

NSE

Nuclear Science and Engineering

science : systems : society

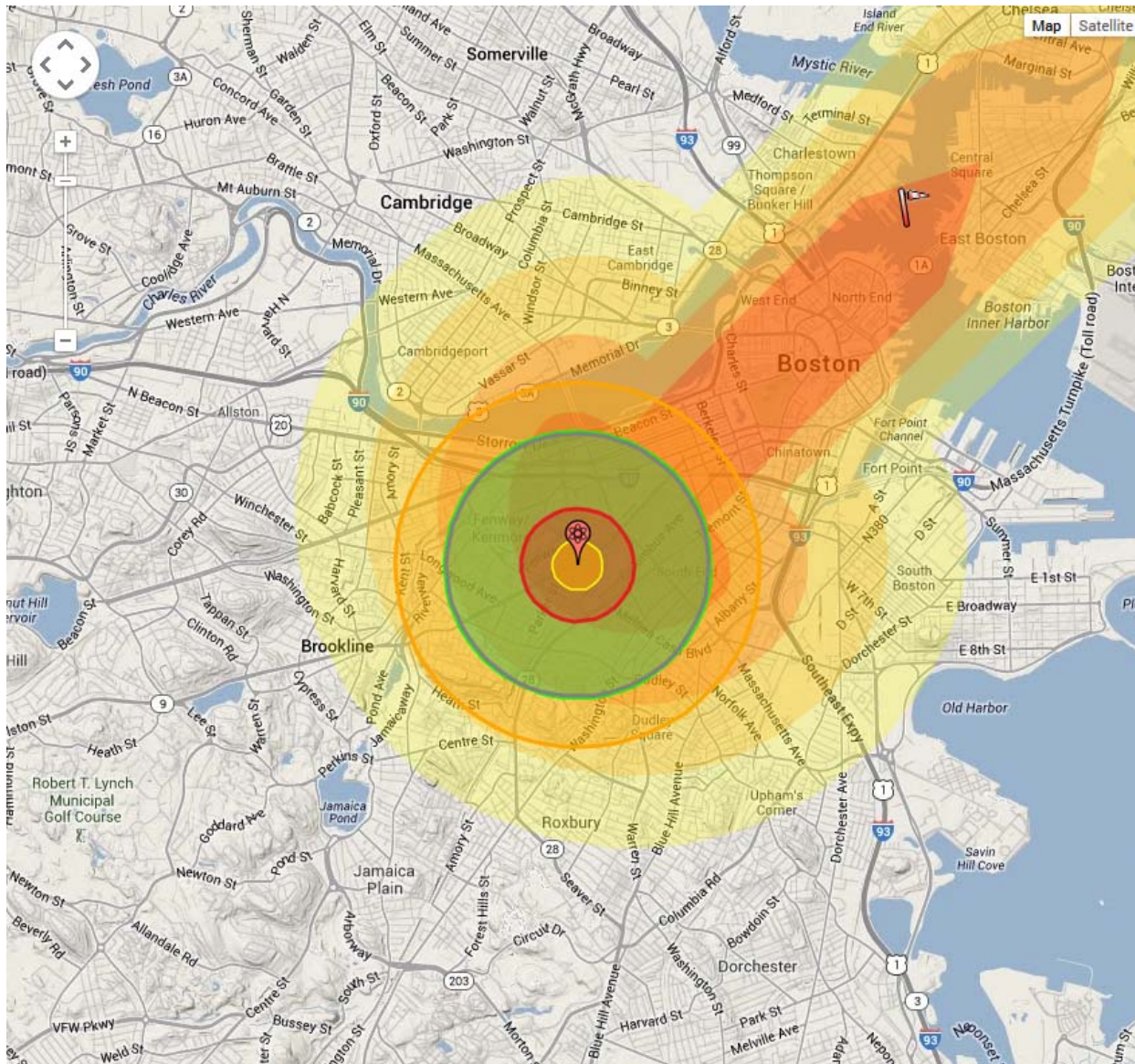


Nuclear reaction based monoenergetic gamma ray radiography system for detection of nuclear materials

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ADSA10 - Explosives Detection in Air Cargo, Northeastern University ALERT May 6, 2014

20 kT centered on AD5A10



NUKEMAP

2.4 - FAQ

You might also try: [NUKEMAP 3D](#)

Detonate Center ground zero Probe location

Note that you can drag the target marker after you have detonated the nuke.

Estimated fatalities:
80,170

Estimated injuries:
128,430

In any given 24-hour period, there are approximately 409,780 people in the 1 psi range of the most recent detonation.

Modeling casualties from a nuclear attack is difficult. These numbers should be seen as evocative, not definitive. Fallout effects are ignored. For more information about the model, [click here](#).

Effects radii for 20 kiloton surface burst (smallest to largest): ▼

- Fireball radius: 860 ft (0.08 mi²)
Maximum size of the nuclear fireball; relevance to lived effects depends on height of detonation. If it touches the ground, the amount of radioactive fallout is significantly increased.
- Air blast radius (20 psi): 1,940 ft (0.42 mi²)
At 20 psi overpressure, heavily built concrete buildings are severely damaged or demolished; fatalities approach 100%.
- Air blast radius (5 psi): 0.86 mi (2.3 mi²)
At 5 psi overpressure, most residential buildings collapse, injuries are universal, fatalities are widespread.
- Radiation radius (500 rem): 0.87 mi (2.4 mi²)
500 rem radiation dose; without medical treatment, there can be expected between 50% and 90% mortality from acute effects alone. Dying takes between several hours and several weeks.
- Thermal radiation radius (3rd degree burns): 1.19 mi (4.45 mi²)
Third degree burns extend throughout the layers of skin, and are often painless because they destroy the pain nerves. They can cause severe scarring or disablement, and can require amputation. 100% probability for 3rd degree burns at this yield is 8.9 cal/cm².

Note: Rounding accounts for any inconsistencies in the above numbers.

Overview

- What are we trying to do?
- How is this problem handled today and what are the limitations?
- What is the new approach and why will we succeed where others have failed
- Assuming success, who cares? Why does it matter and to whom?
- How long will it take? How much will it cost?

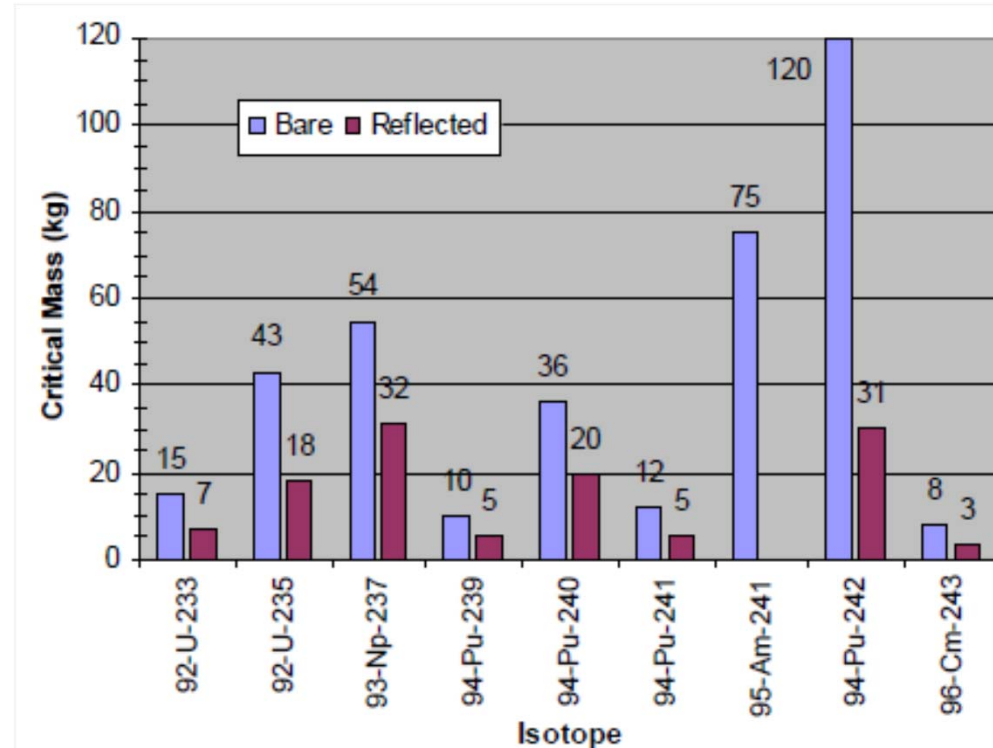
US Nuclear Posture Review

Five key objectives of US nuclear weapons policies and posture:

- Preventing nuclear proliferation and nuclear terrorism;
- Reducing the role of U.S. nuclear weapons in U.S. national security strategy;
- Maintaining strategic deterrence and stability at reduced nuclear force levels;
- Strengthening regional deterrence and reassuring U.S. allies and partners; and
- Sustaining a safe, secure, and effective nuclear arsenal.

Not much material is required

- Nuclear weapons need only about 1-2 critical masses of weaponizable material
- Critical assembly must be supercritical to explode
- Chart shows the critical masses for some weapon isotopes
- Bare refers to the critical mass of a sphere of material without anything surrounding it
- Reflected refers to the critical mass when surrounded by a neutron reflector such as Iron or Tungsten
- Using a neutron reflector always reduces the critical mass
- Generally a few tens of kilograms or less of material will be involved.



Size of Significant Quantities

According to the International Atomic Energy Agency (IAEA), 25 kg of HEU (about the size of a large grapefruit) or 8 kg of plutonium (about the size of a soda can) represent a “significant quantity” required to make a crude nuclear weapon.



Density for uranium and plutonium $\sim 19 \text{ g/cm}^3$.

Large Grapefruit $R = 6.8 \text{ cm}$ $V = 1320 \text{ cm}^3 \sim 25 \text{ kg}$

12" Softball (3.8" ϕ): $R = 4.8 \text{ cm}$, $V = 463 \text{ cm}^3 \sim M = 8.8 \text{ kg}$

Soda Can: $H = 12.2 \text{ cm}$, $R = 3.2 \text{ cm}$, $V = 387 \text{ cm}^3 \sim M = 7.4 \text{ kg}$

From D. Chichester, INL

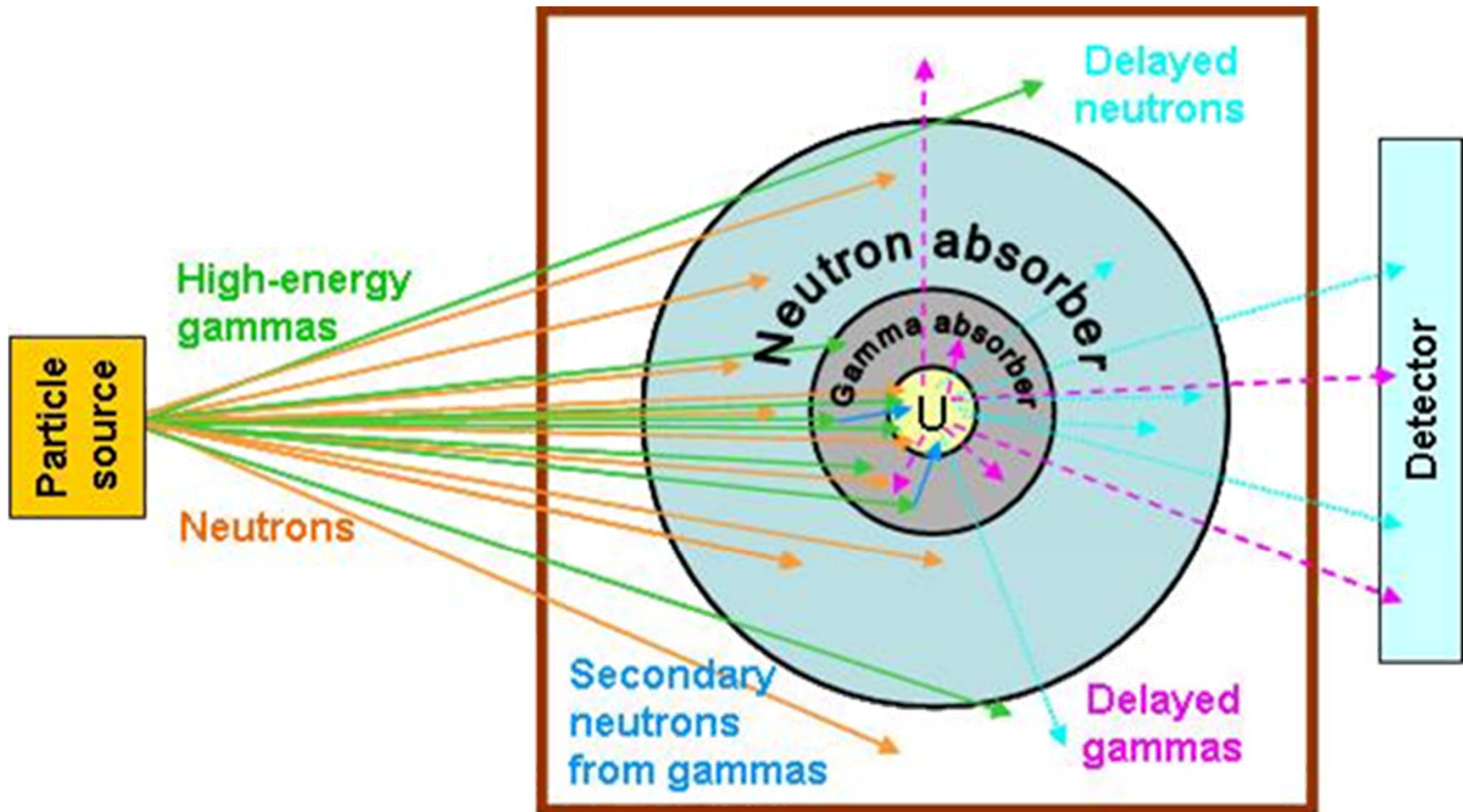
Basic Approach

- The fundamental approach is to generate both neutrons and monoenergetic gamma rays by means of low energy nuclear reactions. By selecting nuclear reactions with large positive Q values, small accelerators producing 3 to 10 MeV protons or deuterons can simultaneously produce fast neutrons and high energy (> 10 MeV) monoenergetic gammas.
- This multi-particle method images the SNM through shielding and also identifies it by inducing fission in the suspect material.
- Use transmission imaging to locate high-Z materials
- Use multiple energies to distinguish materials such as Pb or W from actinides
- Use photofission and/or neutron induced fission as final check
- Doses are well under 1 mrem

Why use Monoenergetic Imaging

- an order of magnitude or more reduction in dose
- enhanced sensitivity in detection and verification
- lower requirements for shielding
- the ability to reduce the size of the source part of the system by an order of magnitude or more while still meeting requirements for detection and identification of SNM
- flexibility in detection through radiography and active probing with the same device

Multi-particle Probing



Dose Matters!

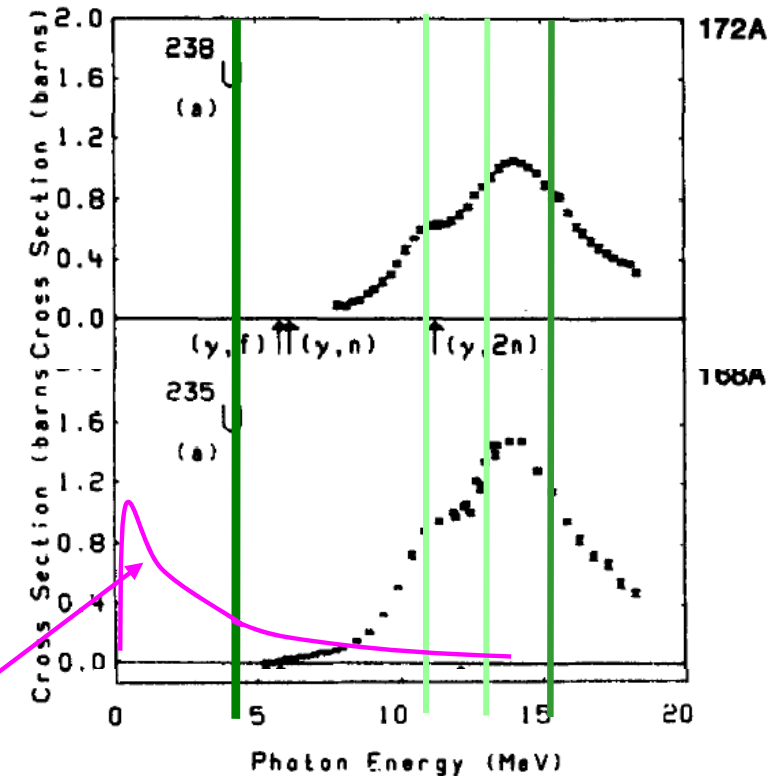
- ANSI 43.14 standard “Radiation Safety Guidelines for Active Interrogation Systems for Security Screening of Cargo”
 - Allows as much as 5 mSv (500 mrem) to potential stowaways
 - But, principle of ALARA remains in place for all such systems
 - requires making every reasonable effort to maintain exposures to radiation as far below the regulatory dose as practical, taking into consideration the state of technology, the economics of improvements in relation to benefits to health and safety, and other societal and socioeconomic considerations
- **Monoenergetic approach reduces dose to less than a mrem**
- Reduced dose meets ALARA and allows for portable systems and reduced amounts of shielding

$^{11}\text{B}(\text{d}, \text{n}\gamma)^{12}\text{C}$ Produces High-Energy Neutrons And Gamma Radiation For Efficient Uranium Fission

$^{11}\text{B}(\text{d}, \text{n})^{12}\text{C}$ gamma lines

The fission cross-section using gammas for two uranium isotopes is shown at the right.

$^{12}\text{C}^*$ gamma lines found for >2 MeV deuterons have intense high-energy-gamma lines at 4.4 and 15.1 MeV and less intense lines at 10.7 and 12.7 MeV. The neutrons have a peak around 12 MeV and a broad distribution at lower energies.

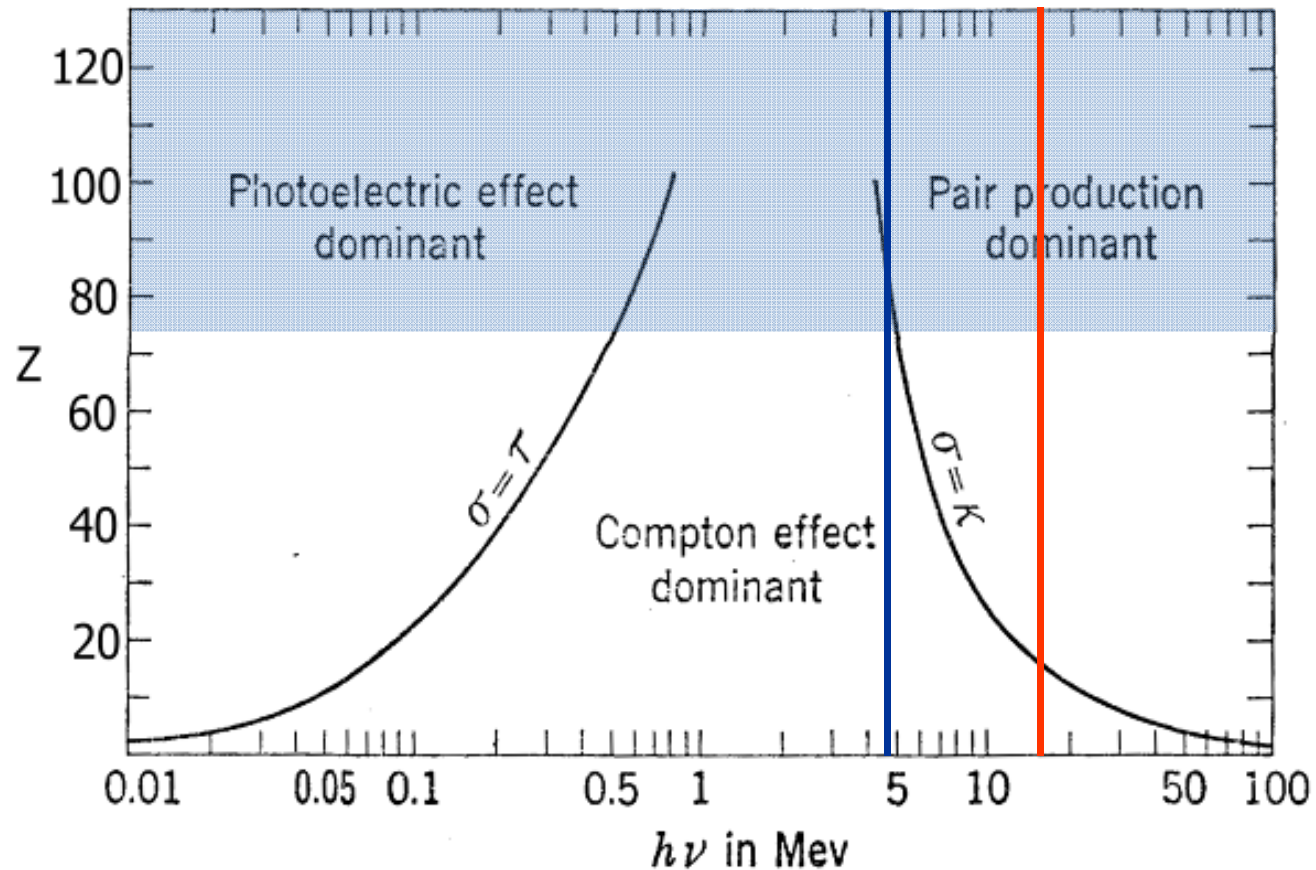


Relative Bremsstrahlung production for a 15 MeV electron beam. Lower energy gammas can be preferentially reduced by filtering but with a reduction in the overall intensity

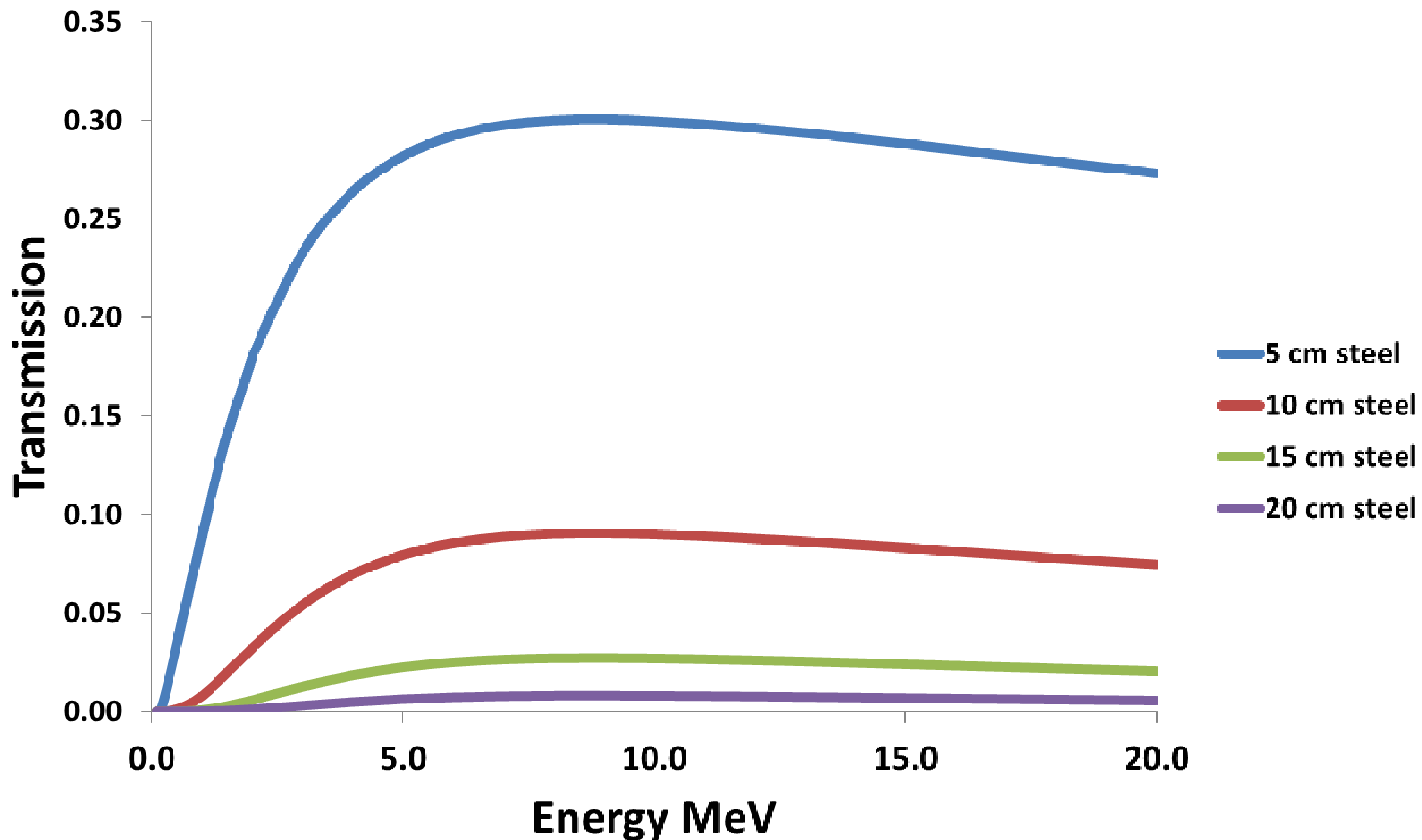
Prototype 12 MeV SC Cyclotron



Transmission Issues



Monoenergetic Gammas





Higher Energy increases penetration

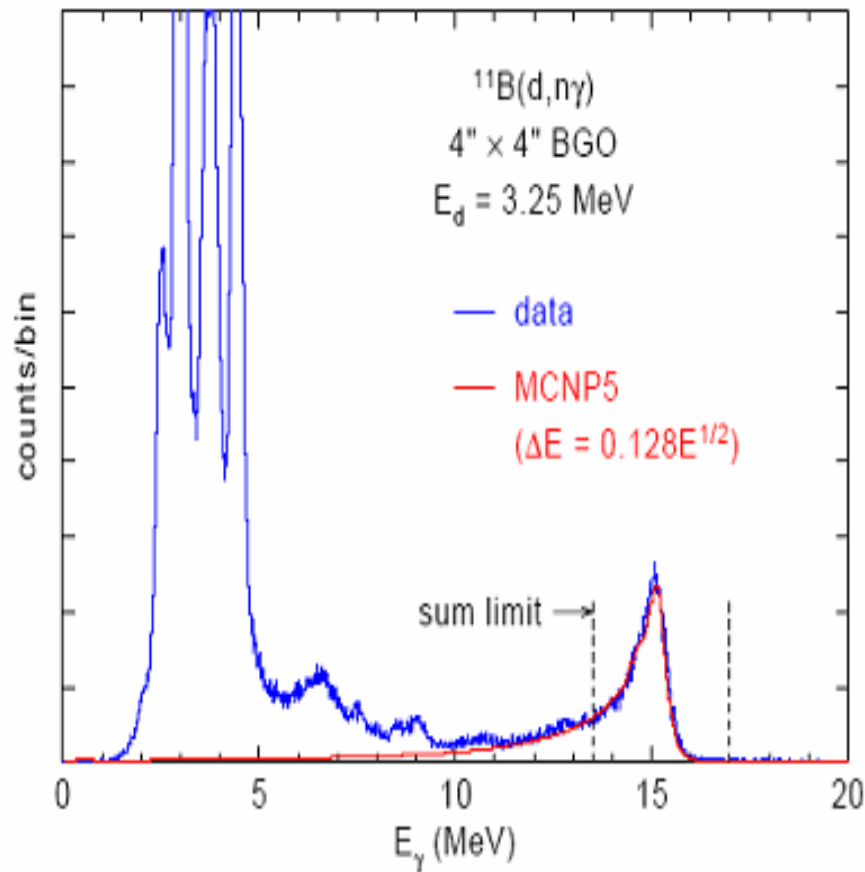
Half-Value Layers in cm for Varying Photon Energies for Various Materials

	10 to 100 KeV	100 to 500 KeV	1 MeV
Concrete	6.56	10.83	12.05
Lead	0.03	0.50	1.31
DU	0.02	0.22	0.65
Tungsten	0.02	0.38	0.87
Steel / Iron	0.36	2.73	3.45
Tin	0.08	1.92	3.27
Aluminum	0.44	9.78	10.94
Water	23.83	26.15	28.71

HVL in centimeters for fast neutrons

Energy in MeV	1	5	10	15
Polyethylene	3.7	6.1	7.7	8.8
Water	4.3	6.9	8.8	10.1
Concrete	6.8	11	14	16
Damp soil	8.8	14.3	18.2	20.8

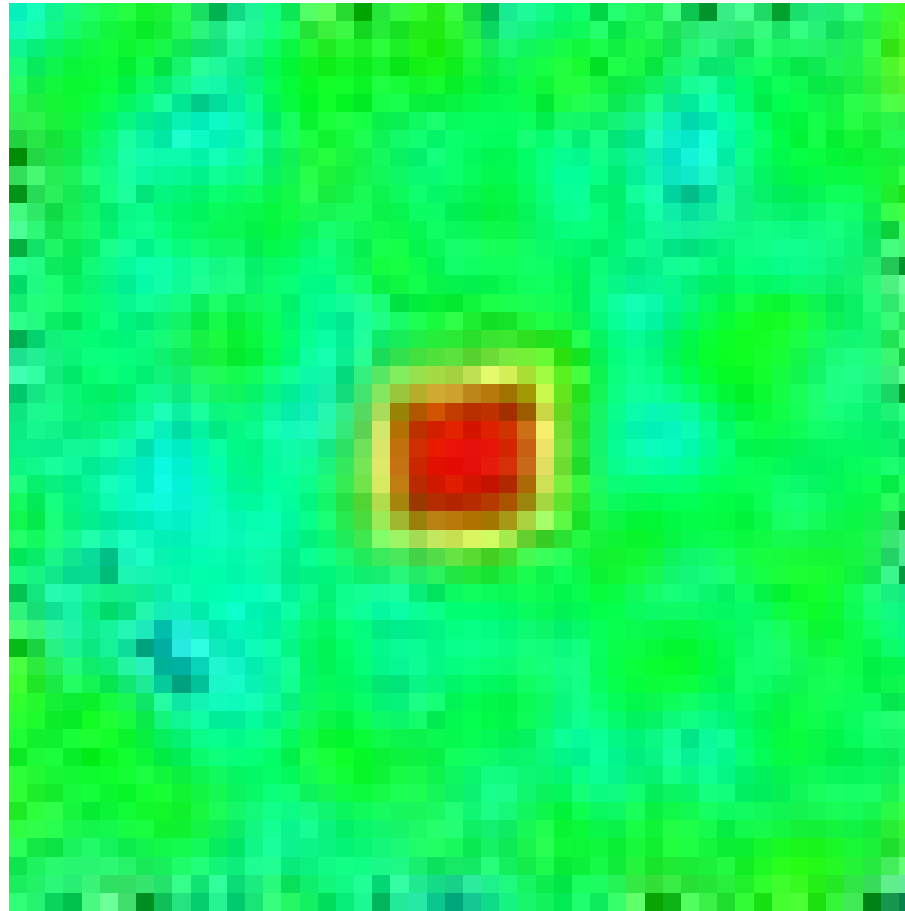
Gamma Production Rates



Gamma Energy (MeV)	Yield (gammas/s/sr)
4.4	4×10^9
10.7	2×10^7
12.7	4×10^7
15.1	6.6×10^8

LA-UR-07-2724

15.1 MeV Transmission Image

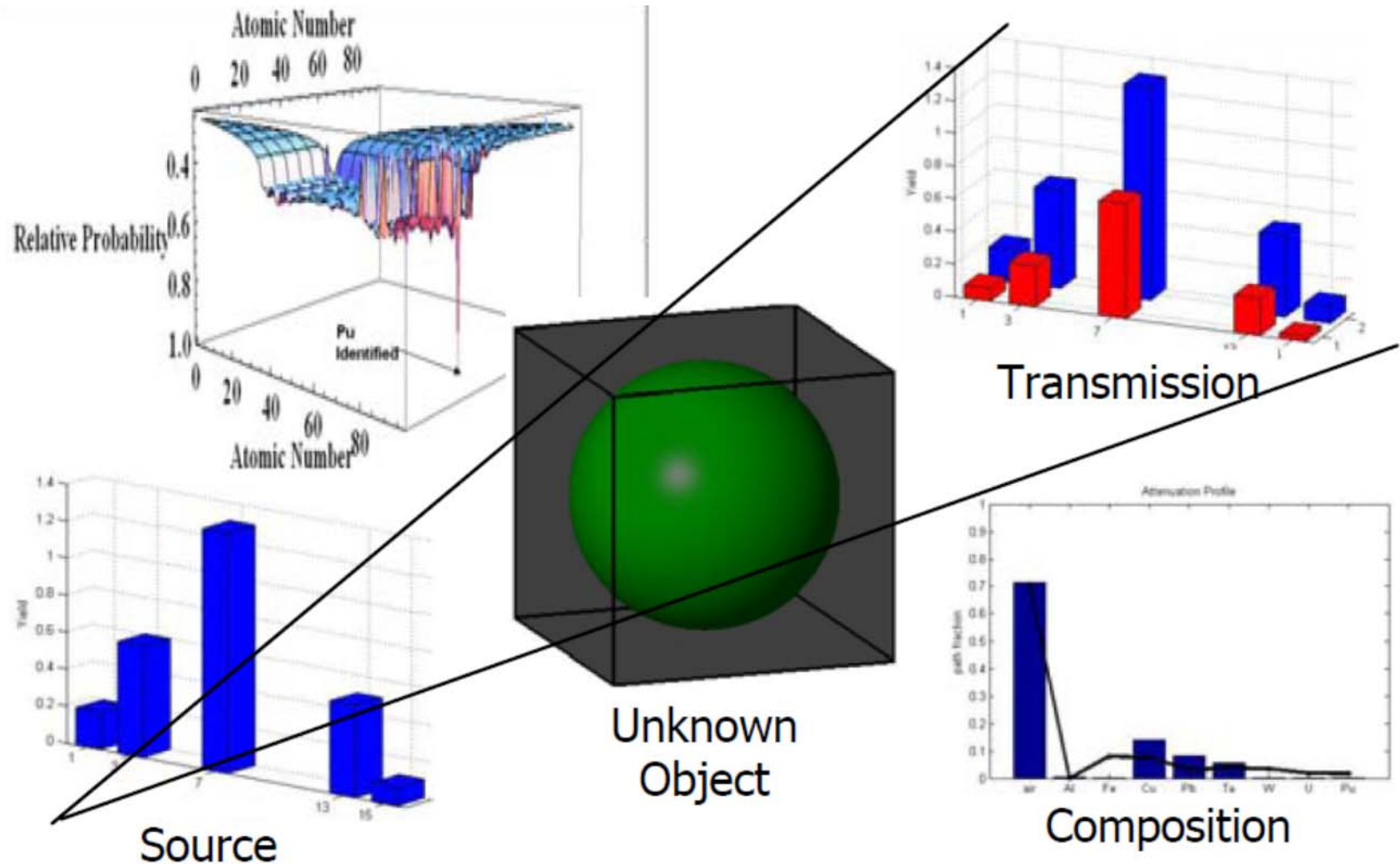


100 cc U cube in 40 cm Fe block imaged with 15.1 MeV gammas (MCNPX simulation)

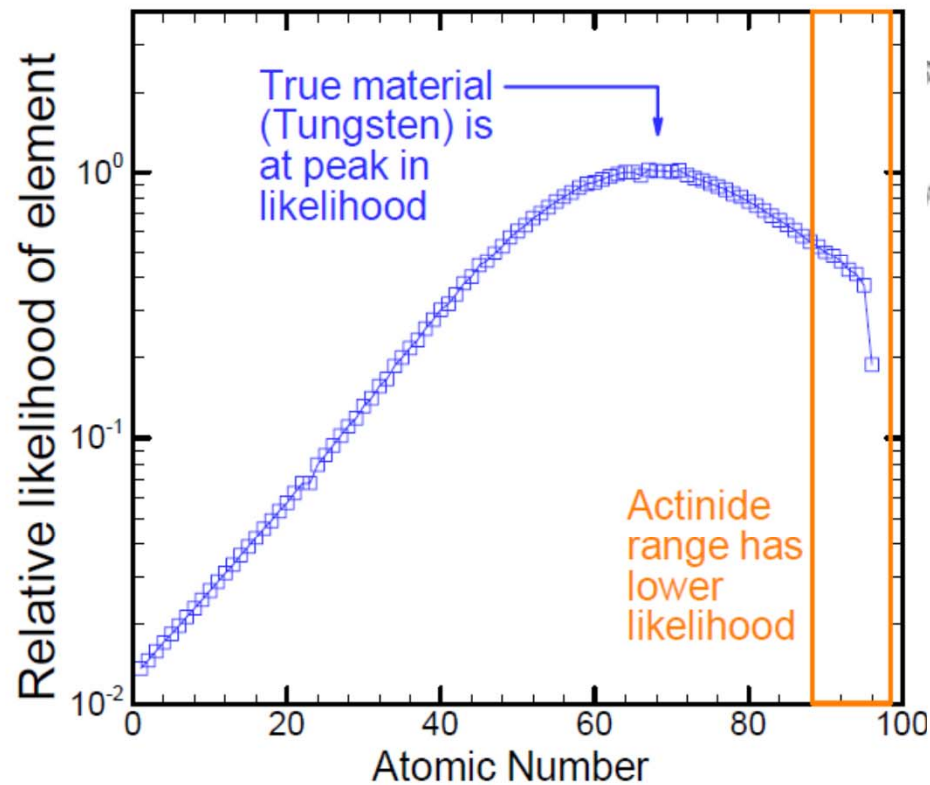
Identifying SNM

- Transmission measurement alone only identifies high-Z material
 - Multi-energy approach can separate actinides from materials such as Pb or W
- Use two approaches to distinguish ^{235}U by detection of fission products
 - Utilize photofission
 - Probe with low energy neutrons ($< 1\text{MeV}$); only ^{235}U will undergo fission

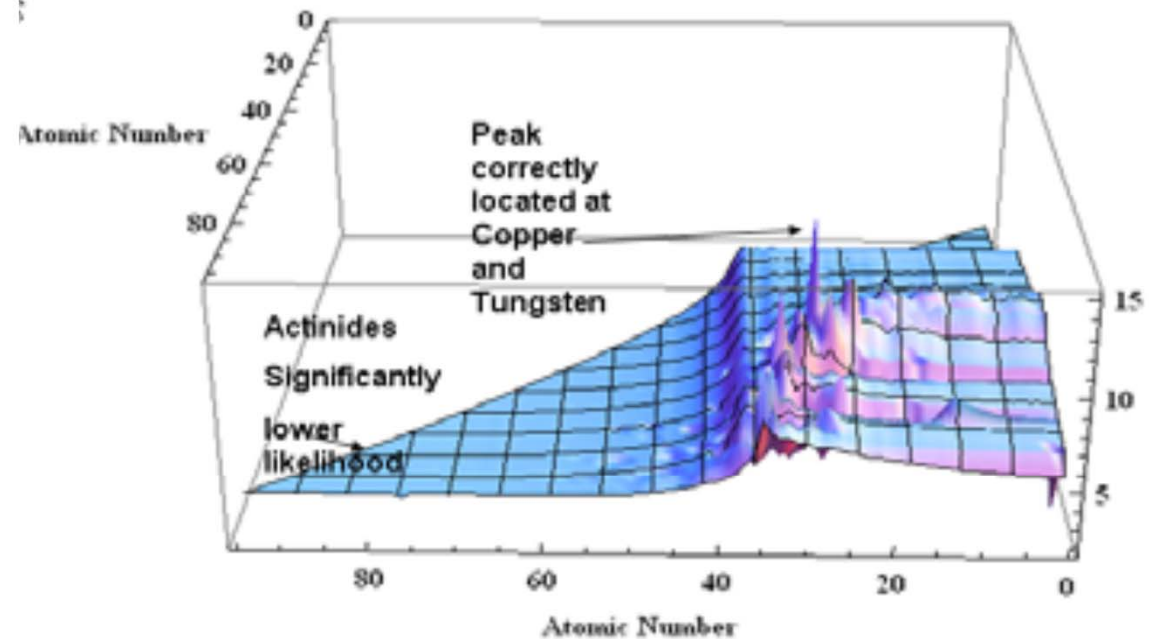
Multiple lines for material identification



Multiple lines for material identification



Two lines separate W from actinides (experimental data)



Four lines separate Cu and W from actinides

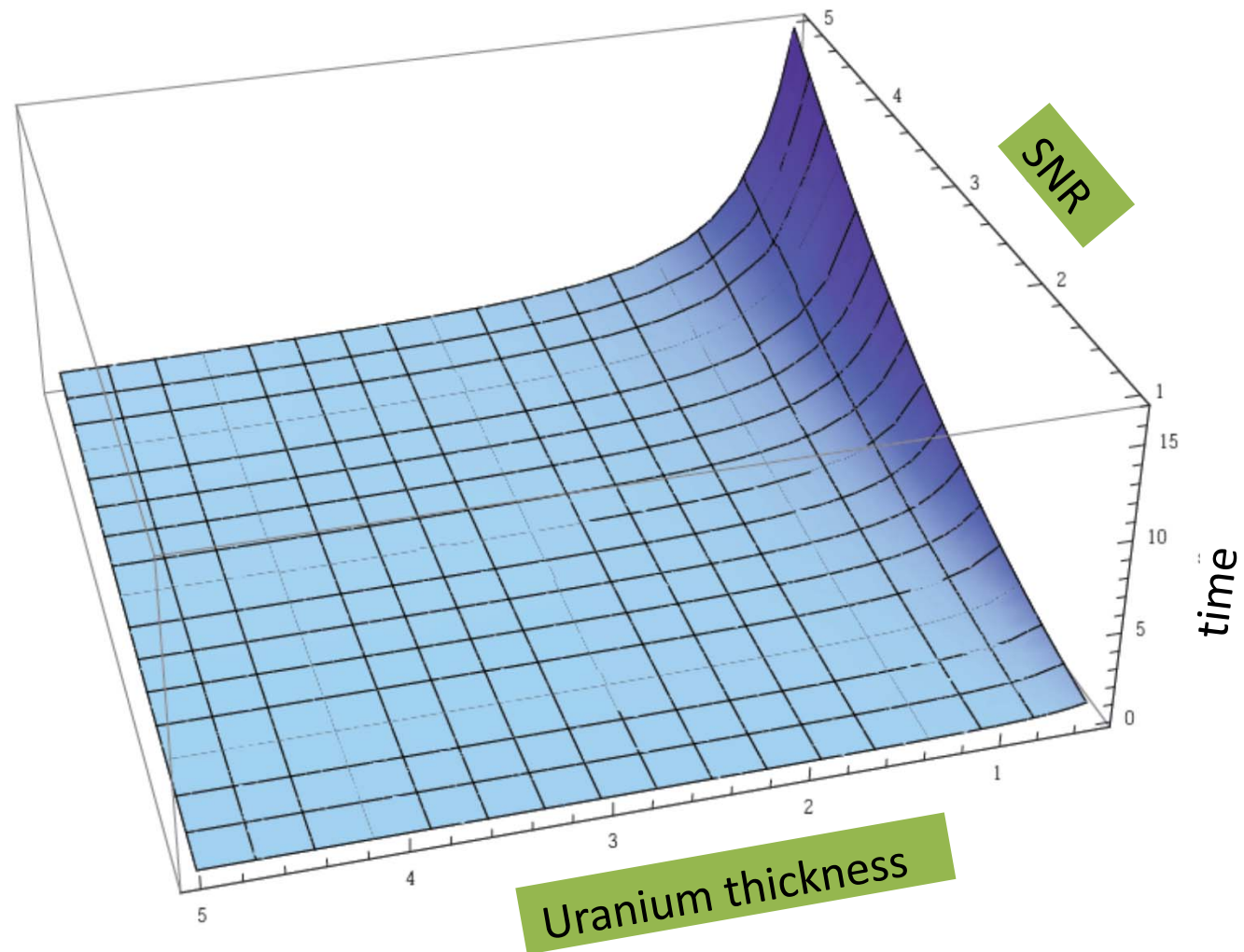
From R. Sheffield, LANL

Neutron probes

- Long term approach will use a small superconducting cyclotrons to generate both gammas and neutrons
- Some examples:
 - 9 MeV SCC
 - Generates 4.5 MeV d, or 9.0 MeV p
 - Use the 9.0 MeV p in a (p,n) reaction
 - e.g. $^{50}\text{Cr}(p,n)^{50}\text{Mn}$ $Q = -8.42$ MeV which results in $E_n < 1$ MeV, *below fission threshold for ^{238}U*
 - ~20 MeV SCC.
 - $^{12}\text{C}(p,p'\gamma)^{12}\text{C}$ generates only gammas below threshold ~19.5 MeV
 - Gammas and neutrons above threshold

Detection Times

- Time to detect 1 cc of U in a 20 cm cube of iron with SNR from 1 to 5
- Accelerator running 90 microA d+ at 3MeV



Detection Times

- Time to detect 1 cc U in 20 cm Fe cube
 - 0.2 s for SNR of 1
- Increase number of lines of detectors
 - 0.01 s for 20 lines
- Increase beam current
 - 0.001 s for 900 microA
- We can scan at 1 m/s
 - Scan cargo container in 6 s

Some Features

- Use physics defined gamma ray energies not dependent on the energy of the electron beam
 - Do not particularly need precise energy accelerator
 - accelerators are available in COTS and should be available in superconducting form soon
- Combine high resolution CdWO₄ detector array (4mm pitch with our 4/15 MeV gamma detectors
 - enables us to produce an overlay of images which combine high spatial resolution and material identification
- Neutrons available for final confirmation of SNM
 - Intensities should enable rapid screening with subsequent ID
- Going to higher power or more detectors is a COTS decision for even faster scanning

Some Conclusions

- Monoenergetic gamma transmission imaging appears practical
- Dose is *orders of magnitude lower* than alternative approaches
- Compact accelerator designs are possible
- Multi-particle approach gives both position and isotopic identification of SNM

Collaborators

- | | | | |
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| • John Fisher | MIT | • Ernie Ihloff | MIT |
| • Buck O'Day* | MIT | • Joe Minervini | MIT |
| • Igor Jovanovic | PSU | | |
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