Experiment 4
Detector Efficiency and Activity of Salt Substitute

Your goal in this experiment is to measure the activity of a Salt Substitute, KCl, that is sold in supermarkets. To measure the activity, you will first need to calibrate your NaI detector for efficiency. The data will be collected in room 4-3-567, and in room 8-35 you will discuss the background material, the details of the experiment, and perform the calculations and analysis. We will split the class up into two groups. Each group will spend around one hour in room 8-35 and around an hour in room 4-3-567. The activities in each room are described below. Then we will all finish the data analysis together in room 8-35.

Room 8-35

A common salt substitute for $NaCl$ is KCl. Most potassium found on earth is ^{39}K, which is stable. However, some of the potassium on earth is the isotope ^{40}K, which is radioactive. ^{40}K has a very long half-life, around 1.277×10^9 years. When ^{40}K decays, it can emit a gamma that has an energy of 1460 KeV. The yield for emitting this gamma is 0.1067. That is, when ^{40}K decays, there is a 10.67% chance that a 1460 KeV gamma will be emitted.

In order to determine the activity of a sample, one needs to know the efficiency of the detector. Basically, the efficiency ε of a detector is defined as (the number of particles detected)/(the number of particles emitted).

$$\varepsilon \equiv \frac{particles\ detected}{particles\ emitted} \tag{1}$$

The efficiency is a number between zero and one. If we know the efficiency of our detector, then measuring the number of particles detected will allow us to determine the number of particles emitted in our sample. The efficiency of a detector will depend on a few factors, the most important are:

A. The source-detector geometry: The number of particles detected will depend on how close the source is to the detector. The closer the source is to the detector, the larger the efficiency will be.

B. The size of the detector: Larger detectors will usually be more efficient, since they have a larger volume for the particles to absorbed in.

C. The energy of the gamma (or X-ray) radiation: The photopeak is produced by photo-absorption. The photo-absorption process has a strong energy dependence. For high energy photons, photo-absorption has a lower probability to occur than photons of low energy.

For solid scintillation detectors, NaI and Ge, the dependence of ε on energy, number 3 above, is quite large. For example, NaI detectors can detect 100 KeV gammas about 4-5 times more efficiently than 1200 KeV gammas. This means that although a photopeak at 1200 KeV is small compared to one at 100 KeV in a particular spectrum, there might be more 1200 KeV gamma emitted than 100 KeV gammas.

The efficiency depends on the three factors listed above, however one often keeps the source-detector geometry fixed during a series of experiments. That is, for a series of experiments one places all the samples in the exact location relative to the detector. In addition, one can use samples that are all the same size and shape. If this is the case, then factors 1 and 2 above are the same for all the samples in a particular experiment. Then, the only calibration necessary is the energy dependence of ε. In our experiment we will try and keep the source-detector geometry the same (or close to) that of the salt sample.

The energy dependence for a particular source-detector geometry is measured by using standardized sources. One can purchase sources in which the activity has been calibrated by the manufacture. If the activity of the source is known, then the number of gamma particles emitted can be calculated. By measuring the number of gammas (of a particular energy) detected during a specific time interval, the efficiency ε can be determined.

In our experiment we will use the following isotopes from our laboratory for our efficiency calibration:

Isotope	Energy (KeV)	Gamma Yield	Activity (μ Ci	date
Cs^{137}	662	0.85	1.12	Feb 1, 1985
Cs^{137}	662	0.85	1.12	March 30 1985
Cs^{137}	662	0.85	1.04	May 20 1977
Na^{22}	511	1.8	9.56	March 9, 2006
	1275	1.0		
Bi^{207}	lower energy	0.977	1.038	May 1, 2007
	higher energy	0.745		
Bi^{207}	lower energy	0.977	1.32	May 1, 1980
	higher energy	0.745		

1. From the data in the table above, calculate the number of gamma's emitted per second by each isotope for the gamma energies listed in the table.

Data from the KCl sample

Since we need to collect data for a long time for good statistics, the spectra for the salt sample has been collected before the lab. Two spectra were taken for each of the eight NaI detectors in room 4-3-567. A two hour reading with the salt sample present, and a two hour reading with no sample. The data is posted on my home page.

2. Using the Gaussian curve fitting program determine the area under the 1460 KeV photopeak for both the salt sample spectra and the background spectra.

Room 4-3-567

Note where the salt sample was placed when its radiation was measured. We need to estimate where the effective center of the salt sample would be. Then, for each of the calibration sources, Cs^{137}, Na^{22}, and Bi^{207}, measure the number of gamma's detected per second when the calibration source is located near the effective center of the salt sample.

Whole class final analysis back in room 8-35

Once you have calculated $\epsilon(E)$ for the 5 standard energies, graph your results. Extrapolate your graph using an appropriate trendline to estimate the efficiency ϵ for the energy of the gamma given off by K^{40} (i.e. 1460 KeV).

Note that the efficiency graph is not as accurate as the calibration of energy for the scintillation detector. One problem is that it is expensive to obtain accurate calibrated standards. In our laboratory, the standards are calibrated for activity to within 5%. Errors also enter due to the uncertainty of the geometry factor and extrapolating. The uncertainty in the efficiency calibration can be as large as 50%.

Carry out the necessary calculations to determine the activity of ${}^{40}K$ in the salt substitute sample in units of decays/sec. Estimate the uncertainty of your value.

We will also calculate the activity of the salt sample in a different way, from only knowing the mass of the KCl sample. This method will be explained in class. Participate in the classroom discussion, and turn in your calculation.

Laboratory Writeup for Experiment 4

1. (8 points) Turn in your data and all calculations for measuring the efficiency ϵ for each of the 5 calibration energies.

2. (6 points) Turn in a graph of ϵ versus E for the 5 calibration energies, and explain how you extrapolated to find $\epsilon(1460\,KeV)$.

3. (4 points) Show all calculations for your estimate of the activity of K^{40} in your salt sample.

4. (2 points) Show your calculation for the activity of the salt sample using only the mass of the salt sample.