San Diego Mesa College Name:___________________________

Physics 197 Laboratory Experiment Date: ___________________________

Title: Radioactivity

Objective:

To investigate the relationships between a radioactive element, its decay rate and the radiation exposure hazard it presents. To familiarize the students with simple radiation detection equipment and shielding sources.

Theory:

The rate at which a radioactive element (the parent) decays into another element (the daughter) is set by a proportionality constant called the half-life. If the half-life is known, information about the decay rate may be used to identify the approximate age of the material.
Stable elements are those that decay at a slow rate and unstable elements decay rapidly. For this experiment we will investigate the decay of the Cobalt 60 isotope. Co-60 has the following decay scheme:

$$Co^{60} \rightarrow Ni^{60} + \beta^{-} + 2\gamma$$

whereby Cobalt decays to Nickel with the emission of an electron and two gamma rays. The emitted electron has a maximum energy of 0.32 MeV, one gamma ray has an energy of 1.33 MeV, the other has an energy of 1.17 MeV. We will examine the effects of these two gamma rays.

The Curie is the unit of radioactive decay and 1 Ci corresponds to $3.7 \bullet 10^{10}$ decays per second. The number of decays per second is also called the activity of a source. The source activity and the energy emitted per decay are related to the total amount of energy emitted by the source. The standard unit of measure is called the Roentgen and is related to the ability of gamma radiation to ionize air.

Since it is desirable to minimize the amount of radiation absorbed by a person, a new unit is created to relate radiation absorbed (the radiation dose) by a biological organism and any biological damage (the response) that may result. The REM (Roentgen Equivalent Man) is defined as follows:
"*The amount of radiation which will cause damage to the tissues of our bodies equivalent to that that would be caused by absorbing 100 ergs of gamma radiation per gram of body tissue*"
In other words, 1 REM = 100 ergs/gram for gamma radiation. Since people are not significantly different from air, 1 REM ~ 1 Roentgen for gamma radiation. The other radiation types have different conversion factors.

Whenever any radiation interacts with the cells of an organism, energy is deposited and ionization results. This leads to damage to the cell may cause it to cease functioning, or to function improperly. Since biological damage occurs at dose levels that cannot be detected by the individual radiation monitoring devices are especially important to minimize health effects. The devices used in this experiment are calibrated to respond to photon energies around 2 MeV and to read the resulting dose rate in units of milliRem/hour (mR/hr)

Since the energy deposited by a source depends on the number of photons (or particles) that strike the target, the radiation flux becomes a convenient way of describing a source. Radiation flux is defined as the number of photons/particles that reach a given area per unit time. For this experiment we will define the photon flux as:

$$\Phi = \frac{N_{photons}}{(cm^2)(s)}$$

The flux will depend on the activity and geometry of the source. In the simplest case, the source emits photons equally in all directions, making the calculation of flux

$$\Phi = \frac{Activity}{SolidAngle} = \frac{A}{4\pi r^2} = \frac{N_{Photons}/s}{cm^2}$$

Since the flux depends on the source activity and the solid angle, once the flux in one location is known it may be related to the flux in another location

$$\Phi_2 = \Phi_1 \frac{r_1^2}{r_2^2}$$

where r_1 and r_2 are the respective distances from the source.

Of course, the flux alone does not tell us enough about the amount of radiation involved. A low flux of highly energetic particles, or a high flux of low energy particles may result in the same radiation dose. To calculate the radiation exposure, a conversion factor that depends on the specific type of radiation is required. The following two conversion factors are used for the Co-60 decays we are examining.

For 1.17 MeV photons

$$4.7 \times 10^5 \frac{\frac{photons}{cm^2 s}}{\frac{R}{hr}}$$

For 1.33 MeV photons

$$4.3 \times 10^5 \frac{\frac{photons}{cm^2 s}}{\frac{R}{hr}}$$

These conversion factors allow for the calculation of dose if activity is measured, or the calculation of source activity if dose is measured.

Consider a 1 Ci source of a Co-60. Calculate the radiation flux at a distance of 50 cm from the source. Show all work, with units. Assume a spherical emitter.

Calculate the flux at a distance of 1 meter from the source.

Each Co decay produces a pair of photons. One photon has an energy of 1.17 MeV and the other has an energy of 1.33 MeV. The photons are produced simultaneously, so the flux we have calculated is too low by a factor of two. But, we can remedy this. By considering the two emitted photons as a single 'equivalent' photon we can relate activity to dose.

Using the information and ideas presented thus far derive an equation that relates the measured radiation exposure in mR/hr to the activity of a Co-60 source.

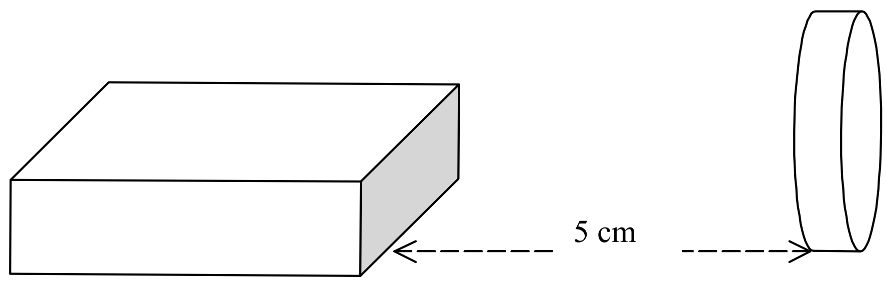
Equipment:

Cobalt-60 Test Source
Shielding Materials
Handheld Radiation Detector
Meter Sticks
Plastic Housing
Unknown Source (Orange Plate)

Note: Although only low levels of radiation will be utilized in this lab, basic radiological safety procedures must be followed.
• Do not contact the sources for longer then is necessary to make measurements.
• Do not eat or drink in the presence of the sources
• If a source container is broken, carefully place it on the table and contact the instructor immediately. Do not leave the area. Minimize contact with others and personal effects until instructed otherwise.

Setup and Procedure Part I: Determination of source activity

1) Unpack the detector from the case and move the selector switch to BATTERY. Once full-scale deflection has been observed, turn the switch to the lowest scale setting.
2) Place the Co-60 test source on edge as shown and place the detector 5 cm away, with the detector window oriented perpendicular to the source. Try to avoid proximity to the groups.



3) Observe the detector. You will note that it 'bounces' quite a bit. This is to be expected, and you will have to select a 'best average' value once the detector has stabilized. You may need to observe the detector for a period of time in order to make your determination. Record the value in the data table.
4) Use this value to calculate the expected source activity.
5) Repeat this process for source-detector distances of 4, 3, 2, and 1 cm.
6) Record the average of these calculated activities as SA1
7) Repeat the entire data collection step, calculate and record the average calculated activity as SA2
8) Record the average of SA1 and SA2 as your Source Activity.
9) Examine your test source and record the manufactured strength as well as the date of manufacture.

Data Part I:

Cobalt 60 Test Source		
Source-Detector Separation (cm)	**Measured dose rate (mR/hr)**	**Calculated Source Activity ($cm^{-2}s^{-1}$)**
5		
4		
3		
2		
1		
	SA1	
5		
4		
3		
2		
1		
	SA2	

Show a sample calculation, with units.

Source Activity ____________________________

Manufactured Activity ____________________________

Date of Manufacture ____________________________

Setup and Procedure Part II: Determination of unknown source activity

During the manufacturing process used to create the orange plate, a coating containing low levels of radionuclides was applied to increase durability and as a result, the plate itself is mildly radioactive. For our calculations we are going to make the simplifying assumptions that the plate may be treated a point source and a spherical emitter. We will further assume that all radioactive activity is due exclusively to the decay of Co-60.

1) Have one of the group members place the plate on edge and hold it in this position
2) Measure the dose rate at a distance of 1 meter and calculate the source activity
3) Repeat these steps for distances of 50, 45, 40 and 35 cm.
4) Record the average of the calculated source activities as Estimated Activity

Data Part II:

Source-Detector Separation (cm)	Measured dose rate (mR/hr)	Calculated Source Activity ($cm^{-2}s^{-1}$)
100		
50		
45		
40		
35		
	Estimated Activity	

Show a sample calculation, with units.

Analysis:

Calculate the percent error between the Manufactured Activity and the Source Activity found in part I.

In part, this discrepancy is because some time has passed since the source was manufactured, and the activity has decreased as the number of Co-60 atoms has decreased. Given that the half-life for Co-60 is 5.27 years, calculate the Modified Manufactured Activity according to the decay relation

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

where the decay constant is given by

$$\lambda = \frac{\ln 2}{5.27}$$

when t is elapsed time from date of manufacture and is expressed in years

Now, calculate the percent error between the Modified Manufactured Activity and the Source Activity found in part I

Assume that the orange plate was manufactured with an initial activity of 1 μCi. Approximately in what year was it manufactured? Explain your reasoning, show all calculations, with units.

Conclusion: Briefly discuss the physics involved in the experiment, summarize the data, address potential sources of error and methods to reduce or eliminate them, and state whether or not the experimental results validate the theory.