Gamma Ray Spectrum Analysis

Author: Stephen Oman

Email: stephen.oman@yahoo.co.uk

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# Overview

The purpose of this program is to determine if a gamma ray spectrum from a test sample contains fissile material. The fissile material gives off a particular spectrum, which can be sourced from known reference warhead or from an on-the-spot reading from a warhead. The program also takes into consideration the background spectrum from the environment.

For example, here is a spectrum for Thorium.

It uses several well-known techniques to match gamma ray spectra. For example, each spectrum can be viewed as a continuous curve, with peaks and troughs. These peaks (also called regions of interest) are spikes in the gamma ray count across a group of nearby frequencies. To match two different spectra, there must be close correlation between these peaks in the reference and test sample.

The program uses Mariscotti’s method to find the peaks in the spectrum. This is a two step algorithm:

1. Find the second derivative of each of the frequencies on the spectrum.
2. Apply a smoothing function to each second derivative, which is the sum of the three nearest neighbours on either side of the frequency. Repeat this step 5 times.

The result is to magnify peaks in the spectrum and also importantly, to separate overlapping peaks.

Here is an example of the above Thorium spectrum, after Mariscotti’s method is applied.

The peaks and troughs are readily identifiable from this process. Here is another example, this time Uranium:

The spectrum from Uranium is more complex than Thorium. There are several overlapping peaks in the first 250 channels, but Marisotti’s method simplifies this and separates out the peaks as shown below.

The smoothed function then lets us identify a region of interest (i.e. a peak), which is bounded by two channels. This boundary is the local minima on either side of the maximum peak value.

To calculate the area of the peak, the standard formula from Simpson’s Rule is used.

Each peak from the reference sample is then compared with the corresponding region of interest in the test sample to see if it matches, within a given tolerance level (since the samples may be affected by noise).

The region of interest in the test sample is also checked for interference. This can happen in many ways, due to environmental interference (temperature, humidity, nearby unrelated sources of gamma rays etc.). A standard check in the literature is to compare the Full Width Half Maximum (FWHM) value against the Full Width at 10% of Maximum.

This means checking how wide the peak is half-way up (how many channels it spans) against how wide it is lower down. From this we can detect if the peak is too fat, indicating interference from nearby frequencies.

Since not all peaks are really interesting (there are lots of small peaks in the higher channels), the program also weights each matched peak as a proportion of the overall spectrum. So bigger, more interesting peaks contribute more to the confidence it has in deciding if there is a match than the smaller peaks do.

Finally, the program decides there is a match and fissile material is present in the sample if it’s confidence value is greater than 95%.

# Program Structure

The spectrum is represented in a file containing a series of numbers. The first two numbers represent the start and end time that the sample was taken over. This is important to normalize the counts between this sample, the reference sample and the background sample. Each additional number is the count of gamma rays detected within a particular frequency.

The program has five parameters:

1. Name of the file containing the spectrum from the sample to be tested
2. Name of the reference spectrum file
3. Name of the background radiation spectrum file
4. Number of frequencies sampled (each data file above should have this number of data points)
5. Threshold (Each sample reading is affected by noise, so they are never going to match exactly. So this number represents a percentage deviation on either side of the reference value that will match a test sample. This should be a floating point number between 0 and 1, with values close to 0 representing less tolerance for noise.)

A sample main.c function is included to demonstrate the required match() function in operation.

The core source files and functions are:

gamma.h / gamma.c

This file contains the main matching function.

int match(double \*test, double \*reference, int bins, double threshold)

Match carries out the following steps:

1. Calculate the overall energy of the reference spectrum. This is equivalent to calculating the area under the whole spectrum curve. It will be used later to apportion a degree of confidence in an individual peak.
2. Identify each region of interest in the reference spectrum. A region will be identified by three integers, representing the leftmost channel, the maximum value channel and the rightmost channel.
3. For each region of interest, check the corresponding region in the test spectrum for the integrity of the peak it represents.
4. Match each region of interest in the reference spectrum with the corresponding region in the test spectrum. Add the weighted match to the overall confidence value.
5. Finally, display some messages to the user depending on what the program has discovered about the two spectra.

utility.h / utility.c

This file contains the following supporting functions:

int get\_data(double \*data, const int bins, const char \*filename)

This function simply reads in the data in the file “filename” and stores it in the memory location pointed to by “data”. It is the responsibility of the calling function to allocate enough memory to store “bins” amount of data.

As mentioned above, the values stored will be normalised to per-second values, to allow spectra with different sampling times to be compared.

int find\_regions(double \*reference, int num\_channels, int \*regions)

There are two major parts to this function. The first part implements Mariscotti’s Method as described above to emphasise the peaks and troughs in the spectrum pointed to by “reference”. The second part scans the resulting emphasised spectrum and identifies regions as three channels (leftmost, maximum, rightmost). These are stored in the array pointed to by “regions”. As usual, the calling function is responsible for memory management.

calc\_peak\_area(double \*channels, int width)

This function calculates the area under the peak (region of interest) using Simpson’s Rule. It is a standard method where a curve is represented by a series of discrete points as is the case with a gamma spectrum.

peak\_integrity(double \*test, int \*region)

This function checks that a peak is well formed. This is done by measuring the full width of the peak at half of it’s maximum value (fwhm) and the full width at 10% of the maximum (fwlm). When FWLM divided by FWHM is less than 1.9, it indicates good peak shape at that point in the spectrum.

double match\_peak(double \*test, double \*reference, int \*region, double spectrum\_energy, double threshold)

This function is responsible for checking that the peak in the test and reference spectrums have similar areas. To avoid double precision rounding and comparison errors, it checks if they are proportionally similar rather than exactly the same.

The peaks may also differ because of environmental noise, so the user can adjust the threshold for a match to be found.

Lastly, it divides the area of the reference peak by the area of the whole spectrum to get a weighted confidence. The effect of this is to give more weight to higher peaks in the spectrum when evaluating if the whole spectrum matches.

# Building The Code

The code is written to the C99 standard and should compile without warnings or errors on all platforms. It does not use any specific compiler-dependent options.

An example build command is:

gcc –o gamma utility.c gamma.c main.c

# Additional Files

Sample spectra are included for example purposes:

background.txt – contains a sample background radiation signature

thorium.txt – contains a sample spectrum for Thorium

uranium.txt – contains a sample spectrum for Uranium

# Example Output



# Sources:

Thorium, Uranium and Background radiation spectrum

https://www.cpp.edu/~pbsiegel/nuclear.html

Y-Spect: A Multi-Method Gamma Spectrometry Analysis Program

P.I. Yazid Center for Nuclear Technology of Material and Radiometry, National Nuclear Energy Agency Jl. Tamansari 71, Bandung 40132, Indonesia

http://aij.batan.go.id/index.php/aij/article/viewFile/222/168

General Topics in Passive Gamma-Ray Assay

J L Parker

Los Alamos National Laboratory

http://www.lanl.gov/orgs/n/n1/panda/00326400.pdf

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