

RADIOACTIVITY IN OUR ENVIRONMENT

GAMMA-RAY SPECTRA II

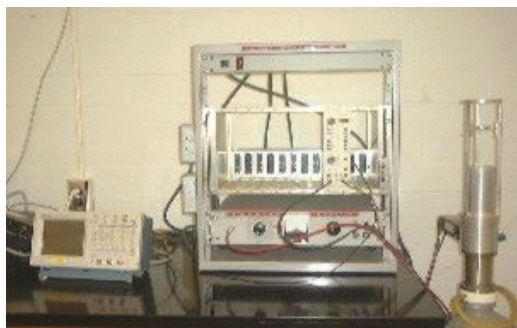
Objectives

- to recognize that each kind of radioactive nucleus emits an unique set of energies of gamma rays
- to become familiar with the use of an high purity germanium detector and multichannel analyzer to detect and determine the energies of gamma rays
- to be aware of sources of radioactivity around us by measuring the gamma rays emitted
- to identify the isotopes in these sources from analysis of the gamma ray spectra

References

W.R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, (Springer-Verlag 1987)
Tables of Gamma-ray and X-ray energies, (compiled booklet available at the Resource Centre)
APTEC PCMCA/Super Manual, chapter 2 (selected sections available at the Resource Centre)
Chart of the Nuclides (on the wall outside the northern door of room 224)
Eugene Hecht, *Physics (Calculus)*, chapter 32 (Brooks/Cole 1996)

Introduction



In this experiment you will be investigating radioactive sources around us. We provide five possible things that you might look at, and let you think up a sixth. These are:

- a. The "natural" background radiation in the room you are working in,
- b. "Fiesta" ceramic tableware; beautiful colourful dishes produced in the 1950s which used uranium to colour their glazes,
- c. Depleted uranium (DU), the same stuff that was used in anti-tank shells during the Gulf War,
- d. Antunite or Pitchblende rock samples,
- e. Fireplace ashes taken from burnt older trees,
- f. Anything else that you bring in that you might suspect as being radioactive and would like to check-out for gamma radiation.

For this 2-weight experiment, you must do sections 1 and 2, in "What to Do" below. This includes the introductory steps of learning and doing all the steps necessary for calibrating the gamma ray spectrometer (the Germanium detector with multi-channel analysis) and for recognizing the gamma-ray spectra. You must also do either section 3 (the room background measurement) or any two of sections 4, 5, 6, 7, 8.

The Germanium Detector

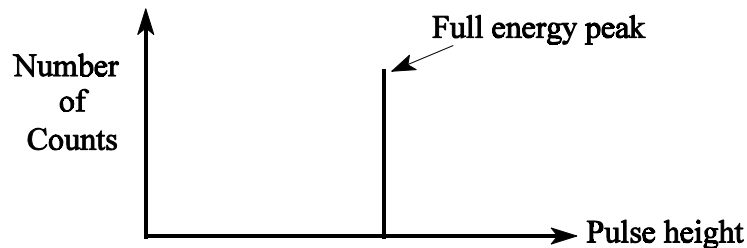
The solid state Germanium γ -ray detector is a device that gives an electrical pulse output whenever a γ -ray is absorbed by the detector. The size of each electrical pulse is proportional to the amount of energy from the γ -ray absorbed by the crystal. The process has two steps: first, the γ -ray gives its energy to a charged particle (electron or positron); second, the charged particle then slows down in the crystal and, in so doing, produces ionization in the crystal. The number of ion pairs produced is proportional to the electron energy. There is a high voltage applied to electrodes attached to the crystal, and so the charge from all the ion pairs is directly collected on these electrodes.

In order to form a spectrometer, the output of the detector is fed into an amplifier (to shape the pulse and make it larger) and then into a multi-channel pulse height analyzer (MCPHA or MCA). The MCA analyzes each pulse that enters it and produces a histogram of numbers of pulses that have been received vs. pulse height voltage. This spectrum is thus really an energy spectrum.

The Shape of the Gamma-Ray Spectrum

It would be most pleasant if all the energy of all γ -rays were always converted into electron energy which always produced ionization in the crystals. Unfortunately the mechanisms involved aren't quite so fair. There are 3 mechanisms by which photon (γ -ray) energies are converted to electron energies:

- *photoelectric effect*: The photon is absorbed by a bound electron in an atom so that the electron leaves the atom with a kinetic energy equal to the photon energy less the electron's binding energy. This process is prevalent for photon energies less than ~ 150 keV.
- *Compton effect*: The photon collides with an unbound electron (or an outer electron in an atom which has a binding energy much less than the photon energy). This resembles an elastic billiard-ball collision in which the photon leaves the collision with reduced energy and the rest of the original photon's energy becomes the kinetic energy of the electron. This process is prevalent for photon energies between ~ 150 keV and ~ 8 MeV.
- *pair production*: The photon, in the vicinity of a nucleus, loses all its energy in the production of an electron - anti-electron (= positron) pair. The total kinetic energy of the electron plus positron is the photon's energy minus the rest-mass energy of the electron plus positron. ($2 m_e c^2 = 2 \times 511$ keV.) This process is prevalent for photon energies greater than ~ 8 MeV.



*Fig. 1 - Idealized γ -ray Spectrum
Showing Only the Full-Energy Peak*

Most radioactive sources emit highly mono-energetic γ -rays, *i.e.* the spectra consist of a series of γ -rays with highly-defined energies. The "width" or variation in energy of γ -rays emitted is generally much less than an eV for photons with energies of the order of MeV. In the "most pleasant" scenario quoted above (all the energy of all γ -rays being always converted into electron energy which always produce ionization in the crystals) a ^{137}Cs spectrum would appear as in Fig. 1. (^{137}Cs emits only one energy of γ -ray, at 661.661 keV.) Such a peak in the spectrum is called the *full energy peak* and can be the result of all the above three processes provided that eventually all the energy is absorbed in the crystal. (*e.g.*, If Compton scattering occurs, not only must the Compton scattered electron be stopped in the crystal so that ion pairs are produced, but also the outgoing photon must also undergo successive photoelectric effect or Compton scattering or pair production *inside the crystal* so that in the end, all the energy produces ionizations in the crystal.)

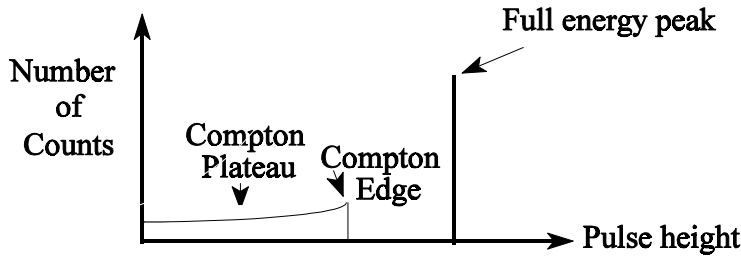


Fig. 2. - Idealized Picture of γ -Ray Spectrum
Showing Only the Full-Energy Peak and Compton Plateau

In actuality, real γ -ray spectra more resemble Fig. 2. The Compton plateau is the result of only part of the photon's energy being absorbed in the crystal. In this case, the incoming γ -ray undergoes a Compton scattering, and the lower energy outgoing photon leaves the crystal, so that a lesser amount of energy is actually absorbed by the crystal. For one compton scattering, simple kinematics (conservation of energy and momentum) forbids the electron from receiving more kinetic energy than

$$E_{\max} = \frac{2 E_{\gamma}^2}{m_e c^2 + 2 E_{\gamma}}$$

E_{\max} is called the compton edge, E_{γ} is the energy of the γ -ray and $m_e c^2$ is the rest-mass energy of the electron. E_{\max} , the maximum energy transfer corresponds to an angle of scattering of the photon through 180° . A 0° scatter transfers no energy. Compton scattering is a slowly varying function of angle and so there is a distribution of Compton events of energy less than the Compton edge.

A further departure from the "most pleasant" case produces a γ -ray spectrum in which each single peak is replaced by three peaks, one at full-energy, one at full-energy less $m_e c^2$ ($= 511 \text{ keV}$), and one at full-energy less $2 \times m_e c^2$ ($= 1,022 \text{ keV}$). This occurs when the photon entering the crystal produces an electron positron pair. When the electron and positron get stopped in the crystal, they lose all their kinetic energy to the crystal which is the γ -ray energy less $(2 \times m_e c^2)$. The positron then annihilates with an electron producing two photons, each of energy $m_e c^2$ ($= 511 \text{ keV}$). If these two photons leave the crystal, then the total energy absorbed in the crystal is $E_{\gamma} - 2 \times m_e c^2$. If the energy of one of these photons is absorbed in the crystal, then the total energy absorbed in the crystal is $E_{\gamma} - m_e c^2$. And if both of these photons are stopped in the crystal, then the total energy absorbed in the crystal is E_{γ} . Clearly this process can only take place for E_{γ} greater than $2 \times m_e c^2$.

Scattering Outside the Crystal

Any photons scattered into the crystal by shielding material, table tops, holders, source backing, etc., will have less than the full energy of the original γ -ray and this process will give rise to a general distribution of pulses across the Compton plateau. However, the kinematics of the problem together with the angular probability of scatter tends to produce a bump on the low energy part of the spectrum and is called the backscatter peak. Even if the holders of the source are removed and the detector is moved far from the table top, this peak, although smaller, still occurs from backscattering within the source itself and also from gamma rays that pass right through the crystal and are scattered back into the crystal from surrounding matter.

Statistical Variations in Pulse Height

The line (peak) shape and width (resolution) of the pulse height distribution are influenced by statistical fluctuations in the number of ion pairs produced in the germanium crystal. The idealized pulse height spectrum of Fig. 2 gets smeared out resulting in a spectrum similar to Fig. 3. The extent of smearing is represented by the *resolution*, the full width at half maximum, of the full-energy peak. Convention has it that what is called the resolution of a γ -ray detector is the full width at half maximum of the 1.333 MeV γ -ray from ^{60}Co . Typical resolutions for the detectors used in this lab are about 2.5 keV.

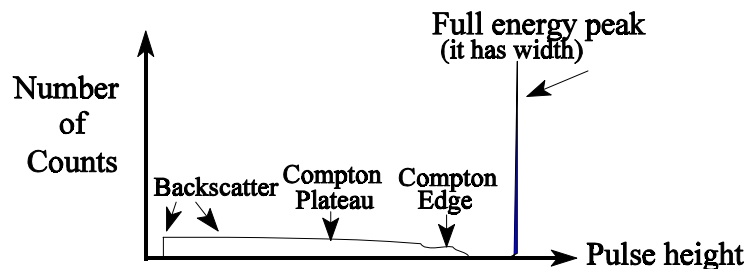


Fig. 3. - A Typical ^{137}Cs γ -Ray Spectrum

WHAT TO DO

1. Connecting the Spectrometer, Observing Pulses and Observing a ^{137}Cs Spectrum

The germanium detector has three connectors. One is for the high voltage. This gets connected to the high voltage power supply which will be turned on with appropriate cautions mentioned shortly. The second gets connected to a low voltage source, to power the preamplifier built-in to the detector, via a plug at the back of the amplifier. This power can be turned on at any time. The third carries the output signal from the detector which should be connected to the amplifier input. To begin, set up the amplifier with:

Coarse gain setting: 30

Fine gain setting: 10.00

Input signal polarity switch: +ve or -ve according to what is written on the detector for output pulse polarity

Time constant: 3.00 μs

Connect the oscilloscope to the amplifier unipolar output.

Set the high voltage supply to be positive or negative according to what is written on the detector for the operating bias voltage. Starting at a zero volts setting, turn on the high voltage supply and *slowly* raise the voltage to the maximum written on the detector for the operating bias voltage. By *slowly* we mean at a rate less than 100 volts change in 5 seconds. The same precautions should be taken when lowering the voltage when you are finished using the detector. Never merely switch off the high voltage supply, as the resulting sudden drop in voltage can produce damaging voltages at the transistor connected to the germanium crystal inside the crystal assembly.

Now put the ^{137}Cs source about 15 cm away from the body of the detector. You should now see pulses on the oscilloscope with time duration around 3 μs and pulse heights over a range of 0.1 volts to 5 volts. Check to see what the amplifier gain control does to the pulses as seen on the oscilloscope. (The "gain" is how much the amplifier magnifies the pulse coming out of the detector.) Check to see what the amplifier time constant control does to the pulses as seen on the oscilloscope. (The pulse height analyzer really likes pulses about 3.0 μs long.) Check to see the effect of moving the ^{137}Cs source closer to and further away from the detector.

Now connect the amplifier output lead to the input of the MCA (MultiChannel Analyzer). (It is good practice to maintain the oscilloscope connected to the amplifier output, using a "T" connector, in order to monitor the pulses while you accumulate data.) The APTEC MCA is located on a board in the computer and is controlled through the Windows programme and screen. An MCA is a device for analyzing the pulse height (voltage) distribution from a set of pulses such as is found from a germanium detector. For example, APTEC MCA used here takes positive pulses from the output of the amplifier, and sorts each of them according to height (voltage) into one of 4096 channels, each channel having a width of approximately 0.5 millivolts. (Thus, for example, a pulse of 5 volts would fall in channel 2000.) Each channel has its own memory position, and each time a pulse of a particular height comes in, one more count is added to the corresponding memory position. Thus, after data is accumulated for some time, the number of counts in each channel represents the total number of pulses of the corresponding height (voltage) that have come in that time. The display plots a histogram of number of counts *vs.* pulse height. Thus, used in conjunction with a γ -ray detector, the display represents (roughly) a spectrum of number of γ -rays *vs.* γ -ray energy.

Start the program that drives the MCA card and does analysis, by clicking on the "aptec" icon. The screen that comes up contains the spectrum last collected on the machine. To clear that spectrum, press <F7> \rightarrow <Enter>, or use the mouse sequence <collect> \rightarrow <clear spectrum> \rightarrow <ok>. To start collecting your own new spectrum, press <F8> \rightarrow <Enter>, or use the mouse sequence <collect> \rightarrow <start normal collection> \rightarrow <ok>. You should now start to see the spectrum of ^{137}Cs being collected. This should resemble the spectrum displayed in Figure 3. You might take the opportunity at this point to try out various features of the Aptec programme, using the self-explanatory pull-down menu items or reading the *APTEC PCMCA/Super Manual*, chapter 2 reference. You might notice that the spectral curve has random fluctuations in it. This is the result of the randomness of the radioactive decay process. As the expected fluctuations in n random events is the square root of n , we find that the percentage fluctuations reduces as n increases, so that the spectrum looks "cleaner" the longer you collect data. Now look at the effect of changing the amplifier gain. Adjust the gain so that the ^{137}Cs full energy peak is near channel 950. Note, as you need to know the channel you are in, if the horizontal axis on the spectrum screen shows energy (keV), you should type the letter "c" to change that scale to channel. Typing the letter "e" changes back to an energy scale.

2. Calibrating the Spectrometer

As you want to use the apparatus as a spectrometer which indicates counts as a function of energy, you need to provide an energy calibration (i.e. which channel corresponds to which energy). You may notice that there is probably an energy scale on the screen, but that is probably not correct as the calibration in the machine is that from the last user who put in their own calibration, and the energy calibration depends, among other factors, on the gain setting of the amplifier. To perform the calibration, you will use three different radioactive sources which emit gamma rays of energies shown in the following table.

| Isotope | Halflife (years) | Energy (keV) |
|-------------------|------------------|--|
| ^{137}Cs | 30.17 y | 661.661 keV |
| ^{60}Co | 5.271 y | 1173.238 keV 1332.513 keV |
| ^{133}Ba | 10.7 y | 80.999 keV 160.609 keV 223.116 keV 276.404 keV 302.858 keV 356.014 keV 383.859 keV |

The first step in calibration is to define the spectral peaks. With the settings used at the end of the above section, count the gamma rays from these calibration sources. (You may count them separately or all together, but be sure to know which spectral peaks belong to which isotope.) For each peak, define a "region of interest" (ROI) by moving the cursor with the mouse to the left edge of the peak and with *<ctrl>* key pressed click the left mouse button. Then do the same at the right edge of the peak. That will define the ROI. Before this procedure, clear all the previously set-up ROIs by the sequence *<ROI>* → *<Delete all>* → *<OK>*. The above sequence is made easier by horizontally expanding the spectrum on the screen by using the *<keypad + >* and *<keypad - >* keys. Note that the *<spacebar>* will move you from the one ROI to the centre of the next ROI. Note also that when you are sitting in a ROI, various data appear at the bottom of the screen which include the centroid, full width at half maximum, full width at tenth maximum, and number of counts in all the channels in the ROI.

Once the spectra with the ROIs are defined, you may calibrate by going to one of the ROIs (using *<spacebar>* and pressing either *<F2>* or pulldown *<setup>* → *<quick energy calibration>*). If this is a new calibration, click on *<clear>*. In that same calibration box, you will notice the channel number of the centroid of the ROI that you are currently on; type in the energy corresponding to that peak. Also select "1" to get a linear calibration fit. Click on *<OK>*.

The more peaks that you use for calibration, the better the accuracy. However, even one peak that you know will give you a good enough calibration to help you to identify which peak is which in such spectra as ^{133}Ba .

Be sure to record the amplifier settings used during the calibration so that, in the future, you don't have to recalibrate if your settings haven't change. Also, after calibrating, save your spectrum in your directory in Faraday by logging on (sequence *<network neighbourhood>* → *<Faraday>*) and then logon with your Faraday account name and password, and double click on your account name. Then minimize the Faraday box. Next, doing *<File>* → *<save as>* with the *<network>* option, in the *<shared directory>* box, select *<Faraday>* and click on your own Faraday account name. When you save a spectrum, all of the spectral data, the ROI data and the energy calibration data are saved with the spectrum file. If, at a later time, you wish to load the calibration data from a saved file, use the *<edit>* → *<load header information>* → etc. sequence. Once you have logged on to the network, you can print whatever is on the screen on the printer in the room by *<file>* → *<print spectrum graph>*.

3. Observation of Background Gamma-Rays in the Room

You are now ready to use the spectrometer to identify some unknown radiations. One interesting measurement is that of the room background. As the background levels are low, you will have to count overnight in order to obtain a spectrum that is statistically precise. Because of the large number of lab sessions that may use the apparatus, we have provided a booking list at your apparatus. Find what time slot is available, and start your data collection at the beginning of that time. See Appendix 1 for the procedure for automatic save collect and save. Please book the apparatus for overnight use on the sign-up sheet at the apparatus and put a "do not touch" sign on the apparatus. You will be able to come back any time after the save time to transfer your data into your own file area. Make sure that there are no other radioactive sources in the room during collection as they may show up in your spectra.

Your data analysis involves looking at the spectrum in the Aptec programme and identifying each peak by forming a ROI for each one. At this point the *<Analyze>* → *<Identify peaks>* routine is very useful. It will try to match all the peaks with what it finds in its isotope table. (You can look at this table by the sequence *<Edit>* → *<Library>*.) If you wish to print out the identification, use *<File>* → *<preview spectrum listing>* or *<ctrl>* → *<shift>* → *<F12>* with the choice of type of information you wish to select in *<setup>* → *<Listing>*. Don't take the programme's identification as the gospel truth. Peak identification is a subtle business and computers are only partially up to the task. You should check on the isotope identification using the "Tables of Gamma-ray and X-ray energies" reference. Whether what you see makes sense can be judged by considering the following section.

At this time, you may wish to add two additional calibration points from the two energies of gamma rays that appear in the background at higher energies: one from ^{40}K and the other from ^{208}Tl .

Understanding what you find in the radioactive background

There are various radioactive isotopes in our environment. Some are manufactured, using nuclear reactions as found in nuclear power reactors or nuclear weapons explosions, or by bombarding nuclei using particles from an accelerator. Intentionally produced isotopes are found in the radioactive sources you will be using to calibrate your spectrometer. Unintentionally produced isotopes were found in quite measurable levels following the large scale nuclear bomb testing that fortunately ended in 1963. The nuclear reactor accident at Chernobyl in Ukraine widely spread radioactive particles. (In this lab we sampled air following that accident in May 1986 and measured gamma rays from dust on filter paper from ^{131}I (8 day half-life), ^{134}Cs (2.1 year half-life), ^{137}Cs (30 year half-life). Air samples taken this current year show none of these.

Other radioactive isotopes occur naturally. Some are currently present because they were formed by the stellar nuclear reactions from which the materials of our planet originate and have half-lives comparable to the age of the solar system. Examples of these are ^{40}K (1.3×10^9 year half-life), ^{232}Th (1.4×10^{10} year half-life), ^{235}U (7.0×10^8 year half-life) and ^{238}U (4.5×10^9 year half-life).

And still other radioactive isotopes occur naturally because a long-lived isotope decays down through a chain of isotopes which are the products of the decay. The three such long-lived parent isotopes ^{232}Th , ^{235}U , ^{238}U are already mentioned above. Their sequences of daughter products are indicated in the footnote¹.

The footnote, with its listing of 45 products of the decay chains, is provided here to help you see the reason for finding gamma rays from various of the isotopes when counting the radioactive background in the room. Note that the presence, in all three chains, of the inert gas, radon ($_{86}\text{Rn}$), is the reason that various of these products appear in the air around us. The radon provides a way that products after radon appear in the air around us, as radon can diffuse through the earth into the air without being caught to form a chemical compound, and then it can decay.

4,5,6,7&8 Preamble: Other Gamma Ray Emitters

To do any of the following, you will use the approach outlined in the second paragraph of "3. Observation of Background". As indicated in the Introduction, there are other items that emit gamma rays that you might want to count. To do so, if they are weak emitters, you will probably put them as close to the detector as possible. (However, if the "dead time" is greater than 5%, move the sample further away from the detector.) In weaker samples, a number of peaks that you measure will probably come from the background. This is particularly important for the fireplace ashes (part 7) and for the "anything else" (part 8) which are very weak sources. If you have already made background measurements, and provided that you have kept the amplifier and high voltage settings the same and are using the same detector, you can use your background spectrum as a means of subtracting the background radiations. If you haven't already measured the background, you will have to count the background for at least as long as you count the particular sample. There are two approaches to background subtraction.

i - Using ROI counts

In this approach you count the new spectrum, create ROIs for all the peaks, identify those peaks, and find the net counts in each peak. Then you use the net counts in each ROI of background peaks that you identified in part 3, and normalizing these net counts to the live times², you can subtract off the background.

¹Products of ^{232}Th decay are ^{228}Ra , ^{228}Ac , ^{228}Th , ^{224}Fr , ^{224}Ra , ^{220}Rn (an inert gas), ^{216}Po , ^{212}Pb , ^{212}Bi , ^{212}Po , ^{208}Tl , ^{208}Pb .

Products of ^{235}U decay are ^{231}Th , ^{231}Pa , ^{227}Ac , ^{227}Th , ^{223}Fr , ^{223}Ra , ^{219}Rn (an inert gas), ^{215}Po , ^{211}Pb , ^{215}As , ^{211}Bi , ^{211}Po , ^{207}Tl , ^{207}Pb .

Products of ^{238}U decay are ^{234}Th , ^{234}Pa , ^{234}U , ^{230}Th , ^{226}Ra , ^{222}Rn (an inert gas), ^{218}Po , ^{218}At , ^{218}Rn (an inert gas), ^{214}Pb , ^{214}Bi , ^{214}Po , ^{210}Tl , ^{210}Pb , ^{210}Bi , ^{210}Po , ^{206}Hg , ^{206}Tl , ^{206}Pb .

See the Eugene Hecht, "Physics (Calculus)" reference for descriptions of decay chains. See the Chart of the Nuclides reference to work out how this happens.

²To normalize the background peaks, multiply their net counts by the ratio of the live time of the new spectrum to the live time of the background spectrum.

ii - Subtracting full spectra

In this approach you subtract the background spectrum from the new spectrum, channel by channel. Open the saved new spectrum by <File> → <open file>. Then from <analyze> → <compare> select the background spectrum file. Both spectra will now appear on the screen. From <analyze> → <normalize>, selecting "by multiplier" and "match compare live time" you get the two spectra on the screen with the background normalized to the new spectrum's live time. Now you can subtract the background using <analyze> → <strip>, and finally you can turn the second spectrum off by again clicking on <analyze> → <compare>. You now have the background-subtracted spectrum on your screen. Note, that because of statistical fluctuations, some channels may show negative numbers of counts.

Note that, in both approaches, it is easiest to save your spectra and then work from the saved files. To call up saved files use <file> → <open file>. Note also that, once you start spectra accumulation you can let that collection continue while, at the same time, working on a file that you have called up. To return to displaying what is being accumulated use <file> → <look at MCARD>.

4. The "Fiesta" Tableware and its Gamma Rays

In the 1960s, a line of dishes under the name "Fiesta" appeared in the US. They were very attractive and had brilliantly coloured glazes. It turned out that nobody did a health check on them; the glazes contained uranium and thorium (probably no more harmful than eating off glazes containing lead). We have managed to get some of those dishes. Identify what radioactive isotopes are in the plates.

5. Gamma Rays from Depleted Uranium

Depleted uranium, which gained fame in the Gulf War, is mostly ^{238}U left over when most of the fissionable ^{235}U , which is naturally found in the uranium ore, is removed to be used in reactors or bombs. ^{238}U emits mainly alpha particles (against which we have shielded in the casing of the sample). However there are gamma rays emitted by the daughter products in the decay. Identify which daughter isotopes produce those gamma rays.

6. Radioactive Ore - Antunite and Pitchblende Rocks

Pitchblende and antunite are naturally found ores. (Pitchblende was the ore Marie Curie refined when she first identified radium.) Identify the gamma rays from one or both rocks and indicate what isotopes they come from.

7. Woodfire Ashes

The ashes in the jar are taken from a woodstove that burned 50-year-old elm. What activities do you find and why do you think they are there? (You may have to count the ashes overnight, do background subtraction and pay attention to having no other sources in the room.

8. What Else?

Do you have any objects that you would like to check to see if they emit gamma rays. Bring them in and count them.

Appendix 1: Automatic Collect, Stop and Save

In order to take data overnight, an automatic function has been provided for data collection. Prior to starting this function, make sure that the high voltage and amplifier gain are set where you want them, and make sure that you have calibrated the spectrometer and saved the calibrating spectrum, with energy calibration performed, in your own directory on Faraday. You can now exit the Aptec program. When you are ready to start data collection, click on the *Autosave* icon on the desktop. You will be prompted for the preset value of time (in seconds). Put in the number of seconds that you want collection to take. (Don't choose a number so big that it will still be running when the next student arrives in the morning, and don't make it so short that the count time is inadequate for good quality data.) The spectrum, as it is being collected will now appear on the screen. Collection will stop at the specified time and the program will be exited, with the data saved in the c:\temp directory under the filename aaa0000*n*.s0, where *n* is an integer which is incremented every time an autosave is done.

When you return to recover your spectrum, click on the *aptec* program, call up the file using <file> → <open file>, go to the c:\temp directory, and get the saved spectrum on the screen. You will notice that it has no energy calibration. Add this calibration by using <edit> → <load header information>, select the appropriate energy calibration spectrum that was saved in your own directory on Faraday, and make sure that only "energy calibration" is checked on the selection list, and then <OK>. You should now save this energy calibrated background spectrum in your own directory on Faraday.

Appendix 2: "Common Sense"

Safety Note

See Health and Safety section in the First Year Lab "Physics Laboratory Manual" with regard to handling radioactive materials and lead. In particular, note the following cautions on radiation: The sources we use in the lab are weak, so that when properly used, they subject the user to a small fraction of the radiation one receives in every-day life. However, as with any toxic material, it is important that you minimize the exposure you receive as any exposure does damage (be it small) to your body. Thus, place the sources you are using in a location away from yourself and other persons. Total radiation exposure is proportional to the source strength, the time you are exposed and a distance factor which for gamma rays drops off as the inverse square of the distance, and for alphas and betas, even faster. In other words, don't put the sources in your pocket, or even immediately in front of you on the bench.

Background Precautions

Radioactive sources placed near your experimental apparatus often affect the data being taken more than being a health problem. In all experiments there are background counts which appear due to radioactivity in the building walls, in the ground, and in other sources in the room, as well as from cosmic radiation. The background from sources in the room can be reduced by keeping your own and your neighbours' unwanted sources far from your counter, and also by shielding your counter.

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