PHSX 222L **Absorption of Gamma Rays** **Name:**______________________

Object: To determine how lead and aluminum absorb gamma rays.

Theory: The radioactive source used to provide gamma radiation for this experiment is a 5.0 μCi cesium-137 sample. This isotope has a half-life of 30.2 years and emits gamma (γ) radiation at an energy of 0.6616 MeV. It also emits a some beta minus (β^-) radiation which we don't want.

It has been found that gamma radiation interacts with matter in a manner quite different than alpha or beta rays. This is due to the fact that gamma rays consist of high energy electro-magnetic waves, while alpha and beta rays are made up of high speed charged particles. As alpha and beta particles travel through matter they scatter off the atoms and thus follow a rather zig-zag path through the material, slowing down as they go. A gamma ray, being an EM wave or photon, can travel at only one speed—the speed of light. The three basic mechanisms of interaction of photons with matter are the photoelectric effect (in which the photon delivers all its energy to the charged particle and disappears), the Compton effect (in which some energy and momentum is transferred to the charged particle and the balance is carried away by another photon created in the process), and pair creation (in which a particle and its antiparticle are created according to $E = mc^2$).

The greater the distance of travel through a substance, the greater probability that the photon will be absorbed; *i.e.*, their number decreases approximately exponentially as they travel through the absorber. This means that for large numbers of photons, the number per minute N that survive a distance x in a substance is modeled by the formula

$$N = N_o e^{-\mu x} \tag{1}$$

where μ is the linear absorption coefficient of the substance, and N_o is the initial number of photons per minute. The slope of the straight line graph of $-\ln(N/N_o)$ vs. x should be μ.

A useful number related to this absorption process is the half-value layer (HVL), also known as the half distance, or $x_{1/2}$ of a substance. This is defined to be the distance through the material $x_{1/2}$ for which one half of the original photons will be absorbed ($N/N_o = 1/2$).

Because the decay process is totally random and predictions can be made only statistically, it is important to get as many counts as you have time for—this reduces the uncertainties. The effect of the air is negligible in this experiment.

Apparatus: Draw a diagram of the apparatus.

Safety: The radioactive sources are of extremely low activity and are not hazardous when used as directed. However, it is a good idea to treat all radioactive materials safely. For example, do not put the source in your pocket or bring it too near your body; handle it only when necessary, and return it when the experiment is over. For the safety of the equipment, please do not touch the end window of the Geiger tube or you will break it and destroy the tube. It cannot be repaired and it is expensive to replace.

Procedure: It would be convenient to make all time measurements in minutes for this lab.

1. With the Geiger tube mounted in its stand and with all radioactive sources placed well away, measure the background radiation. Place one aluminum plate in the stand in the top slot and leave it there for the rest of the experiment. This is done to block out the alpha and beta radiation that may be part of the background (and also emitted by the source). These alpha and beta particles are easily blocked by a single plate of aluminum, whereas most of the gamma radiation (which is what you want to count) passes through. Simultaneously press the reset button on the counter and start your stop watch. Allow the counts to go to at least 200 and record the time. Compute the background rate (in counts per minute or cpm).

2. Place the ^{137}Cs source, printed side up, in the depression at the bottom of the plastic stand.

   Measure N_o in cpm (let the counter reach at least 2500 counts for statistical purposes; more is better). Correct for background radiation by subtracting the background rate computed above. Remember that $x = 0$ for $N = N_o$.

3. By adding additional aluminum plates one at a time compute N for successive values of x, the metal thickness. Do not count the beta-shield in your cumulative plate thickness computations. Correct for background each time and assume the linear absorption coefficient is 0 for air.

4. Plot $-\ln(N/N_o)$ vs. x and compute μ (the least squares slope). Then compute the HVL ($x_{1/2}$) for Al. You might also average your value with those from the other groups in the class.

5. Interpolate the accepted value of $x_{1/2}$ from the chart on the web at `<http://www.safety.queensu.ca/safety/radiation/course/hvlchart.pdf>` and compare your value to it.

6. Either repeat for lead (assume the same background rate and continue to use the single sheet of aluminum to filter out alphas and betas) or verify the inverse square law for intensity as a function of distance from the source, (or both) as you have time. If time permits, play with alpha and beta sources and note their lack of penetrating power.

Questions:

1. Explain why if your data points do not lie well on a straight line.

2. Average your value of $x_{1/2}$ with those of the other groups in the class. How much closer is the average to the accepted value? Discuss systematic vs. random errors.

3. In first-year physics we have gone to great lengths to make our graphs linear. This is because the math of straight lines is straight forward. You linearized your graph today by taking logarithms. Qualitatively sketch a graph of your data *without* linearizing it, *i.e.,* a graph of N/N_o vs. x. No numbers are necessary.

Conclusions: