Active Interrogation of SNMs by use of IEC Fusion Neutron Source

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Nuclear Terrorism Threats

- Conventional gun-type nuclear weapon: 30 – 60 kg of $^{235}$U

- Modern tactical nuclear weapon: 10 – 30 kg of $^{239}$Pu

- $^{235}$U Hiroshima-type – easy to make, no need of test bans, assembling in the target nation is possible, identification by shape is not effective enough, passive detection is impossible unlike $^{239}$Pu.

- “Suicide bombing” makes prevention of terrorism very difficult. We need to block smuggling at its point of entry.

- Transportation of tens kg of $^{235}$U – air cargo, land transportation, spy ship, sea container.
Megaports Initiative (2007)

- Mandatory SNM screening of all US-bound containers at their port of origin from 2012.

- It has been delayed 2 years (until 2014), due to lack of SNM interrogating system.

- Very rapid (2 min/container) interrogation system is required.
  - JPN gov. will setup 2-3 central seaports.
  - Our proposal is to built SNM screening facilities in those central seaports.
Project Overview

1. Neutron-based system for rapid screening
   - 2-3 min. per container
   - false alarm rate < 10%

2. X-ray image for determination of point(s) of interest
   - 10 min / point

3. γ-ray beam for identification of $^{235}$U
   - 10 min / point

Proof-of-principle, prototype experiments, performance evaluation, & scale-up design

- 400 containers / day
- Estimated cost: 12.5M$
- R&D budget: 5.5M$
- 5-year R&D from FY2010
- Mid-term evaluation in FY2012

Image: Diagram of neutron-based system with labels for each component and cost details.
Isotope Identification by $\gamma$-ray beam

Nuclear Resonance Fluorescence (NRF)

Energy [keV]

Flux of gamma-rays

Tunable

$\gamma$-ray beam
✓ monochromatic
✓ energy tunable
✓ well-collimated

$\gamma$-ray beam

- Tunable
- Absorption
- Emission
- Flux of gamma-rays

$2^+ 2657$

$2^+ 846$

$0^+ 0$

$0^+ 0$

$1/2^+ 0$

$7/2^+ 0$

$1^+ 2410$

$1^+ 2464$

$2^+ 2245$

$1^+ 2003$

$1^+ 1862$

$1^+ 1815$

$1^+ 1733$

$1^+ 1846$

$1^+ 1782$

$1^{-} 931$

$1^{-} 680$

$56$ Fe

$239$ Pu

$208$ Pb

$235$ U

$238$ U
10^5 photons/sec has been achieved by the prototype.

Design of 220MeV system is under way.
Neutron-Based Screening System

He-3

NE213

Pulsed DD IEC

$10^8$ n/sec

10 min / 4 containers

Is this possible?
A principal challenge is to distinguish the secondary neutrons from the probing neutrons.

Either DNA or DDT requires a highly intense source of neutrons.

1. Delayed Neutron Noise Analysis (DNNA)
2. High-Energy Neutron Detection (HEND)
DD or DT?

Disadvantage of DD

- DD fusion cross-section is \(~1/100\) of DT.

Advantages of DD over DT

- No need of tritium handling
  - Easy operation, easy maintenance
  - Safe even in case of attack by terrorist

- Lower energy of neutrons
  - We need thermal neutrons to induce fission in SNMs.
  - Less shielding load. Low capital cost.
  - HEND method is applicable.
- 200kV was demonstrated with a dummy load.
- HV test with the IEC device is under way.
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Basic Neutron Noise Analysis (NNA)

- Well developed method in fission reactor physics field.
- Characterizes effective neutron multiplication factor, by measuring neutron fluctuation:

\[
\frac{\sigma^2_M(t)}{M(t)} = \frac{\overline{M^2(t)} - (\overline{M(t)})^2}{\overline{M(t)}} \equiv 1 + Y(t)
\]

- \(Y(\infty) = 0\) Poisson distribution
- \(Y(\infty) > 0\) fission chain reaction

Y-value as function of gate time (KUCA with pulsed DT neutrons)
Delayed Neutron Noise Analysis (DNNA)

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Pulse Interval

Delayed region

Neutron Count

calculate $Y(t)$
Experimental Setup

U-235: 0.5 kg
NPR (DT): $1.7 \times 10^5$ n/sec
Pulse width: 10 μsec
Rep. Rate: 10 Hz

F: HEU, H1-H9: He-3 detectors
Experimental Results

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Estimation from these results:

Required number of He-3 detectors for 20ft sea container screening is

30 detectors for 1kg HEU,
10 detectors for 5kg HEU.
detection time: 10 min
DD IEC NPR: $10^8\ n/sec$
- Detect high-energy secondary neutrons above the maximum energy of probing neutrons.
- Use of DD neutron source is mandatory. Neither DT nor RI source is applicable.
- Either dc or pulsed source is applicable.
Distances from the Cf-252 source to NE213 detector is 30cm, which corresponds to ~6 kg HEU in sea container.

NPRs:
- DD IEC
  - $10^5 - 10^7$ [n/sec]
- Cf-252
  - $2.9 \times 10^4$ [n/sec]

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Neutron Spectra from Cf-252 & U-235

- **Cf-252**
- **U-235**

Energy (MeV) vs. Neutron flux [a. u.]
Experimental Results

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2.45 MeV = 121 ch

DD + Cf-252

DD

i.e. background (pile-up and/or γ-ray)

2.45 MeV = 121 ch

Cf-252
**Concluding Summary**

- Nondestructive screening as fast as 2 min/container is required in order not to block sea container distribution.

- Two neutron-based methods are being developed that require as low NPR as $10^8$ n/sec.

- DNNA method is very promising. ½-scale tests are planned next year.

- Results from HEND experiments are also encouraging. Background due to pile-up of neutrons below the threshold energy needs to be minimized.

- HEND method is very attractive, because DC neutron source is applicable, i.e. very much reduced size and weight.
Transportable system is also possible.

- Ministry of Defense & National Police Agency are more interested in (trans)portable system than the big facility.
- HEND is advantageous, because DC PS is small & lightweight.

Transport IEC & PS by either truck or ship.

Use of a separate truck for detectors is not mandatory.
Ministry of Defense & National Police Agency are more interested in (trans)portable system than the big facility.

HEND is advantageous, because DC PS is small & lightweight.

Also, we don’t need to care about capacitance in long cabling.