Remote Detection of Nuclear Material

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Neutrons have been studied extensively for detection of nuclear materials because they have developed sources; penetrate deeply; and produce strong signatures that penetrate to distant sensors that have undergone extensive development. DOD studies of inspection by beams and sensors at several kilometers led to large beams, detectors, and doses so they were discarded.

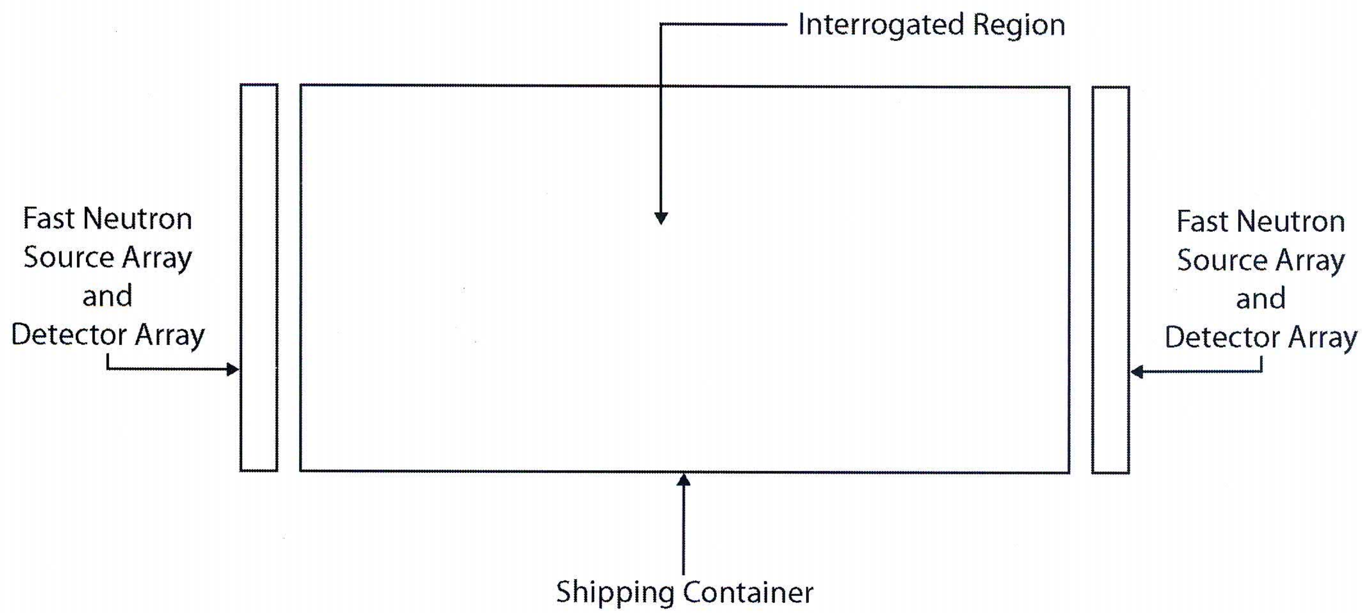
Sources and detectors can be automated and moved close to the object interrogated, but thermal systems can be negated by absorbers and moderators. Boron and Cd absorbers reduce thermal flux 10-fold, and a few cm of Carbon reduces neutron energies to thermal where absorbers are most efficient. Together they could reduce the nuclear signal from thermal neutrons to insignificant levels (Fig. 1).

A fast spectrum avoids absorption by remaining above this threshold. The Fermi Age theory used to design fast reactors can keep track of both the source neutrons and those from fissile material, which represent the noise and signal, respectively (App 1). The source energy can be chosen to fit a cargo container or other object of interest. (Fig. 2) The noise and signal neutron currents are widely separated at any time (Fig. 3), so the fraction of noise that scatters into the signal is small (App. 2). The advantage that gives the signal in energy more than offsets its disadvantage in current. That produces high confidence identification of SNM that is insensitive to absorbers (Fig. 4).

Moderators increase the target surface area and neutron source. 10-20 cm Carbon would reduce neutron energy to roughly the absorber threshold. Thicker moderators could eliminate nuclear signals altogether. However, scattering neutrons from them imprints distinctive energy bands whose spacing carries information on moderator type and number indicates moderator thickness as an indication of intentional concealment.

In summary, compact fast neutron inspection provides high-confidence detection of disseminated nuclear designs, materials, and technologies on the time scale on which they could be integrated to take advantage of the large number of containers entering the U.S. ports. They could be deployed on ships, ports, or at sea to support first line defense of the US against nuclear weapons in a manner consistent with the role of the Coast Guard.

LAYOUT OF SOURCES AND DETECTORS



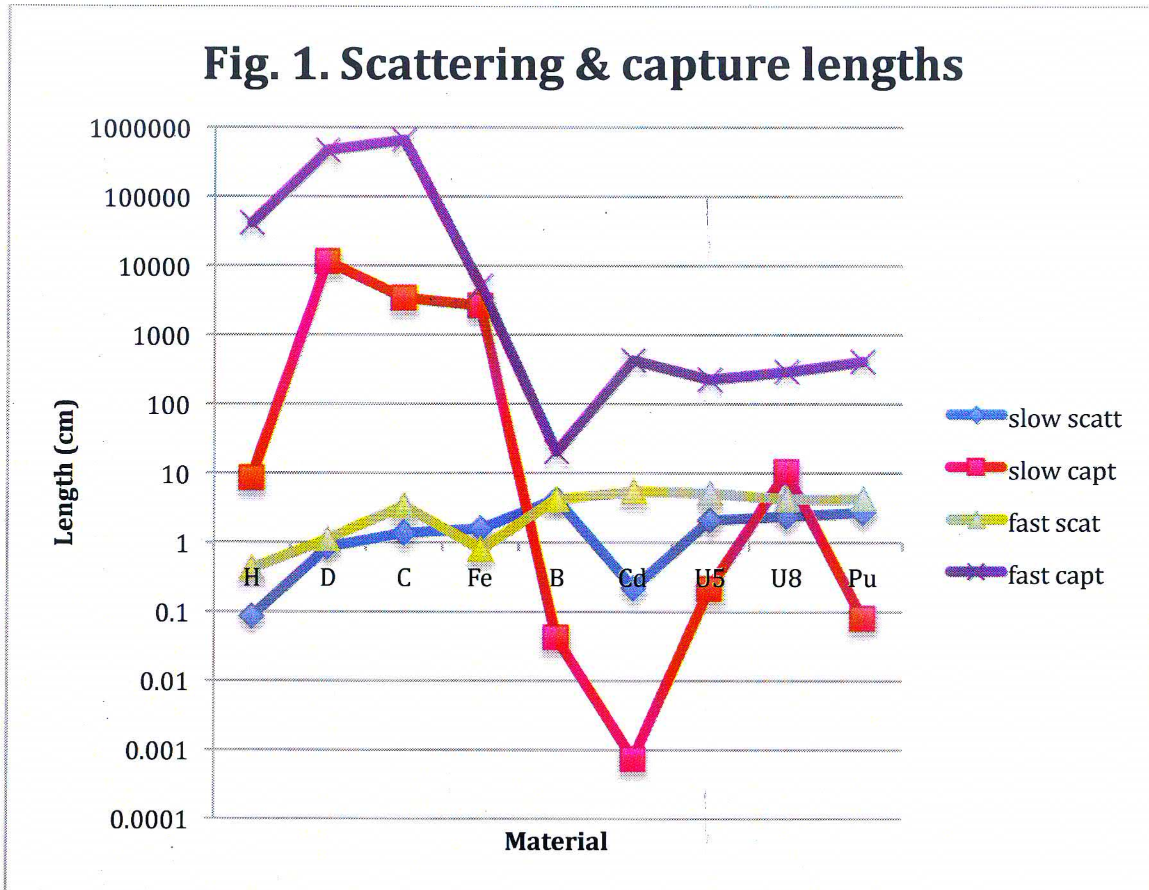


Fig. 1. Scattering & capture lengths
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
Length (cm)
H
D
C
Fe
B
Cd
U5
U8
Pu
Material
slow scatt
slow capt
fast scat
fast capt

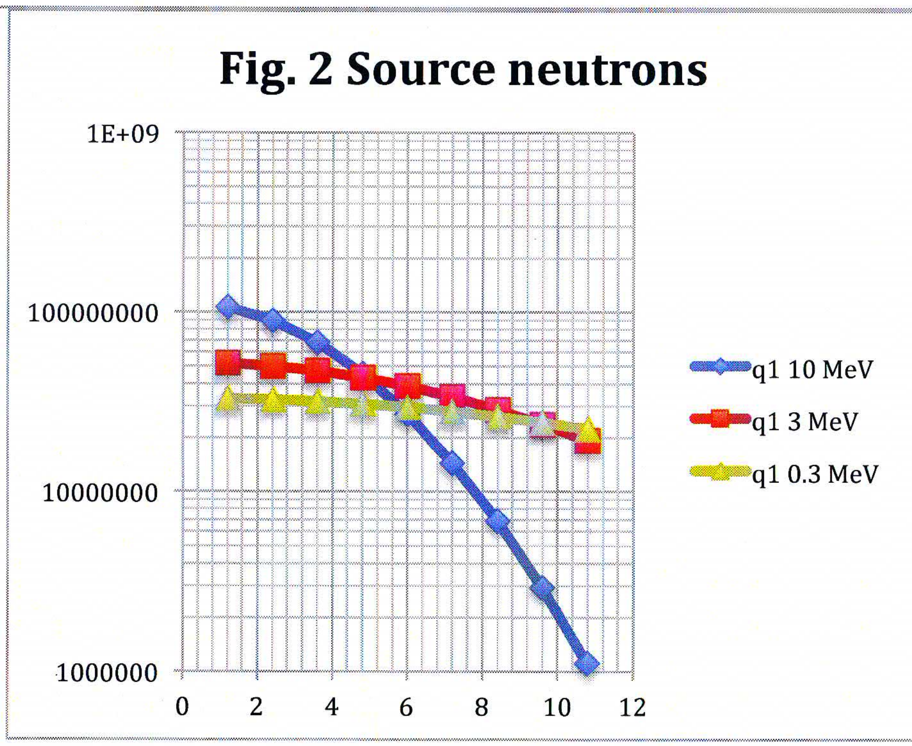
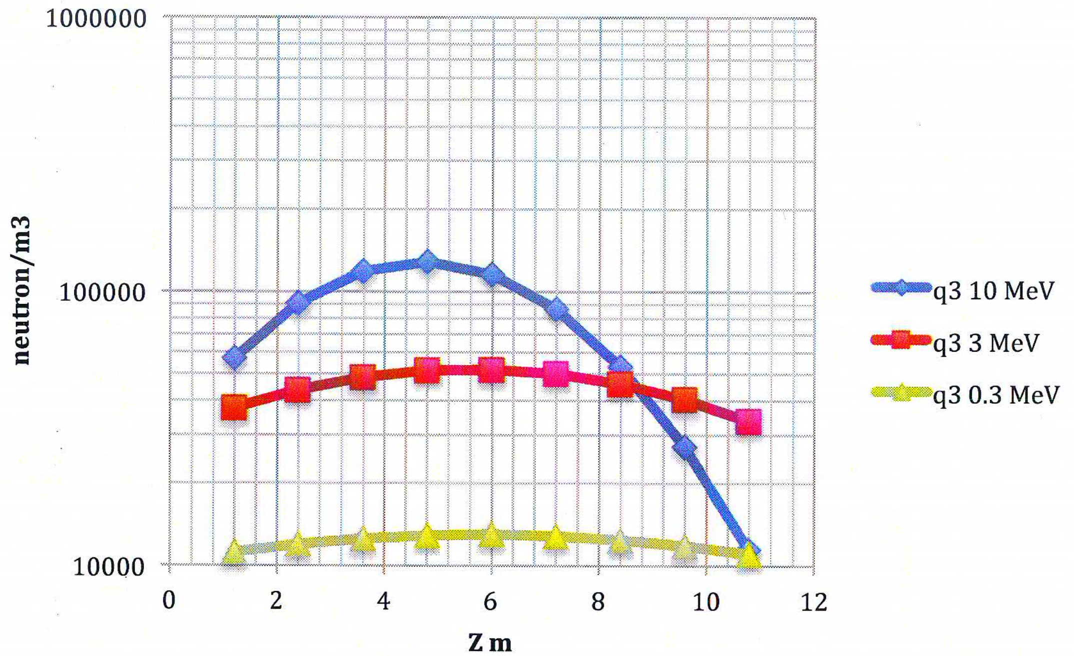


Fig. 2 Source neutrons
1E+09
100000000
10000000
1000000
0
2
4
6
8
10
12
q1 10 MeV
q1 3 MeV
q1 0.3 MeV

Fig. 2b. Signal neutrons



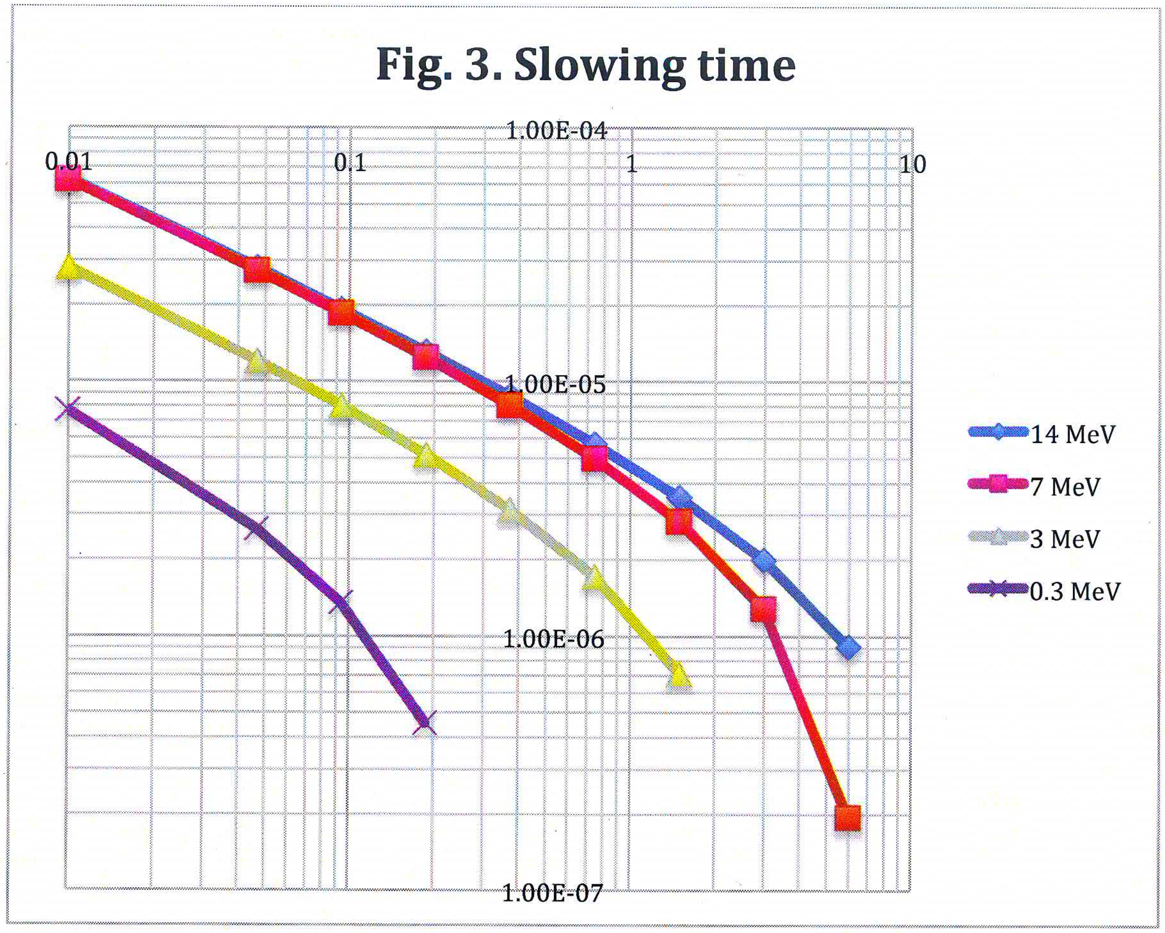
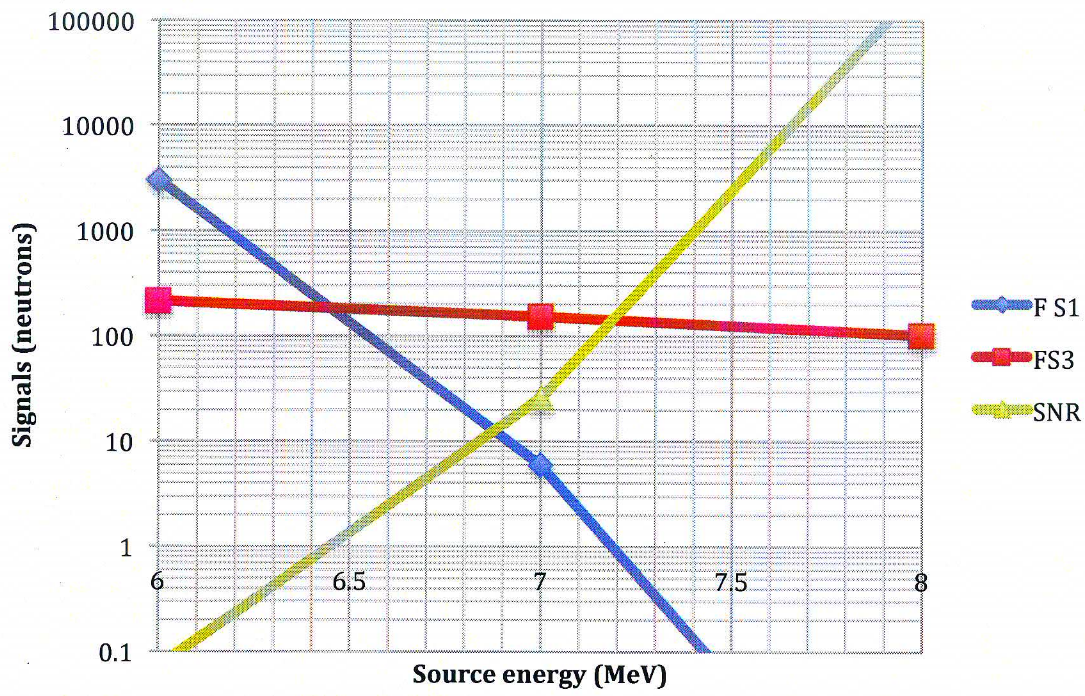


Fig. 3. Slowing time
1.00E-04
0.01
0.1
1
10
1.00E-05
1.00E-06
1.00E-07
14 MeV
7 MeV
3 MeV
0.3 MeV

Fig. 4 Signal, noise, and SNR



App. 1. Neutron Diffusion: Fermi Age

- Greens function for a point source Q_3 at $r = 0$
  - $q_3 = Q_3 G_3 = Q_3 \exp(-r^2/4\tau)/(4\pi\tau)^{3/2}$
- separation variable τ is the Fermi age
  - $\tau = \int d\varepsilon\, \lambda^2/3\xi = (\lambda^2/3\xi)\ \ln(E_o/E)$
- integration over transverse coordinates
  - $q_1 = Q_1 G_1 = Q_1 \exp(-z^2/4\tau)/(4\pi\tau)^{1/2}$
- Source neutrons from array 1-d, follow q_1
- Neutrons scattered from object 3-d, follow q_3

App. 2. Time dependence

- Mean group energy loss rate
  - $dE/dt = (\xi V/\lambda)E$
  - $t = (2\lambda/\xi V_o)(\surd(E_o/E) - 1)$
  - Same t relates source energy to signal energy
- Number of collisions
  - $N = \ln(Eo/E)/\xi$
- Variance of source distribution
  - $\sigma = 0.33(\xi Eo)^2 N$ (Fermi Nuclear Physics)
- Filtering of source neutrons
  - $F1 = 1 - \mathrm{erf}((Esource-Efiss)/\surd(2\sigma)$