



Gamma spectroscopy for nuclear forensics

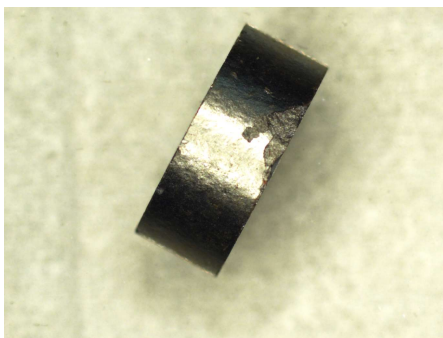
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IAEA Regional Training Course on
Practical Introduction to Nuclear
Forensics

Science. Ingenuity. Sustainability.

Overview



Introduction to gamma
spectroscopy

Radiation Detectors

Sample preparation

Nuclear forensics
analysis



Gamma spectroscopy within nuclear forensics

- Many materials which are of interest to the nuclear forensics processes are gamma emitting radioactive materials
- It is a non-destructive technique
- Initial screening can be performed with very little sample preparation
- Secondary analysis can be performed to determine more information

Questions which gamma spectroscopy can answer



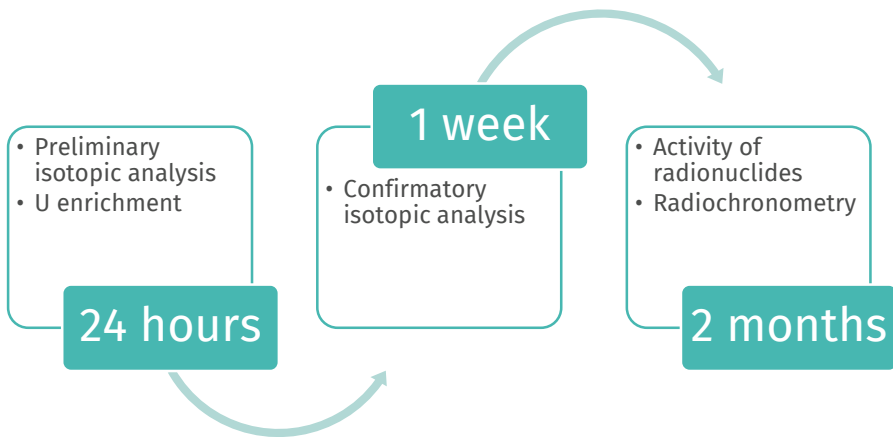
Initial screening

- What gamma emitting radionuclides are present – what is the material
- Isotopic ratios of nuclear material – Has the sample been enriched or is it a by product of the enrichment process

Secondary analysis

- Activity of radionuclides –how much nuclear material is present
- Age dating using radionuclide ratios – when was the material processed or formed

Gamma spectroscopy within the nuclear forensics work flow



Radiation Detectors

Radiation Detectors

Scintillator Detectors

- Crystals which emit light when exposed to radiation
- Two step process using a light detector

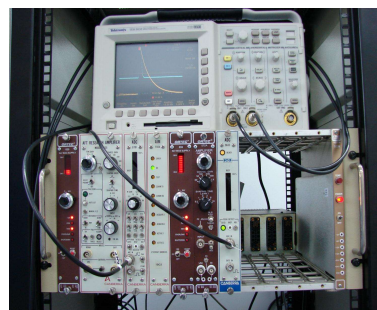


Semiconductor Detectors

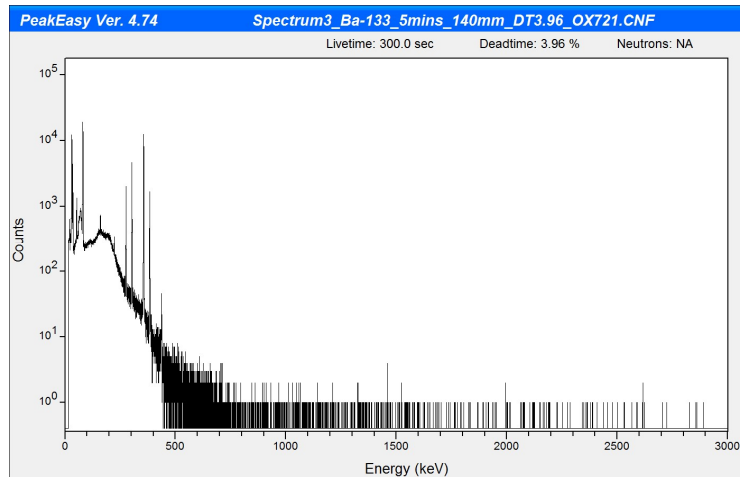
- Semiconductor material interacts with radiation and produces a signal from the crystal



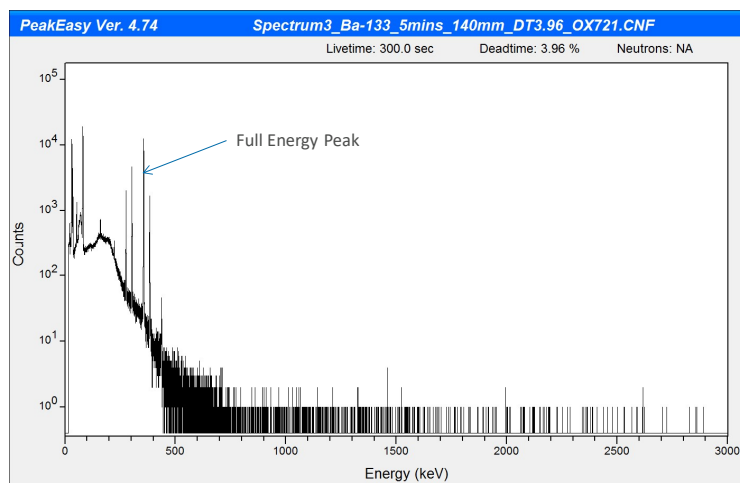
Signal processing



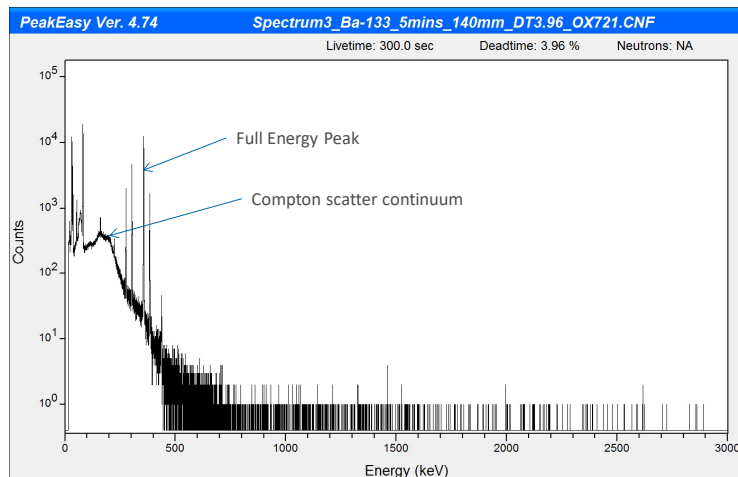
Gamma spectrum



Gamma spectrum

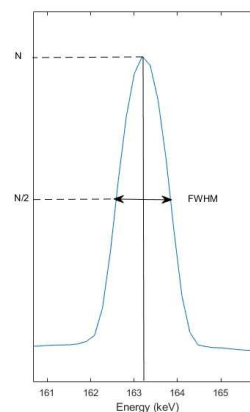


Gamma spectrum



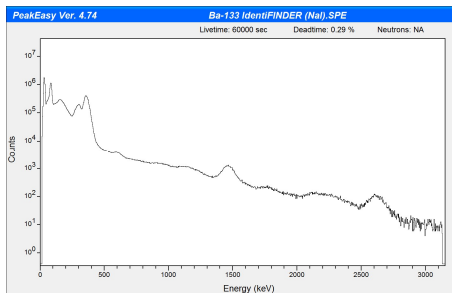
Characteristics of detectors

- **Efficiency** – The percentage of gamma photons which interact within the sensitive volume of the detector compared to the amount of photons emitted from a source.
- **Resolution** – the FWHM of peak within the gamma spectrum. This is effected by detection processes within a sensitive volume and the associated electronics of a detection system.



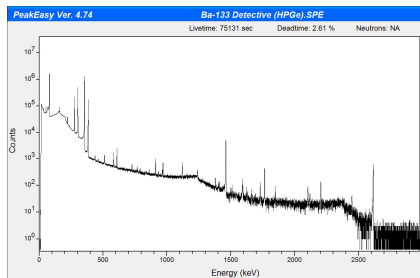
Detector comparison

Scintillator Detector (NaI)



- Robust detectors
- Poor energy resolution compared to HPGe systems
- High efficiency

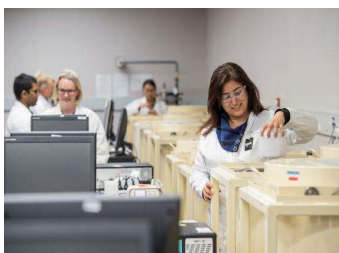
Semiconductor Detector (HPGe)



- Good energy resolution
- Poor detection efficiency
- Required either liquid nitrogen or mechanical cooling



Use of detectors in nuclear forensics



- Most widely used detector is high purity germanium (HPGe) due to their superior energy resolution
- Systems are usually dedicated lab based systems which incorporate cooling and shielding
- Scintillator based devices e.g. NaI detectors are most useful as field instrumentation and are more useful before a sample has been brought to a facility for analysis



Cost of laboratory set-up

Component	Approximate Cost (\$AUS)
Detector	\$20,000 - \$80,000
Lead shield	\$40,000
Signal processing modules	\$20,000
Acquisition Software	\$7,000
Additional analysis software	\$2,000 - \$15,000

Sample preparation

Factors which effect gamma spectrum acquisition



Time – How long a spectrum is acquired for



Distance – How far away a sample is placed from a detector



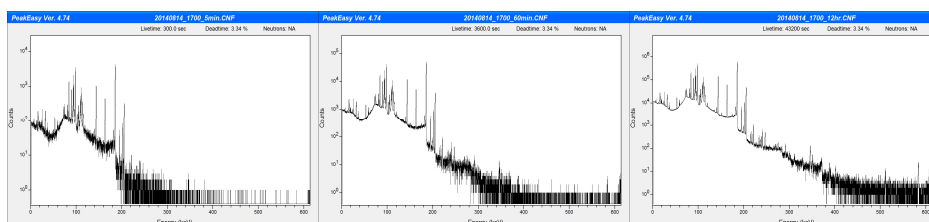
Shielding – The material which is between the sample and the detector. Also self shielding within a sample



Background radiation – Naturally occurring radiation from cosmic and terrestrial sources will be present in all gamma spectrum acquisitions

Time

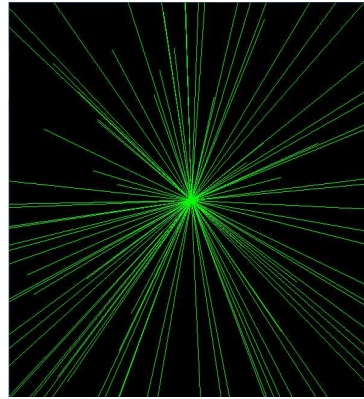
- Counting statistics in radiation detection system follow a Poisson process
- The longer a spectrum is acquired for the easier the peaks are the analyse
- There is not perfect time to acquire a spectrum of an unknown sample for it is a balance between time constraints and data needed for analysis



Distance

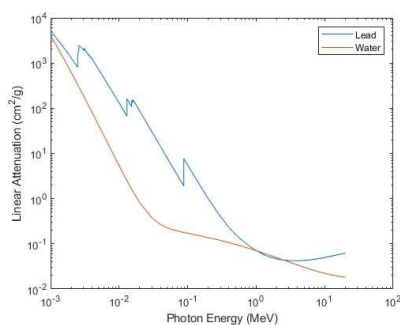
- Gamma photons are emitted in a 360° distribution from the source
- For a point source the reduction in gamma photons is an inverse square relationship

$$I = \frac{1}{d^2}$$



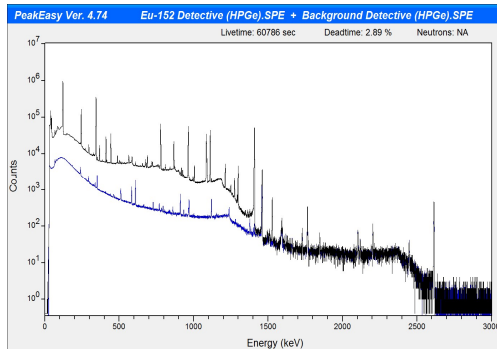
Simulation using TOPAS of a gamma emitting point source showing gamma photon tracks

Shielding



- Any material between your sample and the detector will attenuate a portion of the gamma photons
- This process is energy and material dependent
- This will effect sample preparation depending on the type of analysis that is being performed

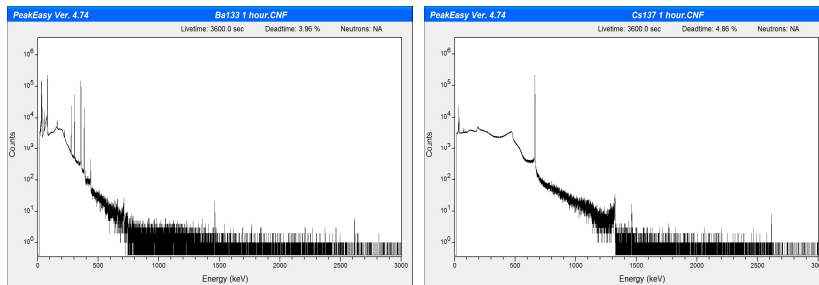
Background radiation



- Background radiation will be present in all gamma spectra
- Techniques to reduce the effects of background are
 - Shielding the detector with lead, copper and cadmium
 - Acquiring a background spectrum for each measurement and subtracting this data in post processing

Nuclear Forensics Analysis

Identification of radionuclides

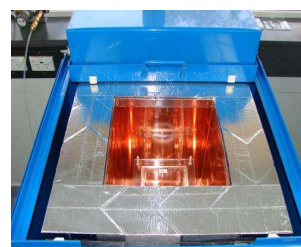


Questions which radionuclide identification can answer

- Is nuclear material present?
- Are fission products present, if so are they short lived or long lived?
- Are daughter products of a radionuclide present?
- Does the sample contain naturally occurring radioactive material i.e. Th-232?
- Has the sample been contaminated with another radionuclide?

Equipment required for radionuclide identification

Equipment required:	Spectroscopic radiation detector. Ideally a HPGe system with low background lead shield
Equipment preparation:	Detector must be energy calibrated using a radionuclide source with known gamma emissions
Sample preparation:	Sample can be analysed in original form with as much shielding material removed as is practical
Analysis of sample:	There are programs available which will identify peaks and assign radionuclide identifications but analysis by an experienced user will give more accurate results



ANSTO

Classification of nuclear material

Nuclear material can be classified by determining the ratio of isotopes present in the sample

Enrichment	U-235
HEU	> 20%
LEU	1-20%
DU	<0.2%
Natural uranium	~0.72%

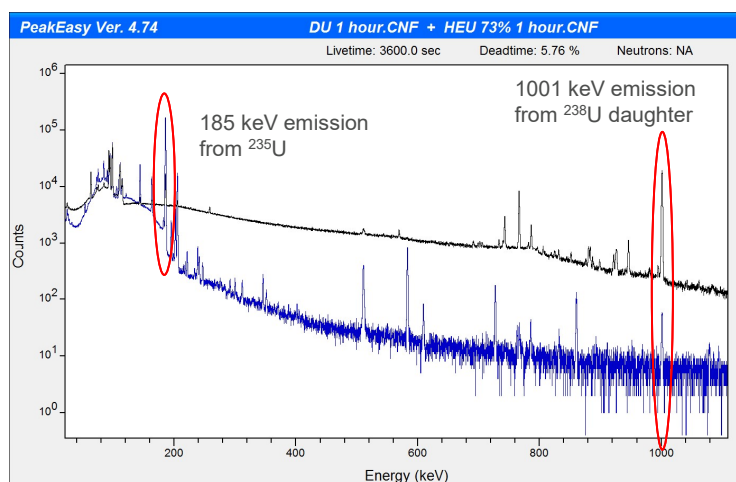
Grade	Pu-239	Pu-240
Weapons	>92%	<8%
Reactor	55-77%	<19%

ANSTO

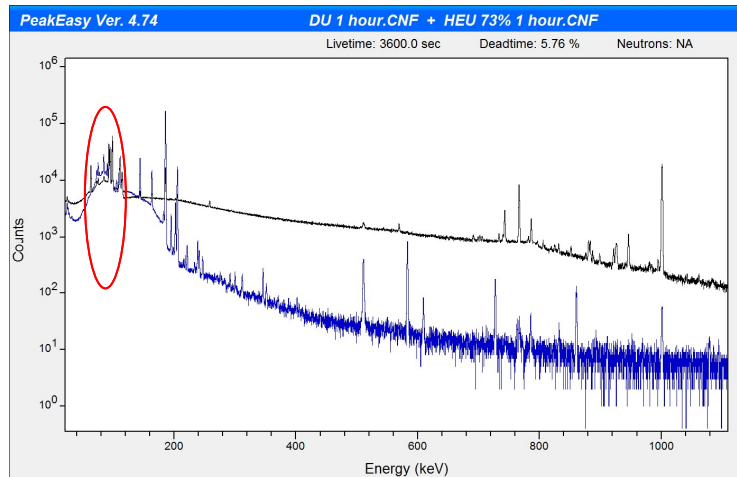
Techniques to determine isotopic ratios

- Ratio of net peak counts using the main emission lines of U-235 and U-238
 - Needs corrections for energy efficiency of detector. Detector has to be characterised
 - Requires corrections for Ra-226 decay
 - Sample needs to be prepared in a specific geometry
 - Does not require dedicated software
- MGAu analysis
 - Sample can be analysed in original packaging and in any geometry
 - Does not require a characterised detector
 - Needs dedicated software
 - Cannot accurately perform analysis if daughter products are present

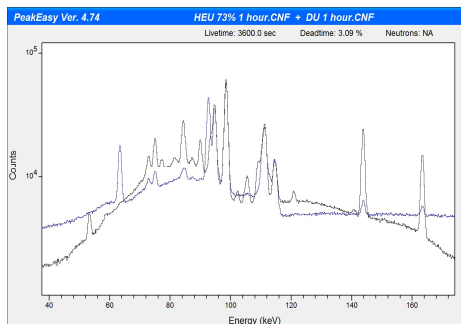
Gamma spectrum region used in net peak ratio technique



Gamma spectrum region used MGAu analysis



MGAu analysis



- By using this region shielding effects are negated as there is no large energy gap between peaks
- A HPGe planar detector is required for gamma spectrum acquisition as peaks are very closely spaced
- An efficiency calibration is not required as the software uses the known emission ratios in this region to compensate for shielding/geometry effects

Questions which can be answered after determining isotopic ratios

- What enrichment/grade is the material?
- Does the sample contain quantities of nuclear materials which are in excess of regulations?
- Are two samples similar ?

Equipment required for nuclear material classification- MGAU

Equipment required: Planar HPGe detector, and CANBERRA MGAU software

Equipment preparation: Detector must have an energy calibration such the it is approximately 0.095 keV/channel

Sample preparation: Sample does not have to be in any certain geometry original packaging should have as much shielding material removed as practical

Analysis of sample: Analysis is performed by running an analysis program. To get results does not require a skilled analysis but interpretation of error or anomalous results can be understood by a skilled analyst

Equipment required for nuclear material classification – activity determination

Equipment required:	Characterised HPGe detector
Equipment preparation:	Detector must an efficiency calibration
Sample preparation:	Sample should be prepared into a standard geometry and have no shielding which hasn't been accounted for
Analysis of sample:	Analysis is performed by a trained expert

Outline of gamma spectroscopy practical

- Familiarisation with HPGe laboratory set up
- Quality assurance procedures required for radionuclide identification and MGAu analysis
- Fuel pellet analysis
- Source preparation and factors which affect gamma spectrum acquisition