Introduction

In this module, we will go more in-depth into how to calculate the absorbed dose, exposure, dose equivalent, inverse square law, half-life and activity, concentration, specific activity as well as others.

Absorbed Dose

Absorbed dose is the amount of radiation that a mass (such as tissue, a kidney, the brain, or blood) will absorb. An example of an absorbed dose would measure the amount administered during radiation therapy.

Absorbed dose is defined as the amount of energy deposited divided by the mass. The amount of energy deposited is expressed in Joules. The outcome is expressed in gray. One gray is the absorption of one Joule of energy, in the form of ionizing radiation, by one kilogram of matter.

EQUATION

$$\frac{\text{Energy (Joules – J)}}{\text{Mass (kilograms – kg)}} = \text{Absorbed Dose}$$

Units of absorbed dose is the gray (Gy)

So, if 100 Joules of energy were deposited into 100 kilograms of mass, you would have one gray. One gray is equal to 100 rad (rad is the older terminology used in the industry).

$$\frac{\text{100 J (Joules)}}{\text{100 kg (kilograms)}} = \text{1 Gy (gray) or 100 rad}$$

Can you determine the energy deposited into the mass? You have 2 Gy of absorbed dose and 15 kilograms of mass.

$$\text{2 Gy} = \frac{\text{? J (energy deposited)}}{\text{15 kg (mass)}}$$

15 kg multiplied by 2 Gy equals 30 Joules.

To calculate the mass, take the joules and divide by the gray.

$$\text{2 Gy} = \frac{\text{30 J (energy deposited)}}{\text{? kg (mass)}}$$

Exposure

As a part of the ALARA plan, you'll need to know how to calculate your exposure at varying distances from the source of radiation.

EQUATION

$$X = \frac{(A \bullet \Gamma)}{d^2}$$

- **A** in the equation: is the activity of the source (**A**) measured in millicuries.
- Γ in the equation: is measured in roentgen centimeter squared per millicurie hour. Each gamma source of radiation has its specific gamma constant. Cesium 137 (Cs-137) has a different gamma constant from Barium 133 (Ba-133).
- **d** in the equation: is the distance between the source and the point of measurement

In this example, let us consider the following:

- **A** = 3500 mCi
- **d** = 4 meters

Γ Γ = $_{\text{Cs-137}}$ = 3.3 R-cm^2/mCi-hr

Before computing calculations, you MUST make sure that corresponding units agree. In this example, change the meters to centimeters or centimeters to meters.

1 meter = 100 centimeters. Therefore, 4 meters (m) = 400 centimeters (cm). The square of 400 cm equals 160,000 cm^2. Now the units agree.

$$X = \frac{3500\ \text{mCi}}{160{,}000\ \text{cm}^2} \bullet \frac{3.3\ \text{R-cm}^2}{\text{mCi-hr}}$$

X = 0.0722 roentgen per hour

This gives us the exposure of 0.0722 roentgen per hour. Since this is still a large unit, it is best to describe the exposure in smaller units if possible – in this case, milliroentgen per hour (mR/hr). The answer, 0.0722 roentgen per hour, needs to be converted.

0.0722 • 1,000 = 72.20 milliroentgen per hour (mR/hr).

So, in **10 hours** the person would have received **722.00 mR**

Activity and Decay

The property possessed by some elements (such as Uranium) of spontaneously emitting energy in the form of radiation as a result of the decay (or disintegration) of an unstable atom. Radioactivity is also the term used to describe the rate at which radioactive material emits radiation. Radioactivity is measured in curies (Ci), becquerels (Bq) or disintegrations per second. *U.S. NRC*

The half-life is defined as the time required for half the nuclei in a sample to undergo radioactive decay.

The activity of a sample remaining after a specified period of time has passed can be determined by using the following equation:

To determine the remaining activity, you'll need to know:

EQUATION

$$A \quad = \quad A_0(e)^{-\lambda t}$$

A in the equation is the final activity (in mCi)

A_0 in the equation is the original or initial activity

λ in the equation is defined as the ln |2| divided by the half-life. (ln|2| equals to 0.693

t in the equation is the elapsed time, which is the time between the date of calculation and the assay date.

Radio-Isotope: Iodine-131 (^{131}I)

A_0, 20 mCi

$T^{1/2}$ 8.02 days

t Date of calculation - Assay date (August 4 – August 2 = **2 days**)

λ ln |2| / $T^{1/2}$ = 0.693 / 8.02 days = **0.086**

Start with the base equation: $\mathbf{A = A_0\, e^{-\lambda t}}$

1. Calculate the values of λ and t respectively. $A = 20 \text{ mCi } e^{-(0.086)(2)}$
2. Multiply λ and t, leave the product negative $A = 20 \text{ mCi } e^{-(0.172)}$
3. Find the exponent of the product of λ and t $A = 20 \text{ mCi } (0.842)$
4. Multiply the value of e-(0.172) and A_0 **A = 16.84 mCi**

So, if you start with a sample of 20 mCi of Iodine-131, you will have **16.84 mCi** after two days.

Inverse Square Law

Inverse square law is a physical law stating that some physical quantity or strength is **inversely proportional to the square of the distance** from the source of that physical quantity.

EQUATION

$$\text{I}_{\text{ntensity}1}\ \text{d}_{\text{istance}}{}^{2}{}_{1} = \text{I}_{\text{ntensity}2}\ \text{d}_{\text{istance}}{}^{2}{}_{2}$$

I_1 Intensity of the exposure at the first location

d_1 Reference distance from the source of radiation

I_2 Intensity of the exposure at the second location

d_2 Distance at which you wish to evaluate the exposure

Typically, I_1, d_1, and d_2 are known, and the task is to identify the exposure at I_2. To identify the exposure at I_2, you must solve for I_2, which will, therefore, give you the following equation:

$$I_2 = \frac{(I_2 \bullet d^2{}_1)}{d^2{}_2}$$

Likewise, if I_1, d_1, and I_2 are known, and you wish to find d_2, solve for d_2, which will give you the following:

$$d_2 = \sqrt{\frac{(I_2 \bullet d^2{}_1)}{I_2}}$$

Consider the following illustration scenario. Your manager is seated several feet away from a source of radiation. He is wondering if he is at a safe distance from the source. You have been called upon to evaluate the concern and advise. The unit of distance will not matter as long as they agree. We will continue with the distance unit of feet (ft).

1. The source is ^{137}Cesium (Cs-137)
2. From the exposure equation, you calculated the reference exposure to be 500 mR at a distance of

   1 foot. Therefore,

   I_1 = 500 mR

   d_1 = 1 ft

3. You measured the distance between your manager and the source of radiation to be

   d_2 = 20 ft
4. Now you can use the inverse square law to calculate the exposure **(I_2)** at your manager's desk.

$$I_2 = \frac{(I_1 \bullet d^2{}_1)}{d^2{}_2}$$

$$I_2 = \frac{500 \text{ mR} \bullet (1 \text{ ft})^2}{(20 \text{ ft})^2}$$

$$I_2 = \frac{500 \text{ mR} \bullet (1 \text{ ft})^2}{(20 \text{ ft})^2}$$

$$I_2 = \frac{500 \text{ mR ft}^2}{400 \text{ ft}^2}$$

$$\mathbf{I_2 = 1.25 \text{ mR}}$$

Specific Concentration

Liquid radioisotopes can be ordered and then mixed with other liquid chemicals. When this occurs, it is important that the accurate concentration of radiation be recorded. A formula can calculate this.

The equation for radioactive concentration is:

The activity of the sample divided by the volume of the sample.

$$\textbf{Concentration} = \frac{\text{Activity}}{\text{Volume}}$$

Concentration will typically have units of millicuries per milliliter (mCi/mL), curies per liter (Ci/L) or similar.

Example, what If you have 30 mCi of activity in a volume of 15 mL, what would the radioactive concentration be?

EQUATION

Concentration = Activity / Volume

What if you know the concentration, but not the activity? Try this one.

Problem: You have 2 mCi/mL and 15 mL of volume.

2 mCi/mL and multiply by 15 mL, which equals 30 mCi of activity.

Activity = Concentration x Volume

Activity = 2 mCi/mL x 15 mL = **30 mCi**

Likewise, what if you need to determine the volume? Try this one.

Problem: You have 50 mCi and a concentration of 100 mCi/mL.

50 mCi and divide by 100 mCi/mL, which equals 30 mCi of activity.

Volume	=	Activity	/	Concentration		
Volume	=	50 mCi	/	100 mCi/mL	=	**0.5 mL**

Specific Activity

Certain calculations involving solid radioisotopes require that you know or calculate their specific activity. The unit of activity is usually represented as Bq (Becquerels), Ci (Curies) or DPS (Disintegrations per second). While the unit of mass is typically represented in grams (g). Like concentration, the specific activity can be calculated by dividing the ***activity*** of the sample by the ***mass*** of the sample.

EQUATION

Specific activity = Activity (in mCi) / mass (in mg)

What if you had an activity of 10,000 µCi and a mass of 25 mg. You are asked to determine the specific activity of the sample. In mCi/mg

First, you will need to convert µCi to mCi. We know that there are 1000 µCi in 1 mCi.

So, 10,000 µCi x (1 mCi / 1000 µCi) = **10 mCi**

Now, we can apply the proceed to substitute the variables.

Specific Activity	=	Activity	/	Mass		
Specific Activity	=	10 mCi	/	25 mg	=	**0.40 mCi/mg**

Conclusion

This concludes Module 2: Radiation Safety Calculations (RS102) Course Material. You must complete the Module 2 Assessment to receive credit for the course. The passing score is 90% or higher. Those who do not complete both modules in a timely period may be un-enrolled from the course. Should this happen, you can re-enroll and retake the course.

Want to Learn More?

UAB's Department of Environmental Health & Safety (EHS) has many training courses available to all UAB active employees and students including topics as radiation safety, biosafety, bloodborne pathogens, chemical safety, controlled substances, building life safety, hazardous and medical waste, universal waste, PPE, hazard communication, etc. EHS developed a **decision tree** to assist you in choosing the right course(s) to help you develop and maintain a healthy culture of safety and compliance. For more information or if you have questions, contact EHS at (205) 934-2487.