## Laboratory Experiment on Natural Radiation

Your goal for this experiment is to measure the radioactive isotopes in an environmental sample. You can pick a soil sample from the laboratory, your own soil sample, or other samples available for analysis. Possible isotopes found in environmental samples include: $^{40}K$, isotopes from the $^{238}U$ series, isotopes from the $^{232}Th$ series, isotopes from the $^{235}U$ series, and sometime $^{137}Cs$ from nuclear fallout. Your task is to measure the activity, in units of decays/sec/Kg or Bq/Kg, of any of these isotopes, as well as any other isotopes you find. Since we know the natural abundance of $K^{40}$, you can also determine the amount of potassium in the soil.

For the analysis we will be using our high resolution Ge detector. The spectrum analysis techniques are similar to those of the NaI detector, and you can apply what you learned from the previous experiments. We would like to let you figure as much out on your own, like a real experimentalist. This manual will give you guidance.

In your environmental sample you will see many photopeaks. The equation that relates activity (decays/time) to (gammas counted)/time is

$$\begin{aligned}\frac{counts}{time} &= (Activity)(gamma\ yield)(efficiency)\\ \frac{counts}{time} &= AY\epsilon(E)\end{aligned}$$

where Activity equals decays/time, and the efficiency $\epsilon$ depends on gamma energy $E$. A very useful quantity for our environmental analysis is (counts/time)/(yield). Dividing both sides by the yield gives:

$$\frac{counts/time}{Y} = A\,\epsilon(E) \tag{1}$$

where the efficiency has a strong energy dependence.

To determine the energy dependence of the efficiency $\epsilon(E)$, a $^{232}Th$ sample can be used. The $^{232}Th$ decay series is in secular equilibrium, which means that every isotope in the series has the same activity $A$. Thus, a graph of (counts/time)/yield as a function of gamma energy will give a curve that is proportional to the efficiency of the detector for our sample.

We will first calibrate the Ge detector, then analyze the environmental samples.

### Detector Calibration

To calibrate the detector we will take spectra of $^{137}Cs$ (cs137.cnf), a spectra of $^{137}Cs$, $^{22}Na$, $^{207}Bi$, and $^{60}Co$ all at the same time (cal.cnf), and a $^{232}Th$ (lantern.cnf) sample. From these three spectra determine:

1. **FWHM**: The FWHM at 662 $KeV$ can be measured from cs137.cnf.
2. **Energy calibration equation**: An energy calibration equation can be obtained from cal.cnf. Determine the accuracy of the calibration equation from the residues in comparing with the standard energies.
3. **Energy dependence of efficiency**: By graphing counts/yield for the gamma's emitted in lantern.cnf, you should be able to identify a range of energy where the efficiency decreases as a power law relation, $\epsilon \sim E^b$. We will refer to this energy range as the "power-law energy range".

Environmental Sample Analysis

From the graph of the $^{232}Th$ sample you can identify the "power-law energy range" where the efficiency $\epsilon$ has a power law dependance. That is $\epsilon(E) = KE^b$. For gammas in this energy range we have

$$\frac{counts/time}{Y} = A\ KE^b \tag{2}$$

This equation will apply to all gammas emitted from the environmental sample in the "power-law energy range". You need to find $K$ and $b$ to get a quantative measure of the activities. Here are some guidelines:

1. The exponent $b$ is critical, and you should find it first. Measure the (counts/time)/yield for the high yield gammas in the $^{238}U$ and $^{232}Th$ decay series in the "power-law energy range".
2. Use the soilfit program to find the best fit to the two decay series, and hence the best fit value for $b$.
3. To determine $K$, use the $KCl$ "standard" sample which has the same size and shape as the environmental samples. Since we know its mass, we can determine the activity of $^{40}K$. Measuring the (counts/time) for the 1460 $KeV$ photopeak, you can determine $K$. Note, the value for $K$ obtained this way is somewhat approximate since the $KCl$ sample will have different absorption properties and

a different density than the environmental sample. However, since the gamma has a high energy, these differences are reduced.

Once you have determined $K$ and $b$ you can obtain the activity of any isotope in the environmental sample that emits a gamma in the "power-law energy range".

Note that to be sure you have single gamma peaks, you will need to check that the width parameter $\sigma$ is consistent with other single peaks. If $\sigma$ is unusually large, the single peak might be made up of two gammas that are very close in energy. If this is the case, then you can use the "double Gaussian Peak fit" option in the code. If you know there are two peaks close in energy from the tables, you can resolve them using the double peak option.

## Writeup for Experiment 5

1. Turn in the data and show your calculation for determining the FWHM of the detector at gamma energy 662 $KeV$.
2. Turn in the data and graph for determining your best fit equation for the relationship between channel number and energy. How accurate is your energy calibration equation. Explain how you estimated the energy uncertainty for your equation.
3. Turn in the data and graph for the Thorium decay series. For what range of energies does the efficiency have a power-law dependence? Explain how you obtained this "power-law energy range".
4. Turn in the data for your measurement of the (counts/time)/yield for the gammas in the decay series that you measured.
5. Show your results (and graph) from using the soilfit program.
6. Show your data and calculation for determining the constant $K$.
7. Show your calculations and discuss your results for measuring the activity per Kg (Bq/Kg) in your sample for: the $^{238}U$ series, the $^{232}Th$ series, the $^{235}U$ series, $^{40}K$, and any other radioactive isotopes you find.
8. Show your calculation for determining the amount of potassium, in units of percent by weight, in the soil sample.
9. Discuss any other samples you analyzed for this experiment.