PURDUE NUCLEAR ENGINEERING

Article Summary, Critique, and Extension

Gozani, T., McDaniel, F. D., & Doyle, B. L. (2009). *Conventional and Non-Conventional Nuclear Material Signatures*. AIP Conference Proceedings, 599(1), 599-605. doi:10.1063/1.3120108

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Presentation Outline

- Summary of Article
    - Pulsed Fast Neutron Analysis
    - Nuclear Resonance Fluorescence
    - Dual Energy X-Ray Radiography
    - High Energy Bremsstrahlung Backscattering
- Critique of Article
    - Audience/Target
    - Work Presented
- Extension of Article
    - Comparison of Techniques

Article Summary

Description and Sectionwise Review of Gozani's *Conventional and Non-Conventional Nuclear Material Signatures*

Article Motivation

Figure 1: NAE - Grand Challenges - “Prevent Nuclear Terror” Banner

- Detection of nuclear material for national security
- Hinges on the detection of Special Nuclear Material (SNM)
- SNM can be detected by taking advantage of nuclear structure and high Z nature of isotopes

Pulsed Fast Neutron Analysis

Technique Summary

- Active interrogation technique
- Relies on $(n, n'\gamma)$ reaction
- SNMs have large (on the order of $10\ b$ cross sections for $(n, n'\gamma)$)
- Relative motion of detector and accelerator allow for creation of 3-D spatial map

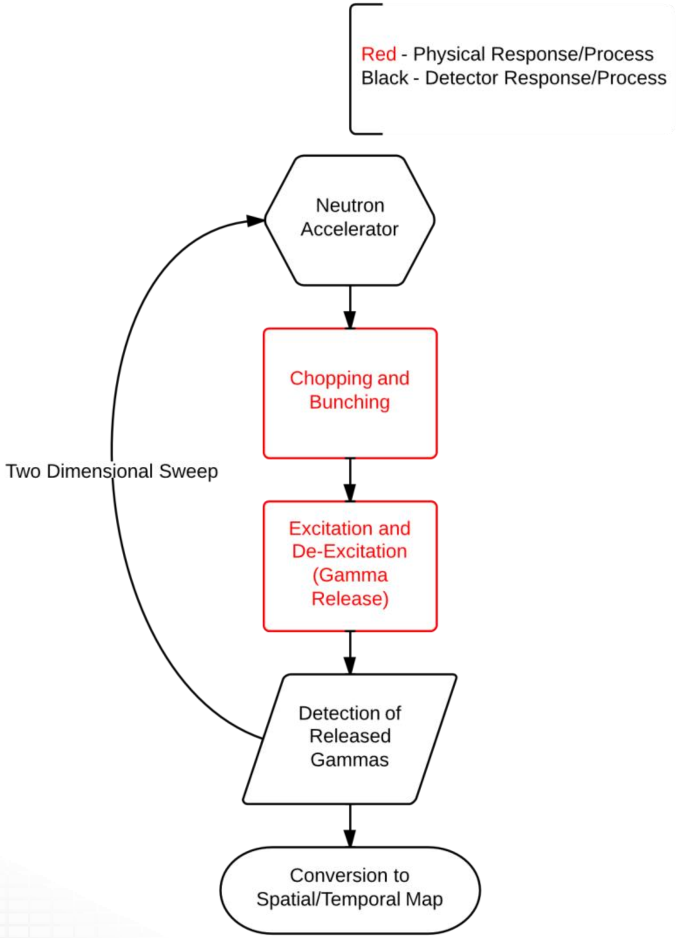

Figure 2: PFNA Process Diagram

PFNA - Example Result

- Non Fissile Materials provide characteristic peaks specific to each material
- Fissionable materials provide spectrum from fission contribution to γ emission

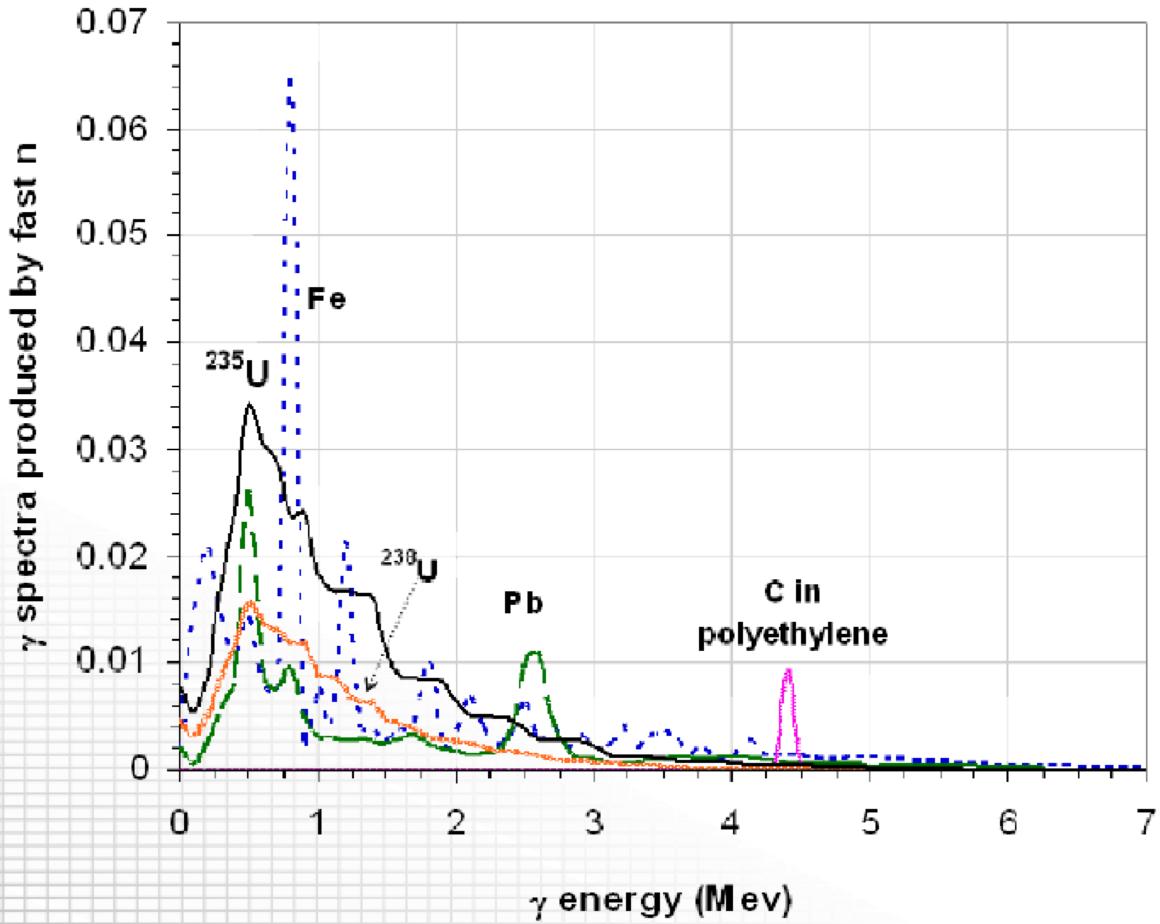

Figure 3: Simulated Gamma Spectra by Fast Neutrons [6]

Nuclear Resonance Fluorescence

Technique Summary

- High powered Bremsstrahlung source used on target
- γs from Bremsstrahlung source cause fluorescence in nuclear resonances
- Array of detectors can detect a spatial map of secondary γs

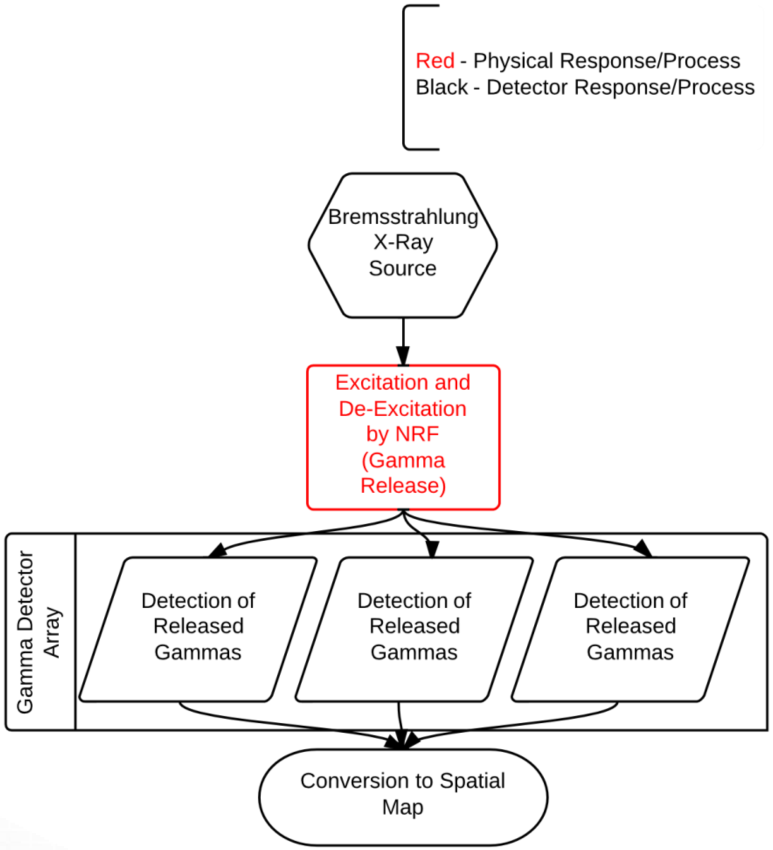

Figure 4: NRF Process Diagram

NRF
Example Result

- Provides spectra with peaks which are characteristic of isotopes present

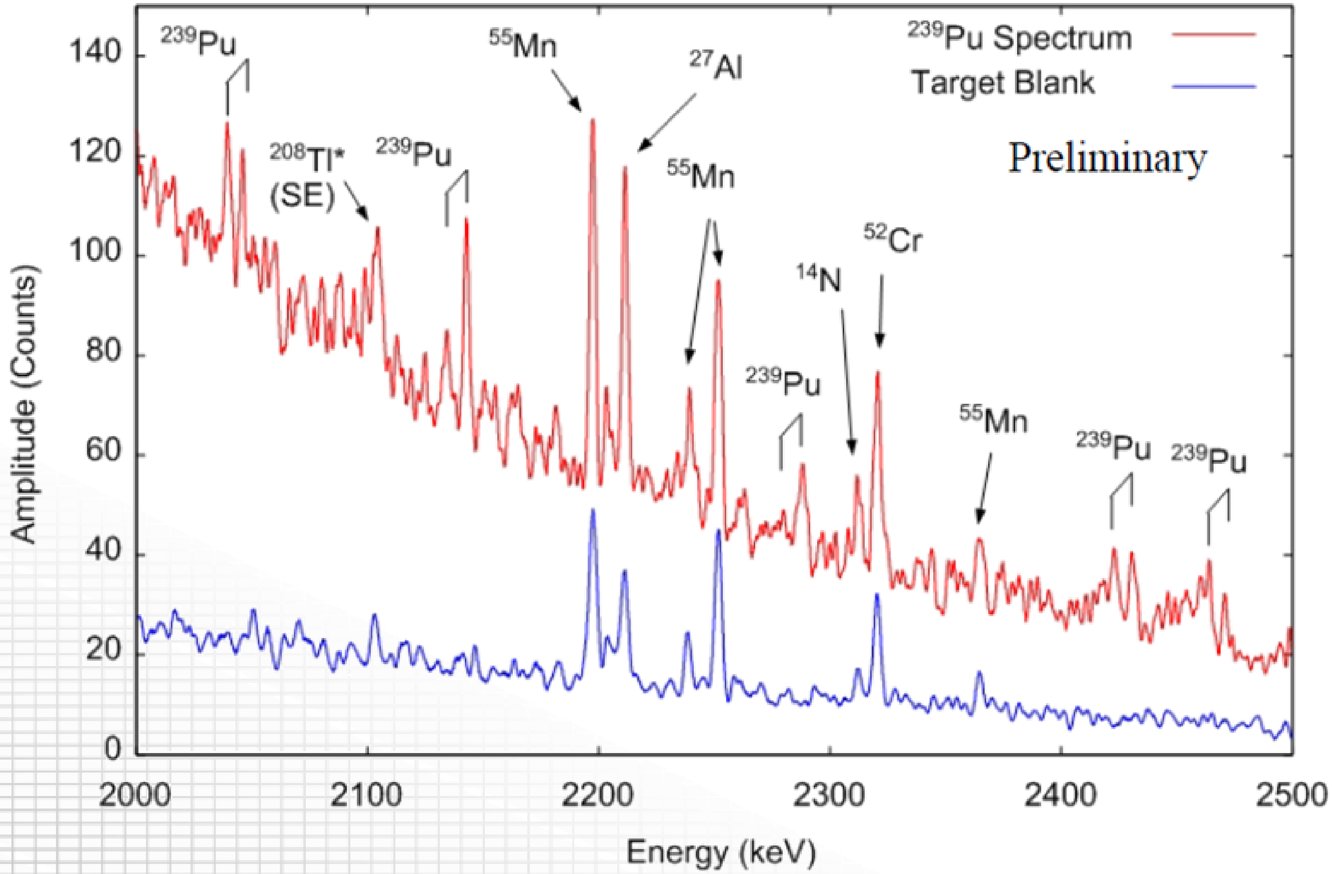

Figure 4: NRF Spectrum of Pu and Target Blank in Energy Range of 2.0 to 2.5 MeV [1]

Dual Energy X-Ray Radiography

Technique Summary

- Similar to conventional X-Ray imaging
- Two different X-Ray energies used
- Can find integration of high and low Z areas using integral equation
- Requires array of detectors for spatial mapping

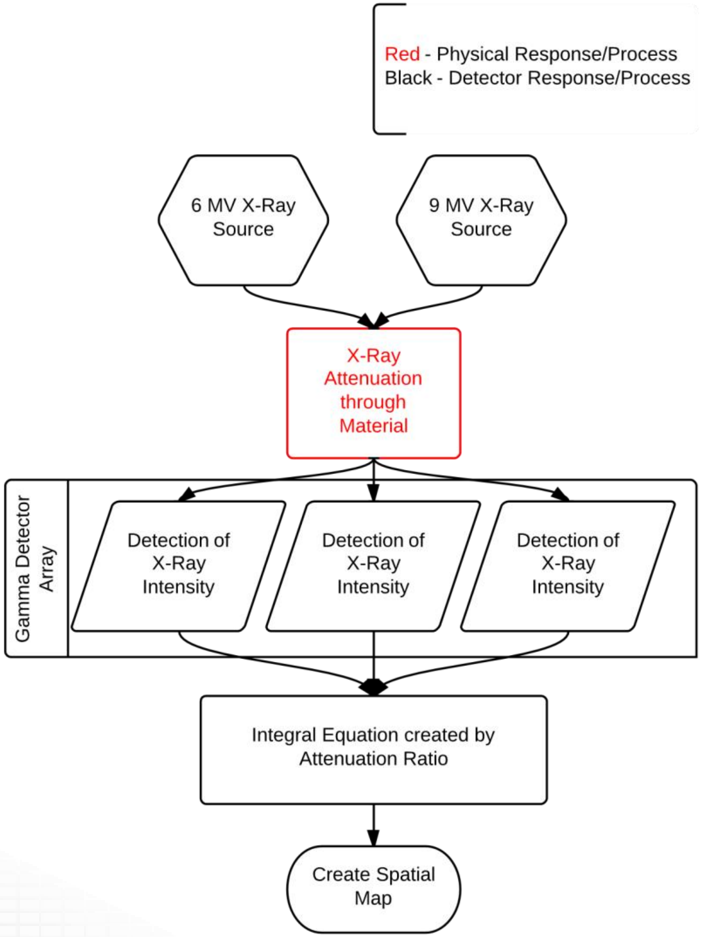

Figure 4: DEXR Process Diagram

High Energy Bremsstrahlung Backscattering

Technique Summary

- Linac X-Ray source causes Bremsstrahlung and annihilation in high Z material
- Placement of energy sensitive detectors in the backscatter regions
- Detectors pick up high energy component of high Z material Bremsstrahlung backscatter and annihilation
- Requires array of detectors for spatial resolution

Dual Species Radiography

Technique Summary

- Use of both X-Ray and Fast Neutron radiography provides increased information
- Behavior with changing Z is wildly different
- Allows for pinpoint of Z value because of two pieces of data, instead of estimation of Z
- Requires two accelerators and arrays of detectors

Dual Species Radiography

- Different response to Z number between gamma and neutrons
- Allows for resolution of low and high Z materials

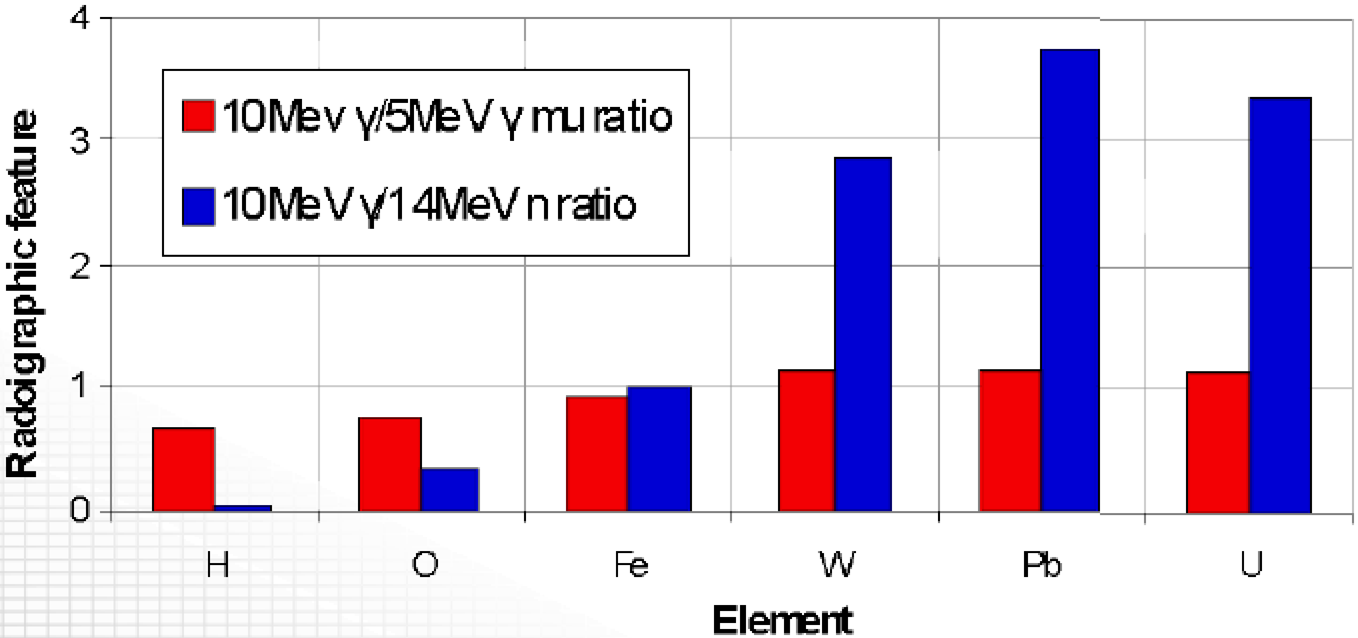

Figure 5: Dual Species Radiography Ratio of Transmissions [5]

Article Critique

Discussion of citations, work presented, and target of Gozani's paper

Motivation

- NAE Grand Challenges show that the detection and interdiction of nuclear material has been identified as an important field
- Gozani's past work on explosives interdiction presents him as an expert on implementation, although relatively new in the field of radiation detection

Audience

- Presented to the 2008 *Conference on the Application of Accelerators in Research and Industry* in "Technologies for Detecting Nuclear/Radiological Contraband" General Session
- Other presentations in track give specific technology except one, which was chosen as review paper

Table 1: CAARI '08 Schedule of Events Excerpt

NHS02	Title: Technologies for Detecting Nuclear/Radiological Contraband
R. Leon Feinstein	*Active Interrogation Technologies for Nuclear Detection - Overview*
Tsahi Gozani	*Conventional and Non-conventional Nuclear Material Signatures*
Steve Korbly	*A Novel Electron Accelerator for Non-Intrusive Interrogation Applications*
Christopher P.J. Barty	*Tunable, Monochromatic X-rays in Interrogation - Production and Use*
Donald P. Umstadter	*Development of a source of quasi-monochromatic MeV energy photons for detection of special nuclear materials*
Timothy Shaw	*Fissile Material Detection by Differential Die Away Analysis*

Citation Diversity

- The paper's main section describes work he completed in 1987 – 4 citations of his own work (1,2,3,7)
- The paper provides too few citations on other methods
  - NRF – 2 citations (4,5)
  - DEXR – 1 citation (6)
  - HEBB – no citations

High Energy Bremsstrahlung Backscattering

- No citations for origin for experimental status of technology
- Provides experimental results without sufficient methods for reproduction
- Makes claims without published results
  - “In addition the size of the detector collimation determines the degree of debasing…”
  - “…modeled with photon/electron Monte Carlo transport codes… …and reliably measured.”

HEBB
Literature Provided

- Gozani does not cite any source for HEBB
- Uses the small overview from Bertozzi's paper
- HEBB used in American Science and Engineering's Z Portal technology

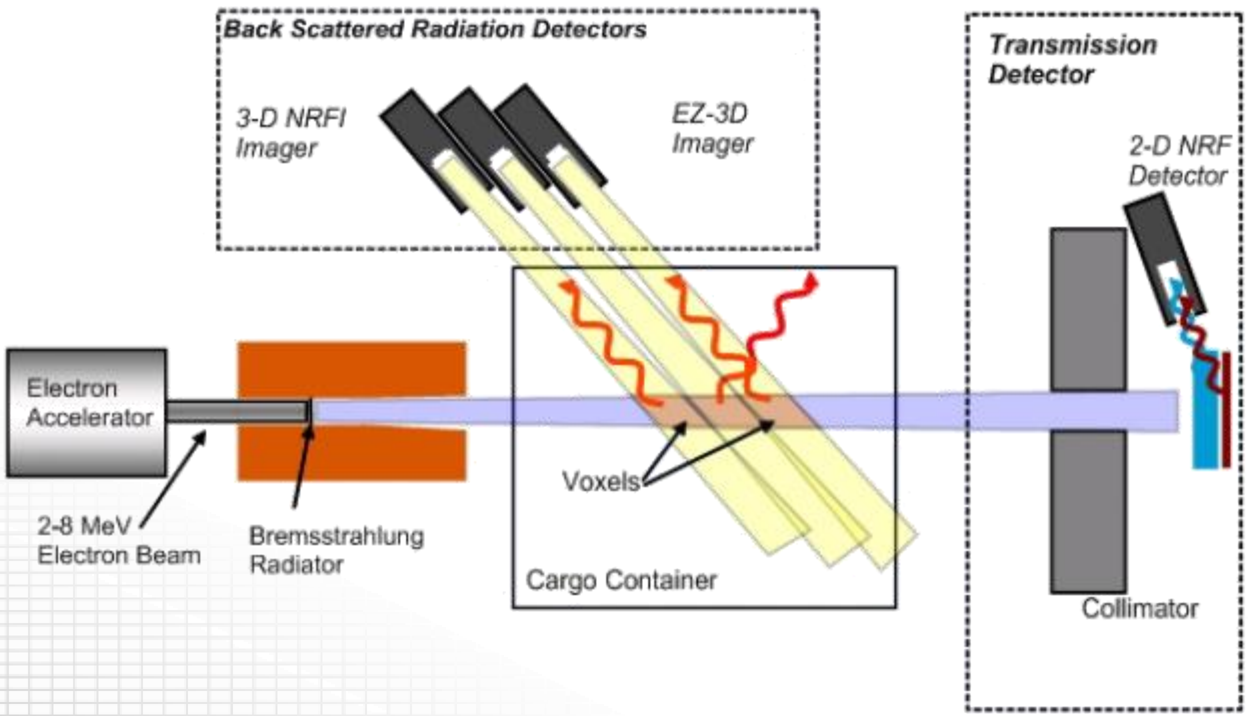

Figure 6: High Energy Bremsstrahlung Backscattering Idea Diagram [1]

Detection Modes

- Paper provides no description or analysis into detection methods
- Uses previously created γ detection methods
- Provides no indication of methods response in high γ environments

Article Critique - Overall

- Well placed to impact field
- Provided an overview paper into the area "Technologies for Detecting Nuclear/Radiological Contraband"
- Described one unverified technique
- Did not describe detector physics for any methods
- Provided very little implementation instructions for any technique

Article Extension

Proposal of additions or changes to article

Extension Proposals

- More technical basis
- More implementation based descriptions
  - Cost
  - Efficiency
  - Resolution
  - Implementation
- Direct comparison between methods
- Modeling of methods for insight into efficiency and applications

Chosen Extension Proposal: Methods Comparison

- Includes factors:
  - Complexity
  - Efficiency
  - Resolution

$$\lambda = w_{BOM}(\lambda_{BOM}) + w_{eff}(\eta) + w_{res}(\lambda_{res})$$

$$w(\lambda) = \begin{cases} \lambda_{BOM}, 2\eta, 2\lambda_{res} & \lambda_{BOM} < 0.50 \\ \lambda_{BOM}^2, \eta, \lambda_{res} & \lambda_{BOM} \geq 0.50 \end{cases}$$

Complexity

- Complex designs have distinct disadvantages
  - Increased modes of failure
  - Increased cost
  - Increased difficulty of use
  - Increased difficulty of implementation
- Current measure of complexity is only Bill of Materials parts count, could be changed to describe the complexity of each part in respect to cost, rate of failure, and difficulty of use

Efficiency

- Higher efficiency is desired for several reasons
  - Increased utilization of accelerated γ or n
  - Increased difference from background
  - Decreased waiting time to resolve
- Factor currently is the efficiency given by

$$\eta \equiv \frac{\#\ events\ detected}{\#\ n/\gamma\ accelerated}$$

- Could determined by the amount of information provided by each event

Resolution

- Increased resolution is crucial to interdicting nuclear material in a timely manner
- High resolution will decrease search time and help to increase customs clearance speed
- Current factor is the inverse of the resolution compared to the state of the art resolution

Article Extension Summary

- Creation of weighting scheme and identification of key factors
- MCNP modeling, more sophisticated mathematical weighting, and close look into price and implementation of systems is required

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Questions

Detector Resolution

- Industry standard quotes Energy resolution of NaI 1"x1" at [10]

$40\ keV$ for ^{137}Cs

- Germanium detector is quoted as a minimum detector resolution of

$400 - 600\ eV$ for ^{60}Co

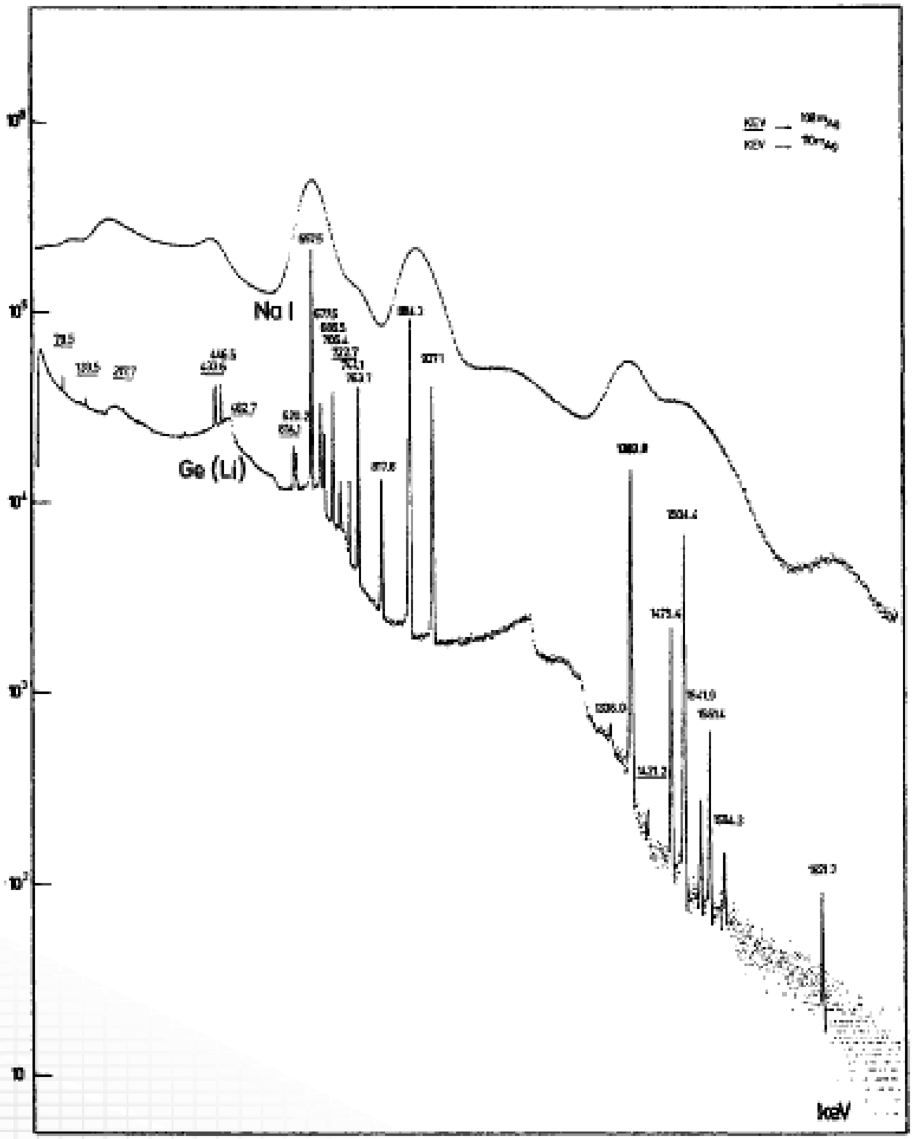

Figure A1: Comparative Spectra between NaI and Ge [10]

Special Nuclear Material (SNM)

- Defined by Title I of Atomic Energy Act of 1954
- Is defined as only Pu, ${}^{233}U$, or enriched ${}^{233}U$ or ${}^{235}U$.
- Does not include source material (e.g. ${}^{238}U$), which could be important to detect