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Title: Nondestructive Assay for Nuclear Safeguards

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Nondestructive Assay for Nuclear Safeguards

Actinide Science and Technology Lecture Series

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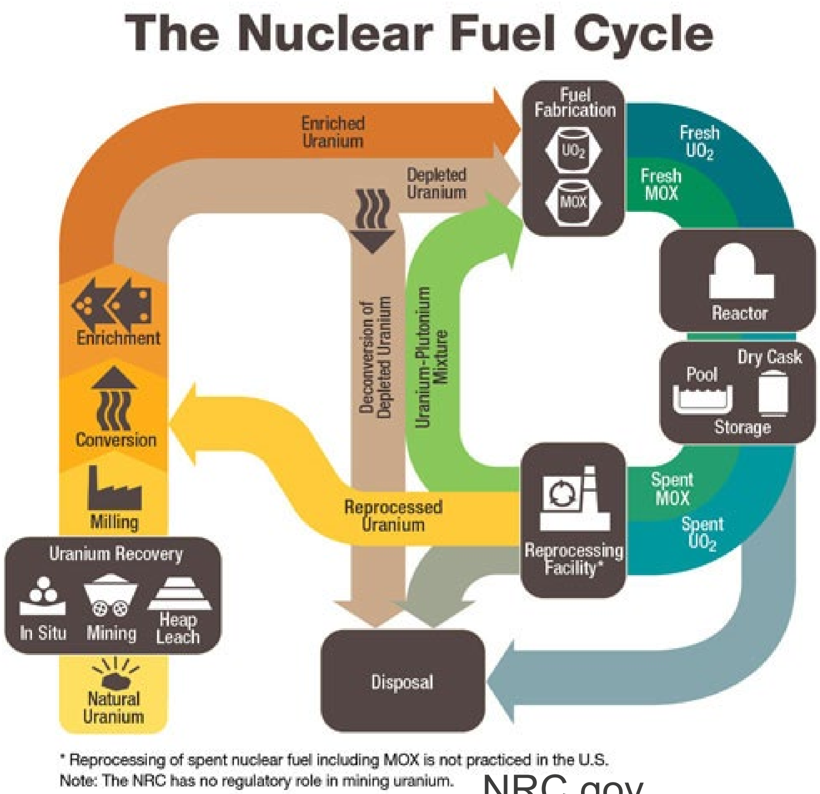
International Safeguards

- "Delivering Effective Nuclear Verification for World Peace"
- The objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons
- Inspect nuclear facilities worldwide, monitor amounts of nuclear materials to ensure that it isn't going to illicit uses



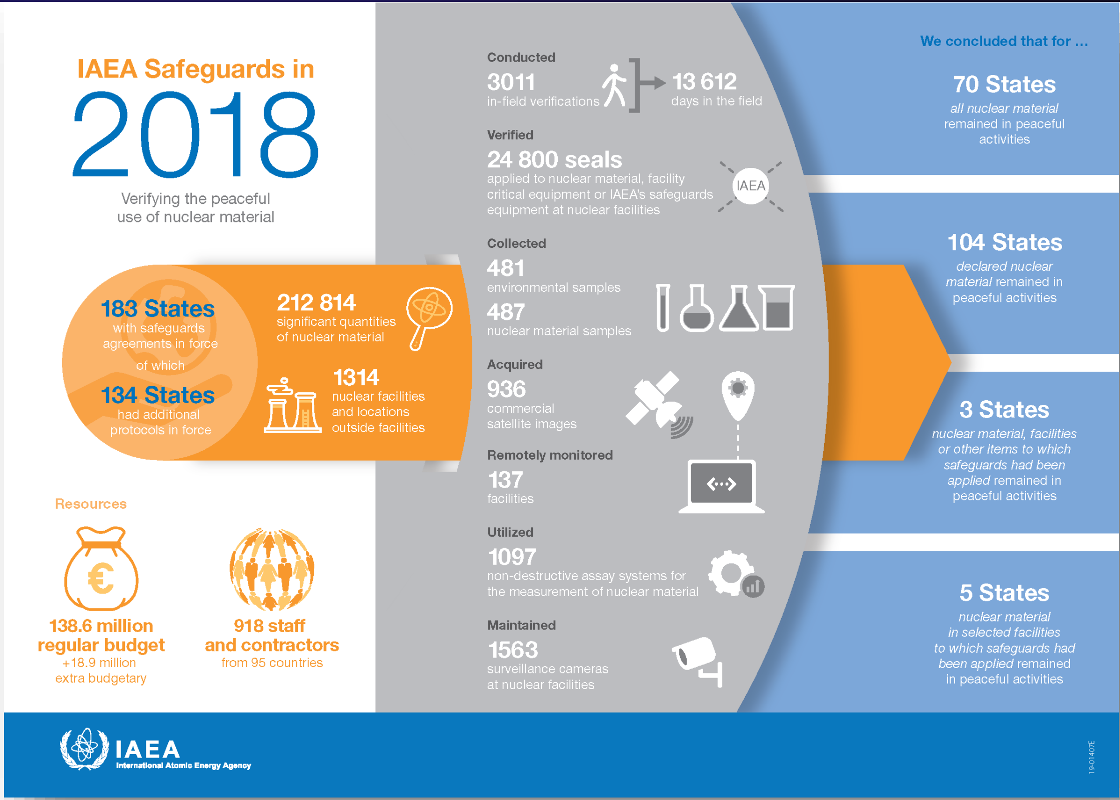
NRC.gov

The IAEA Today

Source(s):
http://www.iaea.org/safeguards/statements-repository/overview.html
http://www.iaea.org/safeguards/documents/LongTerm_Strategic_Plan_%2820122023%29-Summary.pdf

Currently, the IAEA is working to achieve….

- Universal acceptance of the AP
- Safeguards-by-design
  - Integrated within a facility's design, covering safeguards and security
- Unattended monitoring & data integration
  - Robust data management systems to reduce on-site inspector presence



- State-level concept/approach
  - Assessing each State as a whole, using all available safeguards indicators
  - Deciding upon a consistent, unbiased state-level approach development strategy

Special Nuclear Materials

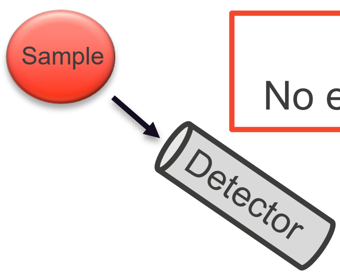
- What are we trying to verify?
  - Special nuclear material (SNM) is where it should be, and in the proper amount

Weapons Grade Pu clad in Stainless Steel and surrounded by a Tungsten Reflector

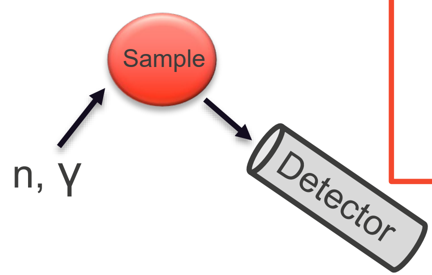
- SNM: Nuclear materials that can be used to make a weapon
  - Highly Enriched Uranium (HEU)
    - Diversion path for HEU: enrichment facilities
    - Certain isotopes of U undergo fission primarily when induced with a neutron source
  - Weapons Grade Plutonium (Pu)
    - Diversion path for Pu: spent fuel (repositories, interim storage, reprocessing facilities)
    - Certain isotopes of Pu undergo fission spontaneously, without any prompting

Nondestructive Assay (NDA)

- NDA is the most commonly employed technique for material accountancy
- A series of gamma or neutron detectors are typically used to measure radiation emitted from the sample of interest
- Energy, timing, and intensity of radiation may be correlated to isotope type and quantity in the sample



Passive:
No external source



Active:
Neutrons or gammas irradiate source to magnify signal

Rail radiation portal monitor (RPM) at the Port of Antwerp, Belgium

- **Passive interrogation requires good signal intrinsic to sample (^{240}Pu, ^{252}Cf)**
- **Active interrogation requires fissile material or material prime for gamma interactions (^{235}U, ^{239}Pu)**

Neutrons and Photons

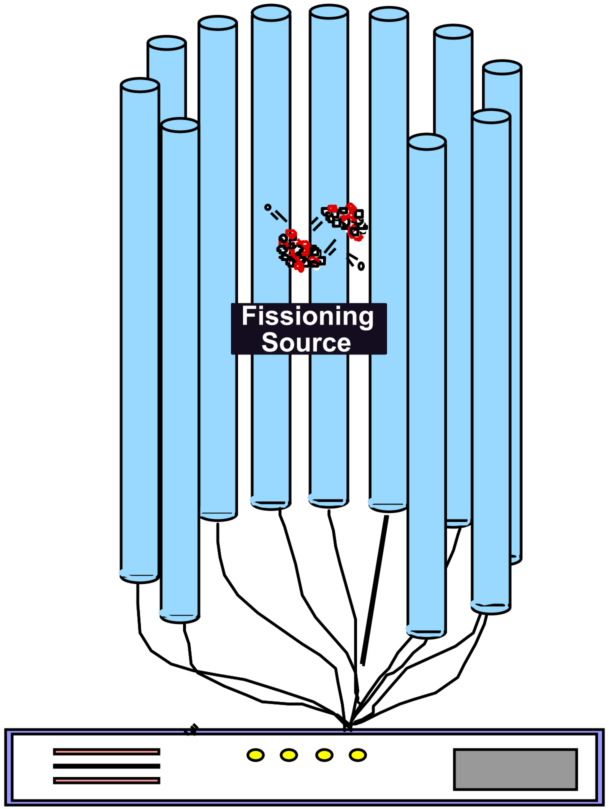
	Neutrons	Photons
Origins	– Spontaneous and induced fission – (α,n) – Cosmic rays – (p,n) – (n,2n) – (γ,n) (Cosmic rays, (p,n), (n,2n), (γ,n): Less common)	– Nucleus (gamma-ray) – Nuclear collision (gamma-ray) – Electron cloud (x-ray)
Signal	Time and correlations	Energy
Shielding	Low Z material	High Z material
Detectors	^{3}He, Scintillators, fission chambers	HPGe, Scintillators, NaI

Neutrons

History of Neutron Counting

- TOTAL NEUTRON
  - Record the total number of neutrons detected in a certain amount of time
  - Accurate assays can be obtained only for very few types of SNM
- COINCIDENCE COUNTING
  - Record the number of times two neutrons arrive within a set time window (gate)
  - Wide application for international safeguards
    - focused on verifying declared materials
- NEUTRON MULTIPLICITY COUNTING
  - Extension of neutron coincidence counting
  - Record the number of times we detect 2, 3, 4, etc. neutrons within a gate
  - It improves neutron assay accuracy dramatically by adding more measured information

Passive Neutron Counter



Pulse-processing Electronics

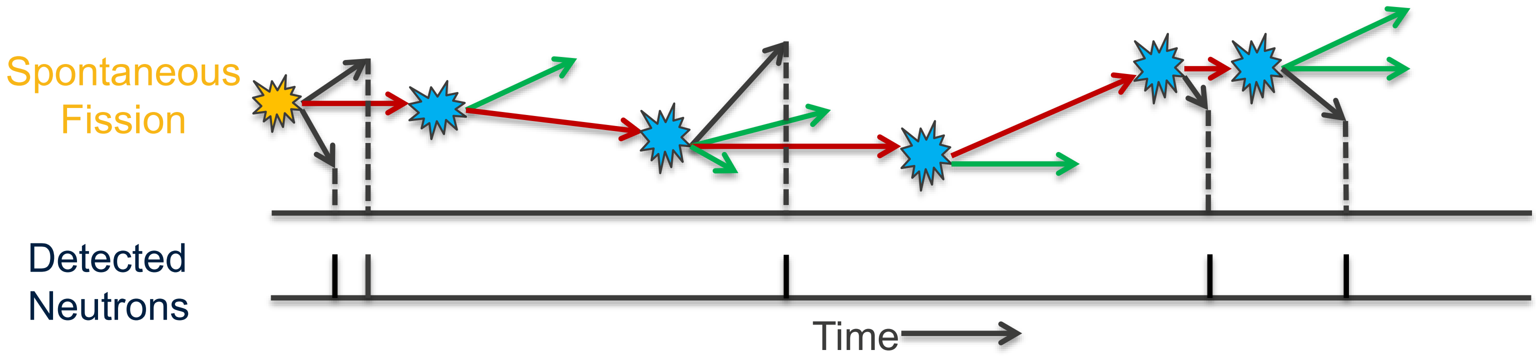
^{3}He neutron detectors

Fissioning source surrounded by neutron detectors

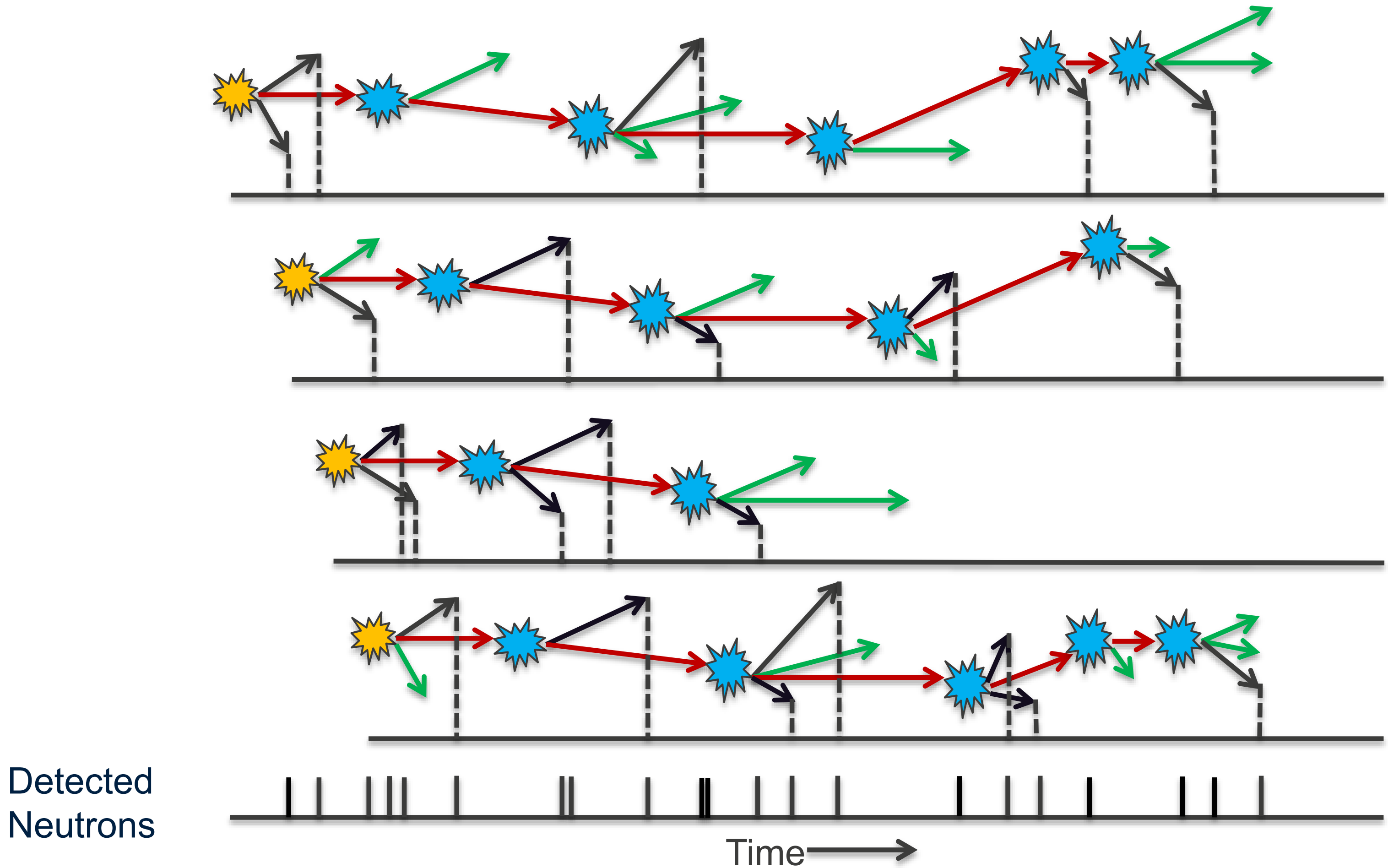
Emission of multiple **prompt** neutrons from fission detected as coincident neutron events

Multiplicity information is used to calculate the mass of fissioning isotopes

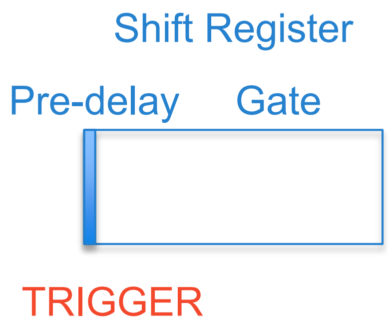
Neutron Coincidence Counting



Neutron Coincidence Counting



Neutron Coincidence Counting

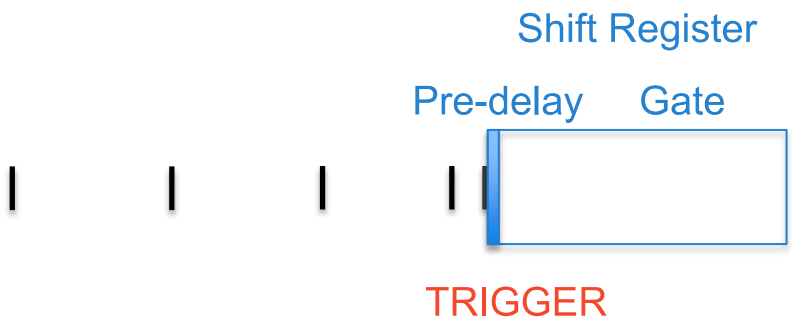


Singles:

Doubles:

- First neutron detection triggers the shift register

Neutron Coincidence Counting

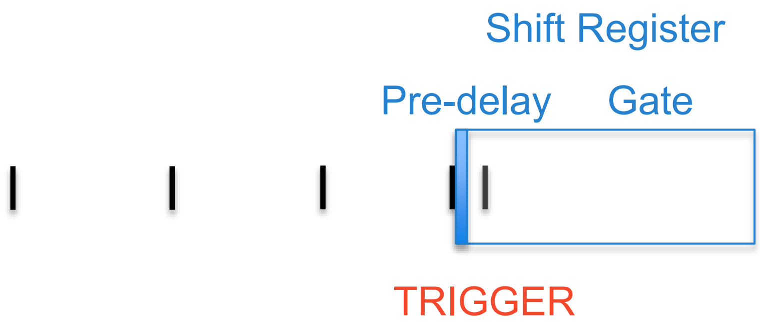


Singles:

Doubles:

- First neutron detection triggers the shift register
- **Next neutron detection triggers the shift register again; this time, one neutron is already in the shift register, so we have one coincidence**

Neutron Coincidence Counting



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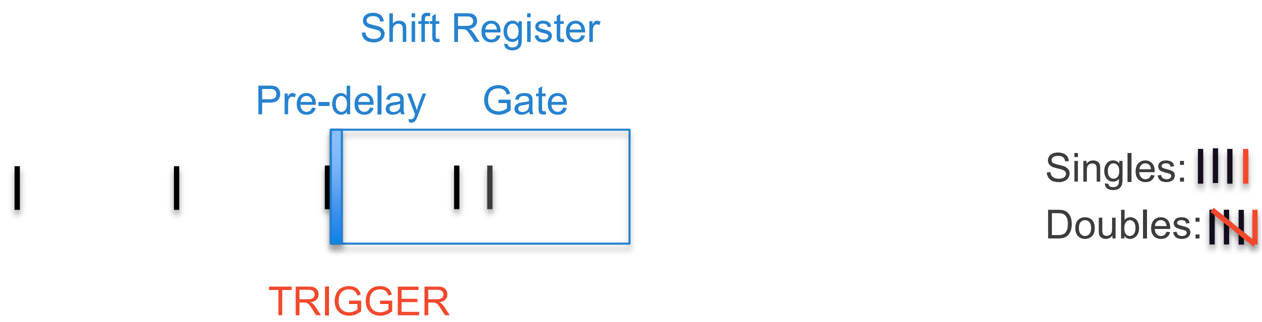
Neutron Coincidence Counting



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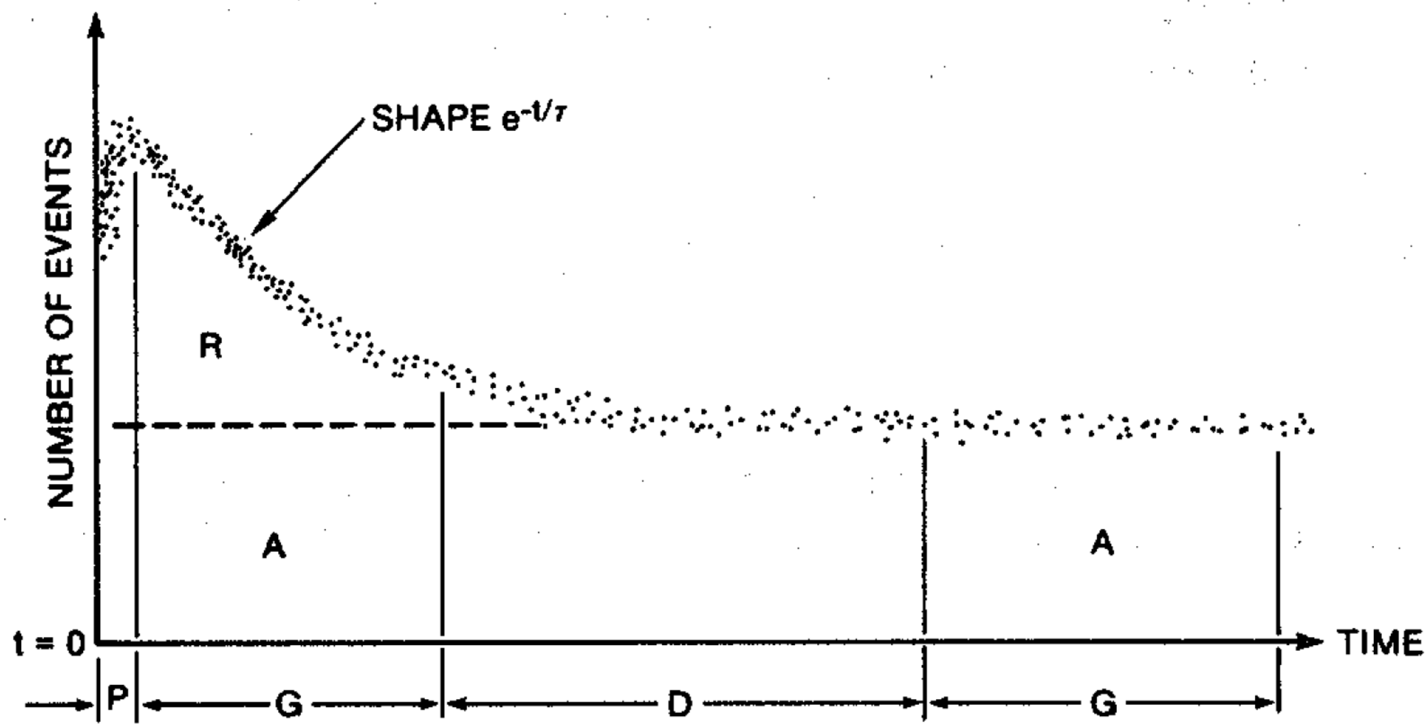
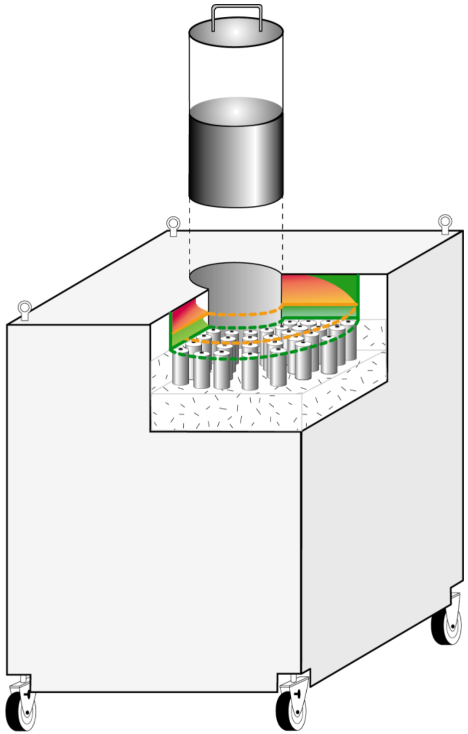
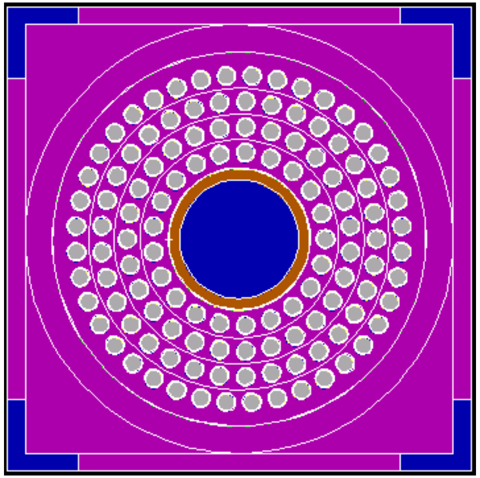
Rossi-Alpha Distribution



Epithermal Neutron Multiplicity Counter (ENMC)



- ε = 65.0%
- τ = 22.0 μsec
- 121 tubes
- 27 preamplifier channels



Photons

Photons

- Generic Assay Equation

$$M_{SNM} = \frac{R_{Rad} \times CF}{Cal}$$

M_{SNM} = Mass of special nuclear material

R_{Rad} = Measured radiation rate (counts per unit time) from SNM item

CF = Correction for losses due to:

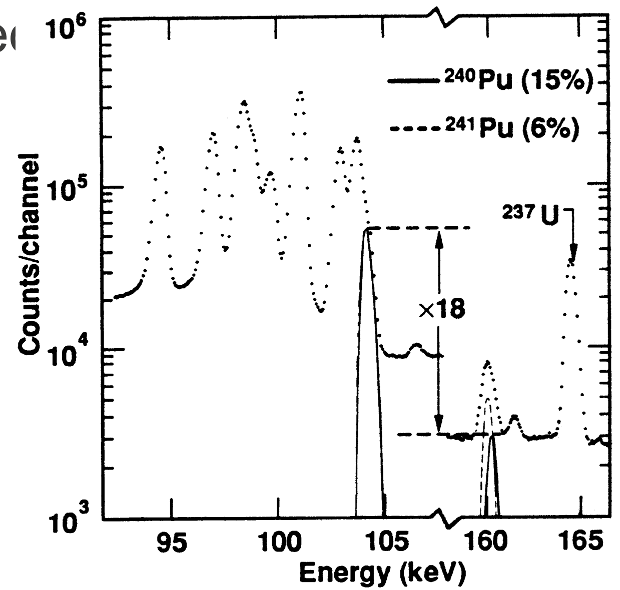
- item self absorption
- container absorption
- measurement system electronics

Cal = Calibration constant

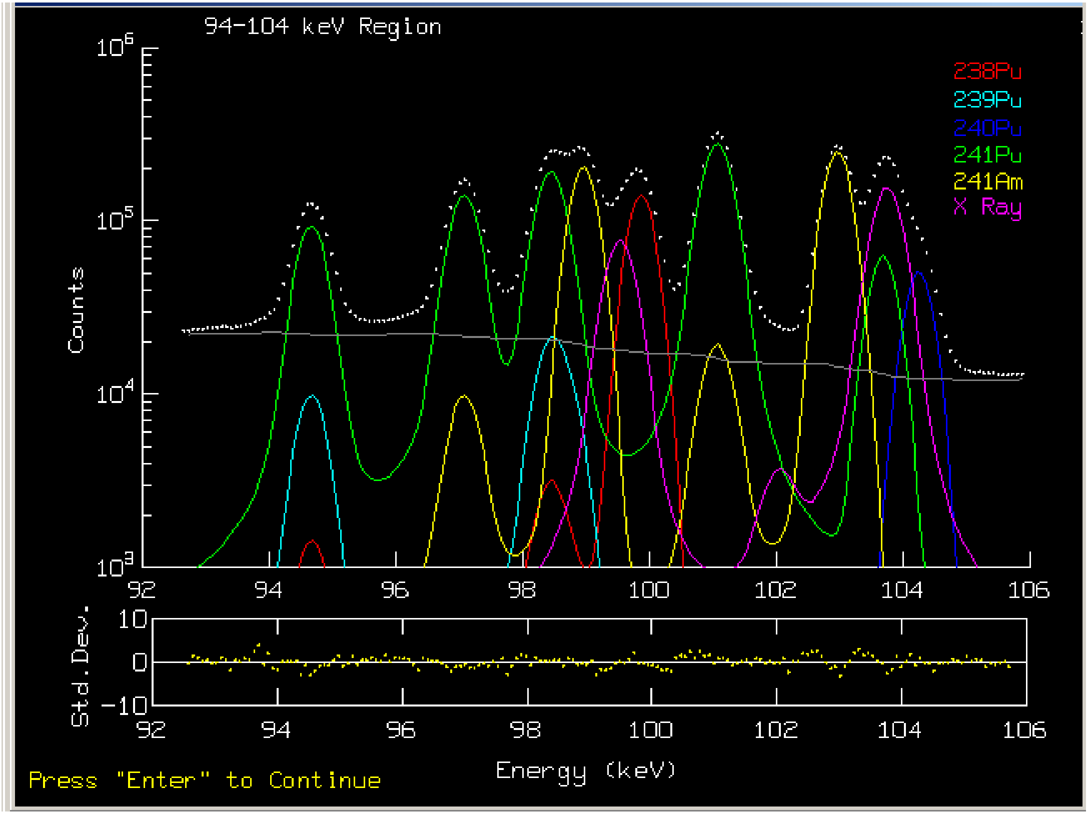
MGA

- Multi-Group Analysis of 100 keV x-ray and gamma-ray region
- Plutonium isotopics determination
- Uses multiple peaks to create an efficiency curve, eliminating the need for a separate efficiency measurement
- High-resolution Ge detector nee

^{240}Pu Peak Intensity:
Compare the intensity of the peak at 104 keV with that of the one at 160 keV

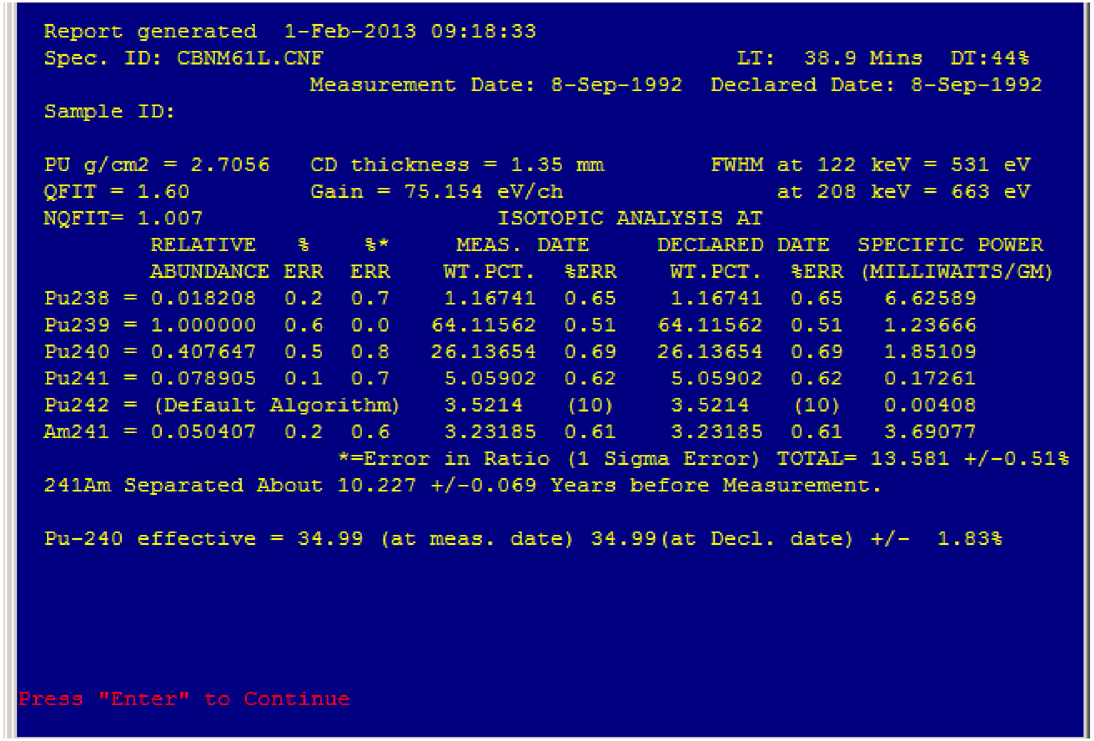


MGA



94-104 keV Region
Counts
Std.Dev.
Energy (keV)
238Pu
239Pu
240Pu
241Pu
241Am
X Ray
Press "Enter" to Continue

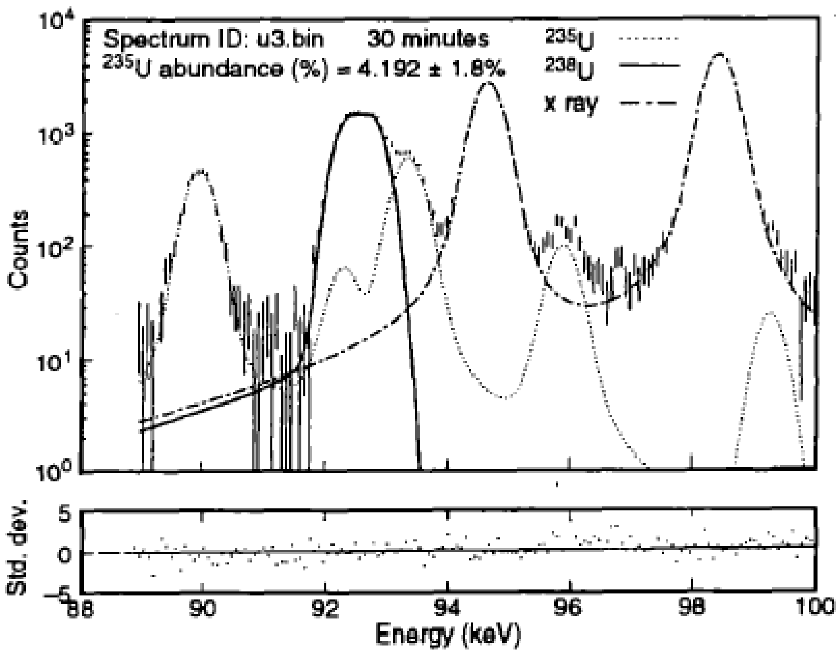
MGA



```
Report generated  1-Feb-2013 09:18:33
Spec. ID: CBNM61L.CNF                                LT:  38.9 Mins  DT:44%
                                 Measurement Date: 8-Sep-1992  Declared Date: 8-Sep-1992
Sample ID:

PU g/cm2 = 2.7056   CD thickness = 1.35 mm        FWHM at 122 keV = 531 eV
QFIT = 1.60         Gain = 75.154 eV/ch                   at 208 keV = 663 eV
NQFIT= 1.007                          ISOTOPIC ANALYSIS AT
        RELATIVE   %     %*      MEAS. DATE      DECLARED DATE  SPECIFIC POWER
        ABUNDANCE ERR   ERR    WT.PCT.  %ERR    WT.PCT.  %ERR (MILLIWATTS/GM)
Pu238 = 0.018208  0.2  0.7    1.16741  0.65    1.16741  0.65   6.62589
Pu239 = 1.000000  0.6  0.0   64.11562  0.51   64.11562  0.51   1.23666
Pu240 = 0.407647  0.5  0.8   26.13654  0.69   26.13654  0.69   1.85109
Pu241 = 0.078905  0.1  0.7    5.05902  0.62    5.05902  0.62   0.17261
Pu242 = (Default Algorithm)   3.5214   (10)    3.5214   (10)   0.00408
Am241 = 0.050407  0.2  0.6    3.23185  0.61    3.23185  0.61   3.69077
                      *=Error in Ratio (1 Sigma Error) TOTAL= 13.581 +/-0.51%
241Am Separated About 10.227 +/-0.069 Years before Measurement.

Pu-240 effective = 34.99 (at meas. date) 34.99(at Decl. date) +/-  1.83%

Press "Enter" to Continue
```

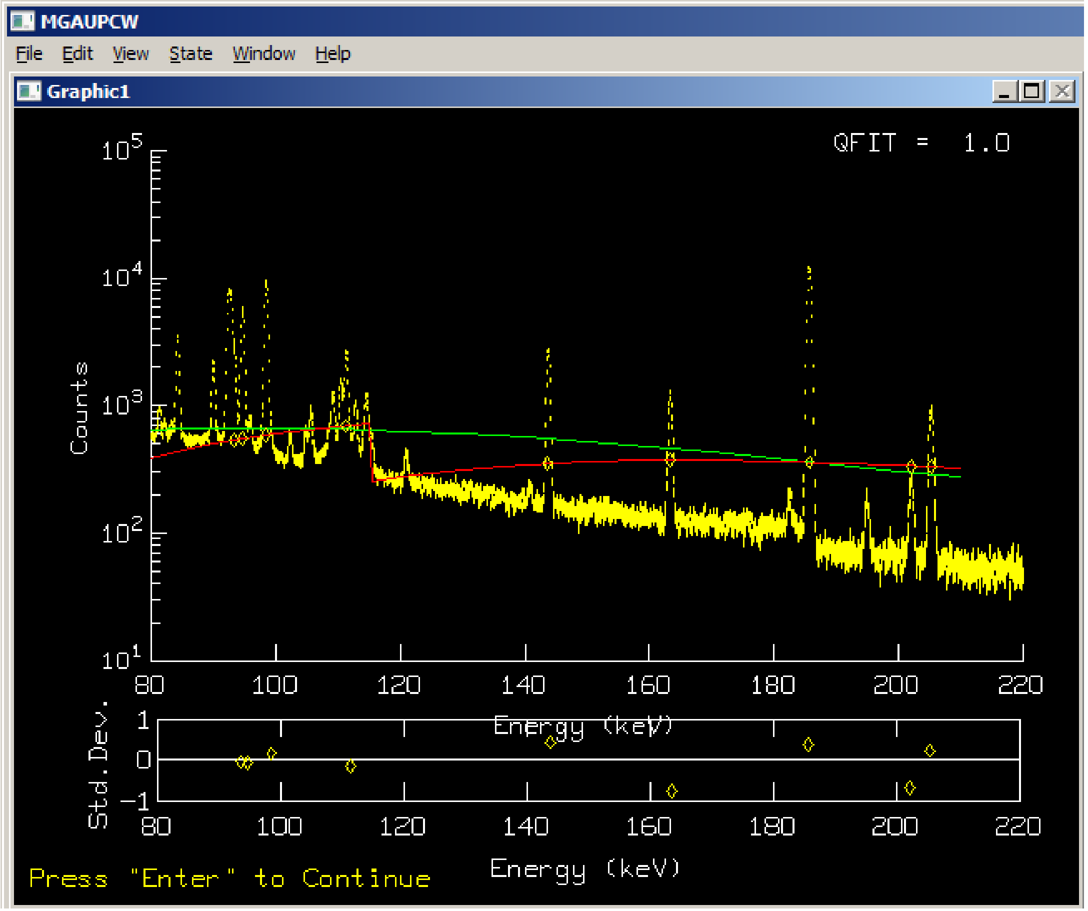
MGAU

- Multi-Group Analysis for Uranium
- Uranium enrichment measurement method
  - Uses 89-120 keV region of uranium gamma-ray spectrum

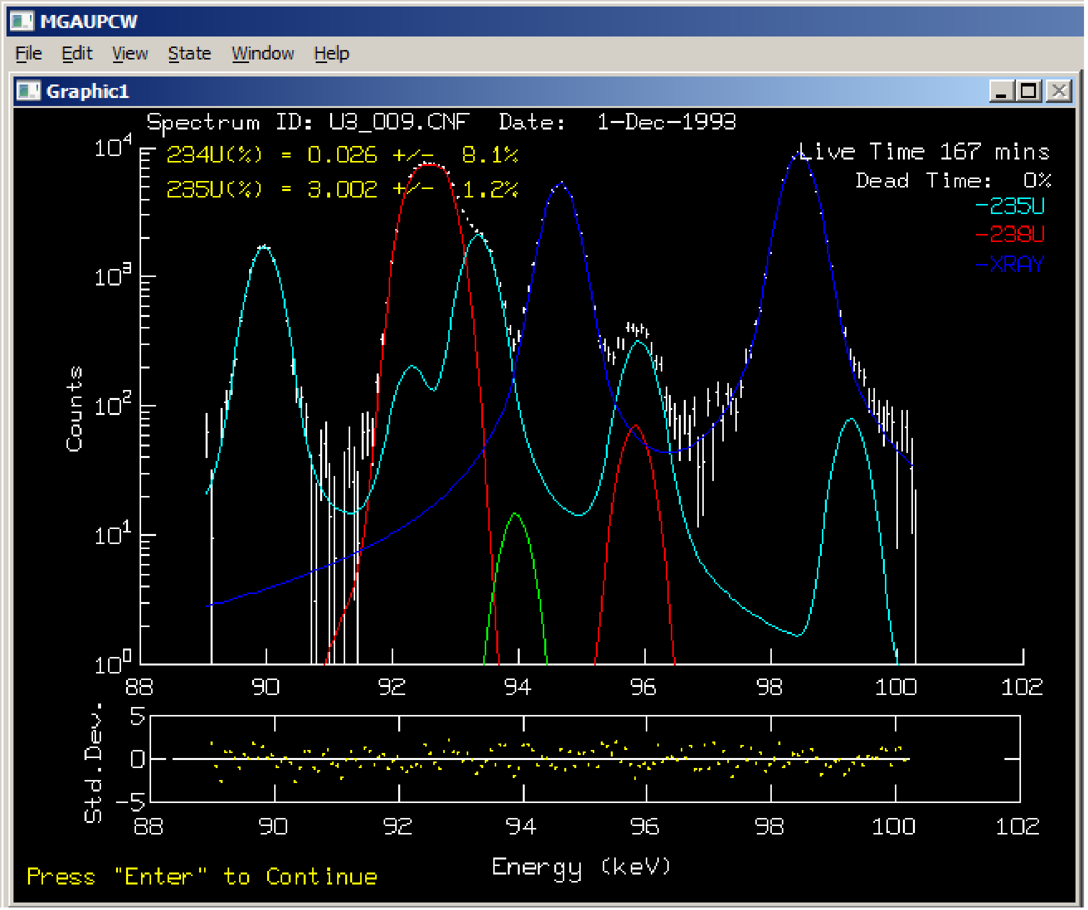


- **The low energy region of the spectrum is very complex with many overlapping X-ray and gamma ray peaks**

MGAU


MGAUPCW
File Edit View State Window Help
Graphic1
QFIT = 1.0
Counts
Energy (keV)
Std.Dev.
Energy (keV)
Press "Enter" to Continue

MGAU



MGAUPCW
File Edit View State Window Help
Graphic1
Spectrum ID: U3_009.CNF Date: 1-Dec-1993
234U(%) = 0.026 +/- 8.1%
235U(%) = 3.002 +/- 1.2%
Live Time 167 mins
Dead Time: 0%
-235U
-238U
-XRAY
Counts
Std.Dev.
Energy (keV)
Press "Enter" to Continue

Heat

Calorimetry

- Well-established, precise method of NDA
- Uses thermal power generated by radioactive decay in the sample to determine the mass of special nuclear material
- Heat flow calorimetry is most commonly used for safeguards NDA
- 60 Wheatstone bridge calorimeters currently being used for Pu and tritium measurements at LANL
- Bulk measurements can be taken without issues from absorption or self-shielding
- Takes much longer than other NDA techniques

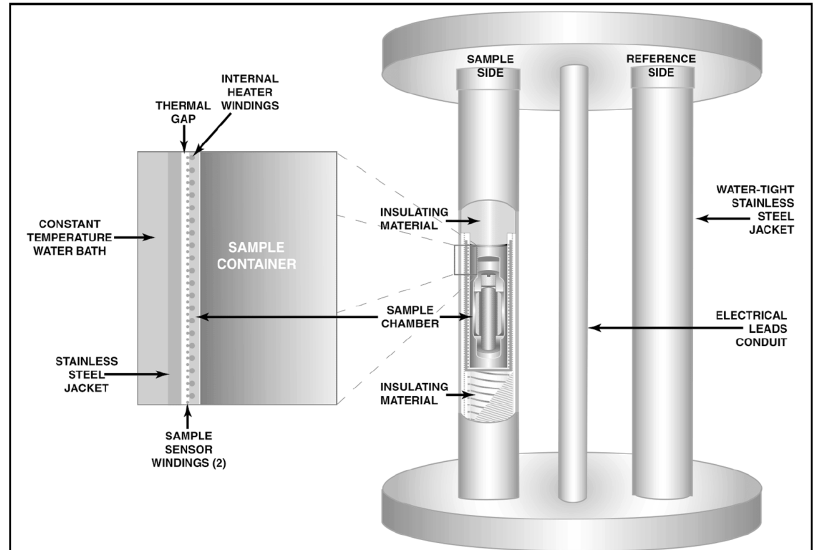


Figure 3. Schematic of a twin-bridge heat-flow calorimeter with basic components labeled.

Safeguards at LANL

Thank you!