Neutron Based Techniques for the Detection of Illicit Materials and Explosives

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IAEA CRP F1.10.12 – South Africa 2009
IAEA CRP CODE F1.10.12

Research Agreement 13726

Slow Neutron Interrogation for Detection of Concealed Substances
Graduate Student Work

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IAEA – South Africa 2009
Efforts to test slow neutron based techniques aimed at detecting and identifying illegal substances, including explosives, are carried out at the electron linear accelerator facility in Bariloche, Argentina, as part of graduate student research work.

Preliminary results show:
A capacity to detect several substances through pulsed neutron induced prompt gamma emission and to reveal the presence of special nuclear material (SNM) through detection of fission neutrons.
Time of flight and slow neutrons are employed taking advantage of higher capture cross sections at low energy.
APPLICABILITY OF MODERATED NEUTRONS

Slow neutron time of flight (TOF) was tested for position determination of a target test object placed at different positions over realistic distance range (within 2 m).

As much effort is devoted elsewhere through the use of fast neutron induced reactions, we seek to explore a complementary path by means of testing the applicability of moderated neutrons. These, although not penetrating thick objects as a beam, they do diffuse into substances.

Overcoming reduced neutron penetration due to a surrounding thick hydrogenated matrix, was explored through alternative irradiation with fast neutrons and the ensuing moderation inside the matrix, although with loss of TOF information.
PART ONE

SUBSTANCE IDENTIFICATION THROUGH SLOW NEUTRON INDUCED GAMMA RESPONSE

Thermal and epithermal components distinguished through neutron TOF
PART ONE

INITIAL RESULTS

GAMMA SPECTRA FROM SOME SAMPLES IN FAVOURABLE CONDITIONS
Fe sample, 6 mm thick

Gamma Spectrum
Gamma Spectrum

S sample, 140 g
Cl in NaCl sample, 215 cm³
Gamma Spectrum

Ag sample, 0.125 mm thick sheet

Counts / Monitor

E\text{\gamma} [keV]

\begin{itemize}
  \item $^{109}$Ag - 117.45 keV (Th abs. table)
  \item $^{109}$Ag - 198.72 keV (Th abs. table)
  \item $^{109}$Ag - 549.56 keV (Th abs. table)
\end{itemize}

thermal neutron absorption

epithermal neutron absorption
NITROGEN DETECTION

Irradiated LN2 mass = 100.9 g
NITROGEN DETECTION

Sensitivity to N/Fe

5 min irradiations. Irradiated LN2 mass = 100.9 g
PART ONE

INITIAL RESULTS

TOF POSITION SENSITIVITY OF SAMPLE GAMMA RESPONSE IN ABSENCE OF CONCEALING CARGO
POSITION DETERMINATION
TOF through capture gammas in sample. 4 NaI(Tl) array

1kg NaCl LARGE MOVEMENT

Time-of-flight (µs)

1000 2000 3000 4000 5000 6000 7000 8000

6 m flight path
7 m flight path
8 m flight path

a.u.
PART TWO

URANIUM DETECTION THROUGH SLOW NEUTRON INDUCED FISSION RESPONSE
INITIAL TESTS

Initial work was aimed at identifying a way to detect the presence of SNM, testing the applicability of slow neutron irradiation for that purpose.

TOF is also tested as a method to find the SNM position inside a concealing array of neutron scattering cargo.
Initial (basic) Experimental setups

Test if observed signal is caused by thermal neutrons
Initial (basic) Experimental setups

Test if signal is fission

![Graph showing normalized counts over time of flight for HEU, Al sample, and Pb sample.](image-url)
The partial Fuel Bundle (FB)

Number of fuel pins = 13
Total $\text{UO}_2$ mass = 6.05 kg
$^{235}\text{U}$ mass = 38.38 g
Probable irradiated fraction = ~ 1/10
Enriched uranium sample diluted in aluminium

Four plates in ‘expanded’ configuration on a board.

$^{235}\text{U mass} = 27.5 \text{ g}$

Total sample mass $= 152.8 \text{ g}$

18% U-235 in Al

Max. U-235 irradiated by direct beam $= 10.7\text{ g}$
‘New’ Experimental setups

2 m merchandize thickness (considerably hydrogenated)
‘New’ Experimental setups

- Sum of Raw Spectra
- Time of Flight [µs]

- 1pc40cmHEU
- 1pc40cmFB
- 1pc60cmHEU
- 2pc60cmHEU
- PCsBackground
To produce integral results that represent each sample condition, the TOF spectra have to be integrated. Influence of lower and upper integration limits are studied through Figures-of-Merit (FOM) to enhance results contrast.

\[ S = \sum \text{Sample/Monitor} \]
\[ Bg = \sum \text{Background/Monitor} \]

\[ \text{FOM} = \frac{[S - Bg]}{[\sigma S]^2 - (3\sigma Bg)^2]^{1/2}} \]
Integral Results

5 minute irradiations (at 200 n/cm²/sec)

Normalized Integral Counts

Individual Measurements

- 1CPU+HEU*(40cm)+PCs
- 1CPU+FuelB(40cm)+PCs
- 1CPU+HEU*(60cm)+PCs
- 2CPUs+HEU*(60cm)+PCs
- PCs Background
- Dashed line: Mean Background
- Dotted line: 4 SIGMA
The 4 σ level suggested by IAEA-TECDOC-1312 (2002) has not been difficult to attain by any of the 5 minute irradiations with a narrow weak incident beam, in the midst of a thick scattering cargo array and with SNM mass well under 30g.

Tests with densely scattering and absorbing media are a natural next step. Unusually high neutron absorption should be detected by the prompt gamma detector array.

If cargo has undergone X-ray scanning as an initial screening, neutron interrogation would be called in to verify merchandize composition.
PART TWO

TEST SNM POSITION DETERMINATION THROUGH SLOW NEUTRON TIME-OF-FLIGHT
HEU Position

HEU sample to detector distance - 90 cm displacement

![Graph showing normalized counts over time of flight for HEU-detector 45 cm and 135 cm.](image)
In a clean situation (low scattering), TOF is useful to locate the approximate depth at which SNM is placed in the container slice being investigated.

In the worst imaginable situation of densely hydrogenated cargo, TOF would be rendered useless and detection of SNM, as expected, turns increasingly difficult in the midst of low neutron transmission cargo.
PART THREE

TEST WIDE AREA FAST NEUTRON DETECTORS AND LIMITS OF DETECTION FOR CI AND U
Experimental setups with Wide Area Detectors

2 m merchandize thickness (considerably hydrogenated)
70 cm x 100 cm active area neutron detector
Integral Results for Chlorine
5 minute irradiations (at 200 n/cm²/sec)
50 mm neutron beam
4 NaI(Tl) array

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Transmission Results

![Graph showing transmission results for different items.

- PCs
- PC monitors
- Paper reams

Transmission (relative to empty container) vs. Number of Units]
Integral Results for HEU

Mean value of 5 minute irradiations
Uncertainty smaller than symbols

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FINALLY

PRESENT SITUATION
Having the sample 6 to 8 m away from the target mimics a smaller neutron source.

The low intensity falling on the sample:

- 200 thermal n/cm²/sec and
- 90 near epithermal n/cm²/sec
  (above cadmium cut-off energy)
- 40 mm thick polyethylene slab neutron moderator

This reduced flux and the limited amount of sample irradiated by the 50mm neutron beam, allowed most experiments to be carried out during 5 min counting times with the described detectors.
The thermal vs. epithermal interrogation through the Cd difference method allows better substance identification and also helps confirm that fission is being detected.

In moderate scattering arrays, TOF provides approximate information about SNM position.

High slow neutron fission cross section allows the 4 $\sigma$ level to be reached even for samples in the tens of grams range.

Delayed neutron emission can be added as a confirmation tool at no extra cost.
As a consequence

The beam and the neutron detector should be extended to cover a much increased portion of viewed container slice, retaining the sensitivity achieved.

Screening against dangerous contraband through investigation of realistic volumes, like a container slice put in evidence by previous X-ray scanning, seems promising even with a small incident thermal/epithermal neutron flux.

Combination with fast neutron irradiation that moderates inside cargo should enhance capability.
Thank you

Good bye