Non-Destructive Assay: An Overview

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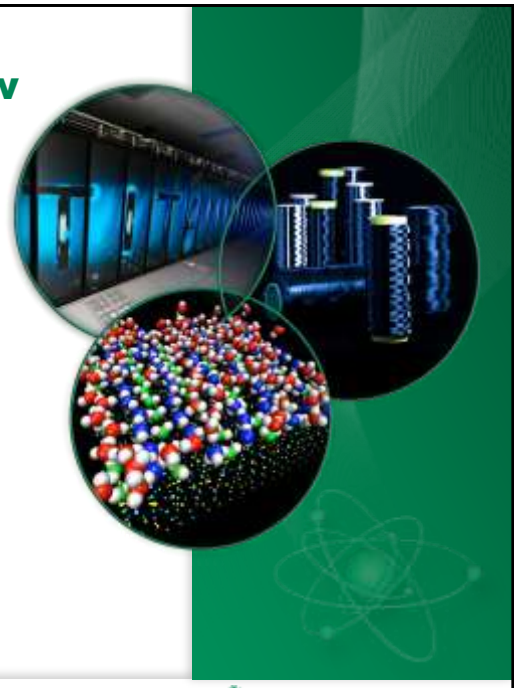
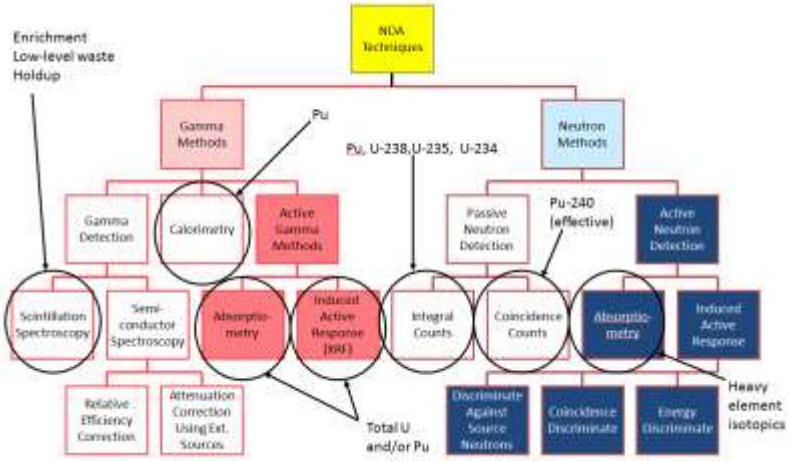
Thursday, June 27, 2013



Purpose

To provide an introductory overview of the methods used in Non-Destructive Assay (NDA).



Recent Examples

Bulgarian Official Discusses May 1999 HEU

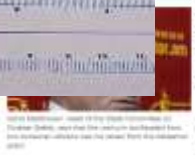
Aug. 14, 2000

In an interview with Khorizont Radio Network (Sofia), the Chairman of the B
Peaceful Uses of Nuclear Energy, Georgi Kaschiev, discussed Bulgarian-US
combat illicit nuclear trafficking. Kashiev noted that the recent [May 1999] se
Bulgaria was a "unique case." [for details of this seizure, see abstracts 1999
He said that "this is the first case discovered in recent years of trafficking in
uranium, over 90 percent, 10 grams in an ampo
to the efforts of the Ruse [border checkpoint] cu
were well-trained psychologically and extremely
US government had sent a written request to Bu
could be sent to the United States for analysis.
agencies, he added, "we decided that the best s
without breaking it or removing the material."

Smuggled uranium-238 seized in Moldova

Georgia President: Enriched Uran

s Link With Uranium Seized



YEREVAN -- A senior Armenian official says highly-enriched uranium confiscated by Georgian authorities from two Armenian citizens was not stolen from the Metsamor nuclear power plant or any other facility in Armenia, RFE/RL's Armenian Service reports.

Ashot Martirosian, the head of the State Committee on Nuclear Safety, insisted on November 10 that nuclear material security in the country is "at a level corresponding to international standards."

Highly-Enriched Uranium Seized in Czech Republic Reveals a Growing Risk of Nuclear Terrorism

Six Moldovan 'uranium smugglers' arrested

Analysis Techniques

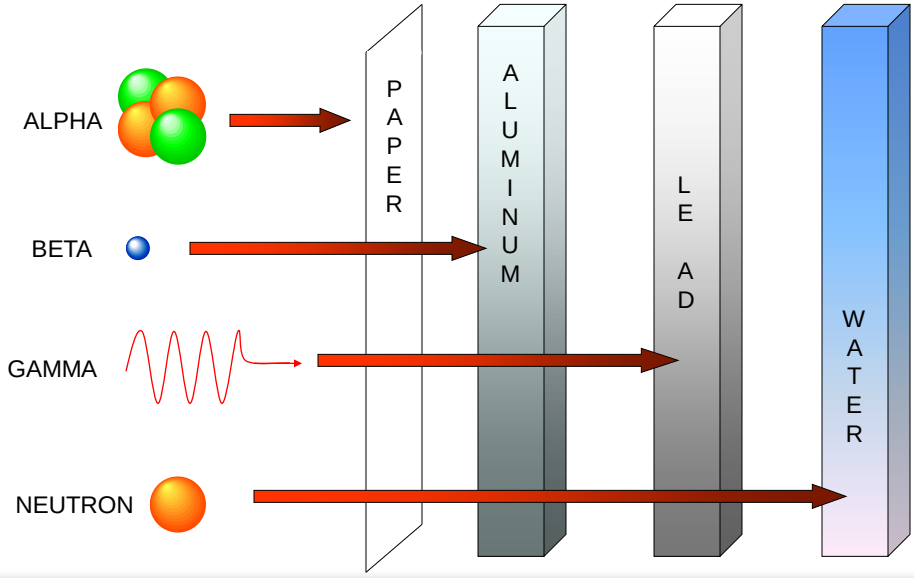
Destructive Analysis

- Pros
  - High precision and accuracy
  - Allows characterization of standards
  - Allows total analysis
- Cons
  - Time consuming
  - High cost per analysis
  - Intrusive
  - Generates waste
  - Destroys material

Nondestructive Analysis

- **Pros**
  - **Cost effective**
  - **Retains item integrity of sample**
  - **Nonintrusive on facility**
  - **Maintain material seals**
  - **Eliminates hazardous waste**
  - **Rapid measurements possible**
  - **Portable equipment**
- **Cons**
  - **Less precision and accuracy than DA**

Penetration of Radiation



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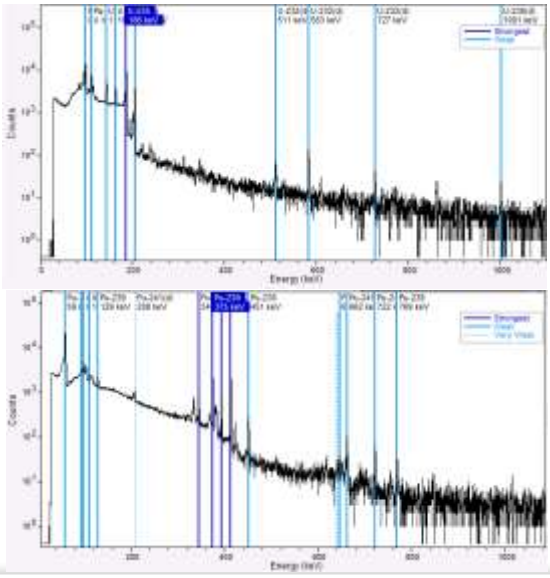
Typical Gamma Ray Energies



U-235: 186 keV

U-238: 1001 keV

Pu-239: 375 & 414 keV

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SNM Attributes

In approximate order of "uniqueness"

- Emits infra-red (heat) radiation
  - from α emission into the matrix
- Emits gamma radiation
- Emits alpha radiation
- Emits single neutrons
  - from (α,n) matrix interactions and delayed neutrons
- Emits coincidence neutron radiation
  - fission neutrons (from 0 to 8 in a burst)
- Is fissionable
  - prompt fission, delayed neutrons, delayed gammas

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NDA Techniques

- Gamma-ray measurements
  - Detailed energy information available
  - Instruments can be very portable
  - Measure isotopic composition or grams of specific isotopes
  - Gamma-ray absorption is significant (must be corrected for)
  - Gamma measurements impractical if sample is large, dense, or heterogeneous
- Neutron Measurements
  - Prompt (coincidence) or delayed neutrons from fissions
  - U assays usually require active techniques
  - Absorption is a minor problem
  - Good for many large, dense, or heterogeneous samples
  - Hydrogenous (moderating) materials greatly affect response

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Measurement Repeatability is Governed by Several Factors

- Counting statistics
  - Poisson distribution: Standard deviation equals square root of total counts
  - Represents minimum attainable measurement uncertainty
- Detector positioning
  - Inverse-square law and item type govern positioning effect
- Environmental factors, especially if no environmental controls in place (temperature, humidity, etc.)
- Background (especially for holdup)

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Gamma Rays

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Gamma Ray Measurements

- Identify nuclides
  - Use spectroscopy to identify gamma rays
- Measure enrichment levels of material
  - Use peak ratios or peak fitting to determine enrichment
  - Use calibration standard to compare and determine enrichments
- Quantify amount of material present
  - Perform efficiency calibrations to quantify amount of material
  - Use computer models to quantify amount of material

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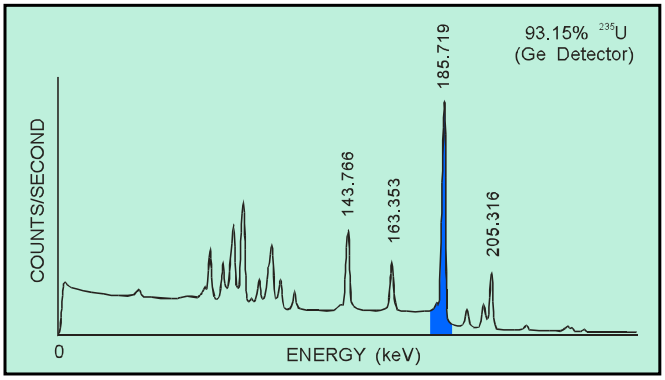
Identify Material

- **IdentiFINDER**
- **Interceptor**
- **Inspector 1000**
- **Transpec**
- **Detective**
- **Falcon 5000**



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Gamma Instrumentation

- Thermo IdentiFINDER
  - Uses NaI for detection and ID
  - Auto-calibrates using ^{137}Cs source
  - Continuous stabilization
  - Provides visible and audible alarms
  - Records and saves spectra
  - Compatible with NaIGEM software allowing enrichment measurements

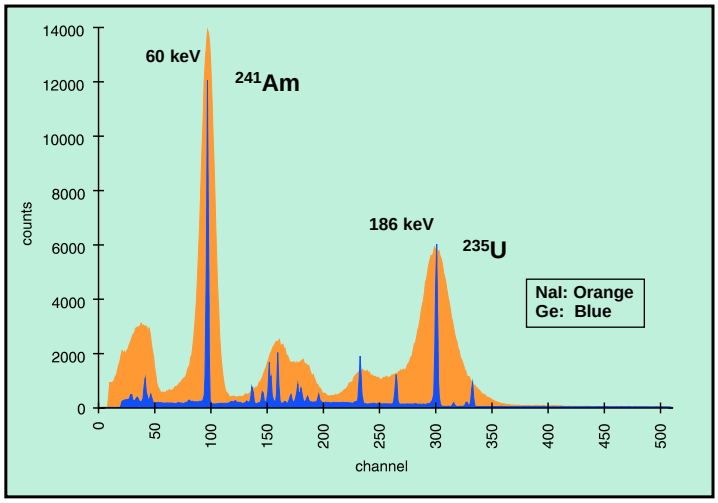
Gamma Instrumentation

High Purity Germanium (HPGe)

- **ORTEC Detective**
- Canberra Falcon 5000

- **Portable Ge detector used for detection and ID**
- **Mechanically cooled (No LN_2 required)**

NaI vs. HPGe Gamma-Ray MCA Spectra



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Gamma Instrumentation

Others

- Canberra Inspector 1000

(Sodium iodide)

- **Thermo Interceptor**

(CZT)

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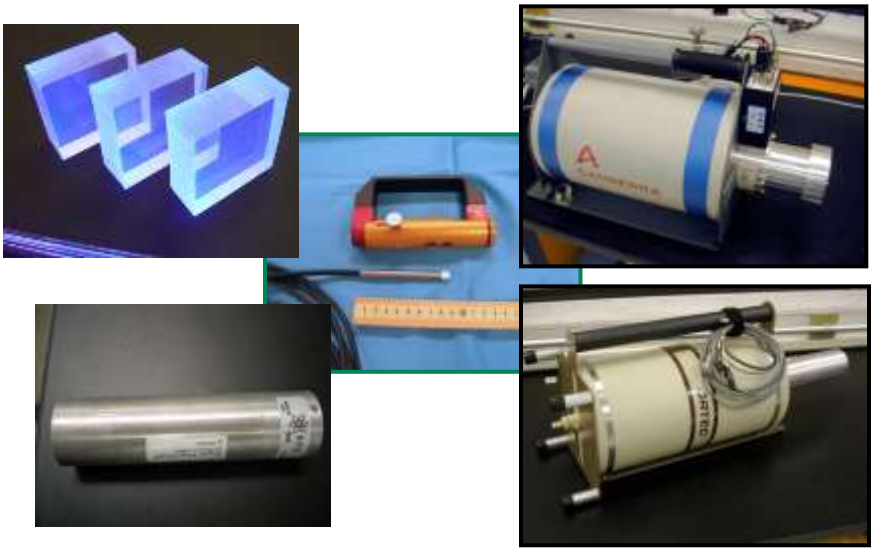
Portable Gamma Detectors



Multichannel Analyzers (Portable)

Enrichment Measurements

- Multigroup Analysis for U (MGAU) / (MGA)
  - Requires planar detector to examine and ratio lower energy x-rays from U and U daughters
  - Requires no calibration source

- **NaI Gamma Enrichment Measurements (NaIGEM)**
  - **Use peak fitting method**
  - **Requires calibration source**

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Enrichment Measurements

- **Fixed Energy Response function Analysis with Multiple Efficiency (FRAM)**
  - **Uses coax detector to ratio gamma rays from U and U daughters**

- WINU235
  - Uses Enrichment Meter mode
  - Requires 2 calibration sources

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Quantitative Measurements

- Holdup Measurement System (HMS-4)
  - Generalized Geometry Holdup to quantify material in pipes

- **In Situ Object Counting System (ISOCS)**
  - **Uses MCNP models instead of sources to calibrate allowing for quantitative results**

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Neutrons

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Neutron Counting

- What are the sources of neutrons from a sample?
  - Fission neutrons
  - Neutrons from (α,n) reactions with light elements in the sample matrix
    - Alpha decay is usually much more common than spontaneous fission
    - Graphic on next slide

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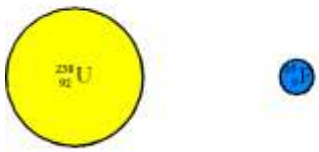
Alpha Decay creating Neutrons



http://www.wise-uranium.org/img/alphan.gif

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Neutrons: Total Counting vs. Coincidence Counting

- Total neutron counting is useful for large area surveys
  - Indicated presence of nuclear material
  - Cannot distinguish sources of neutron radiation
- Neutron coincidence counting
  - Distinguish neutron sources
  - Determine effective masses
  - Use in combination w/ gamma isotopic measurements to determine total U or Pu mass

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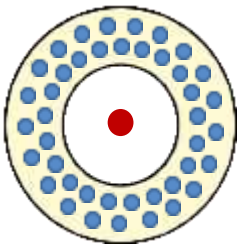
Typical Neutron Detectors

- **Well Counters**
- **Neutron Collars**
- **Drum Counters**



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Total Neutron Counting of Pu

- For Pu metal:
  - All neutrons come from spontaneous fission. ^{240}Pu dominates.
  - Total counting essentially generates the effective ^{240}Pu content of the material
- For PuO_2:
  - Neutron production is evenly divided between (α,n) reactions in the oxygen and spontaneous fission of the Pu
  - ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am contents are all important
  - We measure a combination of these isotopes
- For PuF_4:
  - Neutron production is almost purely from (α,n) reactions
  - again the ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am contents are all important
- Generally, we must know the isotopic composition and chemical form of the Pu

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Total Neutron Counting of U

- For U metal:
  - All neutrons come from spontaneous fissions.
  - ^{238}U dominates the neutron production for any enrichment below ~80%
  - Total neutron counting is effectively counting ^{238}U content
- For UO_2:
  - (α,n) rate is small but at higher enrichments ^{234}U becomes important
  - ^{238}U is the dominant source of neutrons
  - ^{234}U and ^{238}U isotopic compositions are important
- For UF_6:
  - Neutron production rate is dominated by (α,n) reactions in F
  - ^{234}U, ^{235}U, and ^{238}U are all important
- Again, for total neutron counting of U, we need to know the isotopic composition and chemical form of the material

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Standard Coincidence Counting

- Principle
  - Count the number of times 2 neutrons are detected at the same time (coincidences)
  - Coincidences are related to fission not uncorrelated neutrons
- Result
  - Measures spontaneous fission neutrons
  - Related to the fissile content of the sample
- Benefit
  - Combining total and coincidence counting allows you to distinguish between alpha-n and spontaneous fission
  - Can correct for multiplication effects if alpha is known
  - Can determine quantitative characteristics of a sample

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Summary

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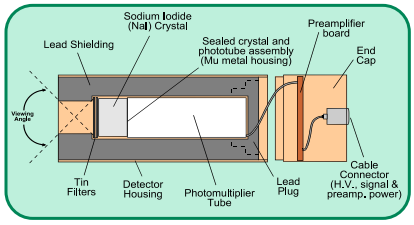
Measurement Challenges

- Sample homogeneity
- Varying matrix effects
- Hostile physical environments
- Radiation background
- Poorly characterized materials
- Sample Shielding



Element	Thickness	Tranmission of 186 keV gamma	Transmission of 414 keV gamma
O	1 m	98 %	99%
Al	1 cm	72 %	78 %
Fe	1 cm	32 %	49 %
Pb	1 cm	<< 1%	< 10 %

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Conclusion

- NDA techniques typically focus on measuring gamma rays and/or neutrons.
- Various techniques for both gammas and neutrons exist, designed to suit different applications.
- The primary drawback to NDA is less precision than DA; however, the cost and speed relative to DA often makes it appealing.

Confiscated Uranium.

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Questions?