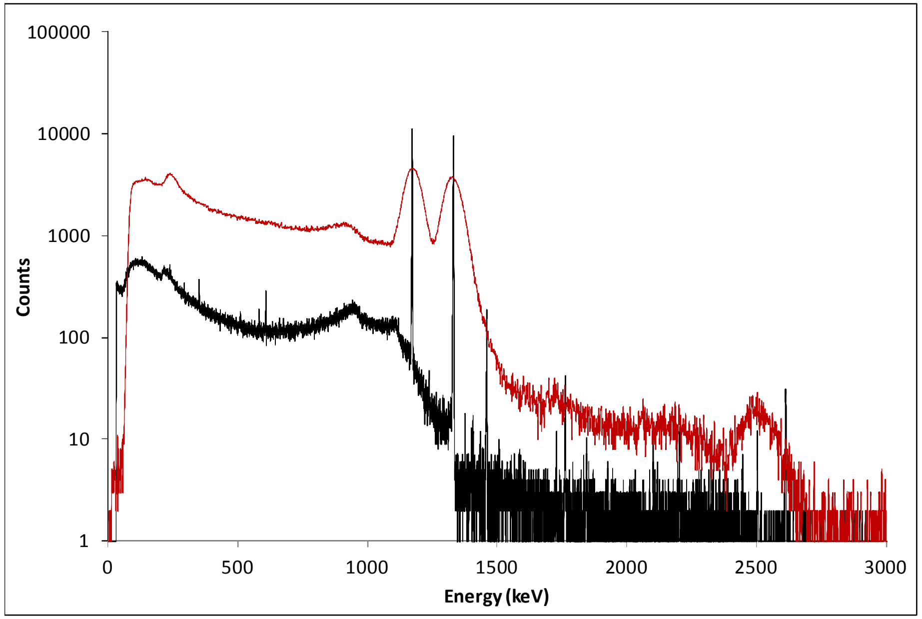
Gamma Spectroscopy for First Responders



Radioactive Material Identification

All radioactive materials consist of radioisotopes that emit one or more gamma-rays. Each gamma-ray has a specific, well defined energy. The gamma-ray energies from all radioisotopes are tabulated in a gamma-ray database.

By measuring the gamma-rays from a radioactive material and comparing them with a gamma-ray database, one can identify the radioactive material.

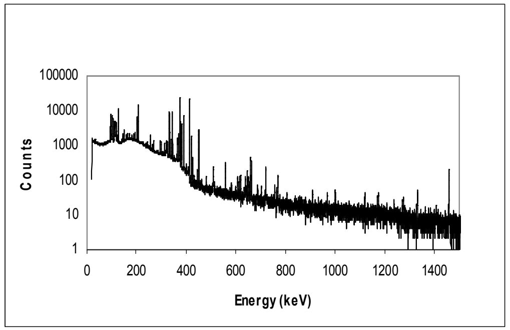
The gamma-rays are the unique *"fingerprints"* of radioactive materials.

Isotope	Half-life	Energy (keV)	Yield
Cs-134	**2.06 y**	**Energy (keV)**	**Yield**
		475	1.5%
		563	8.1%
		569	14.0%
		605	97.5%
		796	85.4%
		802	8.6%
		1038	1.0%
		1168	2.0%
		1365	3.3%
Cs-137	**30.1 y**	**Energy (keV)**	**Yield**
		32	0.05%
		662	85.1%
Co-57	**271 d**	**Energy (keV)**	**Yield**
		122	85.5%
		135	10.8%
		570	0.01%
		692	0.16%
Co-60	**5.2 y**	**Energy (keV)**	**Yield**
		1173	100%
		1332	100%

Excerpt from a Gamma-Ray Database

What is Gamma-Ray Spectroscopy?

Gamma-ray spectroscopy is the process of measuring the gamma-ray energies of a radioisotope. Simple radiation detectors are useful for detecting gamma-rays. However, gamma-ray spectroscopy employs a radiation detector coupled to advanced electronics to form an energy spectrometer. The energy spectrometer not only detects gamma-rays but measures their energy. By comparing the measured gamma-ray energies to a database of gamma-rays from all radioisotopes, it is possible to identify the radioactive material.

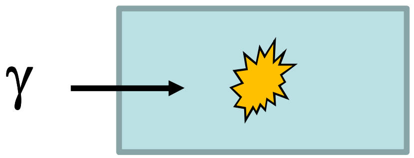


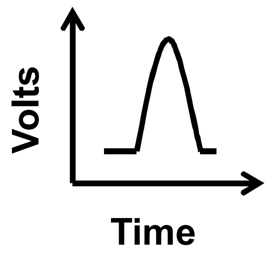
Spectral Analysis

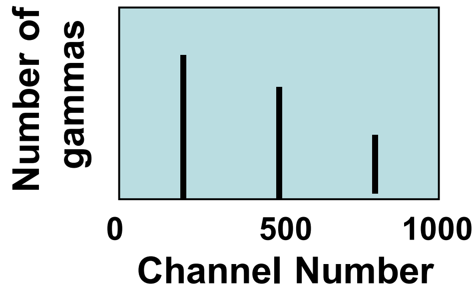
Radiation source contains Pu-239

How are Gamma-Rays Measured?

The following shows the 6 steps in measuring gamma-rays







A gamma-ray interacts with a detector and deposits its energy

Step 1

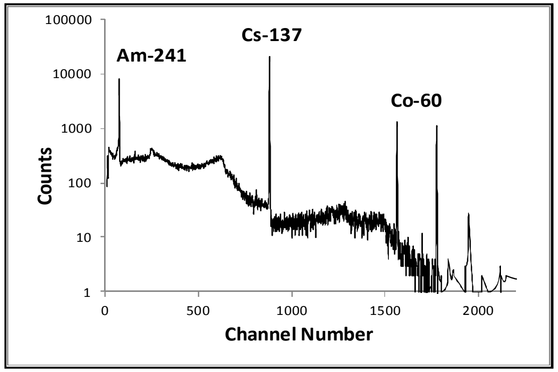
The detector electronics converts the energy to an electronic pulse with 0-8 volts

Step 2

A multi-channel analyzer bins the voltages of the electronic pulses into channels

Step 3

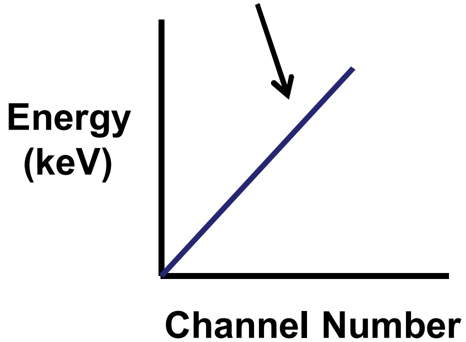
How are Gamma-Rays Measured?



A spectrum of known radioisotopes and gamma-ray energies is measured

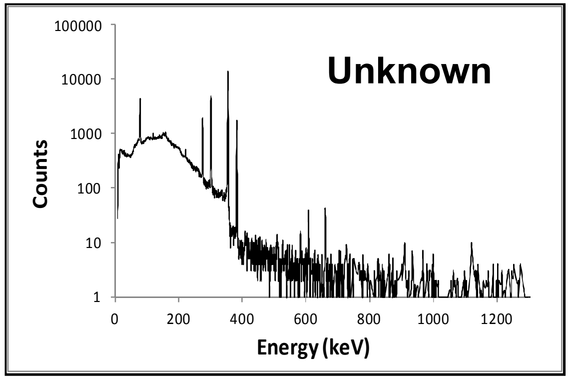
Step 4

$$\text{slope} = \frac{\text{Energy (keV)}}{\text{Channel Number}}$$



The energies are used to calibrate the energy scale using a linear relationship (y=mx+b)

Step 5



An unknown spectrum is then measured and the radioisotope identified by the gamma-ray energies

Step 6

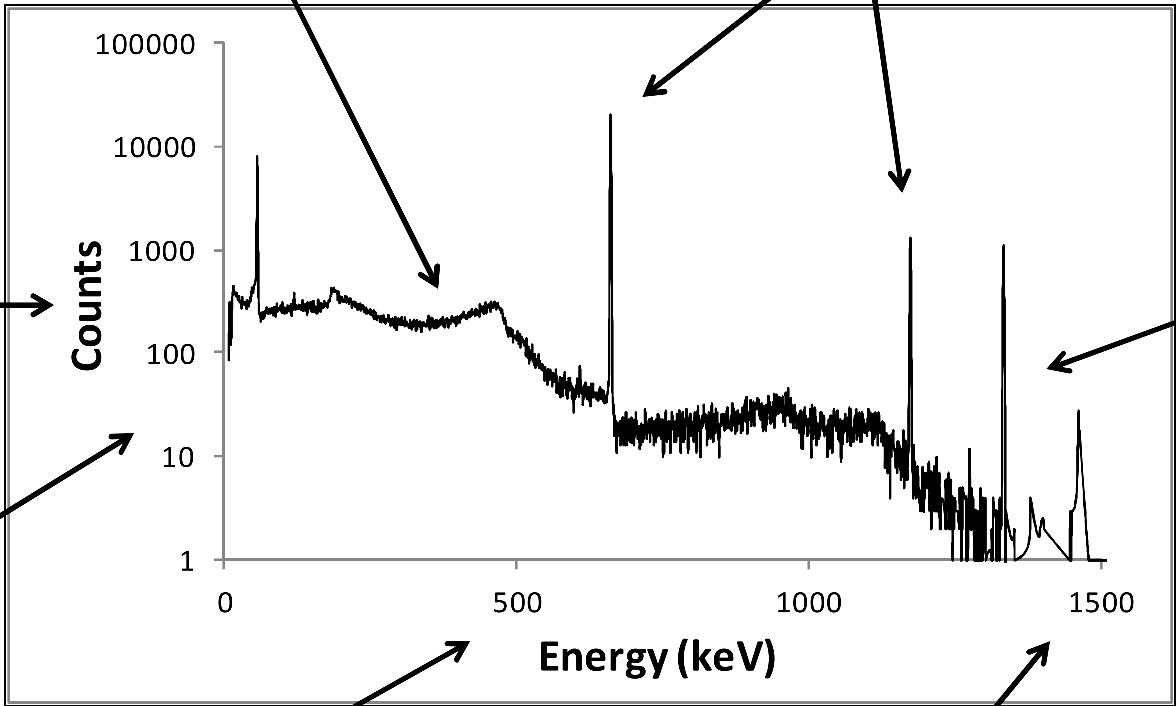
Gamma-Ray Spectrum Features

Valleys are scattered gamma-rays

Peaks are full energy gamma-rays

Gamma-ray counts

Log base 10 scale



Sum of gamma-rays at each energy

Gamma-ray energy scale in kilo-electron volts (keV)

Scale typically 0-1500 keV or 0-3000 keV

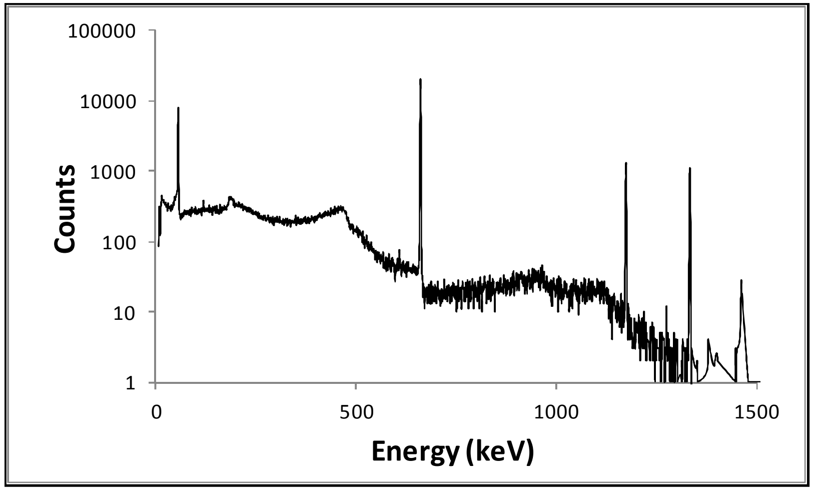
Graphing Gamma-Ray Spectra

Log versus Linear Scale

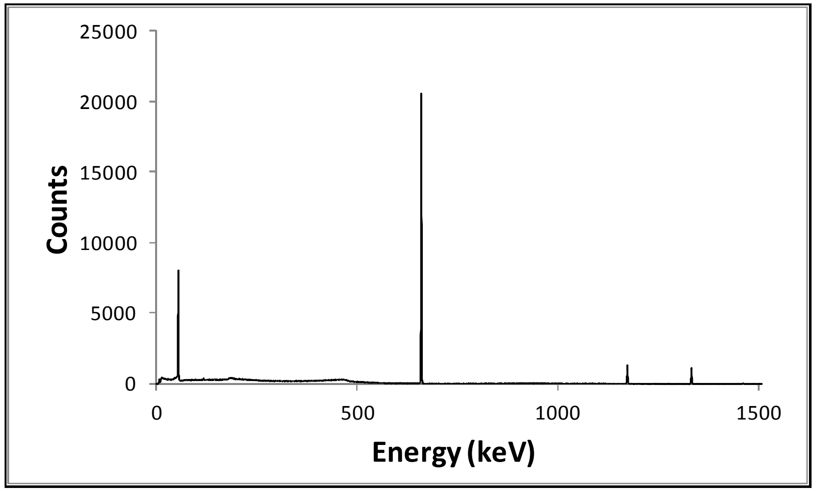
A gamma-ray spectrum is typically graphed with the counts on a log scale. The log scale allows the visual display of the characteristic features of the spectrum.

A linear scale of the counts does not provide this level of visual detail.

Log Scale →

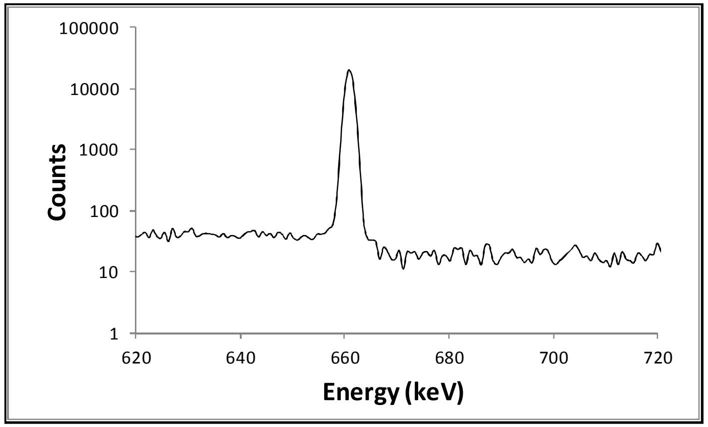


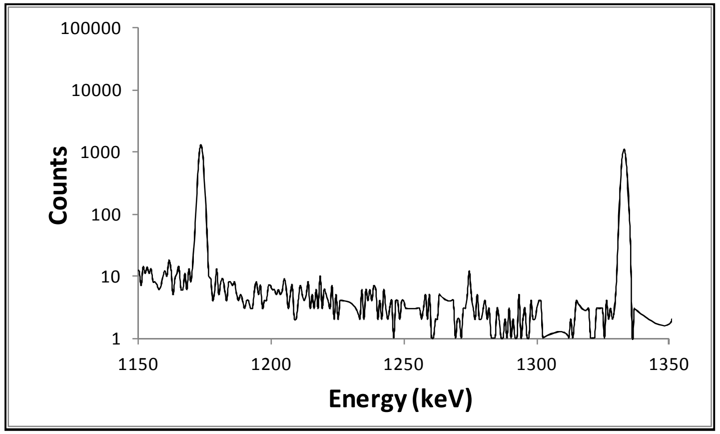
Linear Scale →

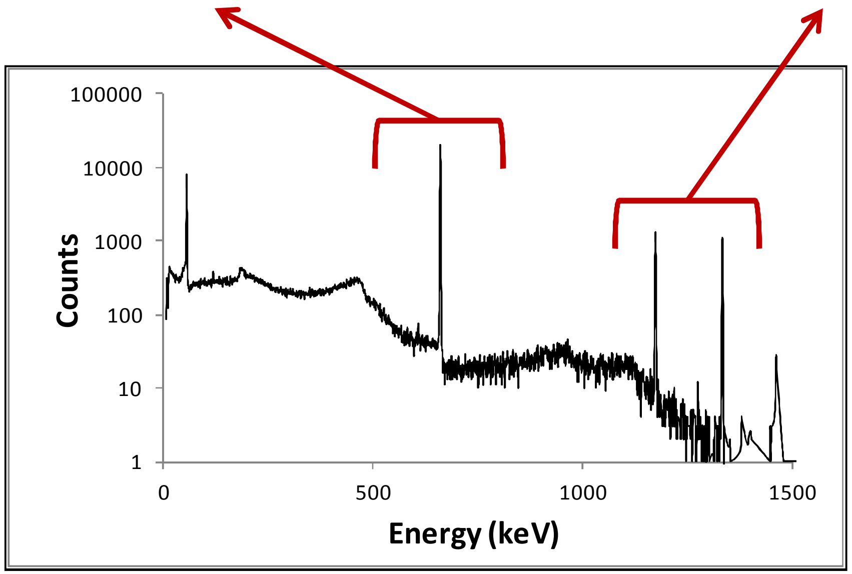


Gamma-Ray Peak Shapes

Expanded view of gamma-ray peaks

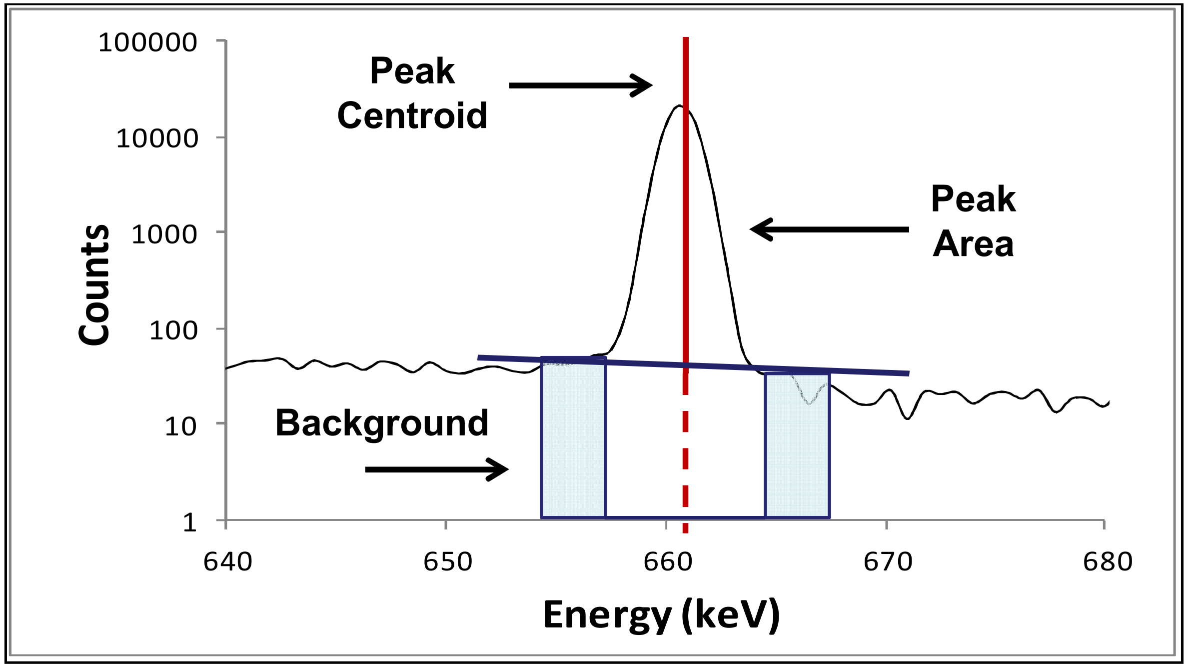






Gamma-ray peaks have Gaussian shapes. The centroid is the gamma-ray energy and the area under the peak is proportional to the radioactivity of the source.

Extracting Peak Data



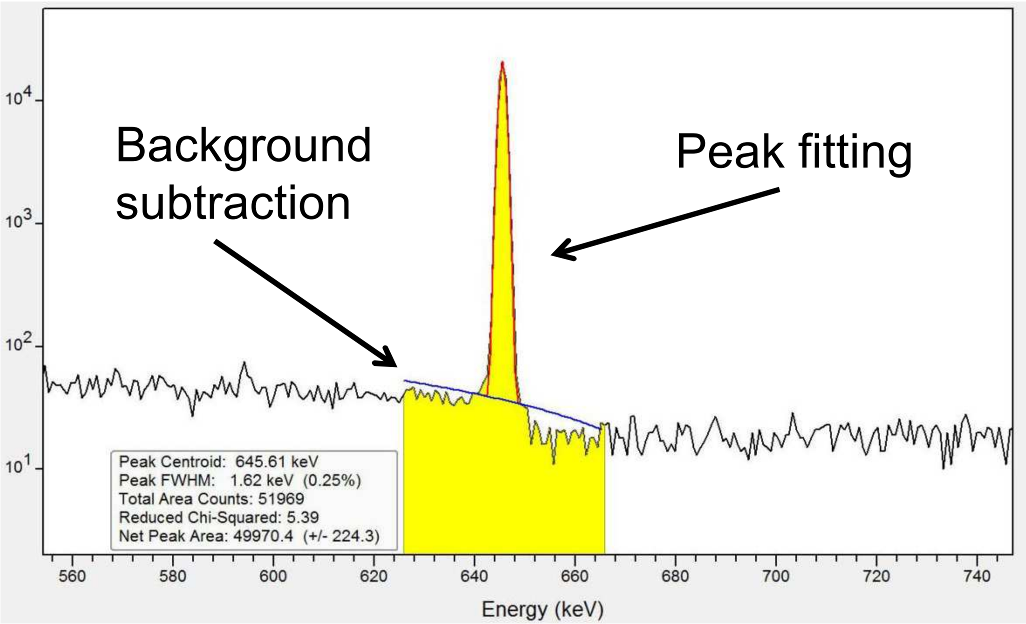
The key information from the peak data:

1. Peak centroid - provides the gamma-ray energy
2. Peak area - proportional to the source radioactivity

The background counts on each side of the peak are averaged and used to subtract the background under the peak, yielding the peak area.

Extracting Peak Data

In practice, commercial gamma-ray spectroscopy software is used to analyze gamma-ray data. The software typically uses advanced statistical analysis techniques such as linear least squares peak fitting and background subtraction to extract the gamma-ray energy, detector energy resolution, total area counts and net peak area counts.



Example of software analysis of gamma-ray peak

Estimating Source Activity

The peak area can be used to estimate the source activity

$$\text{Peak Area (Counts/Second)} \sim \frac{C \times S \times B \times A \times E \times e^{-(\mu \times \rho \times D)}}{4\pi \times D^2}$$

where:

C	1 disintegration/second/Bq
S	radiation source activity (Bq)
B	gamma-ray yield (branching ratio)
A	detector geometric cross section (cm^2)
E	detector total intrinsic efficiency
D	detector to source distance (cm)
μ	air mass attenuation coefficient (cm^2/g)
ρ	air density (g/cm^3)

Natural Terrestrial Radiation

The natural terrestrial radiation is produced by uranium, thorium (including their decay products) and potassium which exist in minute quantities in all materials. This radiation will be the background in all gamma-ray measurements and will be subtracted in the analysis.

Typical concentrations of U, Th and K in soils

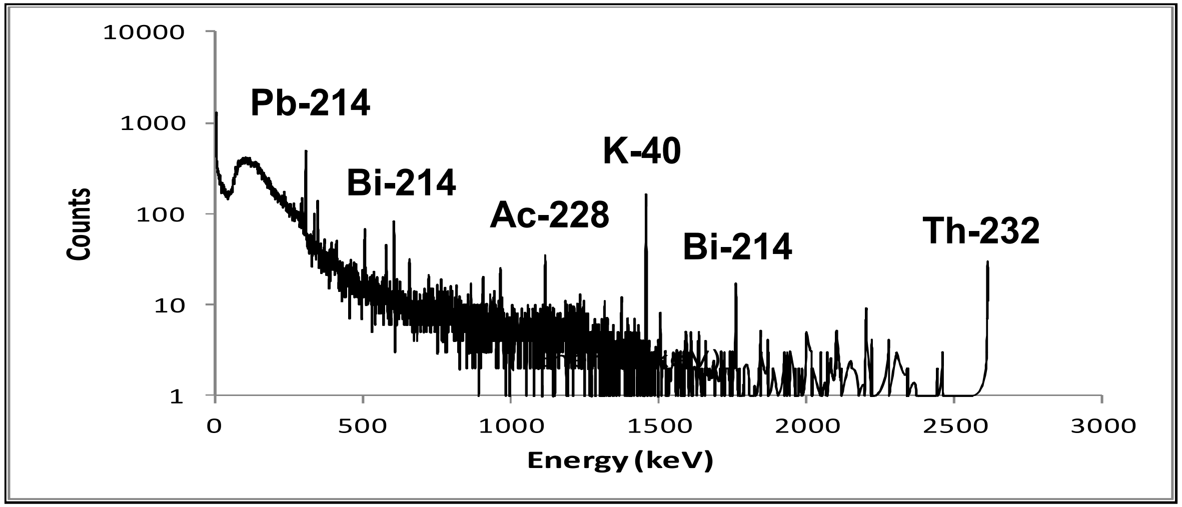
Uranium (U)	0.7 pCi/g	(0.026 Bq/g)	2 ppm
Thorium (Th)	0.6 pCi/g	(0.022 Bq/g)	8 ppm
Potassium (K)	10 pCi/g	(0.37 Bq/g)	1.5%

(1 Bq = 27 pCi or 1 pCi = 0.037 Bq)

Note: Cs-137 exists at 1.7 pCi/g uniformly distributed worldwide due to fallout from atmospheric nuclear weapons tests

Natural Background Spectrum

This background will be measured with all spectra



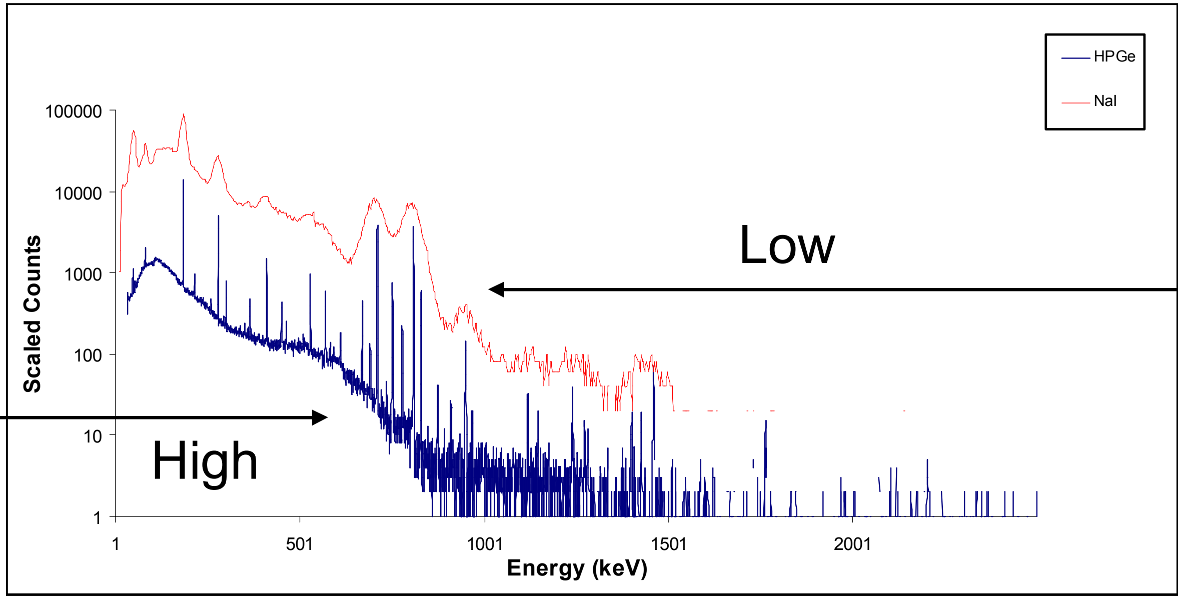
Uranium-series	**Energy (keV)** ***(bolded are most intense peaks)***
Ra-226	186.2
Pb-214	242, **295.2**, **351.9**
Bi-214	**609.3**, 768.4, **1120.3**, **1238.1**, **1764,** 2204
Thorium-series	
Ac-228	338.5, 463, 794.9, **911.0**, **965/967**
Pb-212	**239/241**
Tl-208	277, 510, **583.1, 2614.7**
Bi-212	727.2
Potassium	
K-40	**1460**

Radioactive Material Identification

High Resolution versus Low Resolution Gamma Spectroscopy

"ability to resolve adjacent gamma peaks"

HPGe



NaI

Comparison of a sodium iodide spectrum (low resolution) to a high purity germanium spectrum (high resolution)

Radio**I**sotope **ID**entifier (RIID)

Low resolution sodium iodide gamma detector for initial ***screening*** of radioactive materials. Spectral data is analyzed via radioisotope library. Contains a small neutron detector.

RIID Alarm Display

Display showing radioisotope identification information based on acquired spectrum

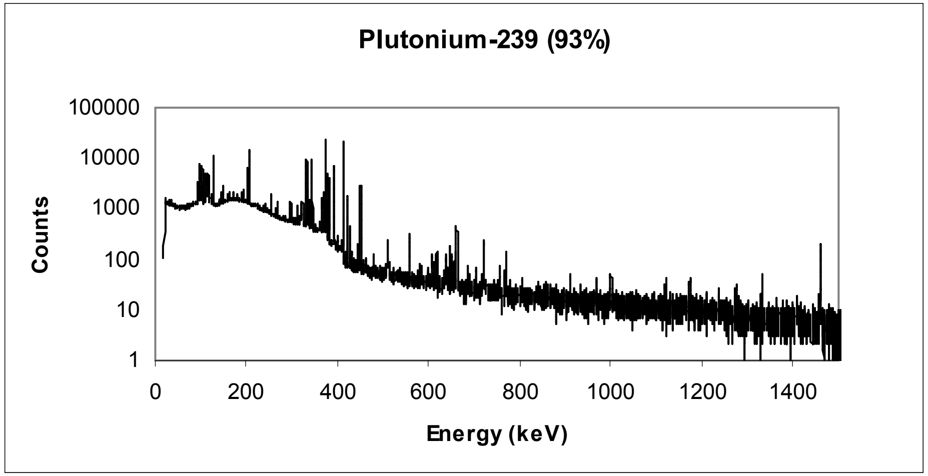
Screening with a RIID is the first step to identifying the radiation source. Data can be downloaded and sent to experts for analysis and further guidance.

Radionuclide Identification (High Resolution RIID)

High Purity Germanium (HPGe) gamma detector ***for laboratory quality spectroscopy in the field*** and accurate radioactive material identification

HPGe Alarm Display

Display showing gamma energy spectrum and dose rate



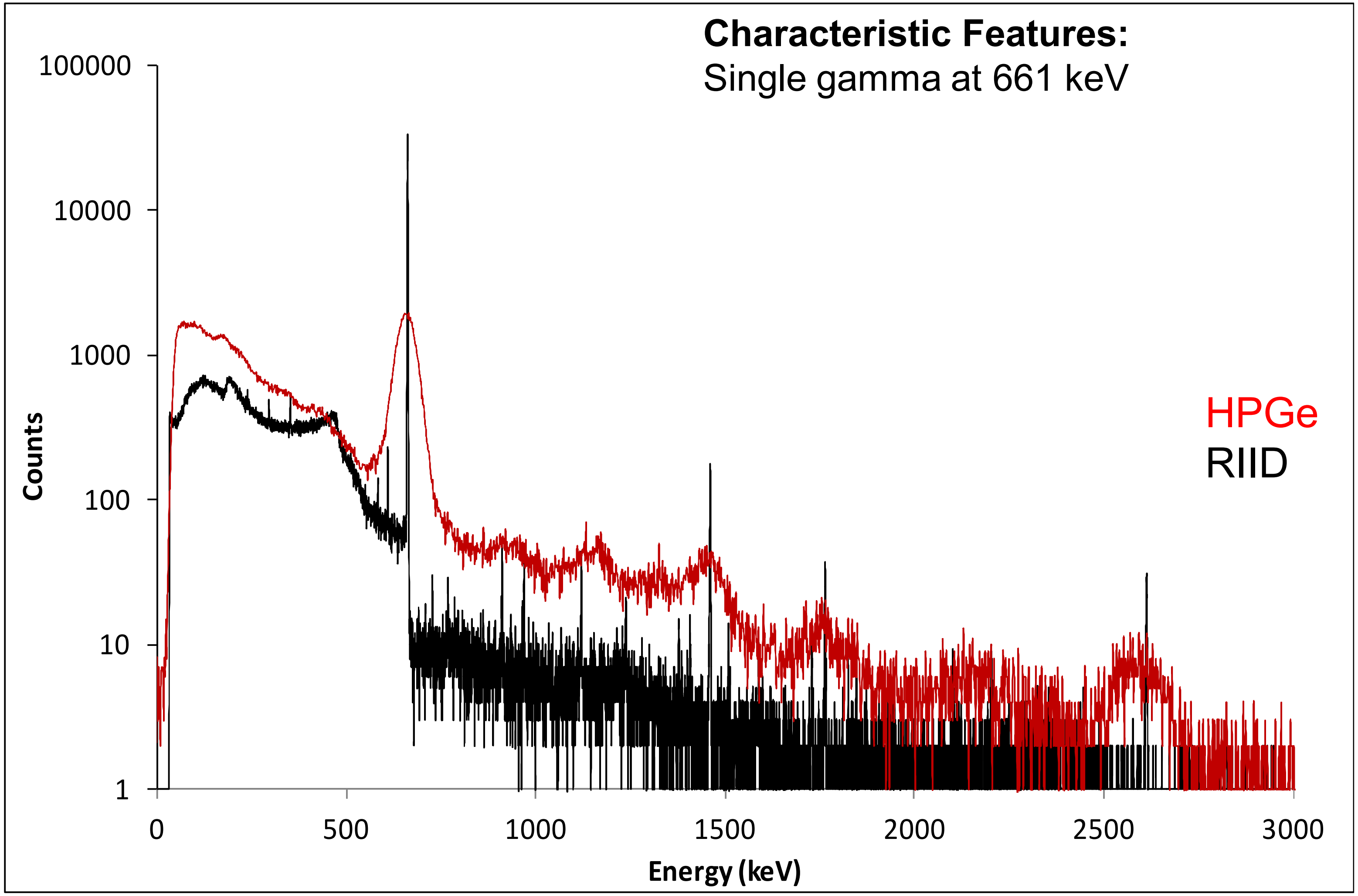
Every radioisotope has a unique spectral fingerprint

Examples of Spectra

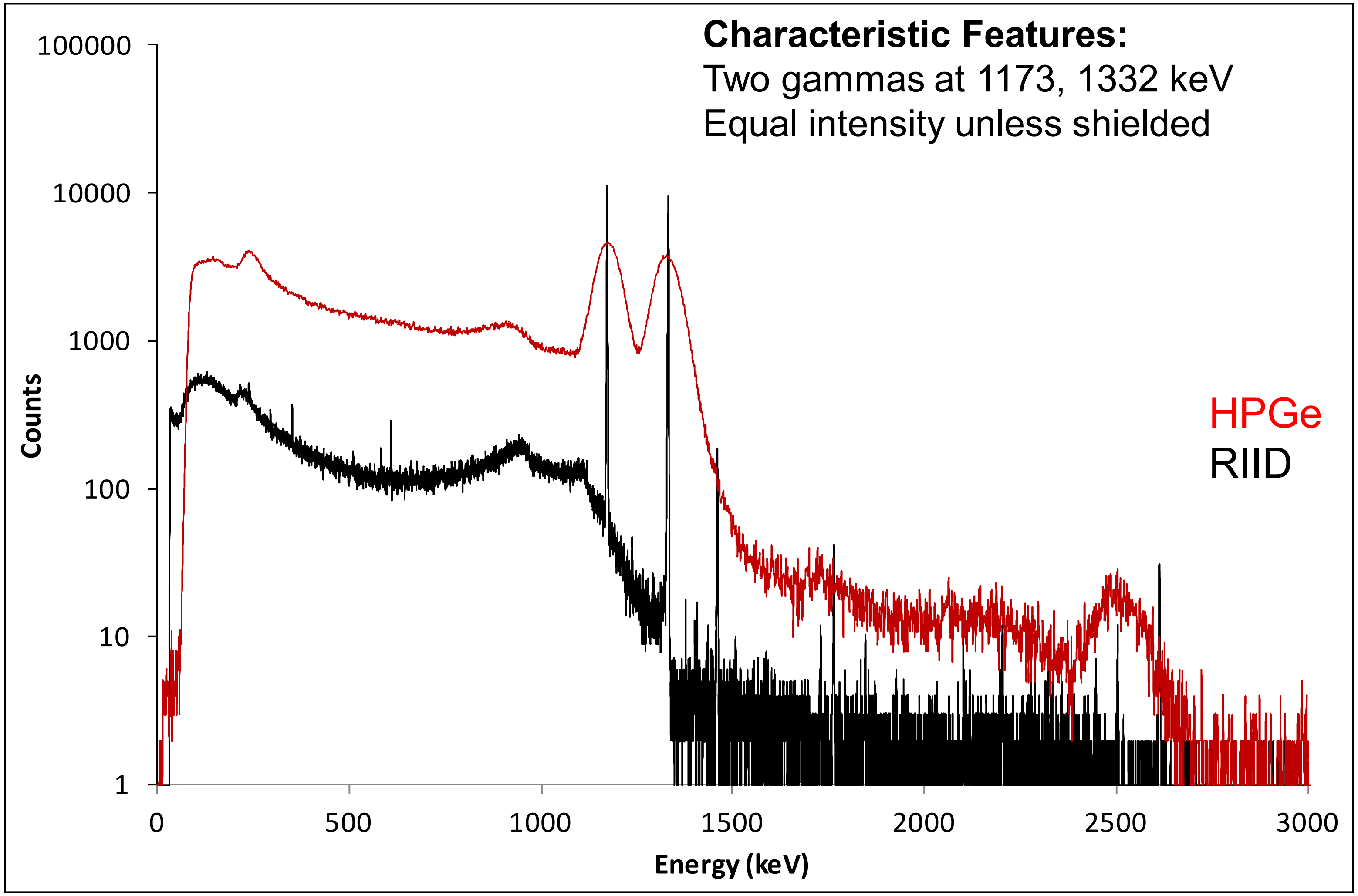
The following section compares the HPGe (high resolution) spectra with RIID (low resolution) spectra for a variety of radioisotopes with simple and complex gamma-ray structures and identifies the characteristic features.

Cs-137	industrial source	simple spectrum
Co-60	industrial source	simple spectrum
Am-241	industrial source	more complex spectrum
Eu-152	industrial source	complex spectrum
Th-232	industrial source	complex spectrum
U-235	special nuclear material	simple spectrum
Pu-239	special nuclear material	complex spectrum

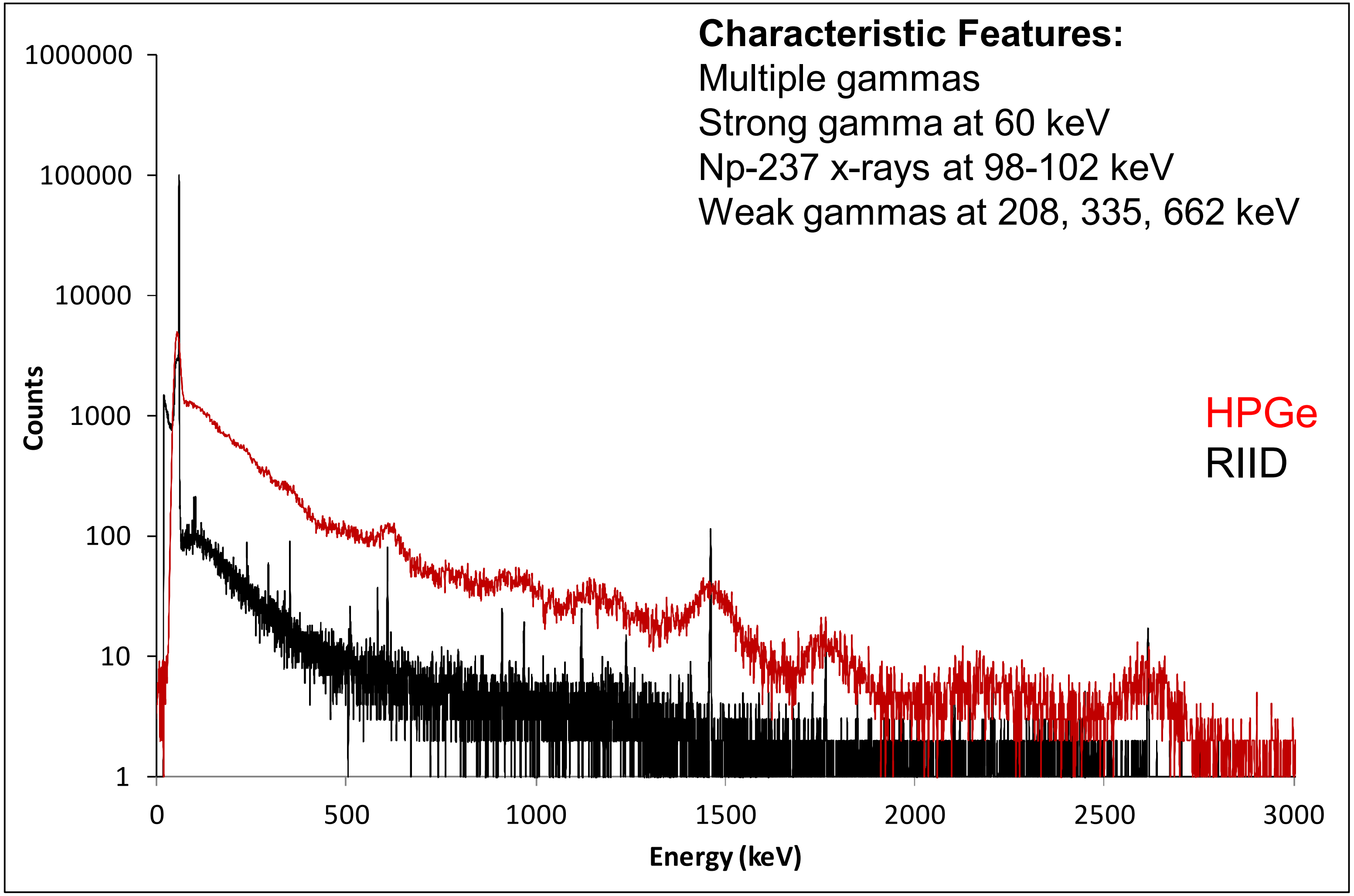
Cs-137 Gamma Spectrum



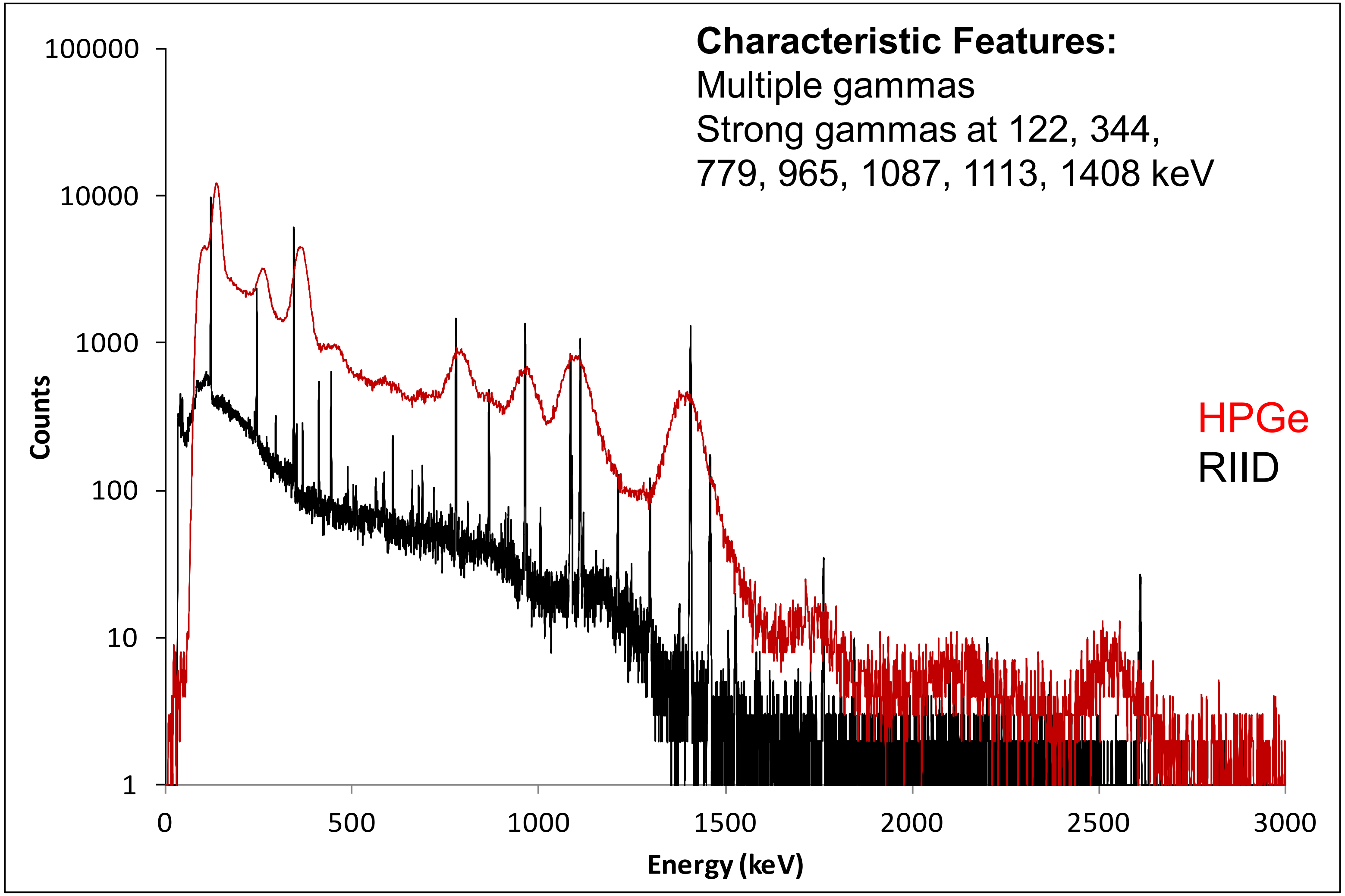
Co-60 Gamma Spectrum



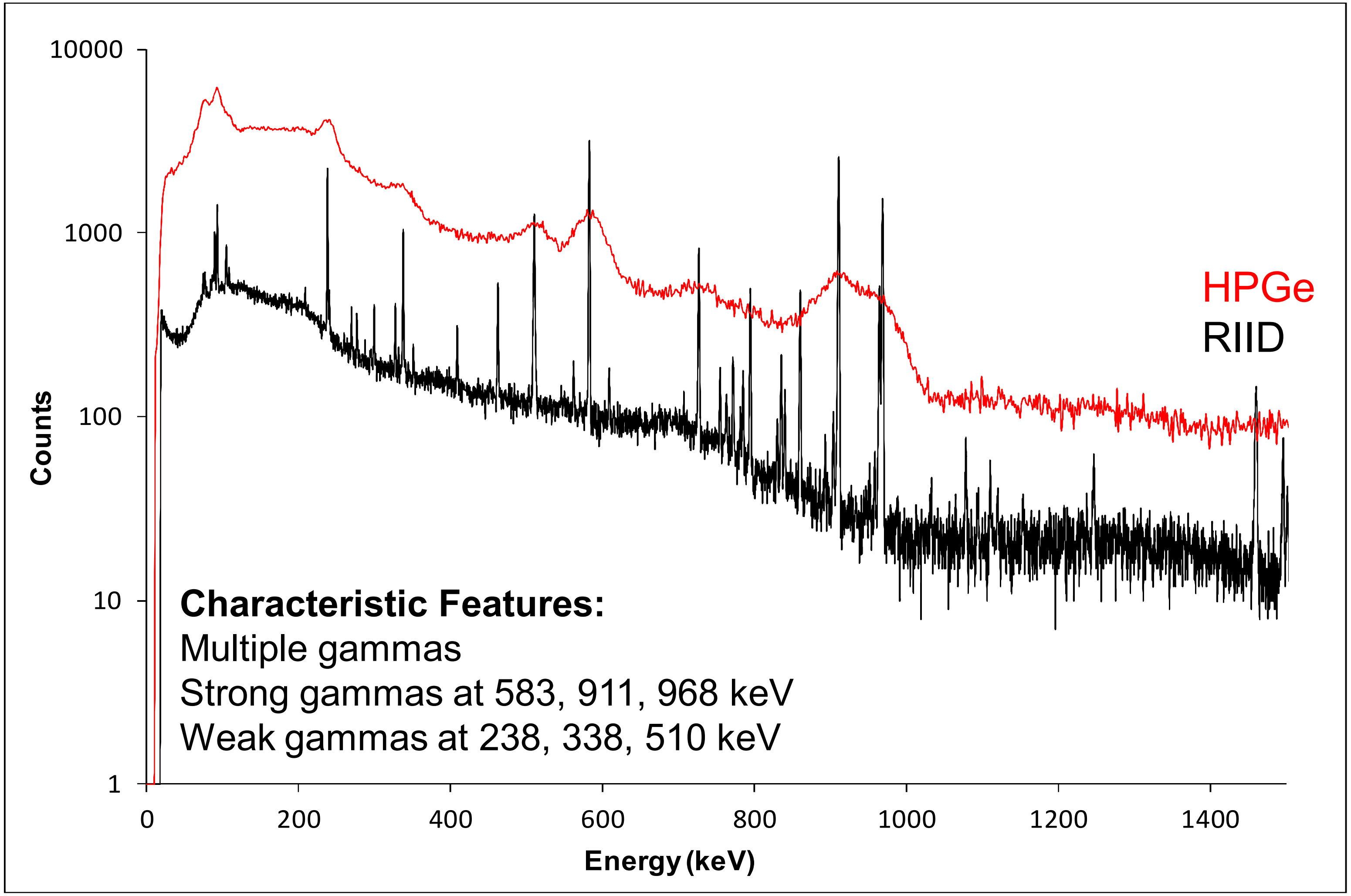
Am-241 Gamma Spectrum



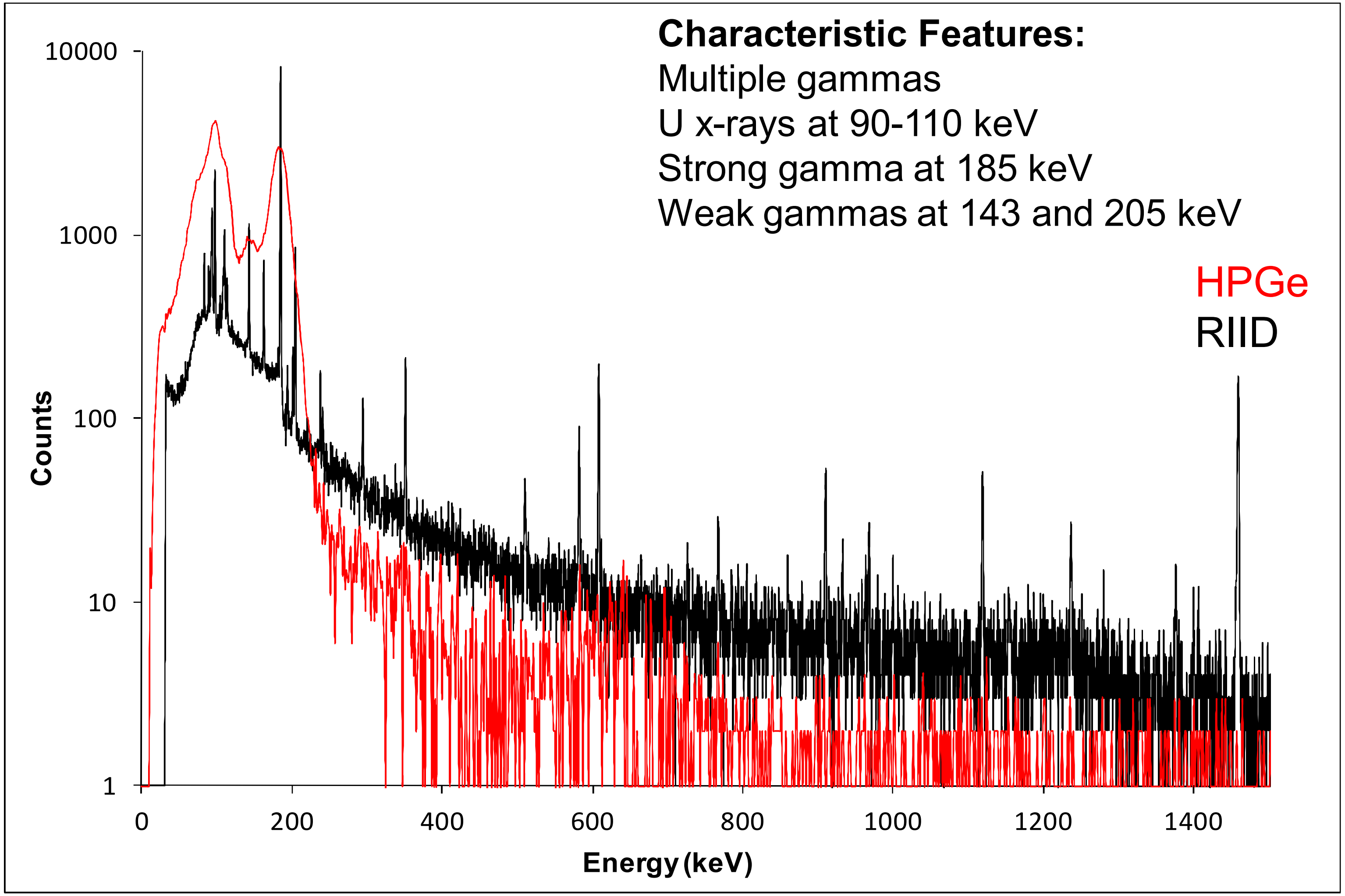
Eu-152 Gamma Spectrum



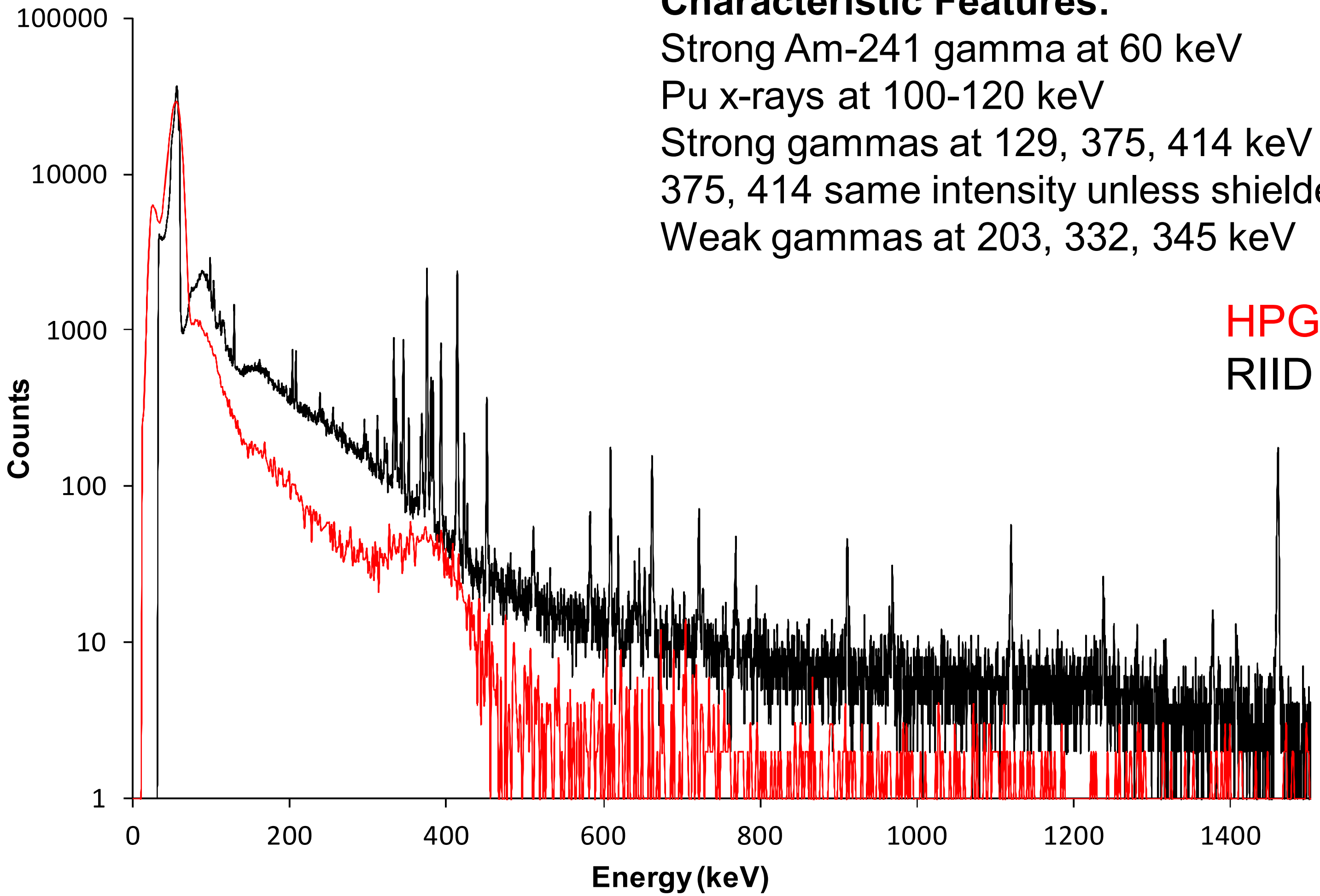
Th-232 Gamma Spectrum



U-235 Gamma Spectrum



Pu-239 Gamma Spectrum



Characteristic Features:

Strong Am-241 gamma at 60 keV
Pu x-rays at 100-120 keV
Strong gammas at 129, 375, 414 keV
375, 414 same intensity unless shielded
Weak gammas at 203, 332, 345 keV

Gamma Spectroscopy

Gamma spectroscopy is a critical tool for first responders allowing critical information to be obtained about the radiation source

Critical information includes:

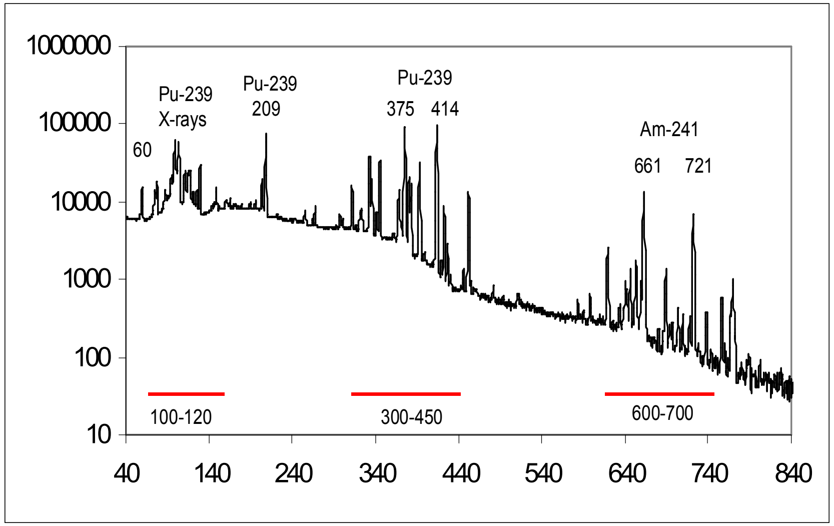
Radioisotope identification

Isotope enrichment

Shielding thickness

Surrounding materials

Quantity of Radioactivity



Pu-239 Spectrum

Radiological TRIAGE

Expert Advice and Assistance for Radiological Data

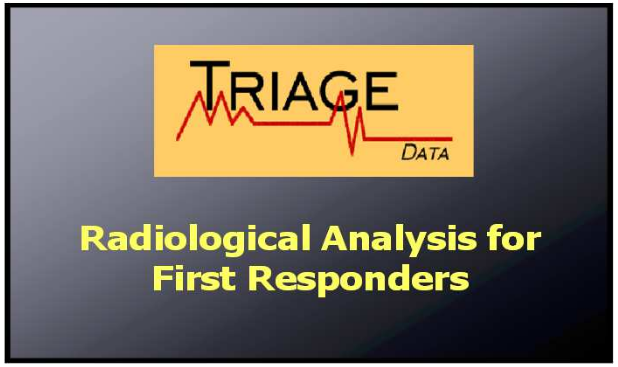
Many first responders are trained to acquire spectral data but often it takes an expert in gamma-ray spectroscopy for proper analysis.

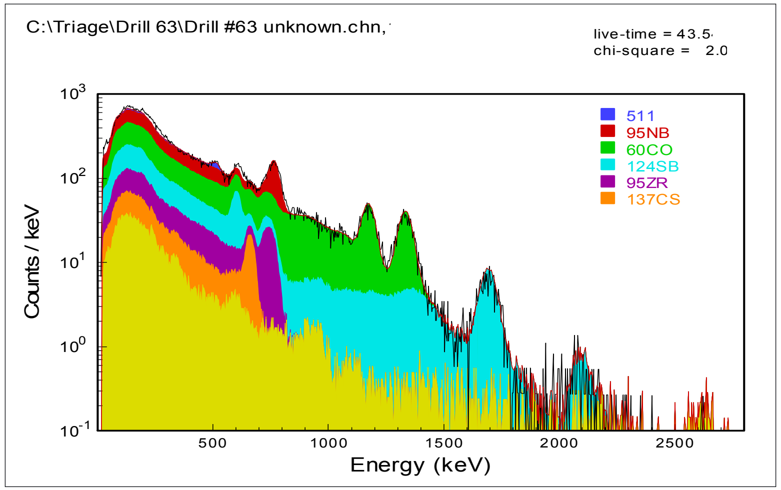
Radiological TRIAGE helps prevent an unnecessary full-scale response when there is no threat, or can ***"pull the fire alarm"*** if the threat appears to be serious.

International Reach Back

The Radiological TRIAGE System is available 24/7 to provide:

- Radionuclide identification using advanced spectral analysis tools
- Review for the presence of Special Nuclear Materials
- Isotopic analysis of nuclear materials
- Estimates of radioactivity
- Assess potential risk





DOE TRIAGE Access

The DOE TRIAGE System is registered with the International Atomic Energy Agency (IAEA) and can be activated by the IAEA Host Country Competent Authority by calling:

U.S. Department of Energy

Emergency Operations Center

+1-202-586-8100

You will be requested to provide your name and an international call back number. An Emergency Response Officer will return your call within 15 minutes and assist you with the process to email the spectral data or other radiological data to TRIAGE for expert analysis.

DOE TRIAGE Checklist

Summarize the following in a document and email to TRIAGE:

- Point of contact name and international phone number
- Type of Event – Real World or Drill
- Brief description of event
- Description of object and sketch with dimensions
- Intervening materials between detector and object
- Gamma detector - Type/Model
- Gamma detector - isotopes identified
- Gamma detector - detector to object distance
- Gamma detector - collection time (minimum 300 sec)
- Neutron detector - Type/Model
- Neutron detector - count rate (neutrons/sec)
- Neutron detector - detector to object distance
- Neutron detector - collection time (minimum 300 sec)
- Neutron detector - orientation with respect to object
- Data filenames and description (examples include):
- Filename, Gamma calibration spectrum
- Filename, Gamma background spectrum
- Filename, Gamma object spectrum
- Photo of the detector measurements with object

Radioisotope Reference

Natural Occurring (Background) Radiosotopes			
Radioisotope	**Symbol**	**Half-life**	**Gamma Energy (keV)**
Uranium Series	U-238	4.5×10^9 years	
Radium-226	Ra-226	1600 years	186
Lead-214	Pb-214	27 min	242, 295, 351
Bismuth-214	Bi-214	20 min	609, 1120, 1238, 1764
Thorium Series	Th-232	1.4×10^{10} years	
Actinium-228	Ac-228	6.1 hours	911, 965
Lead-212	Pb-212	10.6 hours	239
Thalium-208	Tl-208	2.1 min	583, 2614
Bismuth-212	Bi-212	60.6 min	727
Potassium Series			
Potassium-40	K-40	1.3×10^9 years	1460
Common Medical Radioisotopes			
Radioisotope	**Symbol**	**Half-life**	**Gamma Energy (keV)**
Technicium-99m	Tc-99m	6 hours	141
Thalium-201	Tl-201	73.1 hours	70, 80, 167
Iodine-131	I-131	8 days	284, 364
Galium-67	Ga-67	78.2 hours	185, 300
Indium-111	In-111	67.4 hours	171, 245
Xenon-133	Xe-133	5.2 days	81
Common Industrial Radioisotopes			
Radioisotope	**Symbol**	**Half-life**	**Gamma Energy (keV)**
Cesium-137	Cs-137	30 years	32, 661
Cobalt-60	Co-60	5 years	1173, 1332
Iridium-192	Ir-192	74 days	295, 308, 316, 468
Americium-241	Am-241	432 years	60
Uranium-238	U-238	4.5×10^9 years	766, 1001
Radium-226	Ra-226	1600 years	186, 609, 1120, 1764
Special Nuclear Materials			
Radioisotope	**Symbol**	**Half-life**	**Gamma Energy (keV)**
Uranium-235	U-235	7.1×10^8 years	185
Plutonium-239	Pu-239	24,000 years	129, 203, 375, 414
Common Neutron Radioisotopes			
Radioisotope	**Symbol**	**Half-life**	**Neutron Energy (MeV)**
Californium-252	Cf-252	2.6 years	2
Americium-Beryllium	Am-241/Be	432 years	4

Gamma Spectroscopy for First Responders

Questions?