

LA-UR-17-28445

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Title: Isotope Identification


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Intended for: Training Course

Issued: 2017-09-18

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**NONPROLIFERATION AND
ARMS CONTROL (NPAC)**

Isotope Identification





Fundamentals of Non-Destructive Assay for International Safeguards

Los Alamos National Laboratory

September 26, 2017

Pete Karpus

Los Alamos National Laboratory

-  SAFEGUARD NUCLEAR MATERIALS TO PREVENT THEIR DIVERSION OR THEFT
-  CONTROL THE SPREAD OF WMD-RELATED MATERIAL, EQUIPMENT AND TECHNOLOGY
-  NEGOTIATE, MONITOR AND VERIFY COMPLIANCE WITH INTERNATIONAL NONPROLIFERATION AND ARMS CONTROL TREATIES AND AGREEMENTS
-  DEVELOP PROGRAMS AND STRATEGIES TO ADDRESS EMERGING NONPROLIFERATION AND ARMS CONTROL THREATS AND CHALLENGES

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Estimated Module Duration: 30 minutes

Required Tools and Materials:

1. Projector, screen, laptop with Word and PowerPoint programs
2. Participant guides, with slides and supplemental material

References:

1. *Passive Nondestructive Assay of Nuclear Materials (PANDA)*, Chapter 5:
<http://www.lanl.gov/orgs/n/n1/panda/>
2. *Nuclear Forensics Analysis* by Moody, Grant, and Hutcheon

Supporting Documents:

1. None

Job Aids:

1. None

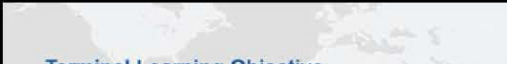
Terminal Learning Objectives (TLOs):


- TLO-1: Examine the process of using gamma spectroscopy for radionuclide identification

Enabling Learning Objectives (ELOs):

- ELO-1: Apply pattern recognition to gamma spectra
- ELO-2: Identify methods of verifying energy calibration
- ELO-3: Discuss potential causes of isotope misidentification

Additional Information for Students:





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Terminal Learning Objective

- Examine the process of using gamma spectroscopy for radionuclide identification.

Instructor Notes:

Review learning objectives with the participants.
Encourage participants to ask questions during the lecture.

Additional Information for Students:





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Enabling Learning Objective

- Apply pattern recognition to gamma spectra
- Identify methods of verifying energy calibration
- Discuss potential causes of isotope misidentification


Instructor Notes:

Review learning objectives with the participants.
Encourage participants to ask questions during the lecture.


Additional Information for Students:

Identification of Unknowns is an Important Use of Gamma Spectroscopy

- True detective work
- Simple in concept
- Can be very difficult in practice
- Bounding the problem can greatly reduce complexity
- Numerous systems attempt this with software – success levels vary
- Expert consensus is the best source of real confidence



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Identifying unknown radionuclides is an important nuclear security problem, but it is also relevant to nuclear facility operators and safeguards inspectors. Gamma spectroscopy is one of the best tools available for identifying unknown items, but all available sources of information should be considered.


Instructor Notes:

Gamma spectroscopy is one of the best tools available for identifying unknown radionuclides because each radionuclide will produce a characteristic pattern of gamma-ray energies. However, as we will see in this module, confidently identifying unknown radionuclides is a very difficult problem. It requires true detective work and consideration of all available sources of information. Therefore, although automated systems are useful, they have limits. Expert review of the data is often needed before a confident identification can be made.

Point to the appropriate parts of the diagrams as you describe how x-rays are produced.

Additional Information for Students:

The Basics



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- Identification is performed by pattern recognition or energy measurement
- Visual pattern recognition is a very powerful tool, but requires experience to develop
 - Best for spectra with unique patterns
 - Reference to spectrum libraries
 - Some software uses this approach
- Energy measurement is necessary for unfamiliar or complicated spectra
 - Simple mono-energetic spectra often require the use of energy for ID
 - Spectra with multiple gamma emitting isotopes are best done using energy information

Visual pattern recognition is analogous to recognizing your friend's face. If the unknown spectrum looks like one you have seen before, you may be able to quickly identify it. However, it is also easy to be fooled because many radionuclides have similar spectra. Measuring peak energies and comparing them with reference data is necessary when you do not

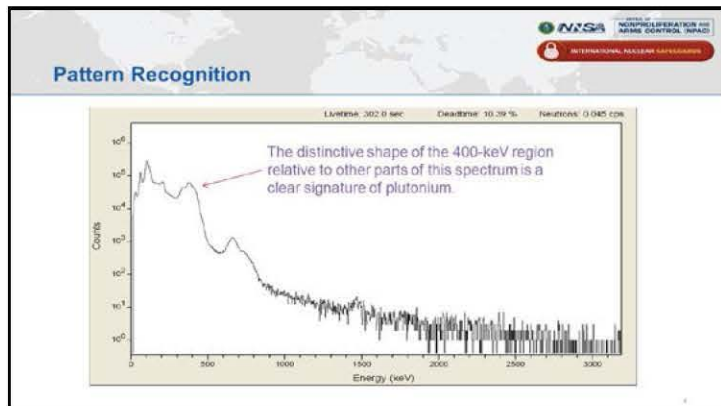
recognize a pattern and is always valuable as a way to check an identification by pattern recognition.

Instructor Notes:

The two primary methods of identifying radionuclides from a gamma spectrum are visual pattern recognition and measurement of peak energies that are compared with reference data. Visual pattern recognition is used by experienced gamma spectroscopists, who are familiar with spectra from a variety of radioactive materials. They can say "this looks like uranium" because they have seen a similar spectrum before. Visual pattern recognition is analogous to recognizing your friend's face. Some modern computer analysis uses pattern recognition, but it is a difficult method to implement in software. For unfamiliar or complicated spectra, the best approach is to measure peak energies and search reference data for isotopes that emit those characteristic energies. Confidently identifying an unknown sample usually requires careful study of the spectrum and use of both identification methods.

Use the diagram to explain how x-ray fluorescence is observed in real measurements. Point to features in the spectrum and relate them to the diagram.

Additional Information for Students:



Visual pattern recognition can work even if the spectrum is not energy calibrated. If you think you recognize a pattern, that can be useful because it bounds the problem. The question then becomes “is this spectrum consistent with plutonium?” rather than “what is this completely unknown spectrum?”

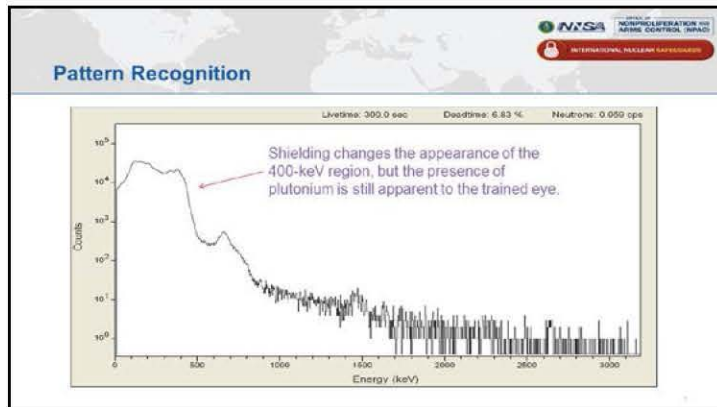
Instructor Notes:

The pattern of a high-resolution plutonium gamma spectrum consists of a cluster of peaks near 100 keV, the pair at 203 keV and 208 keV, then a cluster of peaks around 400 keV and 600 keV. You may be able to recognize much of this pattern by looking at the relative spacing and intensities of features in the spectrum. There are no units on the energy scale of this spectrum, and they are not always required for visual pattern recognition.

Point to the features in the spectrum at approximately 200, 400, and 600 keV. Note that the 100 keV region is not visible due to the low-energy threshold of the detector.

Ask if anyone knows a peak in typical plutonium spectra that interferes with W Ka1. (It is the 59.5 keV peak from Am-241, which is produced from the decay of Pu-241.)

Additional Information for Students:



Shielding is often used with radioactive materials, and it can make identification more difficult. Remember that low-energy gamma rays will be attenuated more than high-energy gamma rays.

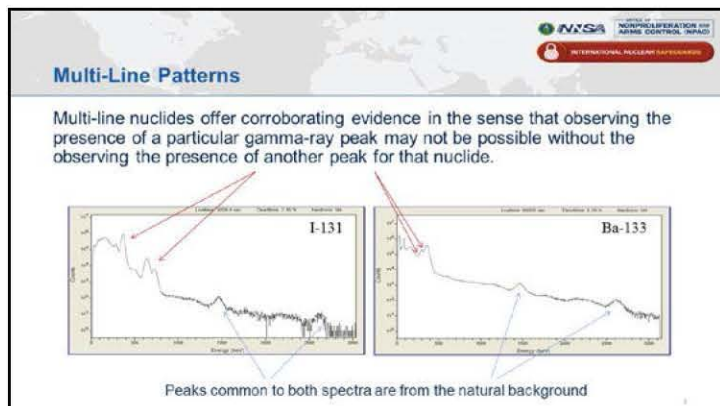
Instructor Notes:

If you are familiar with the unshielded spectrum we just saw, maybe you would recognize the pattern in this spectrum from a shielded plutonium item. Low-energy gamma rays are attenuated more than high-energy gamma rays and are now harder to resolve.

Switch back and forth between the previous slide and this one several times so that participants notice the differences. Note that the 600 keV region is nearly unaffected by shielding and the 400 keV region is somewhat affected, but the peaks at lower energies are almost completely attenuated by the shielding.

Point to the diagram as you explain the step-by-step process of gamma emission. Note the probabilities involved at each step.

Additional Information for Students:



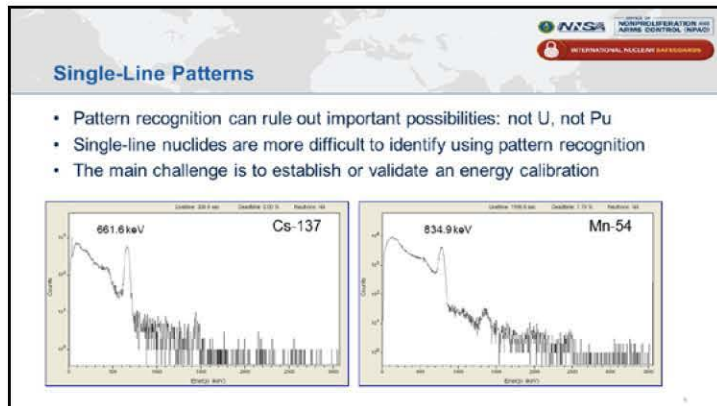
Most nuclides emit multiple gamma-ray energies. Observation of multiple peaks can help to confirm the presence of a particular nuclide. Remember that shielding can prevent observation of low-energy peaks and that peaks from naturally occurring radioactive materials are often present.

Instructor Notes:

Most nuclides emit multiple gamma-ray energies, and observation of multiple energy peaks can help to confirm an identification. It is important to use all of the information in the spectrum when making an identification. As noted on these spectra, peaks from natural background are often observed. The easiest way to determine the background peaks is to just measure the background. Simply subtracting the background spectrum from the unknown spectrum can be risky because it can sometimes lead to confusing spectral artifacts.

Point to some of the most intense gamma rays observed from U-235 decay on the energy-level diagram as you talk through how they are produced.

Additional Information for Students:



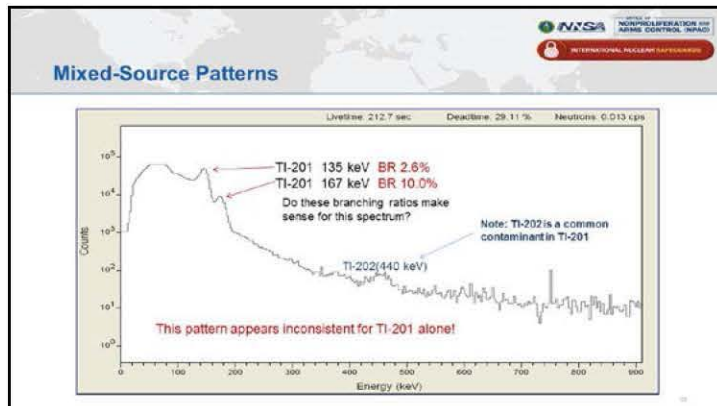
Single-line (mono-energetic) nuclides will have characteristic patterns that are nearly the same, except for the energy scale. To identify a particular single-line nuclide using pattern recognition, the challenge is to validate the energy calibration, which cannot always be trusted. We will discuss energy calibration in the next section.

Instructor Notes:

Single-line, or mono-energetic, nuclides will have an easily recognizable pattern in the spectrum that consists of a photopeak, Compton edge, Compton plateau, and possibly a backscatter peak. This pattern will be almost identical regardless of the gamma-ray energy, so the challenge in identifying a particular single-line nuclide is in validating the energy calibration. The spacing between the Compton edge and the photopeak energy can be used to determine the energy scale. In the limit that the single gamma-ray energy is much greater than 511 keV, this spacing will be 256 keV. Similarly, the backscatter peak will always be at 256 keV or less. If the detector is well characterized, you may be able to use the photopeak width to determine the photopeak energy because energy resolution is a function of energy.

Point out that the four peaks at 144, 163, 186, and 205 keV resemble four fingers, which is an easy way to remember the pattern.

Additional Information for Students:



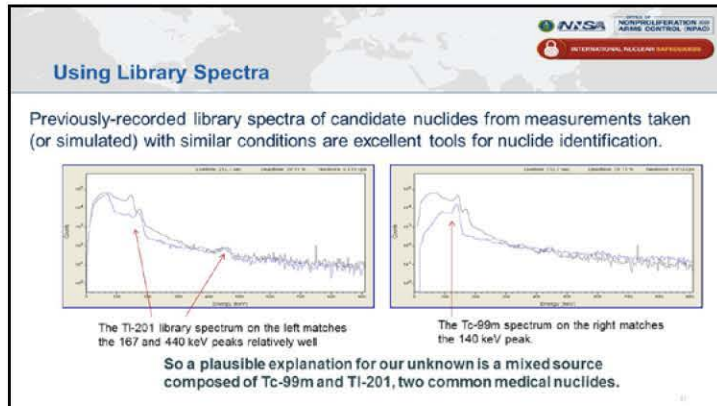
Multiple radionuclides are often present in a single sample. It is important to understand all features of the spectrum in order to identify every nuclide present. Use reference data such as tabulated peak energies and branching ratios to validate a possible identification.

Instructor Notes:

Multiple radionuclides are often present in a single sample. It is important to understand all features of the spectrum in order to identify every nuclide present. This spectrum has two prominent peaks at around 135 keV and 167 keV. These two energies are consistent with TI-201, but their intensities are not consistent with the known branching ratios. These peaks are close enough in energy that the system detection efficiency will be similar for both. The known branching ratios indicate that the 167 keV peak should be about 4 times more intense than the 135 keV peak, but clearly it is not. There is a weak peak at 440 keV that is consistent with TI-202. Isotopes of the same element are often together in the same sample, and this gives us some more evidence that we are seeing TI-201. However, there must be something else in the sample to explain the intense peak near 135 keV.

Emphasize the patterns in the spectrum. Often, multiple radionuclides are present.

Additional Information for Students:



Overlaying library spectra with the unknown spectrum allows you to use visual pattern recognition even if you are not familiar with the pattern. It quickly allows you to determine what features of the unknown spectrum are explained by a nuclide, and which are not.

An online catalog of gamma spectra can be found at:

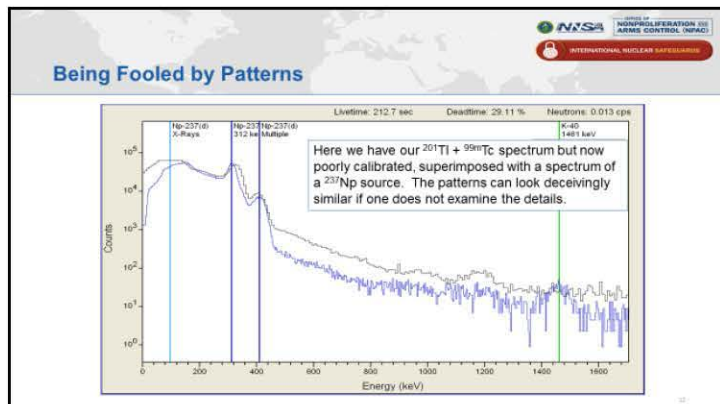
http://www4vip.inl.gov/gammaray/catalogs/ge/catalog_ge.shtml

Instructor Notes:

Emphasize the patterns in the spectrum.

Previously measured spectra or simulated spectra are very useful in understanding an unknown spectrum. By overlaying the Tl-201 library spectrum with the unknown, we can quickly see that the 167 keV and 440 keV peaks are explained by a typical Tl-201 sample. However, the peak near 135 keV is not. This peak appears to be consistent with a library spectrum from Tc-99m, which has a 140 keV peak. Furthermore, Tl-201 and Tc-99m are both used in nuclear medicine and so might be reasonably expected to occur in the same sample. This example also illustrates the importance of good energy calibration and good energy resolution in identifying unknown nuclides.

Additional Information for Students:





Just looking at the pattern can be deceiving even for multi-line nuclides. If the energy calibration can be verified, we will have more confidence in the identification.

Instructor Notes:

Just looking at the pattern can be deceiving even for multi-lines nuclides. Here, we have overlaid the previous spectrum with an Np-237 spectrum in blue. The main peaks match well enough for us to be fooled. In this case, the energy calibration must be off by more than a factor of 2 to make these spectra match. The most intense Np-237 peak occurs at 312 keV, but we previously identified the most intense peak in the spectrum to be 140 keV from Tc-99m. If the energy calibration can be verified, we will have more confidence in an identification.

Additional Information for Students:





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To Summarize Pattern Recognition:


- Pattern recognition can quickly bound the identification problem and sometimes clearly identify a radionuclide
- Some radionuclides have similar patterns, especially when using low resolution detectors
- When pattern recognition does not solve the problem, use the energy measurement technique


Pattern recognition is a fast way for a human to identify the nuclides in a spectrum, but this requires a trained person with significant experience. Often, it is necessary to perform more analysis to identify unknown nuclides.

Instructor Notes:

Pattern recognition depends on the experience of the person performing the identification, and it can only be used to identify sources that you are familiar with. Often, it is necessary to use more analytical techniques or higher-resolution detectors to identify unknown sources.

Additional Information for Students:





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Energy Measurement

Step One: determine an accurate energy calibration

- Often requires peak recognition to choose reference peaks
- For some instruments, the energy calibration is technically fixed – it can still vary somewhat, so verify!
- If you can't initially decide on a definitive energy calibration, you may have to try and few and see which produces the most plausible composition hypothesis

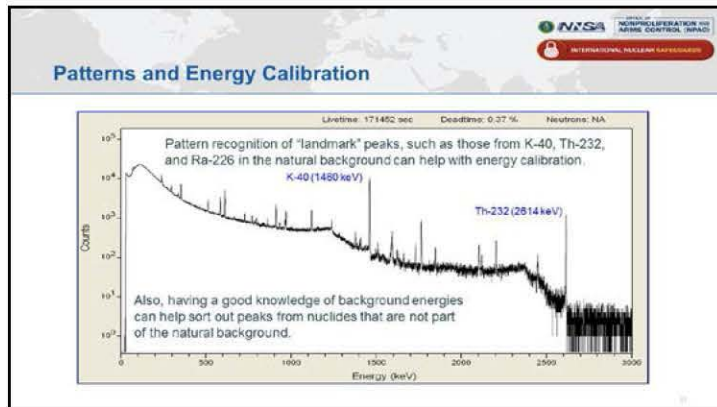
Verifying energy calibration should be the first step in identifying nuclides from an unknown spectrum because then it becomes possible to refer to tabulated peak energies.

Instructor Notes:

We will discuss a systematic method for understanding spectral features and making a positive identification. The first step is to determine an accurate energy calibration. Many gamma detectors have an energy calibration that is not adjustable by the user, but drift can change the calibration over time. Many factors influence the drift, including the detector's electronics and the temperature.

It is best to use reference peaks that you recognize, but sometimes this may not be possible. Sometimes, you may have to just estimate an energy calibration and see if the spectrum can be explained with that calibration.

Additional Information for Students:





Naturally occurring radioactive material (often called NORM) can provide useful reference peaks. K-40, Th-232, and Ra-226 are present in concrete and soil, and they typically provide well-isolated peaks in a background spectrum.

Instructor Notes:

Energy peaks from naturally occurring radionuclides such as K-40, Th-232, and Ra-226 can be very useful in verifying the energy calibration. These peaks are typically well isolated and intense in a background spectrum. It can save time to memorize some of these typical background peak energies because they are frequently present in an unknown spectrum. There are other background nuclides that can sometimes be detected, such as Bi-214 (particularly in this spectrum, at 609, 1764, 1120, 1238, 1337, 2204, 2448 keV, and more). There are also escape peaks present that could be used for calibration (at $2614 - 511 = 2103$ keV, for example).

Additional Information for Students:





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Energy Measurement

Step Two: find all of the peaks

- Real photopeaks are the most useful, but other features in the spectrum can be useful
- For a spectrum with good counting statistics, peaks can be manually found by examination
- For a spectrum with poor counting statistics or overlapping peaks, this can be difficult

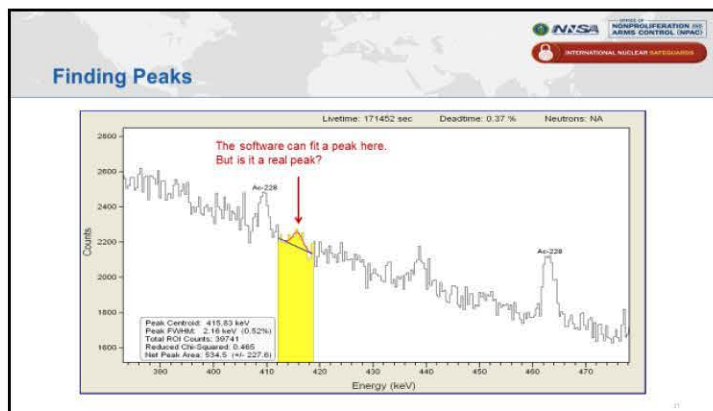
There are many automated algorithms to detect peaks, which may perform differently depending on the detector used and the counting statistics

To confidently identify all radionuclides in an unknown spectrum, all peaks must be explained. Sometimes it can be difficult to determine if a small peak is real or just a statistical fluctuation.

Instructor Notes:

After verifying or determining the energy calibration, the next step is to find all of the full-energy peaks in the spectrum. To confidently identify all radionuclides in an unknown spectrum, all peaks must be explained. Simple spectra may only have only one full-energy peak that is clearly recognizable. When there are many peaks, or weak peaks, it can be difficult to determine which are real and which may be statistical fluctuations in background. The best approach is to start with the most-well-defined peaks and work from there. After verifying or determining the energy calibration, the next step is to find all of the full-energy peaks in the spectrum. to confidently identify all radionuclides in an unknown spectrum, all peaks must be explained. Simple spectra may have only one full-energy peak that is clearly recognizable. When

Additional Information for Students:





Software tools for finding peaks should be used carefully. The “peak” fit here may not be a real peak. You should consider the width of a peak (notice that the escape peak is wider than the others) and the peak shape. Measuring for longer will improve counting statistics and make accurately finding peaks easier.

Instructor Notes:

Start by identifying the most intense peaks in the spectrum, but identifying weak peaks adds confidence to a radionuclide identification. Sometimes, software tools can fit peaks that are simply due to statistical fluctuations in the spectrum. The peak fit here may not be a real peak. The peak labeled “double escape” is fairly weak but can be identified as an escape peak because of its energy relative to a more intense peak in the spectrum and because of its width. Identifying escape peaks helps to rule out the possibility of another radionuclide in the sample.

Additional Information for Students:





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Energy Measurement

Step Three: sort out other spectral features

- Sum peaks (exact double or possibly triple energies of the intense peak(s) in the spectrum)
- Escape peaks (511 and possibly 1022 keV below high energy peaks)
- Annihilation radiation – always at 511 keV, and may mask other actual 511 keV gamma rays

Step Four: tabulate the remaining peaks, listing energy and net area

Step Five: start with a high energy, intense peak and search for possible sources

- Reference books
- Software or internet searches

There are often peaks in the spectrum that are not full-energy peaks but can look similar. Sum peaks and escape peaks will always have a well-defined position relative to more intense peaks in the spectrum. Positron annihilation radiation can give an intense peak at 511 keV, which looks unusually broad in a high-resolution spectrum.

Start by identifying the highest-

energy, most intense peaks in the spectrum because they are the most likely peaks to be easily recognized as full-energy peaks.

Instructor Notes:

There are often peaks in the spectrum that are not full-energy peaks but can look similar. Sum peaks result from coincident events in the detector that are recorded as one event with the sum of their energies. Sum peaks will be associated with the most intense peaks in the spectrum and are more likely at high-count rates. They will not be the most intense peaks in the spectrum. Escape peaks resulting from positron-electron pair production will occur at 511 and possibly 1022 keV below high-energy peaks. Escape peaks can also result from x-rays that escape the detector; for example, an escape peak can occur at 9.9 keV below an intense peak in a germanium detector spectrum because the germanium Ka1 x-ray energy is 9.9 keV. Annihilation radiation produces a 511 keV peak that appears unusually broad in a high-resolution spectrum. This peak can also be a good reference peak for energy calibration. Tabulating the peaks in a complicated spectrum allows you to quickly organize them by net area and energy. Start by identifying the highest-energy, most intense peaks in the spectrum because they are the most likely peaks to be easily recognized as full-energy peaks. Reference books like the Table of Isotopes or online sources provide listings of gamma-ray peak energies and isotopes. As we previously discussed, check for other peaks from a nuclide and determine if their branching ratios are consistent with the observed peak intensities.

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Degenerate Solutions

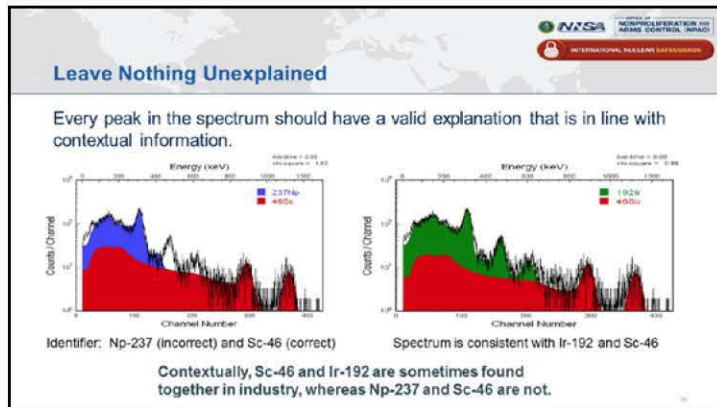
- Sometimes (not often) the search result will clearly indicate a single isotope
- Sometimes there are several possible sources
 - Look for other gamma rays produced by each possible source
 - Match the intensities indicated by the branching ratios to the peak intensities in your table (they won't match perfectly, as we'll see)

Try to match every feature in a spectrum to determine the most likely identification because many nuclides can produce similar spectra. Sometimes, the spectrum may indicate multiple possibilities for identification. You must use all available information to determine the most likely identification.

Instructor Notes:

Sometimes, particularly in a simple spectrum, you will find only one likely identification. However, the most intense peaks in the spectrum may indicate multiple possibilities. Use all of the available information, such as branching ratios, to determine the most likely identification. Note that branching ratios indicate the expected intensities of different-energy gamma rays as emitted from the radioactive material. The intensities of peaks in a measured spectrum will not perfectly match the branching ratios because attenuation and detector efficiency vary with energy.

Additional Information for Students:





To confidently make an identification, you must be able to explain every feature in the spectrum. Apply contextual information, such as where the radioactive material is found and what other nuclides are present.

Instructor Notes:

To confidently make an identification, you must be able to explain every peak and every other feature in the spectrum. In this example, the most intense features of the spectrum are consistent with the Np-237 library spectrum, shown in blue. However, the two peaks around 150 and 200 keV are not. A better match is found with the Ir-192 spectrum, shown in green. Contextual information gives us confidence in this identification because Ir-192 and Sc-46 are sometimes found together in industrial sources.

Additional Information for Students:





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Energy Measurement

- With some software, you can even model scattering in shields you know or believe are present
- Doing these manually on a complicated spectrum can take hours
- High resolution makes this far easier – low resolution is much more difficult
- Keep your common sense engaged; if the spectrum was taken from a very heavy package, consider shielding!
- If you have a background spectrum, compare it to the source spectrum to eliminate some peaks
- Challenges:
 - Peak intensities can be altered by shielding and the detectors' efficiency curve
 - Shielding always works from low energy up; nothing will shield high energies and leave low energies unaffected
 - However, there might be a low energy source outside a shield, and a high energy source inside!

Modeling spectra can be useful in determining a potential match to an unknown spectrum. However, it is usually not practical to simulate all possibilities.

Typically, contextual information can provide some clues. Shielding often is present, which can result in a confusing spectrum.

The best way to determine which peaks are from the natural

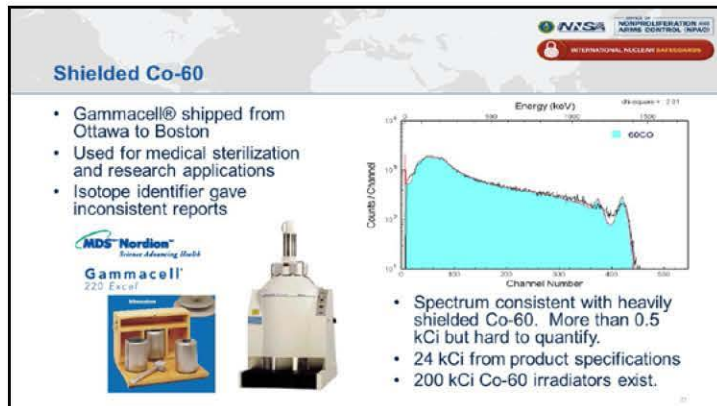
background is to compare against a measured background spectrum. Remember that the spectrum is just what the detector sees, and measured peak intensities are always affected by shielding and detector efficiency. Consider all of the possibilities, including unusual configurations of the radioactive material.

Instructor Notes:

Software is available to model the effects of scattering and shielding on a spectrum. This can be useful in interpreting an unknown spectrum; however, it is usually not practical to simulate all possibilities. Typically, contextual information provides some clues to the configuration of the radioactive material. A measured background spectrum is the best way to determine which peaks come from the natural background, but to be most useful, it should be recently measured in the same location and with the same detector that is used for the unknown spectrum.

Remember that the spectrum is just what the detector sees. Measured peak intensities are always affected by shielding and detector efficiency. Shielding will attenuate low-energy gamma rays more than high-energy ones. Detector efficiency is low for very-low-energy and very-high-energy gamma rays, and it reaches a maximum somewhere in the middle. Consider the possibility of unusual configurations of radioactive material, such a low-energy source outside a shield with a high-energy source inside. In this case, the different items would have different overall detection efficiency curves, and the measured peak intensities could be confusing.

Additional Information for Students:




Intense industrial and medical gamma sources are usually very heavily shielded, and shielding often makes automated identification algorithms fail.

Instructor Notes:

Industrial and medical gamma sources are usually heavily shielded. These sources are often used for sterilization and contain large quantities of radioactive materials. You may think it would be easy to identify a 24 kCi Co-60 source because it has a simple gamma spectrum and the activity is very high, but shielding often makes automated identification algorithms fail. In this case, we can apply contextual information to determine if the spectrum is consistent with heavily shielded Co-60.

Additional Information for Students:

Energy Measurement



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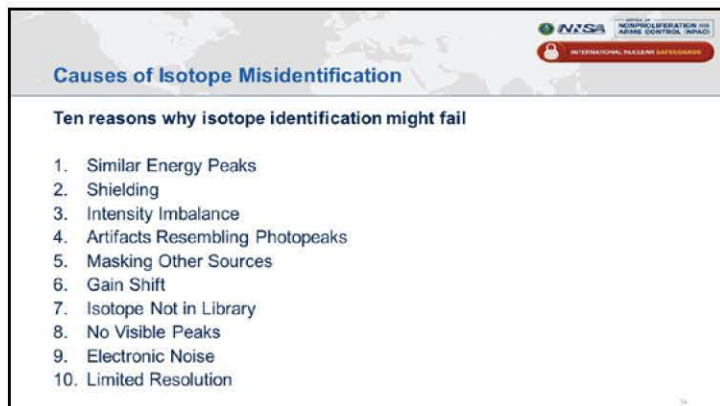
- More challenges:
 - The energy calibration might not be linear (especially with NaI).
 - AC coupling, physical shock, or electronics malfunctions can produce doubled peaks (usually throughout a spectrum).
- Energy measurement requires a broad, deep knowledge of the intentional and unintentional use of radioactive material around the world.
 - Certain furniture companies use wood contaminated with trace levels of cesium from Chernobyl
 - Ceramics and glass often have higher concentrations of naturally occurring radioactive material.

These complications have all been observed in practice. Identifying unknown spectra is true detective work, and all available information must be considered.

Instructor Notes:

Here are some additional problems that have been observed with real spectra. The energy calibration of the detector might not be linear, or it could have drifted during a measurement. Electronic problems can produce spectral artifacts, including tailing and even double peaks, although these problems can often be identified because they are seen throughout a spectrum. Finally, many spectra are automatically saved with confusing filenames, and it is easy for someone to send the wrong file. Be careful that you are analyzing the correct spectrum! Identifying an unknown spectrum is true detective work, and all available information must be considered. Many alarms in shipping and border crossings are from naturally occurring radioactive material or unintentional contamination, for example, furniture with wood contaminated by the Chernobyl accident.

Additional Information for Students:



Causes of Isotope Misidentification

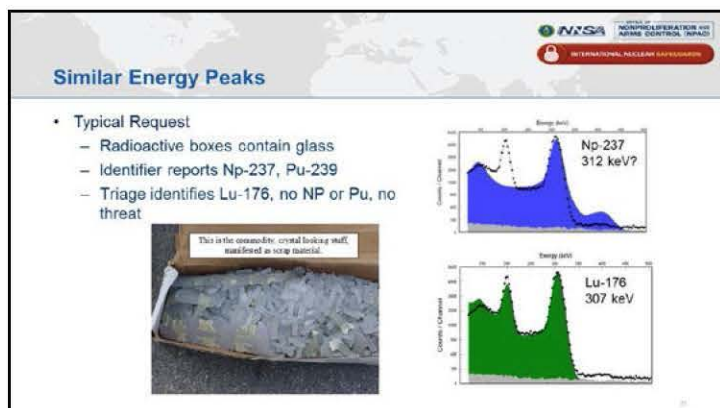
Ten reasons why isotope identification might fail

1. Similar Energy Peaks
2. Shielding
3. Intensity Imbalance
4. Artifacts Resembling Photopeaks
5. Masking Other Sources
6. Gain Shift
7. Isotope Not in Library
8. No Visible Peaks
9. Electronic Noise
10. Limited Resolution

We will now discuss some causes of possible misidentification and share examples of real-world challenges.

Instructor Notes:

Additional Information for Students:

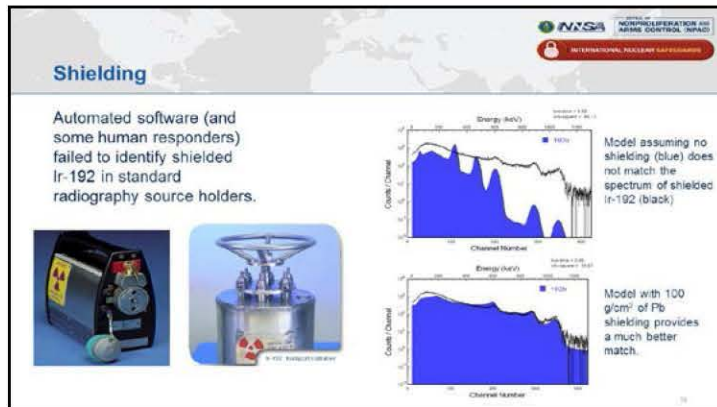


The automated identification algorithm indicated Np-237 and Pu-239 due to the intense peak at roughly 300 keV, and the few counts around 400 keV. However, Lu-176 is a much better match to the data, and is consistent with contextual information.

Instructor Notes:

Why did the automated identification algorithm indicate Np-237 and Pu-239? The Np-237 was likely triggered by the intense peak around 300 keV. With a low-resolution detector, it is hard to tell the difference between peaks a few keV apart. The Pu-239 may have been triggered because there are some counts around 400 keV. However, these isotopes would not explain all of the features in the spectrum. A Lu-176 library spectrum provides a much better match to the data. Lu-176 is also consistent with contextual information because that isotope is known to be found in ceramic materials. The counts around 400 keV do not indicate a clear peak, and so expert analysis concluded that Pu-239 is very unlikely in this material.

Additional Information for Students:

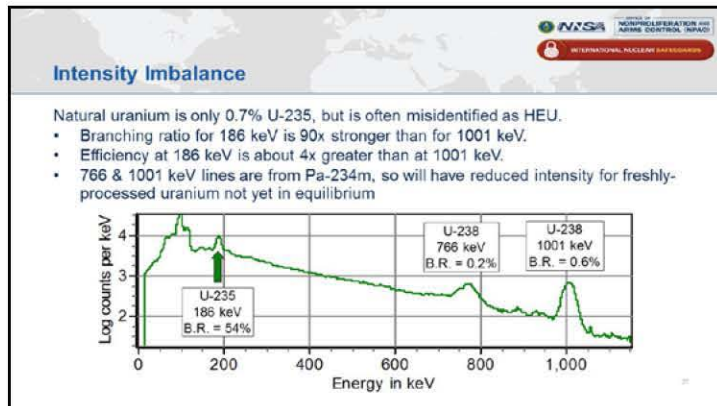


Heavy shielding may be more obvious from contextual information than from the spectrum itself.

Instructor Notes:

Ir-192 is used in industrial radiography sources and is typically heavy shielded. The unshielded Ir-192 library spectrum on the left shows several intense peaks that are not observed in the measured spectrum. Contextual information can be used to determine that heavy shielding is likely, and in this case, a simulated spectrum with 200 grams of lead per square centimeter matches the data well.

Additional Information for Students:

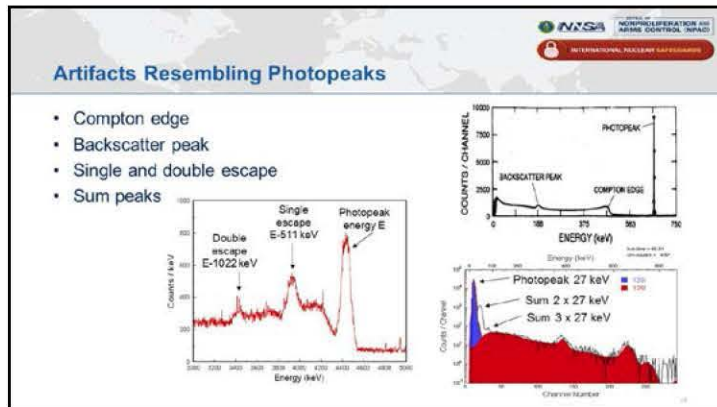


U-235 is a naturally occurring isotope. Determining if a material contains enriched uranium requires measurement of both U-235 and U-238, which can be difficult.

Instructor Notes:

The most intense gamma ray from U-235 is 186 keV. Automated identification software often indicates U-235 if there is a peak at 186 keV. The problem is that U-235 is a naturally occurring isotope and is not always cause for concern. The challenge then is determining if an item contains enriched uranium (U-235 concentration greater than 0.7%). This requires measurement of the U-238 in an item as well, which can be difficult. First, the branching ratio for the 186 keV peak that indicates U-235 is 90 times stronger than for the 1001 keV peak that indicates U-238. Also, the detector efficiency at 186 keV may be 4 times greater or more than at 1001 keV. In facilities that chemically process uranium, measurement of U-238 is a particular challenge because the 766 and 1001 keV peaks are really from the decay of Pa-234m (which results from the decay of U-238). Chemical purification will remove the protactinium, so gamma spectroscopy may indicate that the material contains a very small amount of U-238 compared with U-235. That is, a measurement by gamma spectroscopy may indicate that freshly purified uranium is highly enriched even if it is really of natural isotopic composition.

Additional Information for Students:

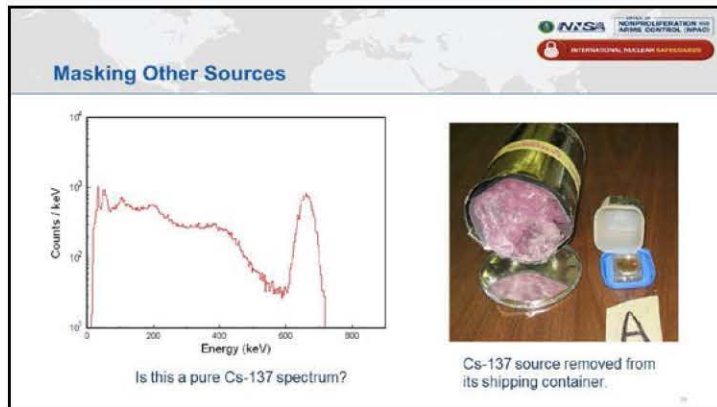


Particularly in low-resolution spectra, it can be difficult to determine which peaks are actually full-energy photopeaks that can be used for identification.

Instructor Notes:

A spectrum from even a single-line (mono-energetic) gamma ray source will show more than just the full energy photopeak. If there are multiple gamma-ray energies, each one will produce a pattern like the single-line source. Particularly with a low-resolution detector, it can be difficult to determine which peaks in the spectrum are actually full-energy photopeaks that can be used for identification and are really backscatter peaks or Compton edges. A Compton edge will occur with a well-defined spacing below a photopeak, and due to the same physics, a backscatter peak will occur at a well-defined energy. This energy will be 256 keV or less. Escape peaks and sum peaks will also occur at well-defined positions relative to intense photopeaks, as shown here in the plots.

Additional Information for Students:



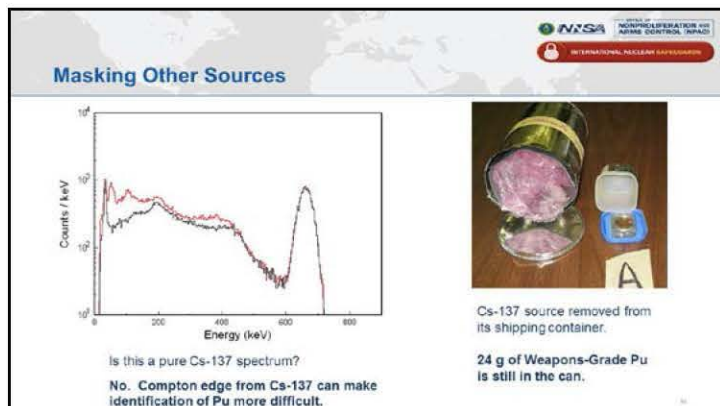
Masking refers to the use of a more intense radioactive source to hide a weaker one. Masking can make it very difficult to identify hidden radionuclides.

Instructor Notes:

Masking refers to the use of a more intense radioactive source to hide a weaker one. In this example, there is a container with a Cs-137 source. The gamma spectrum indicates Cs-137, with a photopeak at 662 keV and a Compton plateau. Is this a pure Cs-137 spectrum?

Ask if anyone sees any evidence that there is a radionuclide other than Cs-137 present. Note the broad peak around 100 keV and another at roughly 60 keV.

Additional Information for Students:

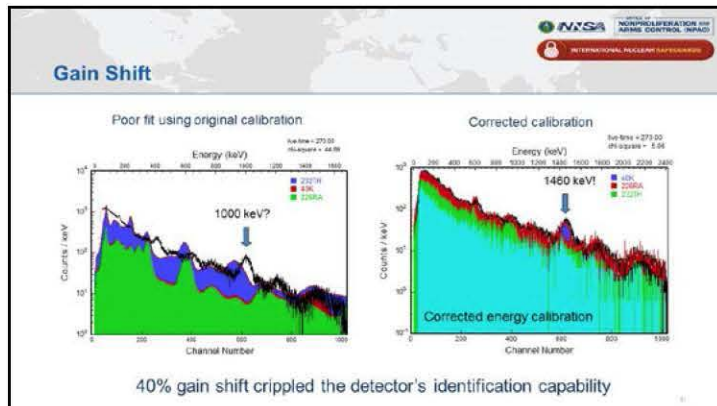


The best evidence of Pu in this spectrum may be the broad peak around 100 keV (the Pu x-ray region) and the peak at 60 keV (from Am-241).

Instructor Notes:

The container actually had a Cs-137 source, along with 24 grams of weapons-grade plutonium. The differences between a spectrum with only Cs-137 and the spectrum from the container are small. With the two spectra overlaid, we can see evidence of the 400 keV region (which is a good indicator of Pu-239), the 100 keV Pu x-ray region, and the 60 keV peak from Am-241 (which comes from the decay of Pu-241).

Additional Information for Students:



Automated identification algorithms especially rely on an accurate energy calibration. The first step for identifying nuclides in an unknown spectrum should be to verify the energy calibration.

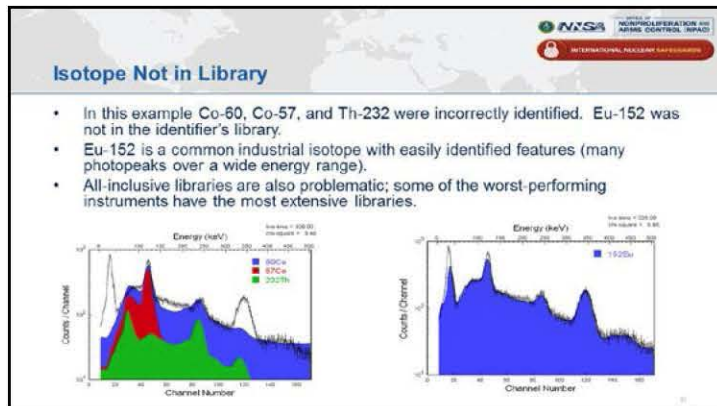
Instructor Notes:

The first step for identifying nuclides in an unknown spectrum should be to verify the energy calibration. Otherwise, it is impossible to identify peaks based on their energy. Automated identification algorithms especially rely on an accurate energy calibration. However, even in instruments that have a calibration that is not adjustable by the user, the energy calibration can change due to gain shift over time. The 40% gain shift shown here is especially large, but even a 5%–10% gain shift can cause problems. If the identified isotopes do not make sense, you may need to recheck the energy calibration. In this example, the background spectrum is expected to show Th-232, K-40, and Ra-226, but initially, their library spectra do not fit the data.

Correcting the energy calibration results in a good match to the data.

Several effects can cause gain shift, such as a changing temperature. With a NaI detector, you can actually track the changes in the room temperature using careful measurements of the gain shift.

Additional Information for Students:



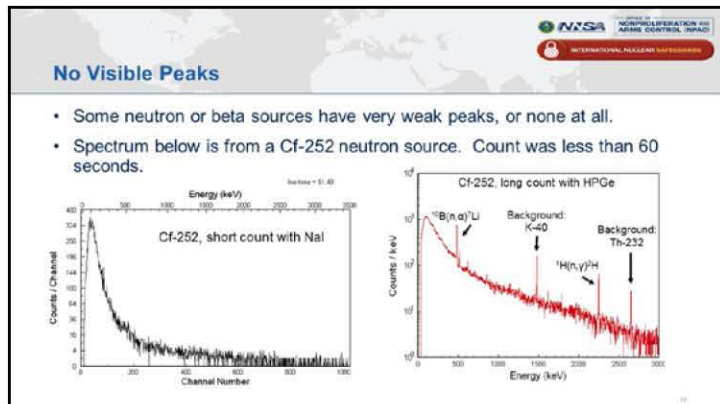
Automated identification software sometimes fails because the unknown isotope is not in its library. However, all-inclusive libraries can sometimes result in false positives or degenerate solutions.

Instructor Notes:

In this example, Eu-152 was not included in the detector's library (this detector is an older GR-135), so it could not be correctly identified. The best match to the data that the software could find was a strange combination of Co-60, Co-57, and Th-232, which clearly does not describe all peaks in the spectrum. Because new applications for nuclides are sometimes developed, the libraries for these detectors must change with time.

Simple identification algorithms that are based on peak energies can also have trouble if there are too many nuclides in their library. This can result in false positives and degenerate solutions. Instrument manufacturers are continuing to improve identification algorithms, but so far, the best results still come from expert review of the data.

Additional Information for Students:



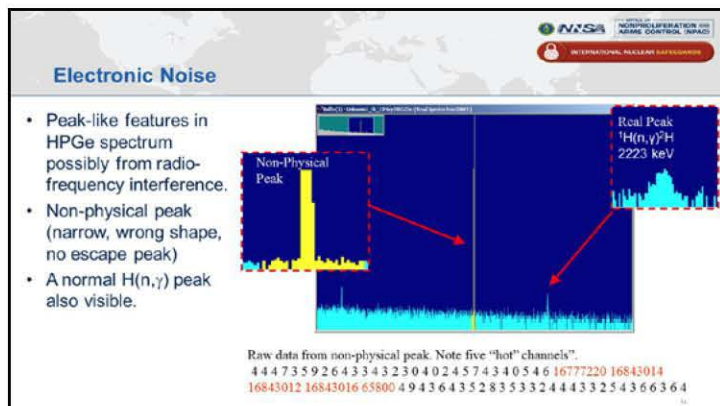
Identification can be very difficult if the spectrum has no visible peaks. In this case, try to measure for a longer time. Some radioactive sources really have no measurable gamma-ray peaks, and in that case, visual pattern recognition and contextual information are most valuable. The gamma spectrum may still be useful for excluding some possible identifications. You can confirm

operation of the detector by measuring a check source or background.

Instructor Notes:

Some radioactive sources, particularly neutron and beta sources, have very weak gamma-ray peaks. They may not be measurable by your detector. The spectra shown here are from Cf-252, which is used as a neutron source due to its high spontaneous fission rate. To observe peaks in the Cf-252 gamma spectrum, you would need a long count time and a high-resolution detector. Even in the measurement shown here, the photopeaks are from background nuclides or other nuclear processes. If there are no peaks in the unknown spectrum, you can apply visual pattern recognition and contextual information to make an identification. The gamma-ray spectrum may still be useful for excluding some possible identifications. You can confirm operation of the detector by measuring a check source or the natural background.

Additional Information for Students:

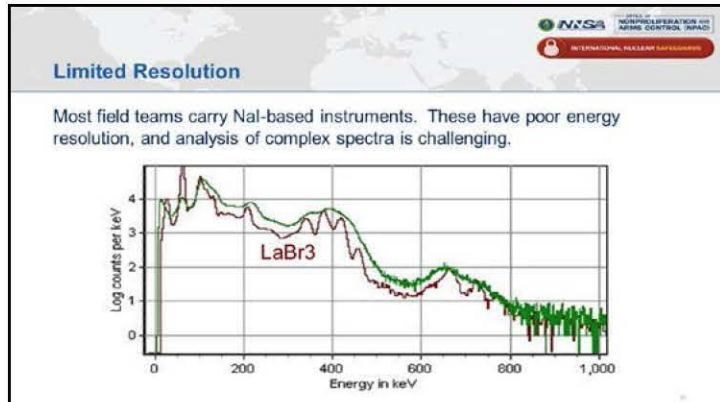


"Peaks" from electronic noise usually do not look like other peaks in the spectrum.

Instructor Notes:

Electronic noise can cause confusing features in gamma spectra. Peaks or features from electronic noise usually do not look like other peaks in the spectrum. Radio frequency (RF) interference results from equipment such as cell phones or large motors causing induced signals in the detector electronics. This will vary depending on the location of the detector relative to the interfering equipment. Mechanical vibrations can also cause interference. A background spectrum can often help in identifying artificial peaks, although sometimes they are intermittent.

Additional Information for Students:



Good energy resolution helps in identifying unknown radionuclides, but germanium detectors are not widely used by field teams because they are less portable than scintillator detectors. LaBr3 is a newer type of scintillator that has much better energy resolution than NaI, and it is gaining acceptance.

Instructor Notes:

Good energy resolution helps in identifying unknown radionuclides; however, most field instruments are low resolution. There are portable germanium detectors that use battery-powered mechanical coolers, but they are less portable and more expensive than scintillator detectors. Lanthanum bromide (LaBr3) is a newer type of scintillator that has much better energy resolution than NaI (about 2x better resolution), and it is gaining acceptance. The spectra shown here are from a plutonium item, with the NaI spectrum, shown in green, and the LaBr3 spectrum, shown in red. You can see the difference in resolution, especially in the 400 keV region.

Additional Information for Students:



Summary

- Manual nuclide identification requires expert experience or rigorous analysis of all peak information
- Many factors affect the identification process, such as detector characteristics, counting statistics, and similar-looking nuclides
- Confident identification requires an accurate and verified energy calibration

We have discussed the general process of nuclide identification. Pattern recognition is dependent on the experience of the spectroscopists, while peak-based identification requires an accurate energy calibration and a thorough explanation of all features in a spectrum. We discussed ten causes of isotope misidentification, although there are more, particularly with

automated identification algorithms.

Instructor Notes:

We have discussed the general process of nuclide identification. Pattern recognition is dependent on the experience of the spectroscopists, while peak-based identification requires an accurate energy calibration and a thorough explanation of all features in a spectrum. We discussed some causes of isotope misidentification, although there are more, particularly with automated identification algorithms.

Ask for questions.