CIH Review Course

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Ionizing Radiation

CIH versus CHP

- Ionizing radiation is just one of many hazards that industrial hygienists may need to anticipate, recognize, evaluate, & control.
- Health Physics is a discipline of itself to the degree that some workplaces may present a unique emphasis on the application of (ionizing) radiations.
- So how much knowledge is enough?

Some perspectives on How Much

- The accepted IH textbooks commit 20 –50 pages to ionizing radiation hazards (< 5%).
- The ABIH Equation sheet provides formulas and conversions suggesting some key concepts.
- The multiple-choice format imposes some constraints on CIH exam radiological content.

So: How to Prepare?

- Focus on ionizing radiation *terminology*.
  - [NSC Fundamentals of Industrial Hygiene chapter has a (short) glossary of terms].
- Review and practice applying the "useful *equations*" from ABIH sheet.
- Review and practice *unit analysis* and application of the *conversions* from the ABIH handout sheet.

Ionizing Radiation Units

- Activity: **Curie** = 3.7 X 10^{10} **dps**

  = 2.2 X 10^{12} **dpm**

  Becquerel = transformation per second

  $\simeq$ disintegration per second (**dps**)

  SO, 1 **Ci** = 3.7 X 10^{10} **Bq**

Rem = (RAD)(QF)

Dose Equivalent = Absorbed Dose times Quality Factor [Sv = Gy X QF]

	<u>Q</u>
• x-rays, gammas, electrons (betas)	1
• thermal (slow) neutrons*	5
• fast neutrons* and protons	20
• alpha particles	20

* Q for neutrons is function of neutron *energy*

The Metric Prefixes

- kilobecquerel,
  kBq = 10^{3} Bq
- megabecquerel,
  MBq = 10^{6} Bq
- gigabecquerel,
  GBq = 10^{9} Bq
- terabecquerel,
  TBq = 10^{12} Bq
- millicurie,
  mCi = 10^{-3} Ci
- microcurie,
  uCi = 10^{-6} Ci
- nanocurie,
  nCi = 10^{-9} Ci
- picocurie,
  pCi = 10^{-12} Ci

The Inverse Square Law

- **Basis:** Radiation intensity (flux) is inversely proportional to the square of the separation distance from the source of the radiation. (derives from the geometry of a sphere)
- **Assumption**: Point source in vacuum; (everything is a point source when you’re far enough away); for x & gamma rays, air interactions approximate a vacuum.

$$I_2 = I_1 \left[d_1 / \ d_2 \right]^2$$

$\mathbf{I_2}$ = radiation intensity (e.g., dose rate) at new distance $\mathbf{d_2}$

$\mathbf{I_1}$ = radiation intensity at initial distance $\mathbf{d_1}$

Equivalent expression: $\mathbf{I_1(d_1)^2 = I_2(d_2)^2}$

Problem:

The dose rate at 2 m from a particular gamma source is 400 uSv/h. At what distance will it give a dose rate of 25 uSv/hr?

Conceptualization:

Since we are looking for a LOWER dose rate, it follows we have to move FARTHER from the source (answer must be > 2 m).

From the ABIH USEFUL EQUATION sheet:

$$I_2 = I_1 \, [\, d_1/d_2]^2$$

Rearranging terms:

$I_1(d_1)^2 = I_2(d_2)^2$ $\qquad$ $400 \times 2^2 = 25 \times (d_2)^2$

so, $d_2 = \left[\, I_1(d_1)^2/I_2 \right]^{0.5}$, $\qquad$ $(d_2)^2 = 64,$ $\qquad$ $d_2 = 8$ m

Problem:

The dose rate at a distance of 1 ft from a certain gamma source is 900 mrem/h. At what distance from the source is the dose rate 25 mrem/h ?

Conceptualization:

Since we are looking for a LOWER dose rate, it follows we have to move FARTHER from the source (answer must be > 1 ft).

From the ABIH USEFUL EQUATION sheet:

$$I_2 = I_1 [d_1/d_2]^2$$

Rearranging terms:

$I_1(d_1)^2 = I_2(d_2)^2$ 900 = 25 X $(d_2)^2$

so, $d_2 = \left[I_1(d_1)^2/I_2 \right]^{0.5}$, $(d_2)^2 = 36$, $d_2 = 6$ ft

Problem:

The radiation exposure rate from 1 g of ^{226}Ra in equilibrium with its daughters is 825 mR/hr at a distance of 1 m. If we had a source containing 100 mg of Ra what would the exposure rate be at 1 m ? To calibrate the 12.5 mR/hr midpoint on the scale of an instrument that measures up to 25 mR/hr, at what distance from the source would we place the detector?

100 mg = 0.1 gm therefore, the source strength is one tenth of above or 82.5 mR/hr at 1 m.

So we have 82.5 @ 1 m and we need the distance to get 12.5... again it should be farther from the source.

From the ABIH USEFUL EQUATION sheet:

$$I_2 = I_1 [d_1/d_2]^2$$

Rearranging terms:

$I_1(d_1)^2 = I_2(d_2)^2$ $\quad$ $82.5 = 12.5 \times (d_2)^2$

so, $d_2 = \left[I_1(d_1)^2/I_2 \right]^{0.5}$, $\quad$ $(d_2)^2 = 6.6$, $\quad$ $d_2 = 2.56$ m

Specific Gamma Ray Emission Γ

- **Basis:**

The radiation intensity from any given gamma-ray source is used as a measure of the strength of the source. The gamma radiation exposure rate from a point source of unit activity at unit distance is called the specific gamma-ray emission and is given in units of coulombs per kilogram per hour at 1 meter from a 1-MBq point source, or in the older system, R per hour at 1 meter from a 1 Ci point source.

$\mathbf{D = \Gamma A/d^2}$

- **D** is gamma exposure rate in R/hr
- **Γ** is specific gamma ray emission for the radioisotope usually given or tabulated.

  (unit: R-m^2/Ci-hr)
- **A** is activity of the source in consistent units (Ci)
- **d** is distance from the source in consistent units (meters)

The Curie-Meter Rule

The only Γ value that even a health physicist carries in memory is the gross oversimplification for Co^{60} -- which happens to come out to approximately 1 in the old system of units.

For Co-60, a common activation product gamma emitter in reactor applications, Γ is about 1 R/hr at 1 m from a 1 Ci pt. source.

Problem:

A 2.5 Ci radiography source of Iridium-192 has been involved in a construction site scaffold collapse. Until equipment is available to check the shield integrity, what exclusion perimeter will ensure no responder is exposed to greater than 100 mR/hr? (Γ for Iridium ^{192} is 0.48 R-m²/Ci-hr)

Conceptualization:

For this radioisotope, 1 Ci would result in an exposure rate of just less than .5 R/hr at a distance of 1 meter. We could have 2.5 Ci unshielded and question asks us to identify a distance that will reduce exposure rate below 0.1 R/hr (100 mR/hr = 0.1 R/hr)

From the ABIH USEFUL EQUATION sheet:

$$D = \Gamma A/d_2$$

Rearranging terms:

$$d = \left[\Gamma A/ D\right]^{0.5}, \qquad (d)^2 = 0.48 \times 2.5/ 0.1 = 12$$

d = 3.464 m, ~ 11 feet

$$A = A_i (0.5)^{t/T\,1/2}$$

- **A** is activity remaining after time t
- $\mathbf{A_i}$ is initial activity at time zero
- **t** is time duration of interest
- $\mathbf{T_{½}}$ is the half-life characteristic for the radioisotope of interest

NOTE: activity and time units have to match

Problem:

P32 has a half life of 14.3 days. A researcher orders 10 millicuries of P32 to label some tracer compounds. When a colleagues' illness causes him to start the experiments 4 weeks later, how much of the activity remains

Conceptualization:

We are given the initial activity and the time duration of interest. We are to calculate the decayed activity.

From the ABIH USEFUL EQUATION sheet: $A = A_i\,(0.5)^{t/T_{1/2}}$

Given:

A_i as 10 millicuries , $T_{1/2}$ as 14.3 days,
t as 4 weeks = 28 days ~ 2 half-lives

Substitute and solve for A:

$$A = A_i\,(0.5)^{t/T_{1/2}}$$

$$A = 10\text{mCi}\,(0.5)^{2} \qquad A = 2.5\text{ mCi}$$

Radioactive Decay Law

The decay of a radioactive sample is statistical in nature. It is impossible to predict when any particular atom will disintegrate. This random behavior is expressed mathematically as:

$$\mathbf{N = N_0\, e^{-\lambda t}}$$

N_0 is the number of nuclei present initially
N is the number of nuclei present at time **t**
λ is the radioactive decay constant.

Half Life

The half-life **($T_{1/2}$)** of a radioactive species is the time required for one half of the nuclei in a sample to decay. It is obtained by putting **$N = N_0/2$** in the previous equation:

$$N_0/2 = N_0\, e^{-\lambda T_{½}}$$

From which $$T_{1/2} = \ln 2/\lambda = 0.693/\lambda$$

radioACTIVITY

Activity is an expression of decay rate (dN/dt) so it also varies exponentially with time:

$$A = A_i \, e^{-\lambda t}$$

$$A = A_i \, e^{-0.693t/T_{1/2}}$$

Linear Attenuation/Absorption

Gamma and x-radations are attenuated exponentially when they [ass through any material. The dose rate due to X- or g-radiation emerging from a shield can be written as:

$$\mathbf{I = I_0\, B\, e^{-ux}}\text{ , where}$$

I_0 is the dose rate without shielding

I is the dose rate after passing through the shield of thickness **x**

u is the ***linear absorption coefficient,*** and

B is the buildup factor

Half Value Layer

The half-value layer (HVL) for a particular shielding material is the thickness required to reduce the intensity to one half its incident value.

$$I_2 = I_1 / 2^{x/HVL}$$

One HVL reduces the intensity to one half, two HVLs reduce the intensity to one quarter, three HVLs to one eighth ($1/2^3$)…

Effective Half Life

In most instances, biological elimination follows first-order kinetics (i.e., exponential elimination via the body's metabolism).

Biological half life ($\mathbf{T}_{1/2\ \mathrm{bio}}$) then describes the period necessary for the body to excrete one half of the initial inventory (burden).

Effective half life is then the combined effect of both radioactive decay and metabolic removal.

Effective Half Life

The effective half life can be derived by *dividing the product by the sum* of the radiological and biological half lives:

$$T_{\frac{1}{2}\,eff} = \frac{(T_{\frac{1}{2}\,rad})\,(T_{\frac{1}{2}\,bio})}{T_{\frac{1}{2}\,rad} + T_{\frac{1}{2}\,bio}}$$

Note: the time units have to be consistent

Example

For sulphur-35, the radiological half life is 87.1 days and the biological half life in the testis is 623 days.

$$\mathbf{T_{eff} = (T_r \times T_b)/ (T_r + T_b)}$$

$$\mathbf{T_E = 87.1 \times 623 / (87.1 + 623) = 76.4\ days}$$

Effective Half-life Insight

Where there are *significant* contrasts between radiological and biological half-lives, the effective half-life will approach the **shorter** of rad or bio half-life.

(This can occasionally allow M/C question to be answered without any calculation.)

What’s in the handout.

Who has Questions?