

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

### **QUESTION 1**

**GIVEN:** A hot particle is removed from an individual, the contact dose rate is measured with an open window ionization chamber, and then it is subjected to gamma spectroscopy with a germanium detector:

Volume of ion chamber = 220 cm<sup>3</sup>.

Window thickness = 7 mg cm<sup>-2</sup>.

Beta shield: 1000 mg cm<sup>-2</sup>.

Chamber calibrated using a gamma-only source.

Gamma pulse height distribution shown.

### **SOLUTIONS AND ANSWERS(C) TO PARTS A THROUGH D:**

- A. The skin area and tissue depth generally assumed for estimating the skin dose are 1 cm<sup>2</sup> and 7 mg cm<sup>-2</sup> respectively.
- B. Three reasons why the dose measured by an ion chamber may not be the “true” skin dose are:
1. In measuring the dose, the source-chamber geometry is commonly such that the chamber volume is not irradiated uniformly.
  2. Depending on chamber design characteristics, e.g., the presence of a central planar electrode as in the Eberline RO-2, and whether all beta radiation enters through the window, beta radiation attenuation may be a problem. For a distributed source, for example, some beta radiation incident on the thick wall of the chamber may be highly attenuated.
  3. The conversion of beta instrument response to tissue dose often requires different conversion factors than are implicit in gamma exposure to tissue dose conversion - e.g., mass collision stopping power ratios vs. mass energy absorption coefficient ratios.
- C. Given that Co-60 was the major radionuclide present, the most likely origin of each of the seven peaks in the given figure is summarized as follows:
1. The 1.17 MeV and 1.33 MeV peaks are the full energy photopeaks or more correctly the *total absorption peaks* (TAP), one for each of the two primary, cascade gamma rays of these energies from de-excitation of the Ni-60 nucleus, the beta decay product of Co-60.
  2. The 2.50 MeV peak is a sum peak resulting from full energy deposition of both of the above cascade gamma rays within the resolving time of the germanium detector.
  3. The 0.819 MeV peak is a single escape peak resulting from escape of one of the 511 keV photons

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

following annihilation of a positron with a conventional electron after the 1.33 MeV photon interacts by a pair production event in the detector. All of the remaining energy is then deposited, i.e.,  $(1.33 \text{ MeV} - 0.511 \text{ MeV}) = 0.819 \text{ MeV}$ .

4. The 0.659 MeV peak also is a single escape peak, as in 3 above, but the pair production interaction is that of the 1.17 MeV gamma photon.
5. The 0.511 MeV peak is likely from the full energy deposition of a 511 keV annihilation photon that originated from positron annihilation outside of the detector volume, e.g., in the sample or detector casing and shield, following a pair production event of either of the primary photons.
6. The 0.308 MeV peak is likely the double escape peak from escape of both of the 511 keV annihilation photons following positron annihilation after a pair production interaction of a 1.33 MeV gamma ray in the detector volume.

**Comment:** It is obvious that the *pulse height distribution* (PHD) shown in the given figure is somewhat artificial, and the secondary peaks arising from multiple interactions may or may not be obvious in a real PHD from the two primary photons associated with the decay of Co-60. The pair production interaction cross section is zero below the threshold photon energy of 1.022 MeV; so the probability for pair production interactions of the 1.17 MeV and 1.33 MeV primary photons within the Ge detector is relatively small at these energies. Unless sufficient counts occur in the peaks associated with these multiple interaction events, especially those following pair production interactions of the 1.17 MeV and 1.33 MeV primary photons in the Ge detector, the secondary escape peaks may not be obvious.

D. Three followup actions to take in the area after discovery of the hot particle include:

1. Monitor other individuals who have been working in the area for hot particle contamination.
2. Identify and isolate, if possible, the source of the hot particles.
3. Minimize the spread of hot particles by proper cleanup of affected surfaces, e.g., use sticky tape rollers to clean up small to moderate sized areas and other methods, such as wetting of surfaces, to minimize potential for airborne suspension of hot particles.

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

### **QUESTION 2**

**GIVEN:** Questions related to radiobiology.

#### **SOLUTIONS AND ANSWERS(C) TO PARTS A THROUGH E:**

- A. Radiation can damage a critical target in a cell by *direct action* and by *indirect action*:
1. If the deposition of energy by radiation, usually by ionization, causes immediate damage to a critical target, such as an enzyme or nucleic acid, in or near the path of the radiation, then it is considered direct action.
  2. If the damage of the critical target is caused by a reaction with a chemical byproduct of the radiation interaction, such as a free radical or peroxide molecule, it is considered indirect action. As the linear energy transfer (LET) of the radiation increases, the contribution from indirect action decreases, e.g., due to recombination of free radicals that are in close proximity, and the direct action becomes the dominant mechanism of radiation caused damage.
- B. Three general types of biological effects of ionizing radiation that are taken into consideration in the derivation of dose limits for radiation workers are:
1. stochastic, somatic effects such as cancer in the exposed individual;
  2. non-stochastic (deterministic), somatic effects resulting in the impairment of the function of organs and tissues when certain threshold doses are exceeded in the exposed individual.
  3. genetic effects in the progeny of the exposed individual.
- C. Five deterministic effects resulting from exposure to acute, high dose rate ionizing radiation include:
1. cataracts, 2. epilation, 3. skin erythema, 4. purpura, and 5. desquamation.
- D. For low LET radiation, the RBE increases with increasing LET up to a maximum at an LET value of about 100 keV/: m.
- E. For the following radiations, the RBE increases from 1 for low to three for high:
1. for 20 keV x-rays, 2. for 5 MeV protons, and 3. for fission-spectrum neutrons.

**Comment:** RBE is defined for a specific biological endpoint and the answers to parts D and E depend on the chosen endpoint as well as on dose and dose rate. The answers provided above for parts D and E are for biological endpoints of cell lethality, cell mutation, and oncogenic transformation based on the irradiation of monolayers of mammalian cells at low dose rates as described in the National Academy of Sciences BEIR V report.

## SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM

### QUESTION 3

**GIVEN:** leakage of hot liquid  $^{131}\text{I}$  waste from a valve in a line into a ventilated room where the released  $^{131}\text{I}$  immediately evaporates and disperses uniformly in the room air:

- C<sub>L</sub>** /  $^{131}\text{I}$  liquid concentration in line = **50 : Ci L<sup>-1</sup>**;
- V** / room air volume = **18 m<sup>3</sup>**;
- Q** / ventilation flow rate = **5 m<sup>3</sup> min<sup>-1</sup>**; so
- K** / **Q/V** / “air turn over rate” and  $^{131}\text{I}$  ventilation removal rate constant = **0.278 min<sup>-1</sup>**;
- L** / liquid drop leakage rate = **10 drops min<sup>-1</sup>**;
- V<sub>d</sub>** / drop volume = 0.05 mL drop<sup>-1</sup> = **0.00005 L drop<sup>-1</sup>**; so
- G** /  $^{131}\text{I}$  activity release rate into room air = **C<sub>L</sub> L V<sub>d</sub> = 0.0250 : Ci min<sup>-1</sup>**;
- T** / estimated exposure time interval for mechanic = **1 h**;
- DAC** / non-stochastic (thyroid)  $^{131}\text{I}$  derived air concentration = **0.02 : Ci m<sup>-3</sup>**;
- T<sub>1/2</sub>** /  $^{131}\text{I}$  physical half-life = 8.05 d = **11,600 min**; so
- λ** /  $^{131}\text{I}$  decay constant =  $(\ln 2)/(T_{1/2}) = 5.98 \times 10^{-5} \text{ min}^{-1}$ ; so
- k** /  $^{131}\text{I}$  total removal rate constant = **K + λ = K + 8 = Q/V = 0.278 min<sup>-1</sup>**;
- w<sub>T</sub>** / thyroid stochastic risk weighting factor = **0.03**; and

given equation for  $^{131}\text{I}$  airborne concentration **C** as function of time **t** post onset of release (Note: It is recognized for this equation to apply that radioactive decay can be neglected compared to ventilation removal of  $^{131}\text{I}$  from the room, i.e. **λ**  $\ll$  **K**. For the units shown by the bolded quantities above, **C** has the units of **: Ci m<sup>-3</sup>** and **t** has the units of **minutes**).

### SOLUTIONS AND ANSWERS(C) TO PARTS A THROUGH E:

A. The  $^{131}\text{I}$  activity release rate **G** into room air is calculated as shown in the list of given data:

$$\text{C } G = C_L L V_d = \mathbf{0.0250 : Ci min^{-1}}.$$

The maximum concentration **C<sub>max</sub>** of  $^{131}\text{I}$  is calculated from the given equation for **t = 4**:

$$\text{C } C_{\max} = G/Q = (0.0250 : Ci min^{-1})/(5 m^3 min^{-1}) = \mathbf{0.005 : Ci m^{-3}}.$$

B. The “air turn over rate”, **Q/V**, or ventilation removal rate constant, **K**, is calculated as shown in the list of given data:

$$\text{C } K / Q/V = \mathbf{0.278 min^{-1}}.$$

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

C. For a ventilation removal rate constant **K** of **0.1 min<sup>-1</sup>** (assumed also to approximate the total removal rate constant: **k = K + 8 = 0.1 min<sup>-1</sup>**), the time **J** for the <sup>131</sup>I concentration **C(J)** to be reduced to 1% or a fraction **f** of **0.01** of its initial value **C(0)** after the leak has been stopped is calculated:

C  $J = (1/k) \ln[ C(0)/C(J) ] = (1/k) \ln[ 1/f ] = 46.1 \text{ minutes.}$

D. For a constant airborne concentration **C** of **0.008 : Ci m<sup>-3</sup>** and an exposure time **T** of **1 h**, the mechanic's CEDE is estimated:

C 
$$\text{CEDE} = \left( \frac{C T}{\text{DAC}} \right) \left( \frac{50 \text{ rem}}{2000 \text{ DAC h}} \right)^{w_T} \text{ or}$$

$$\text{CEDE} = \left( \frac{(0.008 \text{ } \mu\text{Ci m}^{-3})(1 \text{ h})}{0.02 \text{ } \mu\text{Ci m}^{-3} \text{ DAC}^{-1}} \right) \left( \frac{50 \text{ rem}}{2000 \text{ DAC h}} \right) (0.03) = 0.0003 \text{ rem} = 0.3 \text{ mrem.}$$

E. Two actions that need to be taken prior to allowing the mechanic to enter the room include:

1. Obtain an air sample near the release point from the valve and in the ambient air and analyze them to verify the calculated concentrations of <sup>131</sup>I and the worker's anticipated exposure.
2. Obtain external gamma radiation measurements in the room and in the vicinity of the leaking valve to estimate the worker's anticipated external gamma radiation exposure.

## SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM

### QUESTION 4

**GIVEN:** decommissioning of a hot cell used to manufacture  $^{90}\text{Sr}$  thermoelectric generators, worker airborne exposures, air sampling data, urinalysis data, and ICRP Publication 30 models:

- S-ALI<sub>D</sub>** / stochastic inhalation ALI for Class D  $^{90}\text{Sr}$  nitrate = **20 : Ci**;  
**ALI<sub>D</sub>** / non-stochastic ALI for Class D  $^{90}\text{Sr}$  nitrate = **20 : Ci**;  
**S-ALI<sub>Y</sub>** / stochastic inhalation ALI for Class Y  $^{90}\text{Sr}$  titanate = **4 : Ci**;  
**E** / filter paper counting efficiency for GM probe = 25% = **0.25 c per decay of  $^{90}\text{Sr}$** ;  
**F** / flow rate of “high volume air sampler” = **4.0 L min<sup>-1</sup>**;  
**B** / Reference Man’s breathing rate = **20 L min<sup>-1</sup>**;  
**IRF** / fraction of an acute inhalation intake of Class D  $^{90}\text{Sr}$  expected to be present in a 24 h urine void beginning directly after the intake = **0.0857**.

**Comments:** Because the basis for the given 25% counting efficiency **E** is unclear, it is assumed that it represents **0.25 c per decay of  $^{90}\text{Sr}$** , which is assumed to account for all factors including the fact that 64 h half-life  $^{90}\text{Y}$ , the short lived decay product of 28.1 y half-life  $^{90}\text{Sr}$ , is expected to be present on the filter and to contribute as many or more counts than  $^{90}\text{Sr}$  itself. The given sampling flow rate **F** of **4.0 L min<sup>-1</sup>** would not ordinarily be considered as that for a *high volume air sampler* (HVAS) but rather that for a *personal air sampler* (PAS). A HVAS has a sampling flow rate that is typically 10 to 300 times higher than the given value. The given value shown for the S-ALI<sub>Y</sub> is also the ALI<sub>Y</sub> of **4 : Ci** because the stochastic limit is controlling for class Y  $^{90}\text{Sr}$  titanate.

### SOLUTIONS AND ANSWERS(C) TO PARTS A THROUGH D:

- A. Two qualitative measures to see if an individual had an airborne exposure to  $^{90}\text{Sr}$  include: 1. analysis of nose wipes for  $^{90}\text{Sr}/^{90}\text{Y}$ , and 2. detection of beta radiation with a GM pancake probe of contamination present on the face and/or nares.

Three quantitative analyses to estimate exposure include first the estimation of the intake **I** by dividing the following measurements **q** by their applicable *intake retention fraction* (**IRF**): 1. the activity **q** estimated to be present on the filter of a worker’s *personal air sampler* (PAS), whose IRF for a PAS filter with a 100% retention is estimated from the quotient of the PAS flow rate by Reference Man’s breathing rate **B**, 2. the activity **q** estimated to be present in a 24 h urine sample, and 3. the activity **q** estimated to be present in a 24 h fecal sample. The exposure in DAC-h is then estimated by the relationship: Exposure = (I)(2000 DAC-h)/(ALI).

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

- B. Based on stated assumptions in the question, the given class D **IRF** of **0.0857**, and the **S-ALI<sub>D</sub>** of **20 : Ci**, the *committed effective dose equivalent* (**CEDE**) is calculated for a measurement **q** of **2.62 : Ci** of <sup>90</sup>Sr in a 24 h urine sample taken immediately after the exposure to strontium nitrate:

$$C \quad CEDE = \left( \frac{q}{IRF} \right) \left( \frac{5 \text{ rem}}{S \text{ ALI}_D} \right) = 7.64 \text{ rem.}$$

Two reasons why such a dose estimate would not be accurate include: 1. uncertainties associated with biokinetic parameter values needed to calculate the IRF value, especially within the first 24 hours after an acute inhalation intake, and 2. uncertainties associated with the actual physical and chemical forms of inhaled aerosols, which influence the inhalation, deposition, and clearance from respiratory tract compartments, the actual IRF value for a 24 h urine sample, and the appropriate S-ALI.

- C. The concentration **C** in **DAC** units is calculated for a filter having a counting rate **R** of **1,000 cpm** observed on the GM instrument for a high volume air sample in the isolation room over a sampling interval **T** of 5 minutes or **(5/60) hours** when (1) **R** is assumed to be approximately the net rate for a filter with 100% retention, (2) other given data are assumed to apply to class D <sup>90</sup>Sr nitrate, and (3) the concentration **C** is assumed to be constant before and after the release:

$$C \quad C = \left( \frac{R}{E} \right) \left( \frac{1 \mu Ci}{2.22 \times 10^6 \text{ dpm}} \right) \left( \frac{B}{F} \right) \left( \frac{2000 \text{ DAC h}}{ALI_D} \right) \left( \frac{1}{T} \right) = 10.8 \text{ DAC.}$$

For workers wearing respiratory protection having a protection factor or **PF** of **50**, the effective exposure concentration would be about 20% of the DAC. If the concentration is not likely to change then they should be allowed to continue work that might be needed to secure the <sup>90</sup>Sr source and to terminate leakage assumed to have occurred from the hot cell.

- D. If class Y <sup>90</sup>Sr titanate were assumed for the other data in part C, then the calculated concentration **C** in DAC units would be five times higher or **54.0 DAC** because its **ALI<sub>Y</sub>** of **4 : Ci** is one fifth of the **ALI<sub>D</sub>** of **20 : Ci** used in part C. Thus, the concentration in DAC units, the exposure in DAC-h, and the internal dose estimate for the data in part C all would be increased by a factor of five. The given PF of 50 for respiratory protection then would not control the concentration below the DAC. However, work could still take place provided the projected total exposures are adequately controlled and the *total effective dose equivalent* (TEDE) from external and internal sources is maintained ALARA.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 5**

**GIVEN:** Evaluation of potential dose rates from a cobalt sample coupon and systems scheduled for maintenance at a nuclear power plant:

- m** # mass of 1 cm x 3 cm x 0.2 cm sample coupon (100% <sup>59</sup>Co initially) = **5 g**; so
- N** # atoms of <sup>59</sup>Co in sample coupon = (m/59)(6.023x10<sup>23</sup>) = **5.10x10<sup>22</sup> at**;
- :** # <sup>59</sup>Co(n,fl)<sup>60</sup>Co thermal neutron activation cross section = 37 barns = **3.7x10<sup>-23</sup> cm<sup>2</sup> at<sup>-1</sup>**;
- B** # thermal neutron fluence rate in reactor and assumed for sample = **1x10<sup>10</sup> n cm<sup>-2</sup> s<sup>-1</sup>**;
- ,** # <sup>60</sup>Co decay constant = (ln2)/(5.27 y) = **0.132 y<sup>-1</sup>**; and
- fi** # <sup>60</sup>Co gamma constant = **1.3 R m<sup>2</sup> Ci<sup>-1</sup> h<sup>-1</sup>**.

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH C:**

A. The current <sup>60</sup>Co activity **A(τ)** of the sample coupon is calculated at a time **τ** of 9 months or **0.750 y** after removal from the reactor and a neutron activation time **t** of **22 y** assumed for the stated “22 effective full power years” based on other assumptions including: there is no significant neutron burn-up of <sup>59</sup>Co and <sup>60</sup>Co during the irradiation time **t**; the stated value of **B** is the average fluence rate in the sample coupon; and no significant other activity is induced by fast neutrons and other reactions:

$$7 \quad A(\tau) = \sigma \phi N (1 - e^{-\lambda t}) e^{-\lambda \tau} = 1.62 \times 10^{10} \text{ Bq} = 0.437 \text{ Ci}.$$

B. The exposure rate **X** is calculated at a distance **r** of **3 m** from a coupon having an activity **A** of **0.75 Ci** based on the assumptions that the coupon can be considered as a point source and that attenuation of gamma photons in the sample coupon and air can be neglected:

$$7 \quad \dot{X} = \frac{A \Gamma}{r^2} = \frac{(0.75)(1.3)}{3^2} \text{ R h}^{-1} = 0.108 \text{ R h}^{-1}.$$

C. The exposure rate **X(d)** is calculated at a perpendicular distance **d** of **2.5 m** from the midpoint of a sample line having a diameter of 0.5 cm and length **L** of **10 m** and an activity **A** of **4 Ci** of <sup>60</sup>Co based on the stated assumptions as well as the assumptions that (1) the sample line can be considered as a line source; (2) attenuation of gamma photons in the sample line and air can be neglected; (3) the specific activity **C<sub>L</sub>** of **0.4 Ci m<sup>-1</sup>** calculated from the quotient **A/L** applies to the line source; and (4) the angle **θ** of **2.21 radians** that the line subtends at the exposure point is calculated from  $2 \tan^{-1}(5/2.5)$ , and it represents the sum of the angles **θ<sub>1</sub>** and **θ<sub>2</sub>** in the line source equation shown in the attached “Useful Equations and Constants” given to candidates:

$$7 \quad \dot{X} = \frac{\Gamma C_L \theta}{d} = \frac{(1.3)(0.4)(2.21)}{2.5} \text{ R h}^{-1} = 0.460 \text{ R h}^{-1}.$$

## **SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

### **QUESTION 6**

**GIVEN:** bioassay and other data for an inhalation intake of  $^{131}\text{I}$ ; thyroid activities  $q(t)$  in **kBq** and applicable thyroid **IRF** values versus time  $t$  in **days** post an inhalation intake; and the following:

- $\langle H_T/I \rangle$  # intake to dose conversion factor for thyroid =  $2.9 \times 10^{-7} \text{ Sv Bq}^{-1}$ ;  
 $w_T$  # thyroid stochastic risk dose weighting factor = **0.03**; and  
 $T_e$  # effective half-life describing the reduction of the thyroid burden  $q(t)$  after about 24 hours to 48 hours and corresponding to about 25% of the deposition = 7 days.

**Comment:** The given 25% trapped in the thyroid is incorrectly described to be “excreted with an effective half-life of 7 days” when in fact this quoted effective half-life includes both radioactive and biological removal processes. Most removal from the thyroid is dominated by radioactive decay, which corresponds to the physical half-life of 8.05 days. The biological half-life describing excretion of iodine from the thyroid is much longer, about 80 days or about 130 days when redeposition of recycled, metabolized inorganic iodine is considered.

### **SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH D:**

A. A 24 h urinalysis sampling protocol is the preferred *in vitro* bioassay procedure for several consecutive days post the intake, and thyroid counting is the preferred *in vivo* bioassay procedure over each day until the measurements decrease with a constant effective half-life  $T_e$  corresponding to removal by biological processes and radioactive decay. Thyroid counting is the optimal monitoring procedure for this case for the following reasons.

Two advantages for the *in vivo* thyroid counting procedure include: (1) the repetitive thyroid measurements  $q$  can be directly related to the accumulated thyroid activity and thyroid dose, which is the only significant internal dose in this case and (2) the total intake,  $I$ , can be simply estimated from the quotient,  $(\sum q)/(IRF)$ , of the sum of the individual thyroid measurements  $q$  uncorrected back to the time of the intake and the sum of the applicable IRF values corrected for radioactive decay to the time of the thyroid measurement  $q$ . This intake relationship applies to the ratio of the means intake equation. Two disadvantages for the *in vivo* thyroid counting procedure include: (1) it requires the presence of the worker during each thyroid count, and (2) care must be used to assure that the measurements reflect only the thyroid burden and not external contamination nor the burden of  $^{131}\text{I}$  in the respiratory and GI tracts, especially at early times after an acute intake.

Two advantages for the *in vitro* urinalysis procedure include: (1) the exposed person need not be present during the analysis of the 24 h samples, and (2) the total activity  $\sum q$  of consecutive 24 hour urine samples over the first several days, assumed to be corrected back to the time of the intake, represents about 75% of the deposition in the body and about  $(0.63)(75\%)$  or about 47% of the intake  $I$  for 1 . m AMAD aerosols, which is then simply estimated from the quotient:  $I = (\sum q)/(0.47)$  (Note: For the case of airborne  $^{131}\text{I}$  generated from processing  $^{131}\text{I}$  tagged NaI solutions in the premise of this question, the airborne iodine

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

is most often in the form of a diatomic vapor in which the respiratory tract deposition fraction is 1 compared to 0.63 for 1 . m AMAD aerosols. The applicable IRF value for stable iodine then would be 0.75. This same note applies to part B below.). Two disadvantages for the *in vitro* urinalysis procedure include: (1) it requires the cooperation of the worker to submit all urine during each 24 h void, and (2) it represents only the excretion and not necessarily the thyroid burden, especially if a thyroid blocking agent such as KI has been used to block the uptake of <sup>131</sup>I by the thyroid.

- B. Given the metabolic model for iodine and as time goes on, thyroid counting alone would be the preferred bioassay procedure because the measurements  $q$  directly reflect only the thyroid burden of <sup>131</sup>I (See answer to part A above.), which would be decreasing with an approximately constant effective half-life  $T_e$  of about 7 days corresponding to an effective removal rate constant  $k$  of  $(\ln 2)/(7 \text{ days})$  or **0.0990 day<sup>-1</sup>**. The actual value of  $k$  could be determined from repetitive thyroid measurements. The intake  $I$  then could be estimated from the quotient,  $q/IRF$ , of any single thyroid measurement  $q$  and the applicable IRF value, which could be estimated at the time  $t$  post intake:  $IRF = F_d F_T e^{-kt}$ , where  $F_d$  is the fraction of inhaled <sup>131</sup>I aerosols deposited in the respiratory tract and  $F_T$  is the fraction of <sup>131</sup>I in the blood that is deposited in the thyroid and which have values of about 0.63 and 0.3 respectively for 1 . m AMAD aerosols and 1 and 0.3 for molecular iodine vapors. The intake,  $I$ , also could be estimated from the sum of all repetitive measurements  $q_i$  from the relationship:  $I = (\sum q_i)/(\sum IRF_i)$  or by  $I = (\sum q_i)/(F_d F_T e^{-kt_i})$ .
- C. The subject's intake,  $I$ , is estimated from the given thyroid measurements  $q$  and respective IRF values shown in the table:

$$7 \quad I = \frac{\sum_{i=1}^{i=3} q_i}{\sum_{i=1}^{i=3} IRF_i} = \frac{(250 + 230 + 130) \text{ kBq}}{(0.133 + 0.0995 + 0.0751)} = 1,980 \text{ kBq} = 1.98 \text{ MBq}.$$

- D. Based upon stated assumptions, other given data, and an intake  $I$  of 5 MBq or **5x10<sup>6</sup> Bq**, the CDE to the thyroid and the CEDE are calculated:

$$7 \quad CDE = I \left\langle \frac{H_T}{I} \right\rangle = (5 \times 10^6 \text{ Bq})(2.9 \times 10^{-7} \text{ Sv Bq}^{-1}) = 1.45 \text{ Sv} = 145 \text{ rem, and}$$

$$7 \quad CEDE = (CDE) w_T = (145 \text{ rem})(0.03) = 4.35 \text{ rem};$$

therefore, the 50 rem limit in the DOE and NRC regulations for any organ or tissue from internal and external exposures in any control year of practice has been exceeded.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 7**

**GIVEN:** A  $^{99m}\text{Tc}$  spill at a university vivarium with:

**S** # area of spill = **0.25 m<sup>2</sup>**;

**A(0)** # initial activity of spill = **5 mCi**;

**$\lambda$**  # decay constant for  $^{99m}\text{Tc}$  = **0.115 h<sup>-1</sup>**;

**fi** # specific gamma constant for  $^{99m}\text{Tc}$  = 0.06 R m<sup>2</sup> h<sup>-1</sup> Ci<sup>-1</sup> = **60 mR m<sup>2</sup> h<sup>-1</sup> Ci<sup>-1</sup>**;

**r** # distance from spill = **1 m**; and

stated license contamination limits for the free release of areas.

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH E:**

A. The pancake Geiger-Mueller instrument used by the technician to measure the exposure rate is not suitable for this application because:

1. The window is not air equivalent and does not offer an equilibrium thickness for the energies of the primary and secondary photons being measured.
2. It must be calibrated for the specific  $^{99m}\text{Tc}$  source and geometry because the window allows the penetration of non-photon radiations, including secondary electrons produced by the interaction of  $^{99m}\text{Tc}$  gamma photons in the 1 m of air between the source and window, which does represent an equilibrium thickness of air for the low energy 140 keV  $^{99m}\text{Tc}$  gamma photons.

B. The spill is spread over a small area and will be assumed to be a point, isotropic source of only  $^{99m}\text{Tc}$ . The exposure rate will be overestimated by this assumption and by the assumption that all of the activity was excreted in the spill. The activity A(t) at 1:00 pm is calculated where t = 1 h:

$$A(t) = A(0) e^{-\lambda t} = (5 \text{ mCi}) e^{-0.115} = 4.46 \text{ mCi} = \mathbf{0.00446 \text{ Ci}}.$$

The exposure rate  $\mathcal{S}$  is calculated:

$$7 \quad \mathcal{S} = A(t) \text{ fi } r^{-2} = (0.00446 \text{ Ci})(60 \text{ mR m}^2 \text{ h}^{-1} \text{ Ci}^{-1})(1 \text{ m})^{-2} = \mathbf{0.268 \text{ mR h}^{-1}}.$$

C. Five precautions prior to cleanup of the spill include:

1. Prevent animals from spreading the contamination.
2. Monitor the technician, animals, and areas outside of room for contamination.
3. Choose appropriate instruments, monitor, and identify (post areas if necessary) the extent of the contamination.
4. Establish a contamination control area.

***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

5. Choose proper protective clothing and dosimetry for workers and suitable materials for the cleanup operation.
- D. The room cannot be released immediately without additional measures. For a contaminated area  $S$  of  $0.25 \text{ m}^2$ , the average total contamination level can be estimated from the measured values reduced by a factor of four when averaged over  $1 \text{ m}^2$ . The total contamination averaged over  $1 \text{ m}^2$  would be  $18,750 \text{ dpm per } 100 \text{ cm}^2$ . This exceeds the license limit of  $15,000 \text{ dpm per } 100 \text{ cm}^2$ . The removable contamination level of up to  $10,000 \text{ dpm per } 100 \text{ cm}^2$  exceeds the license limit of  $1000 \text{ dpm per } 100 \text{ cm}^2$ . The highest total contamination levels of  $150,000 \text{ dpm per } 100 \text{ cm}^2$  exceeds the license limit of  $5,000 \text{ dpm per } 100 \text{ cm}^2$ , the most restrictive limit in this case.

If no additional measures are taken, the room cannot be released by noon the next day. The elapsed time is approximately 3.5 half-lives of  $^{99\text{m}}\text{Tc}$  (assuming that cleanup began at 1:00 pm) and this decay will result in a reduction of the contamination levels by a factor of about 11. The highest total contamination value of  $150,000 \text{ dpm per } 100 \text{ cm}^2$  will be approximately  $13,000 \text{ dpm per } 100 \text{ cm}^2$ , which still is in excess of the license limit of  $5,000 \text{ dpm per } 100 \text{ cm}^2$ .

**Comment:** Because the contamination is confined to a small area and because of the short half-life of  $^{99\text{m}}\text{Tc}$ , it would be relatively easy to coat or cover the contaminated area until the short-lived contamination has decayed to acceptable levels. The room could be released immediately in this case, as long as the covering is secured. It is assumed that the three different release limits are mutually exclusive and that each limit has to be met before the room can be released. It also is assumed that the  $5,000 \text{ dpm per } 100 \text{ cm}^2$  limit on total contamination is not averaged over a  $1 \text{ m}^2$  area. The limits stated in the problem are somewhat confusing, with a limit on removable contamination that is stated as an average (no area specified), a total contamination limit that is not stated as an average, and a total contamination limit that is stated as an average over a specific area of  $1 \text{ m}^2$ . The fact that this averaged total contamination limit ( $15,000 \text{ dpm per } 100 \text{ cm}^2$ ) is greater than the non-averaged limit ( $5,000 \text{ dpm per } 100 \text{ cm}^2$ ) also is confusing. The averaged limit will always be satisfied as long as the  $5,000 \text{ dpm per } 100 \text{ cm}^2$  limit is met and therefore, the averaged limit is unnecessary.

- E. No detectable activity is calculated because:
1. The fraction,  $f$ , of the activity of  $^{99\text{m}}\text{Tc}$  remaining after a time  $t$  of 7 days or **168 h** is calculated:  $f = e^{-\lambda t} = e^{-19.3} = 4.15 \times 10^{-9}$ . The total activity remaining, assuming no decontamination, would be  $46.1 \text{ dpm}$ . This activity would be undetectable regardless of the decontamination effort.

***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

2. The activity, A, of  $^{99}\text{Tc}$ , assuming the complete decay of  $^{99\text{m}}\text{Tc}$  to  $^{99}\text{Tc}$  is calculated from the initial activity of  $^{99\text{m}}\text{Tc}$  (5 mCi or  $1.11 \times 10^{10}$  dpm) and the ratio of the half-life of 6.02 h for  $^{99\text{m}}\text{Tc}$  to the half-life of  $1.86 \times 10^9$  h for  $^{99}\text{Tc}$ :  $A = (1.11 \times 10^{10} \text{ dpm})(6.6 \text{ h}) / (1.86 \times 10^9 \text{ h})$  or 39.4 dpm, which also would not be detectable regardless of the decontamination effort.

## **SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

### **QUESTION 8**

**GIVEN:** An unconscious woman, who later informed her physician that she had recently learned she was pregnant (likely about 1 month), undergoes various single, radiographic x-rays and fluoroscopy of the abdomen:

**T** / fluoro time for abdomen exam = **4 min**;

**I** / fluoro current for abdomen exam = **2 mA**;

**ESE** / fluoro entrance skin exposure per mA-min = **1.7 R/mA-min**;

**F** / fetal dose, assumed in rads, relative to entrance skin exposure in R = **0.45 rads/R**; and a table of entrance skin exposure data in C/kg for various x-ray procedures, assumed to apply to the given single radiographic procedures.

### **SOLUTIONS AND ANSWERS (C) TO PARTS A THROUGH E:**

A. The radiation dose to the fetus is calculated:

Since the head/neck and chest exposures should contribute no direct exposure to the fetus except for a very small amount of scatter, these will be neglected. It is assumed that the factor F applies to all of the exposures. Contributions from the remaining procedures are estimated below:

Abdomen: **DA** =  $F[(1.08 \times 10^{-4} \text{ C kg}^{-1}) / (2.58 \times 10^{-4} \text{ C kg}^{-1} \text{ R}^{-1}) + (\text{ESE})(\text{T})(\text{I})]$  = **6.31 rads**;

Pelvis: **DP** =  $F[(0.79 \times 10^{-4} \text{ C kg}^{-1}) / (2.58 \times 10^{-4} \text{ C kg}^{-1} \text{ R}^{-1})]$  = **0.138 rads**; and

Lumbar spine: **DL** =  $F[(1.40 \times 10^{-4} \text{ C kg}^{-1}) / (2.58 \times 10^{-4} \text{ C kg}^{-1} \text{ R}^{-1})]$  = **0.244 rads**; so

**C** Total estimated dose to fetus = DA + DP + DL = **6.69 rads**.

B. For an assumed dose in Part A of 3.5 rads, three pieces of advice, based on NCRP-54, given to the woman's OB/GYN regarding terminating the pregnancy or not include:

1. Advise the physician to make an actual recommendation to the woman, rather than simply giving her statistics and risk information.
2. Advise the physician to present a comparison of the risks of continuing the pregnancy compared to the risk of abortion.
3. Advise the physician to inform the woman that the incidence of birth defects in babies, independent of radiation exposure, is about 5% and that any increased risk from fetal doses less than about 10

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

rads, during any stage of pregnancy, is very small compared to this normal risk. Such would be the case here for the 3.5 rad dose.

- C. Three pieces of information necessary to determine the risk of injury to the fetus from this incident include: 1. age of fetus, 2. dose to fetus, and 3. dose to risk conversion factors for the effects possible at this stage of gestation.
- D. Five reasonable explanations as to why the woman appeared to have skin burns from the [fluoroscopy] procedure include:
1. The timer was wrong, and the actual exposure time was greater than 2 minutes.
  2. The current was wrong, and the actual machine current was greater than 2 mA.
  3. The voltage was wrong, and the actual voltage was greater than that assumed.
  4. The machine calibration was in error and the entrance skin exposure factor of 1.7 R/mA-min was not correct.
  5. If the fluoroscopic unit were equipped with a high level control, it is possible that the operating physician made use of this high output system and it was not properly recorded.

**Note:** It seems unlikely that conditions could have been so far off from those anticipated as to produce actual skin burns for this case because several hundred rads of entrance skin dose are required to produce burns. It is likely that the skin irritation could have been due to something other than radiation burns, and this should be followed up.

- E. Five machine parameters that will affect fetal exposure from CT, x-ray, or fluoroscopy include: 1. machine voltage, 2. machine current, 3. beam filtration, 4. beam area, and 5. machine “on-time”.

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

### **QUESTION 9**

**GIVEN:** Lasers are in use for extended durations on a military battlefield tactics range where purposeful staring into the beam is not anticipated nor intended. Tables of eye  $MPE_e$  and skin  $MPE_s$  are provided.

### **SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH E:**

A. For a laser with the following specifications, an appropriate **MPE** is calculated for a justified selection of exposure duration  $T_{max}$ :

Wavelength = 1.06 micrometers;  
Pulse frequency = **F = 0.5 Hz**;  
Beam width (exit, 1/e) = **d<sub>a</sub> = 0.9 cm**;  
Energy/pulse = **A = 1.0 J**;  
Pulse width = **W = 25x10<sup>-9</sup> s**; and  
Divergence = **B = 0.001 rad**.

Per the cited ANSI standard Sections 8.2.2 and 8.2.2.2, an exposure duration **t of 10 seconds** is reasonable for this near infrared wavelength and no purposeful staring into the beam. The eye  $MPE_e$  for a single pulse is calculated:

$MPE_e = 5 C_c \times 10^{-6} \text{ J cm}^{-2} = 5 \times 10^{-6} \text{ J cm}^{-2}$  for  $C_c = 1$ , as given below the table.

For the pulsed laser a correction factor is used to account for multiple pulses and is given by  $C_p = n^{-1/4}$  where n is the number of pulses during the exposure interval. For this case  $n = (t)(F)$  or 5, and so  $C_p = \mathbf{0.669}$ . The adjusted  $MPE_e$  is then calculated:

$$\mathbf{7 \quad MPE_e = (0.669)(5 \times 10^{-6} \text{ J cm}^{-2}) = \mathbf{3.34 \times 10^{-6} \text{ J cm}^{-2}}.$$

The standard also requires a second calculation to protect against thermal effects for multiple pulses in which the MPE is calculated as if for a CW laser for which the  $T_{max}$  value is normally taken as **0.25 s**. For this case the table gives  $MPE = 9 C_c t^{3/4} \times 10^{-3}$ , and  $C_c = 1$ . Thus for a single effective pulse, the MPE is calculated:

$$MPE_e = 9 C_c t^{3/4} \times 10^{-3} = 3.18 \times 10^{-3} \text{ J cm}^{-2}.$$

This would normally be divided by the number of pulses during the 0.25 s interval, but since this is less than 1 pulse, we can assume that this value of  $3.18 \times 10^{-3} \text{ J cm}^{-2}$  is the  $MPE_e$  for thermal

## **SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

effects. This value is clearly greater than the first value calculated above; thus, the first value of  $3.34 \times 10^{-6} \text{ J cm}^{-2}$  would be the appropriate  $\text{MPE}_e$  value. Note that the  $\text{MPE}_s$  for the skin would have been calculated as  $10 \text{ J cm}^{-2}$  from the last entry in the skin MPE table after multiplying by 10 s to convert to energy density. Thus, the eye  $\text{MPE}_e$  is limiting.

B. For the laser in A and an **MPE** of  $7 \times 10^{-6} \text{ J cm}^{-2}$ , the **NOHD** is calculated from the handout sheets of useful equations and the parameter values given in part A of this question:

$$7 \quad \text{NOHD} = (1/B)(1.27 A / \text{MPE} - d_a^2)^{0.5} = 425,900 \text{ cm or } \mathbf{4259 \text{ km.}}$$

C. For the two CW lasers given, the organs at risk for biological damage are determined from unprotected exposure at 1) the exit port and 2) 2 km based upon justified selections of  $T_{\text{max}}$  for the MPE calculated values in  $\text{W cm}^{-2}$  compared to the values for the exit and 2 km irradiance in the units of  $\text{W cm}^{-2}$  and not the incorrect units  $\text{W} * \text{cm}^2$  as shown in the given table to this part of the question:

**Argon laser:** At the wavelength of 0.515 micrometers (green part of spectrum), the retina and skin could be tissues at risk from unprotected exposure. The eye  $\text{MPE}_e$  is calculated from the table formula divided by the exposure time,  $t$ , to obtain  $\text{W cm}^{-2}$  for an assumed exposure time  $t$  of **0.25 s** corresponding to the blink aversion time:

$$7 \quad \text{MPE}_e = 1.8 t^{3/4} \times 10^{-3} / t = \mathbf{2.55 \times 10^{-3} \text{ W cm}^{-2}}.$$

The skin  $\text{MPE}_s$  is calculated from  $\text{MPE}_s = 1.1 C_A \times t^{1/4} / t$  (given table value divided by  $t$  to get it into power density) for exposure times from  $1 \times 10^{-7}$  seconds to 10 seconds and from  $0.2 C_A$  for longer times. Extended exposure times (compared to 0.25 s) to the skin are more likely, especially at the 2 km distance, and for a  $C_A$  value of **1.0** and  $t = \mathbf{10 \text{ seconds}}$  we obtain:

$$7 \quad \text{MPE}_s = 1.1 C_A \times t^{1/4} / t = \mathbf{0.2 \text{ W cm}^{-2}}.$$

Both the eye  $\text{MPE}_e$  and skin  $\text{MPE}_s$  exceed the respective irradiance values given for exit and 2 km; thus, neither tissue appears threatened. The eye is potentially irradiated to a much greater fraction of the MPE, about 0.78, compared to only 0.01 for the skin at the beam exit port. The relative irradiances at the 2 km distance are about 7 times less.

**GaAs laser:** At the 0.905 micrometer wavelength absorption occurs in the skin and all suprachoroidal as well as retinal tissues of the eye. The eye  $\text{MPE}_e$  is calculated from the given table formula again divided by  $t$  to convert it to power density. The value of  $C_A$  is obtained from the given formula:  $C_A = 10^{2(-0.7)} = \mathbf{2.57}$ . An exposure interval  $t$  of **10 s** is assumed based

***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

on the rationale shown in the answer to Part A:

7  $MPE_e = 1.8 C_A t^{3/4} \times 10^{-3}/t = \mathbf{2.60 \times 10^{-3} \text{ W cm}^{-2}}$ .

The skin  $MPE_s$  would be calculated from the same expression used for the argon laser, except  $C_A$  is **2.57** and  $t$  is **10 s**; thus,

7  $MPE_s = 1.1 C_A \times t^{1/4}/t = \mathbf{0.503 \text{ W/cm}^2}$ .

The irradiance of  $0.04 \text{ W cm}^{-2}$  at the exit exceeds the  $MPE_e$  of  $2.60 \times 10^{-3} \text{ W cm}^{-2}$  for the eye in this case, and the eye would be the tissue at possible risk very close to the laser. Even if one allowed for a very long time for possible skin exposure to the GaAs laser at the 2 km distance, e.g., 8 hours, the calculated  $MPE_s$  of  $1.3 \times 10^{-3} \text{ W cm}^{-2}$  for an 8 hour exposure would be greater than the given irradiance of  $6.3 \times 10^{-7} \text{ W cm}^{-2}$  at 2 km.

D. For the two lasers of Part C, additional hazards for use of the lasers on this range include:

1. use of optical aids (e.g., binoculars) by personnel with possible enhancement of energy density to the eye. The effect would be greater for the argon visible light than for the GaAs near I.R. radiation. Possible night use of infrared optical sensing aids could result in enhanced eye impact especially for the GaAs laser depending on the extent of I.R. transmission through the associated optics.
2. reflection and refraction of beams from equipment/aircraft in the field with redirection of the beam to ground personnel or to aircraft personnel. Reflection would be somewhat greater for the argon laser than for the GaAs for many surfaces.

E. For the wavelengths 1 through 5 shown for the lasers in the left column, the tissue(s) A through E with “significant” energy absorption shown in the list in the right column are: 1-D, 2-C, 3-C, 4-B, and 5-E\*.

\* **Comment:** Based on the properties of the given wavelength of  $0.36 \mu\text{m}$  for 5, the skin and cornea tissues shown in C would seem to be an appropriate answer. According to the 1993 ANSI standard Section B5.1 the cornea is at risk and per Section E.6 the lens is at potential risk (opacities) as well as the retina from photochemical retinitis. Other answers would be possible depending on the meaning of the word “significant” in this part of the question.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 10**

**GIVEN:** You are to assess expected radiological conditions during shutdown of a nuclear power plant. Lists of data include: (1) average RCS conditions at 90 days prior to shutdown, (2) containment system parameters, and (3) additional quantities including:

- DAC** # derived air concentration for  $^{131}\text{I} = 2 \times 10^{-8} \text{ Ci cm}^{-3}$ ;  
**w<sub>T</sub>** # thyroid stochastic risk dose weighting factor = **0.03**; and  
**fi** # gamma constant for  $^{58}\text{Co} = 5.5 \text{ R cm}^2 \text{ h}^{-1} \text{ mCi}^{-1} = \mathbf{0.55 \text{ mR m}^2 \text{ h}^{-1} \text{ mCi}^{-1}}$ .

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH E:**

A. When estimating the  $^{131}\text{I}$  airborne concentration in containment 24 hours after shutdown from the RCS and containment data, five considerations include: 1. the  $^{131}\text{I}$  concentration in the reactor coolant, 2. the RCS leak rate to the containment atmosphere, 3. the containment free air volume, 4. the containment atmosphere charcoal filters cleanup flow rate, and 5. the containment atmosphere pressure reduction ventilation rate.

B. The **CDE** to a worker's thyroid and the associated **CEDE** are estimated from an exposure to a constant containment atmosphere concentration **C** of  $8 \times 10^{-9} \text{ Ci cm}^{-3}$  of  $^{131}\text{I}$  for a time interval **T** of **10 h** for the stated assumptions, given data, Reference Man ICRP models, and the assumption that the thyroid is the only significantly irradiated tissue following an intake:

$$7 \quad CDE = \left( \frac{C T}{DAC} \right) \left( \frac{50 \text{ rem}}{2000 \text{ DAC-h}} \right) = \left( \frac{(8 \times 10^{-9} \text{ } \mu\text{Ci cm}^{-3})(10 \text{ h})}{2 \times 10^{-8} \text{ } \mu\text{Ci cm}^{-3} \text{ DAC}^{-1}} \right) \left( \frac{50 \text{ rem}}{2000 \text{ DAC-h}} \right) = 0.100 \text{ rem},$$

and

$$7 \quad CEDE = (CDE)(w_T) = (0.100 \text{ rem})(0.03) = 0.00300 \text{ rem} = 3 \text{ mrem}.$$

C. Four factors that should be considered in the pre-job analysis for containment entry after shutdown to keep the total effective dose equivalent ALARA include: 1. the potential external radiation exposures, 2. the potential internal radiation exposures, 3. the effect of adding shielding to reduce 1 and the additional exposures received by workers who add this shielding, 4. the effect that respiratory protection has on reducing 2 but perhaps increasing 1 because of increased time required to complete the job(s).

D. Adding  $\text{H}_2\text{O}_2$  to the RCS is expected to decrease the level of  $^{58}\text{Co}$  on all internal surfaces of the RCS and increase the level of  $^{58}\text{Co}$  to  $1 \text{ Ci mL}^{-1}$  in the coolant, which is removed by the RCS demineralizer:

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

- 1) Three methods for reducing the RCS  $^{58}\text{Co}$  cleanup time include: (1) increasing the reactor coolant cleanup flow rate above the given value of  $100 \text{ gal min}^{-1}$ , (2) adding new resins to the RCS demineralizer or regenerating the resins prior to cleanup, and (3) increasing the size of the RCS demineralizer resin beds to improve the cleanup efficiency.
- 2) Two benefits of adding  $\text{H}_2\text{O}_2$  to the RCS at the onset of refueling include: (1) external radiation exposures to workers will be reduced, and (2) internal radiation exposures will be reduced to workers who are exposed to internal surfaces of the RCS that are contaminated with  $^{58}\text{Co}$ .

E. The total activity **A** of  $^{58}\text{Co}$  in a pipe having a length **L** of **2 m** and a measured exposure rate  **$\dot{X}(d)$**  of  **$0.25 \text{ mR h}^{-1}$**  at a perpendicular distance **d** of **2 m** from the midpoint is calculated as follows based on the stated assumptions as well as the assumptions that (1) the sample line can be considered as a line source; (2) attenuation of gamma photons in the sample line and air can be neglected; (3) the uniform specific activity  $C_L$  of the line source is represented by the quotient  $A/L$ ; and (4) the angle  **$\theta$**  of  **$0.927 \text{ radians}$**  that the line subtends at the exposure point is calculated from  $2 \tan^{-1} (1/2)$ , and it represents the sum of the angles  $\theta_1$  and  $\theta_2$  in the line source equation shown in the attached "Useful Equations and Constants" given to candidates:

$$\dot{X}(d) = \frac{\Gamma C_L \theta}{d} = \frac{\Gamma A \theta}{L d}; \text{ so}$$

$$7 \quad A = \frac{\dot{X}(d) L d}{\Gamma \theta} = \frac{(0.25 \text{ mR h}^{-1})(2 \text{ m})(2 \text{ m})}{(0.55 \text{ mR h}^{-1} \text{ m}^2 \text{ mCi}^{-1})(0.927)} = 1.96 \text{ mCi.}$$

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 11**

**GIVEN:** criticality accident in a fuel reprocessing facility involving a 45 cm by 45 cm tank containing enriched uranium and the exposure of a technician standing behind a polyethylene shield:

- r** # distance of technician from the center of the tank = **300 cm**;
- x** # thickness of polyethylene shield = **30 cm**;
- ρ** # density of polyethylene shield = **1.5 g cm<sup>-3</sup>**;
- S<sub>F</sub>** # number of *fissions* (f) in criticality accident = **1.0x10<sup>16</sup> f**;
- Y<sub>n</sub>** # neutron (average energy of 2.5 MeV) yield per fission = **3 n f<sup>-1</sup>**;
- Y<sub>fl</sub>** # gamma (average energy of 1.0 MeV) yield per fission = **8 fl f<sup>-1</sup>**;
- C<sub>n</sub>** # dose conversion factor for 2.5 MeV neutrons = 2 mrem h<sup>-1</sup> per 20 n cm<sup>-2</sup> s<sup>-1</sup>, or **2.78x10<sup>-8</sup> rem per n cm<sup>-2</sup>**;
- XC<sub>fl</sub>** # exposure conversion factor for fission fl-rays = 1 R h<sup>-1</sup> per 6.0x10<sup>5</sup> fl cm<sup>-2</sup> s<sup>-1</sup>, or = **4.63x10<sup>-10</sup> R per fl cm<sup>-2</sup>**; so
- C<sub>fl</sub>** # dose conversion factor for fission fl-rays = **(XC<sub>fl</sub>)(0.95 rem/R)** = **4.40x10<sup>-10</sup> rem per fl cm<sup>-2</sup>**;
- T<sub>n</sub>** # neutron dose transmission through 30 cm polyethylene shield = **0.005**;
- μ** # polyethylene linear attenuation coefficient for fission gamma spectrum = **(. /8)ρ**, or = **(0.073 cm<sup>2</sup> g<sup>-1</sup>)(1.5 g cm<sup>-3</sup>) = 0.110 cm<sup>-1</sup>**; so
- T<sub>fl</sub>** # uncollided gamma transmission through polyethylene shield = e<sup>-μx</sup> = **0.0369**.

**Note:** The conversion of 0.95 rem/R shown for calculating C<sub>fl</sub> is based on the given statement that 0.95 rad = 1 R, where the 0.95 rad is assumed here to represent the absorbed dose to tissue equivalent to an exposure in air of 1 R and hence a dose equivalent of 0.95 rem.

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH C:**

A. The technician's neutron dose equivalent **H<sub>n</sub>** in **rem** is estimated from the bolded numerical values shown for the given quantities in the equation:

$$7 \quad H_n = \left( \frac{S_F Y_n}{4 \pi r^2} \right) C_n T_n = 3.69 \text{ rem.}$$

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

The technician's gamma dose equivalent  $H_{\gamma}$  in **rem** is estimated from the bolded numerical values shown for the given quantities in the equation:

$$7 \quad H_{\gamma} = \left( \frac{S_F Y_{\gamma}}{4 \pi r^2} \right) C_{\gamma} T_{\gamma} = \mathbf{1.15 \text{ rem.}}$$

B. The maximum distance **d** in **m** over which a gamma criticality monitor will alarm is calculated from the given data and assumptions stated for this part:

$\$$  # actual gamma exposure rate at alarm set point =  $(0.5 \text{ R h}^{-1})(3500) = \mathbf{1,750 \text{ R h}^{-1}}$ ;

$S_F$  # number of *fissions* (f) in criticality accident =  $\mathbf{1.0 \times 10^{16} \text{ f}}$ ;

$X_F$  # exposure constant for  $S_F = 20 \text{ R}$  at  $2 \text{ m} = \mathbf{80 \text{ R m}^2}$ ;

$>$  # time interval for criticality incident =  $1 \times 10^{-3} \text{ s} = \mathbf{2.78 \times 10^{-7} \text{ h}}$ ; so

$\$$  # exposure rate constant for  $S_F = X_F / > = \mathbf{2.88 \times 10^8 \text{ R h}^{-1} \text{ m}^2}$ .

$$7 \quad d = \left( \frac{\dot{X}_F}{\dot{X}} \right)^{\frac{1}{2}} = \left( \frac{2.88 \times 10^8 \text{ R h}^{-1} \text{ m}^2}{1750 \text{ R h}^{-1}} \right)^{\frac{1}{2}} = \mathbf{406 \text{ m.}}$$

C. Four factors that affect criticality include: 1. the mass of fissile material, 2. the geometry of the fissile material, 3. the presence of moderator, and 4. the presence of reflector, e.g. a worker who may approach a sub critical assembly which becomes prompt critical when the worker comes in close proximity to the assembly of fissile material.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 12**

**GIVEN:** Electron accelerator having a water cooled beam stop in which 90% of beam power is absorbed in the beam stop and 10% or a fraction **f** of **0.1** in the cooling water which has saturation activities per unit power in water,  $A_i(\infty)/P_w$ , in **GBq/kW** listed in the given table for each of five radionuclides **i** along with each half-life, principal emission, decay constant  $\lambda$ , and calculated concentrations for part A:

Nuclide	i	$A_i(\infty)/P_w$ (GBq/kW)	Half-life	Principal Emission	$\lambda$ (day <sup>-1</sup> )	$C_i(t)$ (Bq L <sup>-1</sup> )	$C_i(\infty)$ (Bq L <sup>-1</sup> )
<sup>15</sup> O	1	330	123 s	positron	487	1.10x10 <sup>9</sup>	0.00
<sup>13</sup> N	2	3.7	9.96 m	positron	100	1.23x10 <sup>7</sup>	0.00
<sup>11</sup> C	3	15	20.34 m	positron	49.1	5.00x10 <sup>7</sup>	0.00
<sup>7</sup> Be	4	1.5	53.6 d	gamma	0.0129	1.60x10 <sup>6</sup>	1.47x10 <sup>6</sup>
<sup>3</sup> H	5	7.4	12.3 y	beta	0.000154	1.14x10 <sup>5</sup>	1.14x10 <sup>5</sup>

7             $C(t)$  # ;  $C_i(t) = 1.16 \times 10^9 \text{ Bq L}^{-1}$ , and  $C(\infty)$  # ;  $C_i(\infty) = 1.58 \times 10^6 \text{ Bq L}^{-1}$ .

Other given data include:

**V** # volume of coolant water in which  $A_i(\infty)$  is assumed to be uniformly mixed = **6000 L**;

**E** # electron beam energy = 2.0 GeV = **2x10<sup>9</sup> eV**;

**I** # average beam current = 100 . A = **1x10<sup>-4</sup> A**; so

**P** # average total beam power = (E)(I) = 2x10<sup>5</sup> watts = **200 kw**.

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH D:**

A. The activity concentrations  $C_i(t)$  in **Bq L<sup>-1</sup>** of each radionuclide **i** and total activity concentration **C(t)** in the coolant water after a time **t** of **30 days** of constant beam are calculated from quantities in the above table by

$$C_i(t) = \frac{(1 \times 10^9 \text{ Bq GBq}^{-1} (A_i(\infty)/P_w)) (0.1 P)}{V} (1 - e^{-\lambda t}).$$

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

From values calculated for each radionuclide shown in the above table, C(t) is calculated:

7 
$$C(t) \# ; C_i(t) = 1.16 \times 10^9 \text{ Bq L}^{-1}.$$

The activity concentrations  $C_i(>)$  in  $\text{Bq L}^{-1}$  of each radionuclide i and total activity concentration  $C(>)$  are calculated in the coolant water after a time  $t$  of **30 days** of constant beam and a decay interval  $>$  of **7 days** from quantities in the above table by

$$C_i(\tau) = \frac{(1 \times 10^9 \text{ Bq GBq}^{-1} (A_i(\infty)/P_w)) (0.1 P)}{V} (1 - e^{-\lambda t}) e^{-\lambda \tau} = C_i(t) e^{-\lambda \tau}.$$

From values calculated for each radionuclide shown in the above table, C(>) is calculated:

7 
$$C(>) \# ; C_i(>) = 1.58 \times 10^6 \text{ Bq L}^{-1}.$$

- B. For an accelerator with a beam energy of **4.5 GeV** instead of **2.0 GeV** and average beam current of **50 . A** instead of **100 . A**, its specific activity relative to the original value would be a factor F calculated:

7 
$$F = (4.5/2)(50/100) = \mathbf{1.13 \text{ times higher.}}$$

- C. Six factors to be considered in **planning** the release each day of up to 600 L out of a total coolant water volume of 6000 L into the sanitary sewer include:

1. time for essentially complete decay of the short lived radionuclides, 1 through 3 in the above table, so that the anticipated release each day would involve only 53.6 day half-life  $^7\text{Be}$  and 12.3 y half-life  $^3\text{H}$ ;
2. the activities of any other radionuclides released from the facility into the sanitary sewer in the month and year of the anticipated release of the coolant water and accounting for these in calculating the anticipated fractions of the respective limits.
3. the anticipated total activities of each radionuclide in the coolant water to be released;
4. the monthly volume of sanitary sewage for calculating the monthly average concentrations of each radionuclide in the sanitary sewer from their total activities released in the month.
5. the sum of the anticipated monthly average concentrations in the sanitary sewer relative to their stated limits (e.g., 0.006 . Ci mL<sup>-1</sup> of  $^7\text{Be}$  and 0.01 . Ci mL<sup>-1</sup> of  $^3\text{H}$ ), whose sum should not exceed unity; and
6. the limits for the total activities of released radionuclides in any year (e.g., 5 Ci of  $^3\text{H}$ , 1 Ci of  $^{14}\text{C}$ , and 1 Ci of all other radionuclides).

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

**Comment:** From data shown in the above table, a concentration  $C_4(>)$  of  $0.0397 \text{ Ci mL}^{-1}$  and total activity  $A_4(>)$  of  $0.238 \text{ Ci}$  of  $^7\text{Be}$  and a concentration  $C_5(>)$  of  $0.00308 \text{ Ci mL}^{-1}$  and total activity  $A_5(>)$  of  $0.0185 \text{ Ci}$   $^3\text{H}$  are expected to be present in the 6000 L coolant system 7 days after a 30 day operating period. Such values should not present any problem for release under current NRC regulations, especially when diluted by the monthly volume of sanitary sewage released from the accelerator facility alone.

D. The two factors that should be considered for each of the stated five radiological aspects are the same:

- (1) the calculated activities of each radionuclide expected to be present in the spill taking into account the amount of any decay, and
- (2) the potential for these activities to cause external and/or internal exposures of workers.

**Comment:**

Based on the stated premise that “you discover that 20 liters of water has leaked into the cooling water building and cooling water is still leaking” and “entry into the building by personnel will be required to stop the leak and clean up the spill”, the requirements for any of the stated five radiological aspects will depend on the total activities released and their potential of causing external and internal radiation exposures. At the end of a 30 day operating period (See above table.), the total activities of the first three, short lived, positron emitters (i.e.,  $123 \text{ s } ^{15}\text{O}$ ,  $9.96 \text{ m } ^{13}\text{N}$ , and  $20.34 \text{ m } ^{11}\text{C}$ ) in the 20 liter spill are calculated respectively as 595 mCi, 6.65 mCi, and 27 mCi or a total activity of about 630 mCi. From the approximation for the exposure rate in  $\text{R h}^{-1}$  at 1 foot from a point source,  $\dot{S} = 6 C E$ , the annihilation photons associated with these positron emitters would present an initial external radiation exposure rate potential to workers in  $\text{mR h}^{-1}$  of about  $(6)(630)(1.02) \text{ mR h}^{-1}$  or  $3,860 \text{ mR h}^{-1}$  at one foot from the spill. The spill would not likely be represented as a point source, and the actual exposure rate could be significantly less. In addition, this initial exposure rate of  $3,680 \text{ mR h}^{-1}$ , which is mostly due to  $123 \text{ s}$  half-life  $^{15}\text{O}$ , would rapidly decrease with about a 2 minute half-life; so the total exposure would be only about 270 mR even if a worker were to remain at a distance of one foot until all three radionuclides completely decayed to zero activity. The ultimate exposure at 3 feet would be only about 30 mR for a point source. If volatile, these same three radionuclides might also present some internal exposure, but this internal exposure would be very small based upon their very short half-lives and an unlikely intake fraction of  $1 \times 10^{-6}$  (NRC Regulatory Guide 8.25, “Air Sampling in the Workplace,” 1992). Because there is some external exposure potential, no effort should be made to clean up the spill until these short lived radionuclides essentially decay to zero activity levels. It reasonably can be assumed that the accelerator has been shut down and that sufficient time has elapsed for the first three positron emitters to have essentially decayed to

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

insignificant activities prior to entry into the cooling water building. However, if shutting the accelerator down could cause undue costs and inconvenience to the ongoing research programs, then entry could be made into the cooling water building to terminate the leak with minimal internal and external exposures to workers. Based on the calculations shown above, the external exposure of any worker from the spill certainly would not likely exceed 30 mR, and the internal exposures would be insignificant, certainly less than a CEDE of 1 mrem.

Cleanup of the spill could be delayed until all short lived positron emitters decay to negligible activity levels. The activities of the remaining two radionuclides (i.e.,  ${}^7\text{Be}$  and  ${}^3\text{H}$ ) in the 20 L spill are assumed in the following evaluations to be comparable to respectively 795 . Ci and 61.6 . Ci calculated from values shown for  $C_i(>)$  in the above table. These activities correspond to specific activities  $S_A$  of only 0.0397 . Ci  $\text{g}^{-1}$  for  ${}^7\text{Be}$  and 0.00308 . Ci  $\text{g}^{-1}$  for  ${}^3\text{H}$  in the 20 L of spilled cooling water at 7 days after a 30 day operating period. The maximum absolute concentration  $C_m$  of water in the air cannot exceed the saturation concentration limit for a given temperature, which is 17.3  $\text{g m}^{-3}$  at twenty degrees centigrade. Even if the room containing the spill in the cooling water building is unventilated and even if all of the water vapor in the room were to be derived from water contaminated with tritium at the specific activity  $S_A$  of 0.00308 . Ci  $\text{g}^{-1}$  for  ${}^3\text{H}$  in the spilled cooling water, the airborne activity concentration  $U$  could not exceed:

$$U = C_m S_A = 17.3 \text{ g m}^{-3} S_A = (17.3 \text{ g m}^{-3})(0.00308 \text{ } \mu\text{Ci g}^{-1}) = 0.0533 \text{ } \mu\text{Ci m}^{-3},$$

which is only 0.27% of the DAC of 20 . Ci  $\text{m}^{-3}$  for HTO. The stochastic effect-based inhalation ALIs or S-ALIs of  ${}^7\text{Be}$  and  ${}^3\text{H}$  are respectively 20,000 . Ci (HTO) and 80,000 . Ci (any compound form). In cleaning up the spill, the potential intakes  $I$  of  ${}^7\text{Be}$  and  ${}^3\text{H}$  are calculated from the NRC unlikely intake fraction of  $1 \times 10^{-6}$  as  $7.95 \times 10^{-4}$  . Ci and  $6.16 \times 10^{-5}$  . Ci, which have CEDEs of only about  $2 \times 10^{-4}$  mrem and  $4 \times 10^{-6}$  mrem respectively. The 795 . Ci of  ${}^7\text{Be}$  (total photon energy  $E$  of 0.0494 MeV per Bq s) would yield an exposure rate of only about  $(6)(0.795)(0.0494)$  mR  $\text{h}^{-1}$  or 0.24 mR  $\text{h}^{-1}$  at 1 foot from the spill and 0.026 mR  $\text{h}^{-1}$  at 3 feet from the spill, which again is conservatively assumed to be represented by a point source. The activities of  ${}^7\text{Be}$  and  ${}^3\text{H}$  pose an insignificant potential for external or internal radiation exposures, and none of the five stated radiological aspects would be required except perhaps protective clothing and gloves to minimize contamination of workers and external dosimetry to document the external exposures for reasons other than justified by any potential exposure from the spill, including for example the exposures from normal external radiation fields in the cooling water building if the machine were to remain in operation.

More specific answers to this part D can be made only if sufficient radiological data are provided for the external and internal radiation sources, including information that allows the estimation of potential external and internal radiation exposures. Other than data provided in the premise to this question, which does not necessarily apply to this part, no specific information nor data are given for this part. In general, the evaluation and control of exposures to external and

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

internal radiation sources should include:

1. an inventory of the types and quantities of internal and external radiation sources,
2. the evaluation of potential exposures to both types of sources,
3. the establishment of justified monitoring requirements for both types of sources that provide timely detection of significant exposures so that corrective actions can be taken and follow-up monitoring procedures implemented to improve the accuracy of the exposures and corresponding internal and/or external radiation doses, and
4. the selection of those protective measures for external and internal radiation sources that are thought to maintain the *total effective dose equivalent as low as reasonable achievable* (TEDE ALARA). For example, respiratory protection and other internal radiation protective measures that increase the time required to complete a job should not be used if the external radiation exposure potential far exceeds the internal radiation exposure potential, which is certainly the situation in this case.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 13**

**GIVEN:** an industrial site with several buildings contaminated with natural uranium being remediated, surveyed with an alpha scintillation probe, and evaluated for unrestricted release, where:

- R** # maximum gross measurement = **100 cpm**;  
**DCGL** # *derived concentration guideline level* assuming that no more than 10% of the activity is removable = **500 dpm per 100 cm<sup>2</sup>**;  
**A** # probe area = **50 cm<sup>2</sup>**;  
**E** # “the response of your alpha scintillation probe for U-nat” = 20%  
= **0.2 c per decay of U-nat**;  
**Y** # “surface emission abundance of alphas from a concrete block” = 50%; and  
**B** # probe background = **2 cpm**.

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH E:**

- A. The release criteria are usually regulatory limits expressed in terms of dose or risk. Two critical factors in evaluating equipment or property for unrestricted release are:
1. the types and quantities of radioactive contamination present and
  2. the possible pathways of exposure.
- B. A DCGL is a *Derived Concentration Guideline Level*, which is an action level based on a specific release criterion, exposure pathway, and measurement. The DCGL is a predicted or measured concentration of a contaminant that would cause a dose or risk equal to the release criterion for a specific exposure pathway. Because DCGLs are based on possible exposure pathways, the planned use or reuse of structures does affect the determination of DCGLs. (reference: MARSSIM - NUREG 1575).
- C. The surface specific activity or “concentration” U associated with the probe measurement is calculated:
- 7  $U = (R-B)(100/AE) = (100 \text{ cpm} - 2 \text{ cpm})(100)/[(50 \text{ cm}^2)(0.2 \text{ c d}^{-1})] = \mathbf{980 \text{ dpm per } 100 \text{ cm}^2}$ ;

therefore, the building cannot be released. The measurement value corresponds to a concentration that exceeds the DCGL value of 500 dpm per 100 cm<sup>2</sup>. In addition, it is not known from the probe measurement what fraction of the activity is removable.

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

**Comment:** The given 20% response of the alpha scintillation probe is ambiguous. Because the basis for this percentage is not given and no units are given, this parameter can be interpreted in many ways (e.g., counts per alpha, counts per decay, etc.). I choose to interpret this response as 0.2 counts per decay of natural uranium on the surface of a concrete block. Therefore, I assume that the number of alpha particles emitted by uranium **and progeny** per decay of natural uranium, the fraction of the alpha particles emitted from the surface, and the probability that an alpha particle emitted from the surface of the block is detected are all factored into this value. The value of 50% and definition given for Y, “surface emission abundance of alphas from a concrete block”, is very obscure, and it is considered here as irrelevant and extraneous information.

D. Four factors to be considered in converting gross gamma instrument readings to a specified DCGL (actually to convert them to the same quantity and units for comparison with a specified DCGL) when scanning soils for gamma emitters include:

1. the detector background counting rate,
2. the scanning speed and geometry (technique),
3. the detector intrinsic gamma detection efficiency, and
4. the effect of photon absorption and scatter in soils.

E. Five pathways by which radioactivity in soil can contribute to human dose include:

1. direct terrestrial exposure to penetrating radiations,
2. transfer of radioactivity from soil to water and subsequent ingestion of water.
3. transfer of radioactivity to air by evaporation, emanation, or other physical airborne entrainment with subsequent inhalation of the radioactive aerosols,
4. absorption of radioactivity from soil by plants and subsequent ingestion, and
5. transfer of radioactivity to grazing livestock and subsequent ingestion of milk and other animal byproducts.

Two important parameters when conducting a dose assessment of contaminated soil include:

1. the specific activity of the soil, which determines the mass of suspended soil per unit volume of air that is required to reach a given airborne activity concentration, and
2. the AMAD and geometric standard deviation of the suspended soil particles, which influence their respiration, deposition, and clearance from compartments within the respiratory tract.

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

**QUESTION 14**

**GIVEN:** a table including air sampling data for  $^{125}\text{I}$  in three separate rooms including the sampling flow rate **F** in  $\text{L min}^{-1}$ , duration of procedure which is assumed to equal the air sampling time **t** in **hours**, and  $^{125}\text{I}$  filter activity **A** in **MBq**; a table for the CDE per unit intake for various target organs; a table of stochastic and non-stochastic ALIs and DACs; and additional data specifically given:

- $T_{1/2}$  # half-life of  $^{125}\text{I}$  = 60.14 days =  **$8.66 \times 10^4 \text{ min}$** ; so
- $\lambda$  # decay constant of  $^{125}\text{I}$  =  $(\ln 2)/T_{1/2}$  =  **$8.00 \times 10^{-6} \text{ min}^{-1}$** ;
- R** # air sample filter collection efficiency = **0.95**;
- $F_v$  # exhaust ventilation flow rate in room 3 =  **$15 \text{ m}^3 \text{ min}^{-1}$** ;
- V** # air volume of room 3 =  **$60 \text{ m}^3$** ; so
- K** # room 3 ventilation removal rate constant for  $^{125}\text{I}$  =  $F_v/V$  =  **$0.25 \text{ min}^{-1}$** ; so
- k** # room 3 total removal rate constant for  $^{125}\text{I}$  =  $K + \lambda$ ,  $\lambda \ll K$  =  $0.250 \text{ min}^{-1}$  =  **$15 \text{ h}^{-1}$** ;
- DAC** # non-stochastic DAC for  $^{125}\text{I}$  =  **$0.001 \text{ MBq m}^{-3}$** ;
- S-DAC** # stochastic effect-based DAC for  $^{125}\text{I}$  =  **$0.002 \text{ MBq m}^{-3}$** ;
- <CEDE/I>** # CEDE per unit intake of  $^{125}\text{I}$  =  **$6.53 \times 10^{-3} \text{ Sv MBq}^{-1}$** ; and
- <CDE/I>** # thyroid CDE per unit intake of  $^{125}\text{I}$  =  **$2.16 \times 10^{-1} \text{ Sv MBq}^{-1}$** ;

**SOLUTIONS AND ANSWERS(7) TO PARTS A THROUGH E:**

A. The average airborne  $^{125}\text{I}$  concentration **C** in each room is calculated:

$$C = \frac{(1000 \text{ L m}^{-3}) \lambda A}{R F (1 - e^{-60 \text{ min h}^{-1} \lambda t})},$$

which yields for the three rooms from quantities in the specified units shown above:

- 7  $C_1 = 0.0984 \text{ MBq m}^{-3}$  for room 1;
- 7  $C_2 = 0.0878 \text{ MBq m}^{-3}$  for room 2; and
- 7  $C_3 = 0.172 \text{ MBq m}^{-3}$  for room 3.

B. The exposure **E** in the units of non-stochastic **DAC-h** of a technician exposed to an airborne concentration **C** of  **$0.192 \text{ MBq m}^{-3}$**  compared to the given **DAC** of  **$0.001 \text{ MBq m}^{-3}$**  for a time **T** of **3 h** is calculated:

$$7 \quad E = \frac{C T}{\text{DAC}} = \frac{(0.192 \text{ MBq m}^{-3})(3 \text{ h})}{(0.001 \text{ MBq m}^{-3} \text{ DAC}^{-1})} = 576 \text{ DAC-h};$$

## ***SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM***

therefore, no dose limits have been exceeded because the exposure is less than the exposure limit of 2,000 DAC-h for any control year of practice for a technician having no other internal nor external exposures in that control year of practice.

- C. The CDE and CEDE of a declared pregnant worker with minimal deep dose equivalent who has an intake **I** of **0.27 MBq** of  $^{125}\text{I}$  are calculated:

7 **CDE** =  $I \langle \text{CDE}/I \rangle = (0.27 \text{ MBq})(0.216 \text{ Sv MBq}^{-1}) = 0.0583 \text{ Sv} = \mathbf{5.83 \text{ rem}}$ , and

7 **CEDE** =  $I \langle \text{CEDE}/I \rangle = (0.27 \text{ MBq})(6.53 \times 10^{-3} \text{ Sv MBq}^{-1}) = 1.76 \times 10^{-3} \text{ Sv} = \mathbf{0.176 \text{ rem}}$ .

Given no further information in the question, the **CDE<sub>G</sub>** to the gonads of the pregnant worker is calculated as a surrogate of the **CDE<sub>F</sub>** to the fetus from the given intake to dose constant of  $1.84 \times 10^{-11} \text{ Sv Bq}^{-1}$  or **1.84 mrem MBq<sup>-1</sup>**:

7 **CDE<sub>F</sub>** =  $(0.27 \text{ MBq})(1.84 \text{ mrem MBq}^{-1}) = \mathbf{0.497 \text{ mrem}}$ ,

which is considerably less than the NCRP's fetal dose recommendation of 500 mrem. Therefore, it is not likely that the NCRP's recommendation was exceeded.

**Comment:** Intake to dose conversion factors are available for the fetus of a pregnant worker, and one should have been provided in this part to the question.

- D. Four radiological controls that could be established to reduce exposures to  $^{125}\text{I}$  include:

1. daily screening of each worker's thyroid gland to trigger investigations and corrections of situations in the workplace that might be causing significant exposures;
2. improving the face velocity in the fume hood and procedures used for iodination to limit releases to the ambient air;
3. requiring the animal sacrifice and LPLC procedures to take place in fume hoods; and
4. using iodine continuous air monitors that alarm and trigger evacuations, investigations, and corrections of situations in the workplace that might be causing significant exposures.

- E. For a non-stochastic **DAC** of **0.001 MBq m<sup>-3</sup>**, the exposure **E** is calculated for a repairman who is exposed to a constant concentration **C(0)** of **0.10 MBq m<sup>-3</sup>** for a time interval **T** of **1 h** in Room # 3 during the end of the LPLC procedure and then for an additional time interval **>** of **2 h** when the concentration **C(>)** is assumed to decrease exponentially from its initial value **C(0)** due to ventilation removal and decay with an associated rate constant **k** of **15 h<sup>-1</sup>**:

**SOLUTIONS AND ANSWERS TO 2001 ABHP EXAM**

$$7 \quad E = \frac{C(0) T}{DAC} + \frac{\frac{C(0)}{k} (1 - e^{-k\tau})}{DAC} = (100 + 6.67) DAC-h = 107 DAC-h,$$

which for an **S-DAC** of **0.002 MBq m<sup>-3</sup>** corresponds to a stochastic effect-based exposure of **53.5 S-DAC-h** and a **CEDE** of **134 mrem**. Therefore, the exposure exceeds the **100 mrem** limit for a member of the general public.