Identification of Naturally Occurring Radioactive Material in Sand

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Abstract

Radionuclides that occur in the environment through natural means, known as Naturally Occurring Radioactive Materials (NORM), are mostly by-products of the Thorium and Uranium nuclear decay chains. These are naturally occurring substances that emit gamma rays before reaching their ground state. For this reason we used a high purity germanium detector, to perform a gamma spectroscopy analysis on the samples of sand from the Southeastern shores of Lake Michigan, Notre Dame and Germany. It was determined that Germany rock had the highest levels of NORM when compared to the other samples.

Introduction

The radionuclides that occur in nature can be broken down into two groups. The first group is the primordial group which means that the half-life of the nuclide is comparable to the life of the earth on the order of $10^9$ years. The second group is the secondary nuclides, which have gained existence through the decay of the primordial nuclides. There are three decay chains that are the most common and are all headed by different nuclides. The Thorium decay begins with the Th-232 and the Uranium decay begins with U-238.[4]

The process of these decays go through one of three modes of decay to become a daughter nuclide; alpha, beta minus and beta plus. Alpha decay occurs largely in elements with atomic numbers greater than 83. During this process an
alpha particle is emitted which changes the atomic number of the parent nuclide because an
alpha particle is a He nucleus. The alpha mode of decay can be seen as: $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$

The other two modes of decay are very similar because they are both beta decay but have
different products. Beta minus decay yields a beta particle which is an electron and comes from
the process of a neutron converting to a proton and emitting an electron, it is characterized
by: $^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e + ^{0}_{0}\nu_e$

The beta plus decay goes through a similar process but its product is different from the beta
minus, it begins with a proton and converts it into a neutron while emitting a positron during the
process, which can be seen as: $^{1}_{1}p \rightarrow n + ^{0}_{+1}e + ^{0}_{0}\nu_e$

Both decay modes emit a neutrino, antineutrino for beta minus and a neutrino for beta plus, this
is done to conserve angular momentum and energy [1].

During the process of nuclear decay there is a possibility that when the parent nuclide
decays to the daughter nuclide that the daughter nuclide will be in an excited state or a ground
state. If it is in the ground state it will continue on the decay chain unless it is stable. If it is in an
excited state then it will get to the
ground state by other means, which
is through the emission of gamma
rays. In some cases a nucleus will
emit a single gamma ray and then
drop to the ground state energy. More commonly the nucleus will emit a cascade of gamma rays
to drop to the ground state. Once in the ground state the nucleus no longer emits gamma rays but
it may undergo nuclear decay if it is unstable [4].

The detection system for low count environmental radioactivity experiments is
commonly a coaxial high purity germanium detector. These detectors are used because of their superior energy resolution. When performing low count experiments the background needs to be minimized so that the detector is recording data from the sample and not the background environment. This is especially important when collecting gamma spectra because the building materials that may surround the detector could have nuclides that are gamma emitting. The best example of this is the Potassium-40 that is in all concrete, if this is not taken into account then the Potassium-40 line on the spectra will be much higher than it should be, this is also true for the Uranium, Cesium and Thorium lines. In order to minimize this, shielding must be placed to prevent gamma rays from getting through to the detector. Lead is the ideal shielding material because of its high density. With the use of lead there is a chance that the emitted gamma rays will excite an electron in the lead and the lead K-lines will be visible in the spectra, these K-lines can be minimized by adding another layer of shielding which is usually a copper layer [1].

Experimental Setup

The samples from Lake Michigan were collected over a single day in April 2012, and were taken from a 50-mile stretch of lake shore ranging from Gary, Indiana, to New Buffalo, Michigan. The sand was taken from the surface and collected in amounts of approximately 4 to 5 pounds. The sand was collected in airtight bags and was stored for two months before the experiment started. In order to optimize the data collected, the sand samples were placed in a vacuum oven and baked at 100 °C to remove any moisture contained in the sand. Once the sample had cooled it was then put through a filtering screen to remove any rocks and vegetation that it contained, to ensure the homogeneity of the sample. The samples were stored in airtight bags until ready for use. Then they were placed in a marinelli and sealed for use.

The detector that is used is an HPGe, which is cooled to liquid nitrogen temperature and
biased up to -4000V. The detector is encased in a 10 cm thick lead castle which is lined with .2 cm copper plates, to reduce background and the x-ray fluorescence from the lead castle. The detector was calibrated using a 10.00 µC Co-60 source, with the characteristic gamma lines at 1173.2keV and 1332.5keV. Because drifting can occur, the calibration was checked before each sample ran. Before the sand was analyzed, a background was collected for 172,800 seconds and was used for comparisons with each sample spectrum. Once the samples were ready for use the beaker was massed and placed on the detector where it ran for 172,800 seconds to be consistent with the background run time. The spectrums were recorded using the Maestro MCA which used the Ortec Amplifier and converted the signal from the detector to the spectrums seen.

Results

With the spectra for each run collected, a series of regions of interest (ROIs) were placed on peaks that were produced from NORM [1], [2], [3] which can be seen in the following figure:
The same ROIs are used for each run, where the net number of counts and the centroid energy are the most important pieces of information from the ROIs. The ROIs are also used to look at the spectra from the background as well. In some runs the centroid energy would shift, which would take a closer look to resolve problems, sometimes this would occur because a previously unseen peak would record significant counts and displace the centroid peak. This was corrected by focusing the ROI on the targeted peak. The previously unseen peaks could be of interest for future research.

Analysis

Once the ROIs were identified for all the runs, including the background spectrum, the comparisons between samples were achieved by first subtracting the background counts from the sample spectra. This was simple to do because the background and sample collection times were the same and no scaling factor was used to subtract the background counts. The subtracted
spectrums still looked similar to the unsubtracted but the significant part was that counts in
certain areas changed. In order to make comparisons between samples there must be a constant
that all samples could be compared to, and for this project the 5th sample spectrum was chosen
for that purpose. The normalization of the spectra data was key to looking at the amount of
counts in an ROI and comparing the data to other spectra. However, there were differences in the
amount of sample material between runs so the normalized data was then scaled by mass to
either increase or decrease the counts dependent on the mass ratio to the 5th spectrum.

Since the data had been both normalized and scaled they were easily comparable for
individual peaks, but the goal was to find out whether a sample had more Uranium, Thorium,
Cesium or Potassium than any other samples. For Cesium and Potassium this is simple because
there is only one peak that corresponds to Cesium and Potassium. When looking at Uranium and
Thorium it is more difficult because the decay chains corresponding to Uranium and Thorium
have multiple daughter products, which means there is more than one line associated with
Uranium and Thorium. To address this, multiple peaks corresponding to Uranium and Thorium

![Average Uranium](image1)

![Average Thorium](image2)
were taken and averaged to give the amount of Uranium and Thorium when compared to the normalization run.

The same was done for the amount of Potassium-40 and Cesium-137.

Conclusion

After performing the analysis it was clear that the most active source overall was the run consisting of rock taken from Germany. This result was expected because the rock in Germany is known to be mostly granite, which is more radioactive than other sand [1]. The second most active was a sample from New Buffalo, which had the second highest amount of Thorium and Uranium, but no Cesium and an average amount of Potassium. An interesting result was that the St. Joseph beach sand registered normal levels for all nuclides except Cesium for which it had a larger amount.

The ability to identify the entire NORM in the data spectra is important to figuring out the amount of Uranium, Thorium, Cesium and Potassium, however the results only extend to this experiment because the normalization was a run done during the experiment. The future project
could be to determine the activity of all the nuclides and figure out exactly how much is in a sample. With that known the next thing would be to determine the dosage rate a person can get by being near the beach and the corresponding NORM.
References

[1] Malin, D., 2011, ‘Measurements of NORM in Beach Sand Samples along the Andaman Coast of Thailand after the 2004 Tsunami”

