairy herds in question, and who gets all of his drinking water from the site. State and justify each assumption used, and give intermediate results.

15 B. For an individual with an average daily intake of 15 pCi of radium, compute the maximum possible committed effective dose equivalent from a year's intake.

10 C. What would be the maximum committed dose equivalent to the individual's bone surfaces from a year's intakes under the scenario in Part B?

QUESTION 8.

A new, 25 MeV electron linear accelerator is to be installed at a research facility. Because of a tight installation and operation schedule, the accelerator testing is scheduled to begin before the interior sides of the concrete walls of the room have been painted. The proposed schedule will have the accelerator in operation from 7:00 a.m. to 3:00 p.m., followed by wall painting from 4:00 p.m. to 11:00 p.m.

GIVEN:
Table I shows 3 elements of interest in this problem, their atomic weight and the concentration in the concrete walls. The density of the concrete is 2.37 g/cm^3.

TABLE I: TARGET ELEMENTS IN CONCRETE

TARGET ELEMENT	ATOMIC WEIGHT	CONCENTRATION g/cm^3
Na	22.99	0.012
K	39.10	0.008
Fe	55.85	0.018

Table II gives the thermal neutron macroscopic activation cross section for these three elements. Photonuclear reactions will produce ^{22}Na with a 2.62 year half-life, ^{38}K with a 7.7 minute half-life, and ^{56}Fe with a 2.60 year half-life. The accelerator has a thin tungsten target with a neutron yield of 0.001 neutrons per electron. The average beam current is 200 μA. The electron beam travels from South to North. The North, East and West walls are all three meters from the accelerator target, which is unshielded.

TABLE II: REACTIONS

TARGET ISOTOPE	ABUNDANCE (%)	PRODUCT	HALF-LIFE	CROSS SECTION (cm^2/g)
^{23}Na	100	^{24}Na	15.0 hr	1.39×10^{-2}
^{41}K	6.77	^{42}K	12.4 hr	1.22×10^{-3}
^{58}Fe	0.31	^{59}Fe	45.6 d	3.01×10^{-5}

POINTS:

20 A. Calculate the direct neutron fluence rate (flux) at a distance 3 meters north of the target. Assume isotropic emission of neutrons.

B. For a thermal neutron fluence rate of 2×10^7 n cm^{-2} s^{-1} at one of the concrete walls, calculate the activity of ^{24}Na in 1 cm^3 of the concrete

10 1. at saturation (assume the accelerator can be run continuously);

10 2. after 8 hours of beam on time (that is, at 3:00 p.m.); and

10 3. 8 hours later when the painters go home (that is, at 11:00 p.m.).

20 C. Calculate the ratio of saturation activities for the ^{42}K to the ^{24}Na.

10 D. Give one reason why it would be inappropriate to use a BF_3 proportional counter to measure the neutron flux at the north wall inside the accelerator room.

E. Before the painters enter the accelerator room, you survey the walls with a shielded pancake GM probe, and you find that the readings on the North, East and West walls are essentially the same. Five years later, the accelerator facility is closed because of a lack of research funding. Two weeks after the last use of the accelerator, you conduct a similar survey and find that the East and West walls are close to background, but that the North wall is still showing significant activation.

10 1. Explain why the readings for the East, West, and North walls are the same after the initial run.

10 2. Explain why the North wall shows activation on your last survey but the East and West walls do not.

QUESTION 9.

You are the Senior Health Physicist at a facility that is involved in the treatment and solidification of high-level radioactive waste that was generated from the reprocessing of reactor fuel. You receive a telephone call at home late one evening from the shift supervisor at the plant. He informs you that an hour ago it was discovered that a process line had ruptured, spilling high-level waste sludge into a process area.

Upon your arrival at the plant (30 minutes later), you are informed that a worker had entered the process area when the leak was first discovered, turned off the pump terminating the spill (100 liters had spilled), and participated in "cleaning up the mess." You instruct the shift supervisor to immediately remove the worker from the contaminated area and have him report to the decontamination and survey station.

Upon removing the worker's anti-C clothing (booties, coveralls, gloves) and lapel air sampler, it was determined that the worker had facial contamination (positive nasal swab). A quick survey of the air sample was performed, and it showed considerable beta/gamma activity. Prior to permitting the clean up activities to continue, you must assess the radiological aspects of the situation. Using the data provided, answer the following questions.

GIVEN

Major Radionuclide Components of the HLW:

Isotope	Waste Conc. (Ci/L)	Γ $\frac{R\text{-}m^2}{Ci\text{-}hr}$	DCF* (1 yr)	DCF* (50 yrs)	MPC_a** (μCi/mL)	DAC# (μCi/mL)
^{137}Cs	0.2	0.33	2.9E-2	3.2E-2	1E-8 (I)	7E-8 (D,W,Y)
^{90}Sr	10^{-2}	-	0.32	1.3	1E-9 (S)	2E-9 (Y)
^{238}Pu	10^{-3}	~0	30	310	2E-12 (S)	3E-12 (W)

* Dose conversion factor expressed as effective dose equivalent, rem per μCi inhaled, 1 μm particle size.

** 10 CFR 20, Appendix B, Column 1

\# DOE Order 5480.11, Table 1, Derived Air Concentrations (DAC) for Controlling Radiation Exposures to Workers at DOE Facilities

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Air Sampling Data:

Flow rate of lapel sampler	2 liters/min
Sampling time	90 minutes

Total "long-lived" activity on filter: (corrected for radon progeny decay)

Gross alpha	5×10^3 dpm
Gross beta	5×10^3 dpm (excludes ^{137}Cs and ^{90}Y contribution)
Gross gamma	10^5 dpm (i.e., photons per minute)

Additional Data:

Breathing rate of worker	20 liters/min.
Spill Dimensions:	Circular spill with a diameter of 5 meters

POINTS

20 A. Determine the external dose equivalent from γ rays to the worker. Assume that the worker was located at the center of the spill during the entire 90-minute exposure period and that the point of interest is 1 meter above the spill. Assume that 1 R = 1 rem for the external dose equivalent calculation. State any assumptions used in this determination.

B. The worker was wearing an operating lapel-type air sampler throughout the period of time he was in the contaminated area. You had the filter removed and analyzed immediately after you arrived on the scene. Assume all activity deposited on the filter resulted from resuspension of the spilled high level waste. Using the data previously provided:

30 1. Calculate the effective dose equivalent to the worker from radionuclide intakes that would be received *during the first year* immediately following the incident.

10 2. Calculate the committed effective dose equivalent to the worker from radionuclide intakes.

10 C. Name a currently-implemented, occupational regulatory dose equivalent limit, and state whether it has been exceeded as a result of this incident. Explain your answer and state the applicable regulatory limit (i.e., 10 CFR 20, DOE Orders, etc). Ignore considerations of any other occupational exposures independent of this incident.

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20 D. Assume you are the first person who is contacted by the Shift Supervisor. List **four** instructions that you should give to the Shift Supervisor. (5 points each. NOTE: Number your responses. Only the **first four numbered responses** will be considered for credit.)

10 E. For ^{137}Cs, the 1-year and 50-year dose conversion factors given in the table above are nearly equal, while for ^{238}Pu they differ by more than a factor of 10. Explain the characteristics of these radionuclides that lead to this difference.

1993

QUESTION 10.

POINTS:

9 A. As it applies to lasers, what does the term "stimulated emission" mean?

15 B. Name three characteristics of laser radiation that uniquely distinguish it from other radiation sources. **Number your responses. Only the first 3 numbered responses will be graded.**

20 C. All lasers and laser systems are classified in accordance with the accessible emission limits (AELs). Name each of the four ANSI classes and give a brief (general) description of the applicability of each. Specific numerical AELs do not have to be given.

16 D. Draw this table on your answer sheet. For the four laser types specified, place a Y or N in the boxes indicating whether the tissue may be significantly affected by the laser. (Blank boxes receive no credit. Do not guess. The number of wrong answers will be subtracted from the number of right answers to correct for random guessing.)

Laser Type	Wavelength (μm)	Tissue Significantly Affected			
		Skin	**Cornea**	**Lens**	**Retina**
CO_2	10.6				
Nd-YAG	1.06				
Ar	0.325				
HeNe	0.633				

E. Laser regulations:

5 1. Name the federal agency which promulgates manufacturers' performance standards for laser products.

5 2. Which title of the CFR contains this agency's regulations?

30 F. Name six controls that are specified in the ANSI standard for control of the most hazardous class of lasers. **Number your responses. Only the first 6 numbered responses will be graded.**

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QUESTION 11.

As radiation safety officer at a large medical center, you are consulted by a staff obstetrician concerning a patient who, by the physician's estimation, was one to two weeks pregnant when two abdominal x-rays were taken by the radiology department. The patient is very concerned about the effect this radiation will have on her unborn child. The obstetrician would like you to estimate the dose and direct him to the radiation protection literature on the subject.

GIVEN:

You have the following data on exposure versus added aluminum at 80 kVp, 1 mAs, 50 cm for the x-ray tube used for the abdominal study:

Added Al (mm)	Exposure (mR)
0	40.0
2	23.0
3	17.4

You have the following information from NCRP Report No. 54 for abdominal x-rays using a 14 × 17- inch film/screen and a 100 cm source-to-image receptor distance:

Embryo (Uterine) Dose per Unit Exposure at Skin Surface (mrad/R)				
	Beam Quality (HVL, mm Al)			
View	1.5	2.0	2.5	3.0
AP	133	199	265	330
PA	56	90	130	174
LAT	13	23	37	53

An AP and a PA abdominal film were taken. The patient is 26 cm thick, and there was a 2 cm gap between the patient and the film. The technique used for each film was 80 kVp, 100 cm source to image receptor distance, 200 mA, and 300 ms.

POINTS:

20 A. Calculate the half-value layer for the x-ray tube at 80 kVp.

20 B. Calculate the entrance skin exposure for either of the x-rays.

20 C. Estimate the total absorbed dose to the embryo from the x-rays.

10 D. Are the embryo absorbed doses for the PA and AP projections the same? If not, explain why.

E. Based on human data, for absorbed doses to the embryo/fetus in the 0-20 rad range, name one health effect that might be caused by irradiation

10 (i) 0 to 2 weeks after conception; and

10 (ii) 10 weeks after conception.

10 F. What is the position of the NCRP (as stated in Report Number 54) regarding therapeutic abortion following radiation exposure?

QUESTION 12.

A fission gas hold-up tank at a nuclear power plant is accidentally breached during a maintenance operation and a constant small release of gas occurs into the surrounding room. The leak is discovered three days later, the room flushed and the leak repaired. As a professional on the health physics staff, you are asked to evaluate the calculated airborne concentration of ^{85}Kr in the room (the only significant fission gas in the tank) as a function of time.

You are able to gather the following information to assist in your evaluation.

- The tank is spherical with an inner radius of 50 cm and made of iron with a wall thickness of 1.0 cm.
- The contained gas held 150 Ci of ^{85}Kr at a total gas pressure of 2 atm.
- The measured leak rate at the time of repair was found to be 0.1 cm^3/min at STP (it is acceptable to assume that the leak rate was constant over time)
- The room dimensions are 10 ft $\times$ 10 ft $\times$ 8 ft and the only air exchange occurs through leakage around the door, estimated to be only 100 ft^3 per hour.
- The exposed maintenance worker entered the room four hours after the leak started and spent a total time of 10 minutes in the room. (You may assume that the airborne concentration of radioactivity was constant during his time in the room).

It is acceptable to assume that the released radioactivity is always mixed uniformly with the room air so that the air leaking from the room always contains the average concentration of radioactivity at any given time.

GIVEN

The mass attenuation coefficient (μ/ρ) for 0.517 MeV gamma rays in iron is 0.09 cm^2 g^{-1}.

The density of air is 0.00129 g cm^{-3} and the density of iron is 7.86 g cm^{-3}.

Krypton-85 has a decay half-life of 10.3 y and emits a β particle with average energy of 0.25 MeV in 100% of the disintegrations and a 0.517 MeV γ-ray in 0.7% of the disintegrations.

1 MeV = 1.6×10^{-6} erg = 1.6×10^{-13} J.

You may assume that a gamma ray buildup factor is adequately approximated by $B = (1 + \mu x)$.

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POINTS

25 A. What was the maximum concentration of ^{85}Kr (μCi/cm^3) in the room?

10 B. What was the ^{85}Kr air concentration when the worker entered the room four hours after the leak began?

25 C. Calculate the absorbed dose to the maintenance worker's uncovered skin during the 10 minutes he was in the room. State **two** assumptions and show all work.

20 D. Assuming the ^{85}Kr can be considered to be a point source in the center of the tank for dose estimates and that the worker stood five feet (5 ft.) from the surface of the tank, what deep dose equivalent from gamma rays did he receive? (You may assume that all gamma dose equivalent comes from the gas retained in the tank).

10 E. The range-energy relationship for β particles may be approximated by

$$R\,(\text{mg/cm}^2) = 412\ E_{max}^{1.265 - 0.0954 \times \ln E_{max}}$$

where E_{max} is the maximum β energy in MeV.

Will exposure to ^{85}Kr gas result in a significant dose equivalent to the lens of the eye? **Justify your answer.**

10 F. Discuss the significance of the internal dose equivalent from exposure to ^{85}K gas relative to the resulting skin dose.

QUESTION 13.

After changing a powder diffraction sample on an x-ray diffraction machine, the operator noticed that the mechanical "shutter open" indicator was visible. The operator had pressed the electrical switch to close the shutter before changing the sample and the "shutter open" indicator light had gone out. Investigation revealed that, when the operator pushed the "shutter close" switch, the shutter was blocked open by a loose screw, which also gave the electrical interlock circuit a false "shutter close" indication. The reenactment of the accident showed that the operator's left thumb and first finger were in the primary x-ray beam for about 5 seconds, while the sample was being changed. The beryllium-window x-ray tube with a copper target was operating at 40 kVp and 15 mA. Measurements in the primary beam at the sample holder, which was 15 cm from the focal spot, gave an exposure rate of 5000 R/min with an effective energy of 8 keV as determined by half-value layer measurements in aluminum. The diameter of the beam at the sample holder was determined to be 3.0 cm.

GIVEN:

Material	Atomic Number	Atomic Weight	Density g/cm^3	Mass Attenuation Coefficient cm^2/g @8 keV	Mass Energy Absorption Coefficient cm^2/g @8 keV
Air			0.00129	9.60	9.12
Water		18.00	1.00	9.99	9.50
Tissue			1.00	10.1	9.61
Hydrogen	1	1.00	8.99E-5	0.395	0.015
Carbon	6	12.01	3.51	4.39	4.04
Oxygen	8	16.00	0.00143	11.2	10.7
Aluminum	13	26.98	2.70	50.0	48.8
Chlorine	17	35.45	3.21	110	103
Lucite, $(C_5O_2H_8)_n$			0.96		
PVC, $(C_2H_3Cl)_n$			1.29		

The f-factor @ 8 keV is 0.905 rad/R for water and 0.916 rad/R for tissue.

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POINTS:

30 A. Assuming a depth to the basal layer of the skin of 7 mg/cm^2, calculate the absorbed dose to the skin of the finger and thumb that were exposed to the primary beam.

20 B. At low angles with the radiation detector removed it is possible for a person standing beside the machine to be exposed to the primary beam. What would the exposure rate in the primary beam be at this point, which is 40 cm from the sample holder?

20 C. What thickness of PVC sheet would be required to reduce the intensity of the primary beam by a factor of 10^4? Is it necessary to consider buildup for this case and why?

10 D. From inspection of the absorption coefficients in the table, which would be a better shielding material for a cabinet around this x-ray diffraction unit: poly methyl methacrylate ("Lucite") or polyvinyl chloride (PVC)? Justify your answer.

20 E. What would be the absorbed dose to the lens of eye from scatter radiation from the sample holder while the sample was being changed? Assume that the depth of the lens is 300 mg/cm^2, the quality of the scatter radiation is the same as the primary beam, and the ratio of scatter to primary radiation for a 1 cm^2 beam at the target is approximately 10^{-6} at 1 meter in air. The exposure time for the eye is 1 minute and the eye is 30 cm from the sample holder.