The questions that follow are typical calculations that are performed in the field as part of radiographic operations. They include using the inverse square law to determine shielding thicknesses, dose rates, and restricted/unrestricted area boundaries. While these are similar in nature, these questions are NOT taken from previous Industrial Radiography Certifying Exams. Please concentrate on HOW to solve the problem, not just the final answer.

Additionally, a knowledge of the Radioactive Materials Rules and Regulations, Chapter 391-3-17-.04, and an understanding of safe practices in the use of radiographic equipment, is required in order to perform well on the Certifying Exam. Please prepare accordingly.

**Inverse Square Law**

The inverse square law can be represented as follows:

\[ I_1 D_1^2 = I_2 D_2^2 \]

where

- \( I_1 \) = the initial dose rate (in R/hr or mR/hr),
- \( D_1 \) = the distance from the source where \( I_1 \) is measured
- \( I_2 \) = the second dose rate; units must be the same as \( I_1 \)
- \( D_2 \) = the distance from the source where \( I_2 \) is measured; units must be the same as \( D_1 \)

This equation can be rearranged to isolate the desired variable.

**Half Value Layer (HVL)**

The half value layer (HVL) is the thickness of a given shielding material that will reduce to dose rate by half. For example, if there is a source emitting a dose rate of 50 mR/hr, and you put a HVL of a material between yourself and the source, the dose rate on the far side of the shielding material will be reduced to 25 mR/hr.

A material will have different HVLs for different isotopes; i.e., concrete will have one HVL for Ir-192, and a different one for Co-60.

In most problems, you will need to determine the number of HVLs of shielding material that are needed. The number of HVLs can be determined using the following equation:

\[ N = \frac{\log \left( \frac{I_0}{I_d} \right)}{\log 2} \]

where

- \( I_0 \) = initial radiation intensity (R/hr or mR/hr)
- \( I_d \) = radiation intensity at a desired distance (R/hr or R/hr)
- \( N \) = number of HVLs

**Half-Life and Standard Dose Rate**

The half-life (\( T_{1/2} \)) is the amount of time required for an isotope to reduce its activity by a half. Each radioactive isotope has a set, constant half life, no matter how much (or little) of the isotope is there. For instance, if you have 1 Curie of activity today, after one half life has passed, the activity will be 0.5 Curie. The half life and standard dose rate for common radiography isotopes is as follows:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-Life</th>
<th>Standard Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ir-192</td>
<td>75 days</td>
<td>5.9 R/hr/Ci at 1 foot</td>
</tr>
<tr>
<td>Co-60</td>
<td>5 years</td>
<td>14.0 R/hr/Ci at 1 foot</td>
</tr>
</tbody>
</table>

Intensity (in R/hr) can be determined by multiplying the Standard Dose Rate (above) by the Isotope Activity (in...
In some problems, you will be asked to determine the activity of an isotope at a later date, given only the isotope and its initial activity. The activity at a later point in time can be determined using the same equation as that identified above for HVLs. With some rearranging, and substituting of terms, the equation becomes as follows:

\[
A_d = \frac{A_0}{2^N}
\]

where

- \( A_0 \) = initial activity (Ci)
- \( A_d \) = activity at a later date (Ci)
- \( N \) = number of half-lifes

Sample Study Questions

1. At a distance of 8 feet from a source of radiation, your survey meter reads 100 mR/hr. What is the radiation intensity at 1 foot from the source?

2. At a distance of 20 feet from a source of radiation, your survey meter reads 400 mR/hr. What is the radiation intensity at 30 feet from the source?

3. At a distance of 6 feet from a source of radiation, your survey meter reads 70 mR/hr. At what distance should you post your UNRESTRICTED AREA (2 mR/hr) boundary?

4. Your 2 mR/hr boundary is located at a distance of 10 feet from a source of radiation. At what distance would you post your CAUTION -- HIGH RADIATION AREA (100 mR/hr) boundary?

5. A source of radiation has created a radiation intensity of 128 mR/hr. How much shielding material with a HVL of .5 inch, is required to reduce the intensity to 2 mR/hr?

6. What is the radiation intensity at a distance of 2 feet from an uncollimated 2 Curie Cobalt-60 source?

7. At what distance should you post your UNRESTRICTED AREA (2 mR/hr) boundary from an unshielded 70 Curie Iridium-192 source?

8. An Ir-192 source was last assayed on March 1 with an activity of 80 Curies. What is the activity of the source on July 28?

9. A Co-60 source was last assayed on January 1992 with an activity of 5 Curies. What is the activity of the source in July 1999?

10. You are working with a 20 Curie Ir-192 source. The area is such that the farthest you can be from the source is 20 feet. You have shielding material in the form of concrete (HVL = 1.9 in.). How thick a wall must you build if you want the other side of the wall to qualify as an UNRESTRICTED AREA (radiation intensity < 2 mR/hr)?

11. What is the distance to the RADIATION AREA (5 mR/hr) boundary when using a 80 Curie Ir-192 source through a 20:1 reducing collimator?

12. When using 25 Curies of Ir-192, how many HVLs of shielding material are necessary to establish the “Unrestricted Area” at 25 feet away from the source?
Sample Study Questions -- Solutions

1. Solve using the Inverse Square Rule, rearranging for $I_2$

\[
I_2 = \frac{I_1 D_1^2}{D_2^2}
\]

where:

\[
\begin{align*}
I_1 &= 100 \text{ mR/hr} \\
D_1 &= 8 \text{ feet} \\
I_2 &= ?? \\
D_2 &= 1 \text{ foot}
\end{align*}
\]

\[
I_2 = (100 \text{ mR/hr}) \times (8 \text{ feet})^2 / (1 \text{ foot})^2 = (100 \times 64) \text{ mR/hr}
\]

\[
I_2 = 6400 \text{ mR/hr}
\]

2. Solve using the Inverse Square Rule, rearranging for $I_2$

\[
I_2 = \frac{I_1 D_1^2}{D_2^2}
\]

where:

\[
\begin{align*}
I_1 &= 400 \text{ mR/hr} \\
D_1 &= 20 \text{ feet} \\
I_2 &= ?? \\
D_2 &= 30 \text{ foot}
\end{align*}
\]

\[
I_2 = (400 \text{ mR/hr}) \times (20 \text{ feet})^2 / (30 \text{ feet})^2 = (400 \times 400 / 900) \text{ mR/hr}
\]

\[
I_2 = 177.7 \text{ mR/hr}
\]

3. Solve using the Inverse Square Rule, rearranging for $D_2$

\[
D_2 = \sqrt{\frac{I_1 D_1^2}{I_2}}
\]

where:

\[
\begin{align*}
I_1 &= 70 \text{ mR/hr} \\
D_1 &= 6 \text{ feet} \\
I_2 &= 2 \text{ mR/hr} \\
D_2 &= ??
\end{align*}
\]

\[
D_2 = \sqrt{(70 \text{ mR/hr}) \times (6 \text{ feet})^2 / (2 \text{ mR/hr})} = \sqrt{(70 / 2 \text{ feet}^2)}
\]

\[
D_2 = 35.4 \text{ feet}
\]

4. Solve using the Inverse Square Rule, rearranging for $D_2$

\[
D_2 = \sqrt{\frac{I_1 D_1^2}{I_2}}
\]

where:

\[
\begin{align*}
I_1 &= 2 \text{ mR/hr} \\
D_1 &= 10 \text{ feet} \\
I_2 &= 100 \text{ mR/hr} \\
D_2 &= ??
\end{align*}
\]

\[
D_2 = \sqrt{(2 \text{ mR/hr}) \times (10 \text{ feet})^2 / (100 \text{ mR/hr})} = \sqrt{(2 / 100 \text{ feet}^2)}
\]

\[
D_2 = 1.41 \text{ feet}
\]
5. Initial radiation intensity = 128 mR/hr

Intensity with:

1 HVL = 64 mR/hr
2 HVL = 32 mR/hr
3 HVL = 16 mR/hr
4 HVL = 8 mR/hr
5 HVL = 4 mR/hr
6 HVL = 2 mR/hr

HVL = .5 inch

Thickness = (HVL) * (# HVLs needed) = (.5 inch) * (6)

**Thickness = 3.0 inches**

**ALTERNATE METHOD:** Use the HVL equation

\[
N = \frac{\log \left( \frac{I_d}{I_0} \right)}{\log 2}
\]

where:

\[
\begin{align*}
I_0 &= 128 \text{ mR/hr} \\
I_d &= 2 \text{ mR/hr} \\
N &= ?? \\
\text{HVL} &= .5 \text{ inch}
\end{align*}
\]

\[
N = \left\lfloor \frac{\log (128 / 2)}{\log 2} \right\rfloor = 6
\]

**Thickness = (HVL) * N = (.5 inch) * (6)**

**Thickness = 3.0 inches**

6. Standard dose rate for a Co-60 source = 14.0 R/hr/Ci at 1 foot

Dose rate for a 2 Ci Co-60 source = 14.0 R/hr/Ci at 1 foot * 2 Ci

= 28.0 R/hr at 1 foot

Solve using the Inverse Square Rule, rearranging for \( I_2 \)

\[
I_2 = \frac{I_1 D_1^2}{D_2^2}
\]

where:

\[
\begin{align*}
I_1 &= 28 \text{ R/hr} \\
D_1 &= 1 \text{ foot} \\
I_2 &= ?? \\
D_2 &= 2 \text{ feet}
\end{align*}
\]

\[
I_2 = (28 \text{ R/hr}) * (1 \text{ foot})^2 / (2 \text{ feet})^2 = (28 * 1 / 4) \text{ R/hr}
\]

\[
I_2 = 7.0 \text{ R/hr}
\]
Sample Study Questions -- Solutions

(continued)

7. standard dose rate for a Ir-192 source = 5.9 R/hr/Ci at 1 foot
dose rate for a 70 Ci Ir-192 source = 5.9 R/hr/Ci at 1 foot * 70 Ci
= 413 R/hr at 1 foot

Solve using the Inverse Square Rule, rearranging for D

\[
D_2 = \sqrt{\frac{I_1 D_1^2}{I_2}}
\]

where:

\(I_1 = 413 \text{ R/hr} = 413,000 \text{ mR/hr}\)
\(D_1 = 1 \text{ foot}\)
\(I_2 = 2 \text{ mR/hr}\)
\(D_2 = ??\)

\[
D_2 = \sqrt{\frac{(413,000 \text{ mR/hr}) \times (1 \text{ foot})^2}{2 \text{ mR/hr}}} = \sqrt{(413,000 \times 1 / 2) \text{ feet}^2}^{1/2} = 454 \text{ feet}
\]

8. A period of 150 days has elapsed since the source was last assayed. The half-life of Ir-192 is 75 days. Therefore, divide the number of days elapsed by 75 to find the number of half-lives that have passed.

\[
150 / 75 = 2 \text{ half lives}
\]

After 1 half life, the activity will be 80 / 2 = 40 Curies
After 2 half lives, the activity will be 40 / 2 = 20 Curies

The activity of the source on July 28 will be 20 Curies.

ALTERNATE METHOD: Use the half-life equation:

\[
A_d = \frac{A_0}{2^N}
\]

where

\(A_0 = 80 \text{ Ci}\)
\(A_d = ?? = \text{ activity on July 28}\)
\(N = 2 \) (refer to above solution)

\[
A_d = \frac{80 \text{ Ci}}{2^2} = 20 \text{ Curies}
\]

9. A period of 7.5 years has elapsed since the source was last assayed. The half-life of Co-60 is 5 years. Therefore, divide the number of years elapsed by 5 to find the number of half-lives that have passed.

\[
7.5 / 5 = 1.5 \text{ half lives} = N
\]

Solve using the half-life equation:

\[
A_d = \frac{A_0}{2^N}
\]

where

\(A_0 = 5 \text{ Ci}\)
\(A_d = ?? = \text{ activity in July 1999}\)
\(N = 1.5\)

\[
A_d = \frac{5 \text{ Ci}}{2^{1.5}} = 5/2.828 = 1.768 \text{ Curies}
\]
Sample Study Questions -- Solutions
(continued)

10. standard dose rate for a Ir-192 source = 5.9 R/hr/Ci at 1 foot

dose rate for a 20 Ci Ir-192 source = 5.9 R/hr/Ci at 1 foot * 20 Ci

= 118 R/hr at 1 foot

Solve using the Inverse Square Rule, rearranging for \( I_2 \)

\[
I_2^2 = \frac{I_1D_1^2}{D_2^2}
\]

where:

\[
\begin{align*}
I_1 &= 118 \text{ R/hr} = 118,000 \text{ mR/hr} \\
D_1 &= 1 \text{ foot} \\
I_2 &= ?? \\
D_2 &= 20 \text{ feet}
\end{align*}
\]

\[
I_2 = (118,000 \text{ mR/hr}) * (1 \text{ foot})^2 / (20 \text{ feet})^2 = (118,000 / 400) \text{ mR/hr}
\]

\[
I_2 = 295 \text{ mR/hr}
\]

This is the value if no shielding material is utilized.

For the shielded condition, use the HVL equation:

\[
N = \frac{\log \left( \frac{I_0}{I_d} \right)}{\log 2}
\]

where:

\[
\begin{align*}
I_0 &= 295 \text{ mR/hr} \\
I_d &= 2 \text{ mR/hr} \\
N &= ?? \\
\text{HVL} &= 1.9 \text{ inch}
\end{align*}
\]

\[
N = [ \log (295 / 2)] / [ \log 2] = 7.2
\]

OR round up to 8

\[
\text{Thickness} = \text{HVL} \times N = (1.9 \text{ inch}) \times (7.2)
\]

\[
\text{Thickness} = 13.68 \text{ inches}
\]

OR

\[
\text{Thickness} = \text{HVL} \times N = (1.9 \text{ inch}) \times (8)
\]

\[
\text{Thickness} = 15.2 \text{ inches}
\]

11. standard dose rate for a Ir-192 source = 5.9 R/hr/Ci at 1 foot


dose rate for a 80 Ci Ir-192 source = 5.9 R/hr/Ci at 1 foot * 80 Ci

since using a 20:1 collimator, divide the above value by 20

= 23.6 R/hr

Solve using the Inverse Square Rule, rearranging for \( D_2 \)

\[
D_2 = \sqrt{\frac{I_1D_1^2}{I_2}}
\]

where:

\[
\begin{align*}
I_1 &= 23.6 \text{ R/hr} = 23,600 \text{ mR/hr} \\
D_1 &= 1 \text{ foot} \\
I_2 &= 5 \text{ mR/hr} \text{ (def. of “Radiation Boundary”) } \\
D_2 &= ??
\end{align*}
\]

\[
D_2 = [(23,600 \text{ mR/hr}) \times (1 \text{ foot})^2 / (5 \text{ mR/hr})]^{1/2} = [(23,600 \times 1 / 5) \text{ feet}^2]^{1/2}
\]

\[
D_2 = 68.70 \text{ feet}
\]
12. By definition, an “Unrestricted Area” is an area where the dose rate is less than 2 mR/hr.

standard dose rate for a Ir-192 source = 5.9 R/hr/Ci at 1 foot

dose rate for a 25 Ci Ir-192 source = 5.9 R/hr/Ci at 1 foot * 25 Ci
= 147.5 R/hr at 1 foot

Solve using the Inverse Square Rule, rearranging for $I_2$

$$I_2 = \frac{I_1 D_1^2}{D_2^2}$$

where:  
$I_1 = 147.5$ R/hr = 147,500 mR/hr  
$D_1 = 1$ foot  
$I_2 = ?\text{ }$  
$D_2 = 25$ feet

$I_2 = (147,500 \text{ mR/hr}) \times (1 \text{ foot})^2 / (25 \text{ feet})^2 = (147,500 / 625) \text{ mR/hr}$  
$I_2 = 236 \text{ mR/hr}$

This is the value if no shielding material is utilized.

For the shielded condition, use the HVL equation:

$$N = \frac{\log \left( \frac{I_0}{I_d} \right)}{\log 2}$$

where:  
$I_0 = 236 \text{ mR/hr}$  
$I_d = 2 \text{ mR/hr}$  
$N = ?\text{ }$

$$N = [\log (236 / 2)] / [\log 2]$$  
$N = 4.8 \text{ OR } N = 5$ (via rounding)