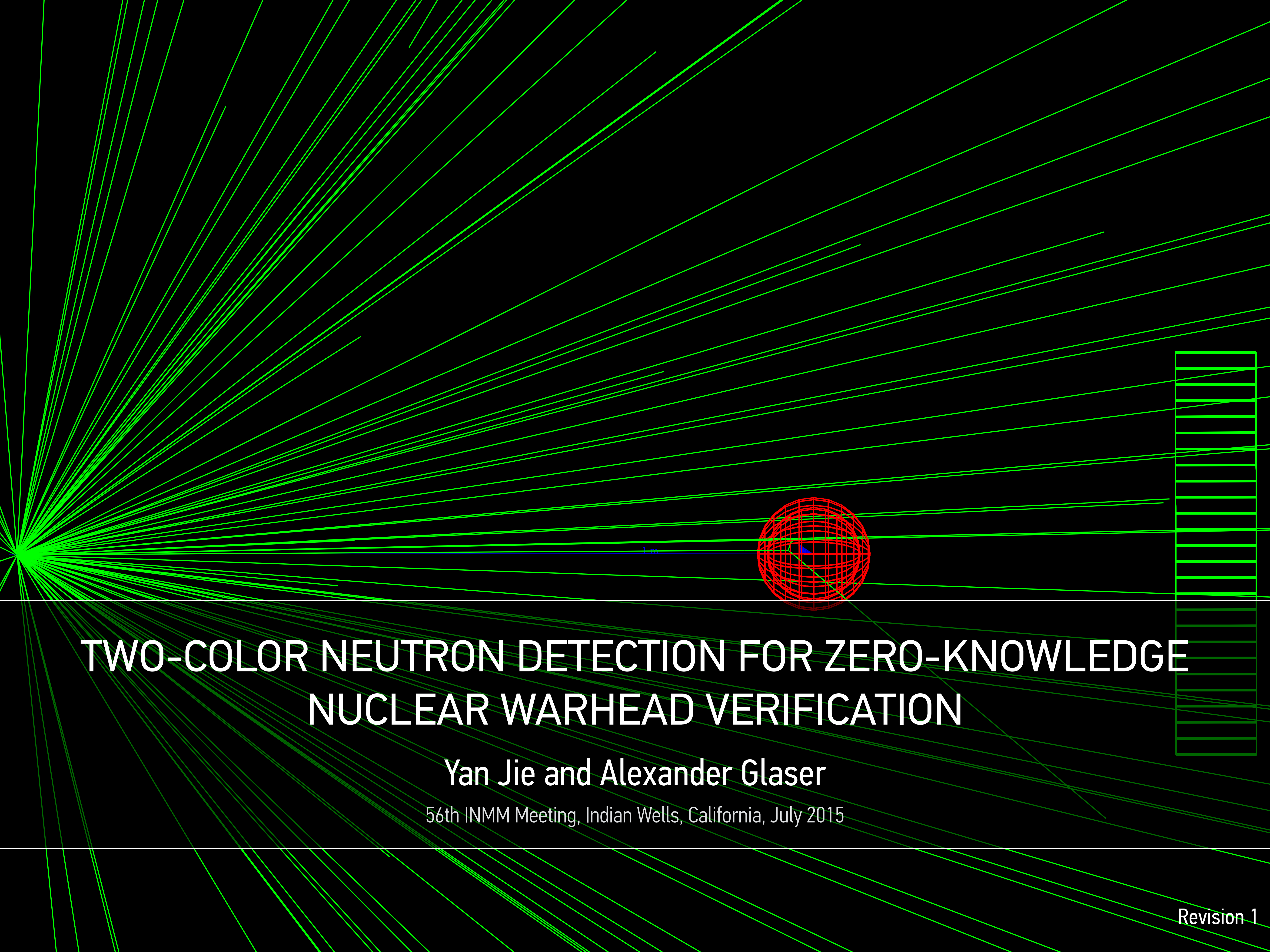


TWO-COLOR NEUTRON DETECTION FOR ZERO-KNOWLEDGE NUCLEAR WARHEAD VERIFICATION

Yan Jie and Alexander Glaser

56th INMM Meeting, Indian Wells, California, July 2015

Revision 1

PREVENTING THE EXCHANGE OF SENSITIVE INFORMATION

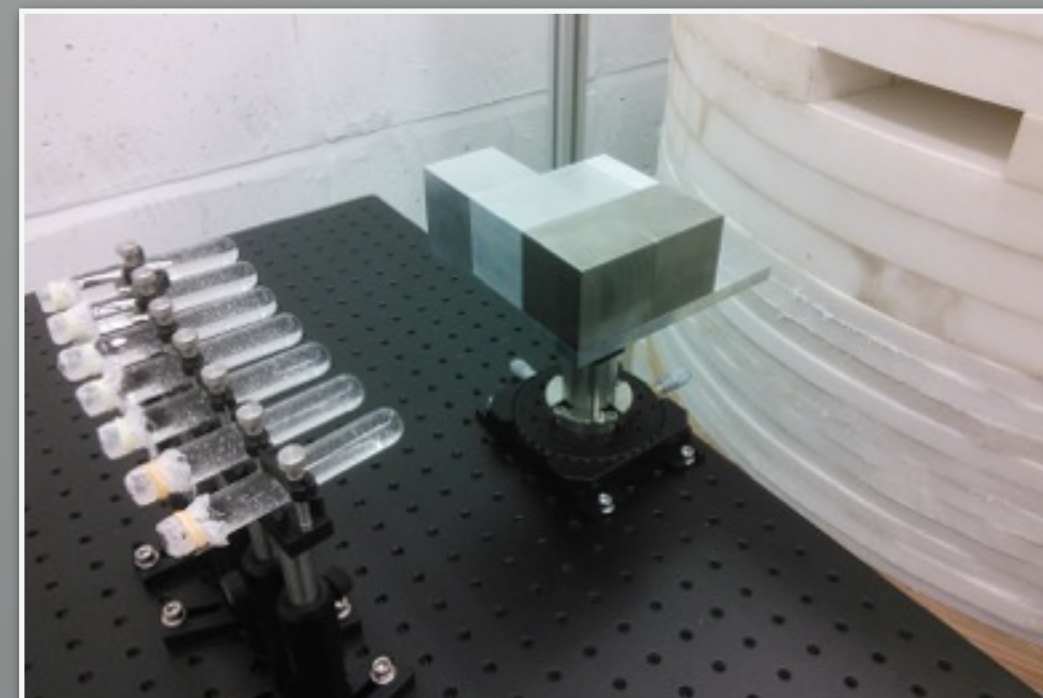
(S. Philippe, B. Barak and A. Glaser, "Designing Protocols for Nuclear Warhead Verification," *this conference*)

Trusted Information Barrier Protocol

Measure sensitive Information

Hard to authenticate and certify

Single-bit observation



Interactive Zero-Knowledge Protocol

Never measure sensitive information

Easier to authenticate and certify

More complex observation

OUR GENERAL APPROACH

TEMPLATE-MATCHING (using active neutron interrogation)

More difficult to implement than attribute approach,
but also more robust against important diversion scenarios

Generally requires “golden warhead” to generate template (reference signature)

INTERACTIVE ZERO-KNOWLEDGE PROTOCOL

Can prove that a statement is true without revealing why it is true

In contrast to “traditional approaches,” no requirement

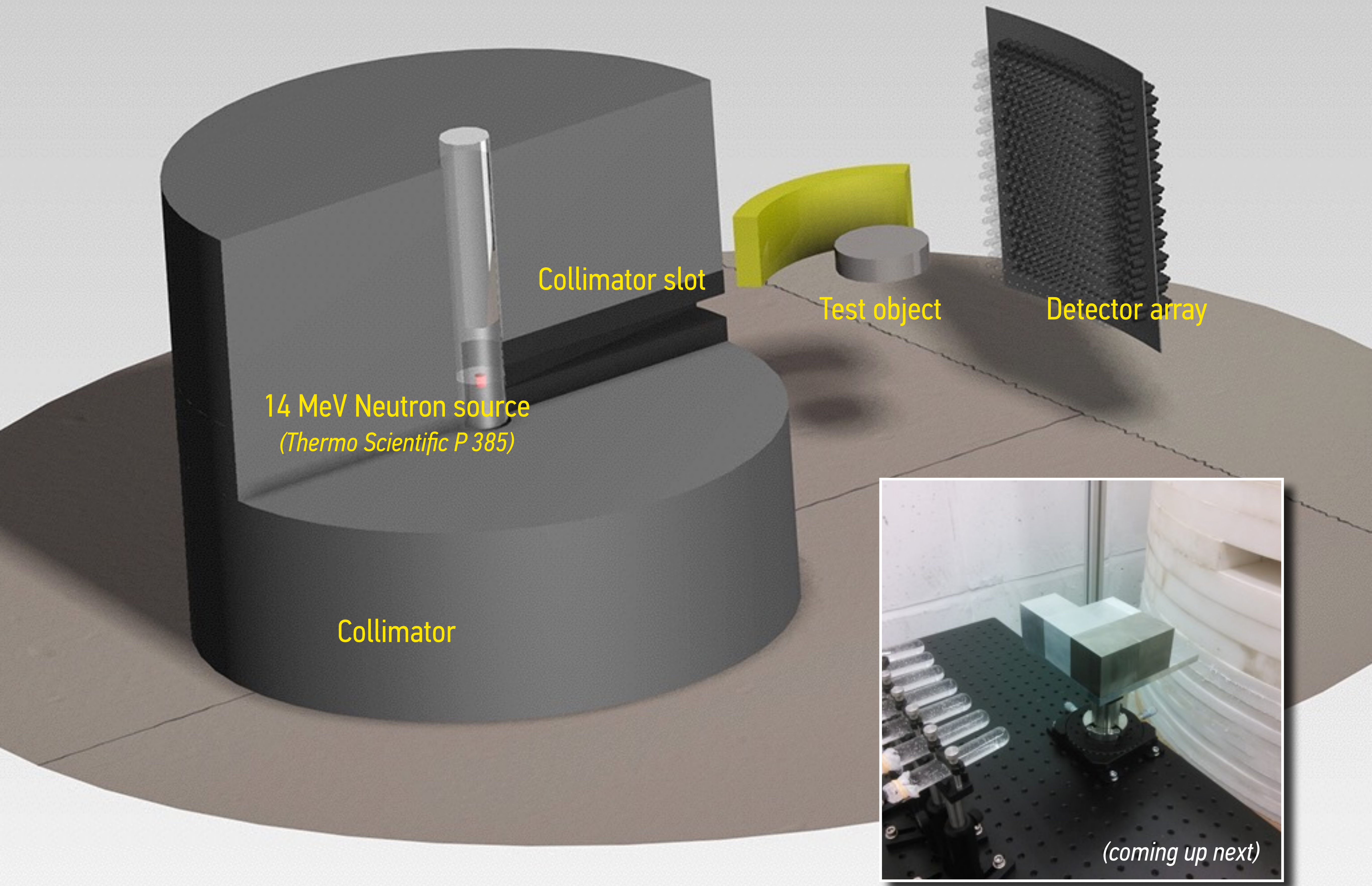
for trusted information barrier

NON-ELECTRONIC DETECTORS

Electronic hardware and software used for detectors and, especially, for
information barriers are hard to certify and authenticate

Technologies based on “physical” detection may offer important advantages

“ONE-COLOR” RADIOGRAPHY



PROOF THAT TWO RADIOGRAPHS ARE IDENTICAL

RADIOGRAPH
ITEM A

+

COMPLEMENT
ITEM A

=

FLAT BACKGROUND

RADIOGRAPH
ITEM B

+

COMPLEMENT
ITEM A

=

FLAT BACKGROUND

ITEM B IS EQUAL TO ITEM A

PROOF THAT TWO RADIOGRAPHS ARE IDENTICAL

RADIOGRAPH
ITEM A

+

COMPLEMENT
ITEM A

=

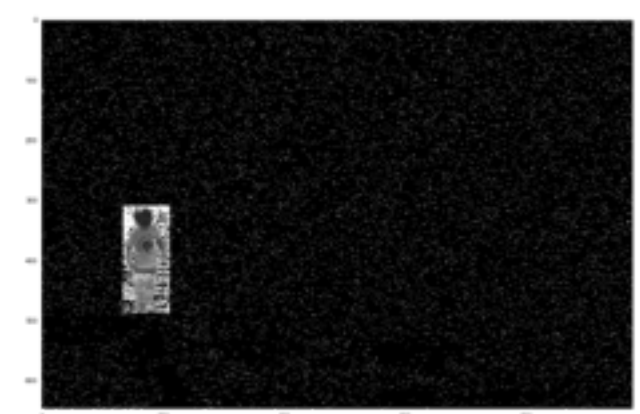
FLAT BACKGROUND

RADIOGRAPH
ITEM B

+

COMPLEMENT
ITEM A

=



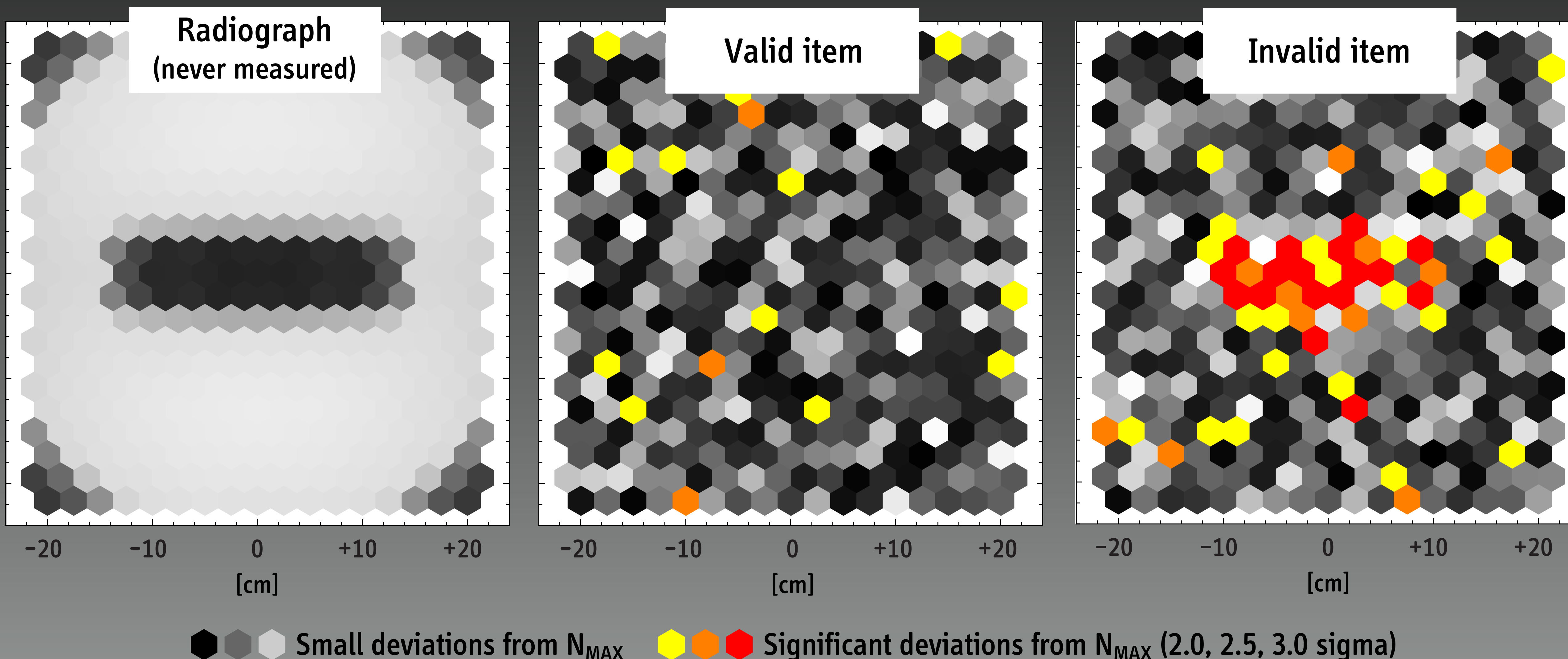
RESIDUAL IMAGE

ITEM B IS NOT EQUAL TO ITEM A

ZERO-KNOWLEDGE VERIFICATION

RADIOGRAPHY WITH 14 MeV NEUTRONS

(Tungsten rings replaced by lead rings)

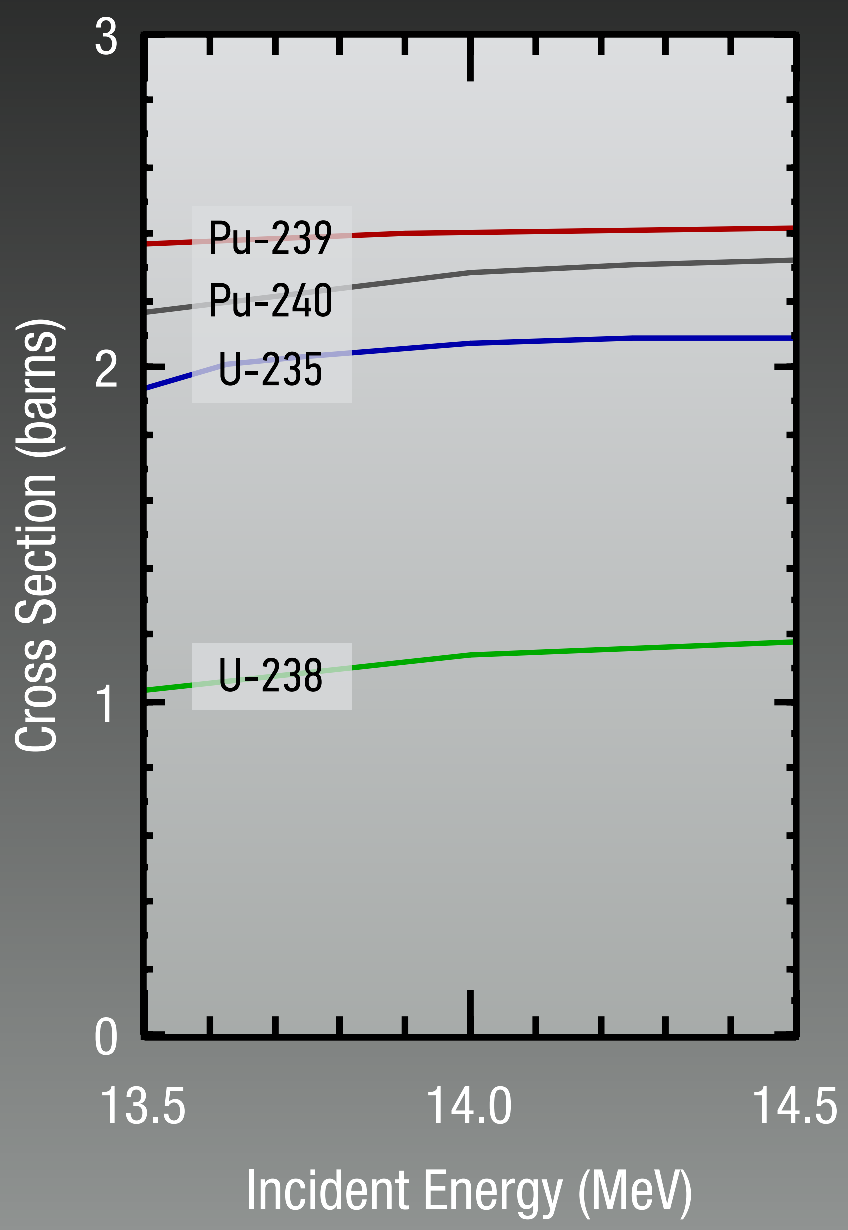


Simulated data from MCNP calculations; neutron detection energies > 10 MeV; N(max) = 5,000

A. Glaser, B. Barak, R. J. Goldston, “A Zero-knowledge Protocol for Nuclear Warhead Verification,” *Nature,* 510, 26 June 2014, 497–502

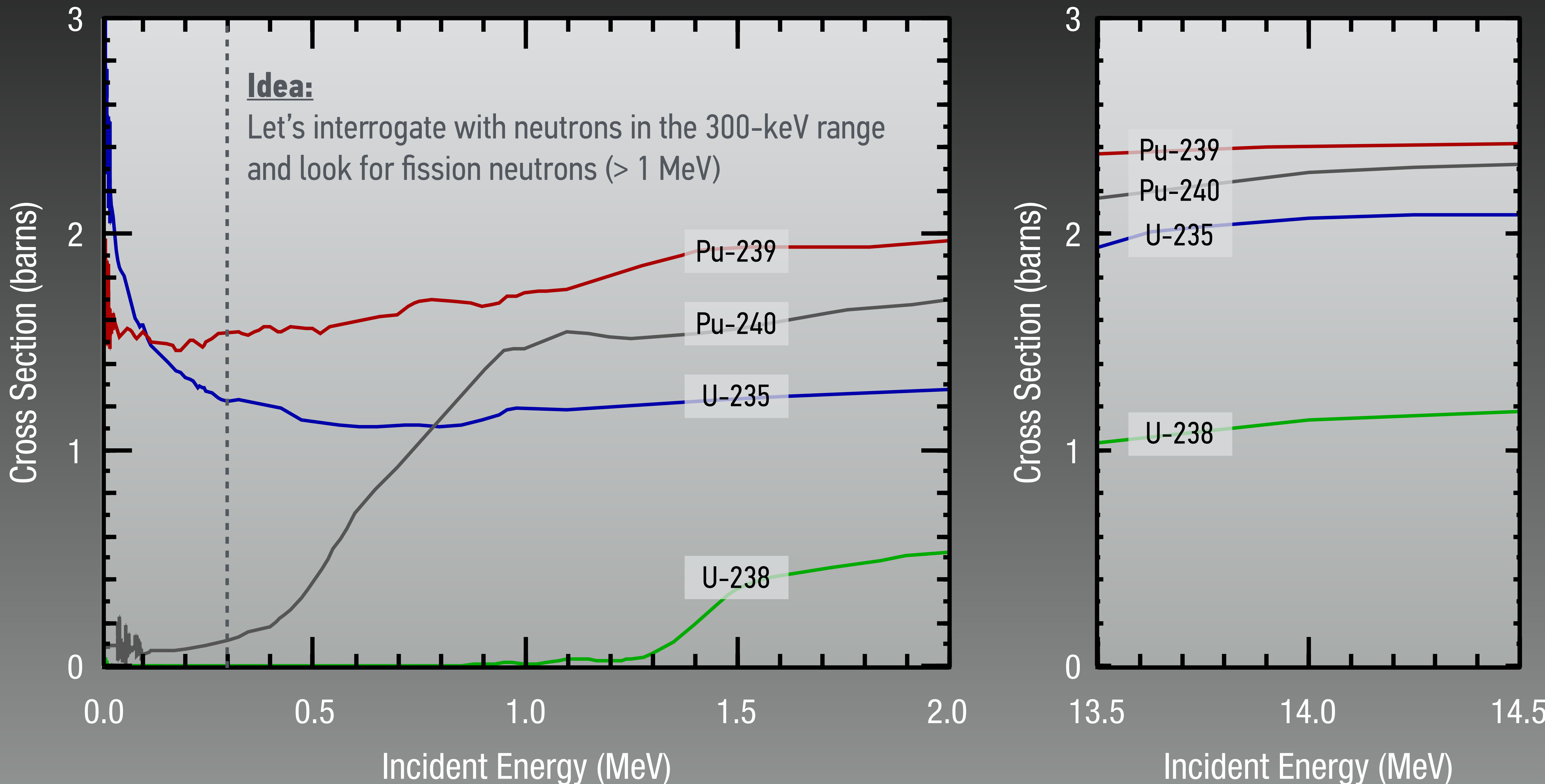
FISSION CROSS SECTIONS

OF THE MAIN URANIUM AND PLUTONIUM ISOTOPES



FISSION CROSS SECTIONS

OF THE MAIN URANIUM AND PLUTONIUM ISOTOPES

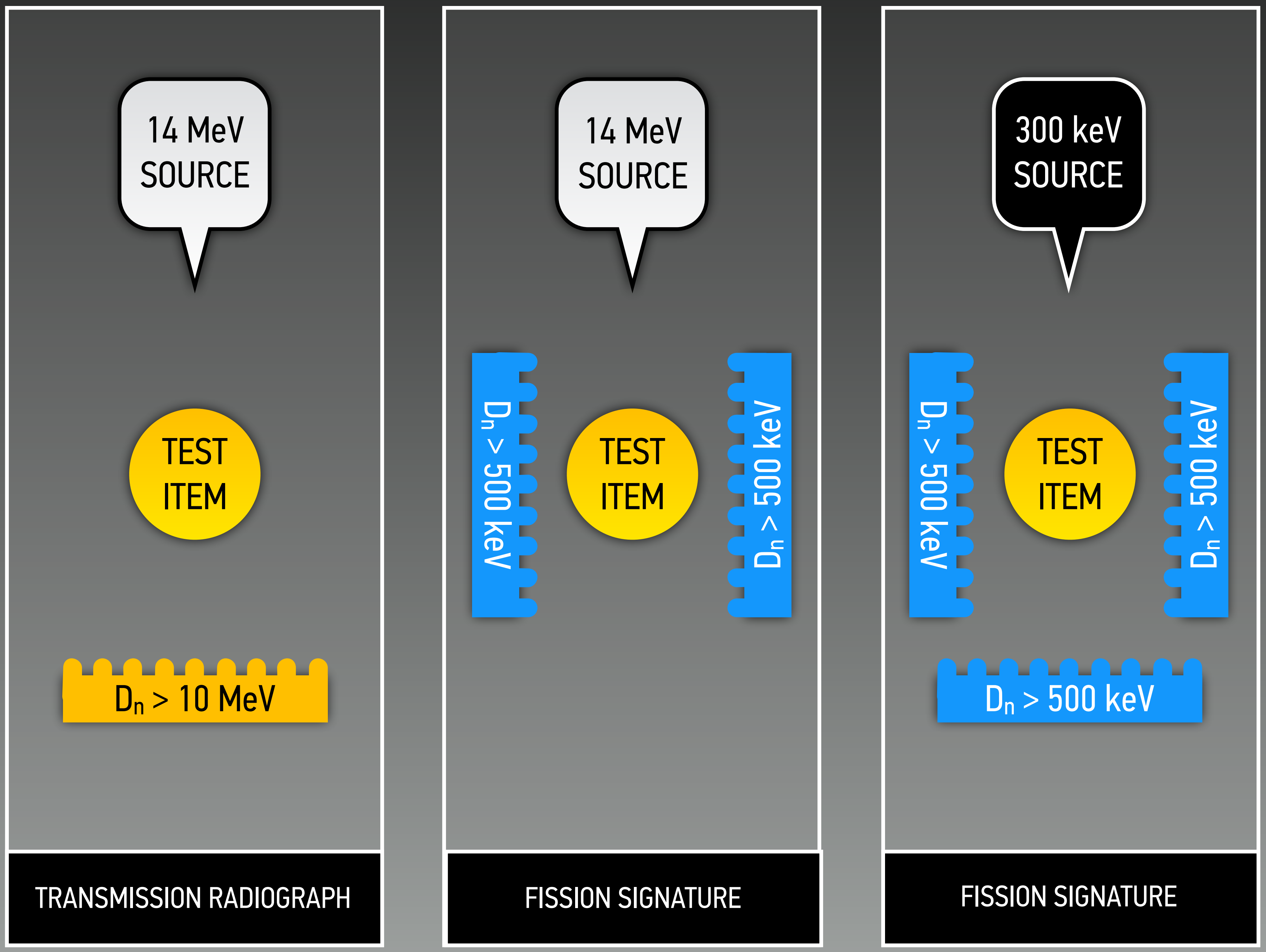


Source: Evaluated Nuclear Data File (ENDF), www-nds.iaea.org/exfor/endf.htm
R. J. Goldston et al., "Zero-knowledge Warhead Verification: System Requirements and Detector Technologies," 55th INMM Meeting, 2014

“TWO-COLOR” NEUTRON SETUP

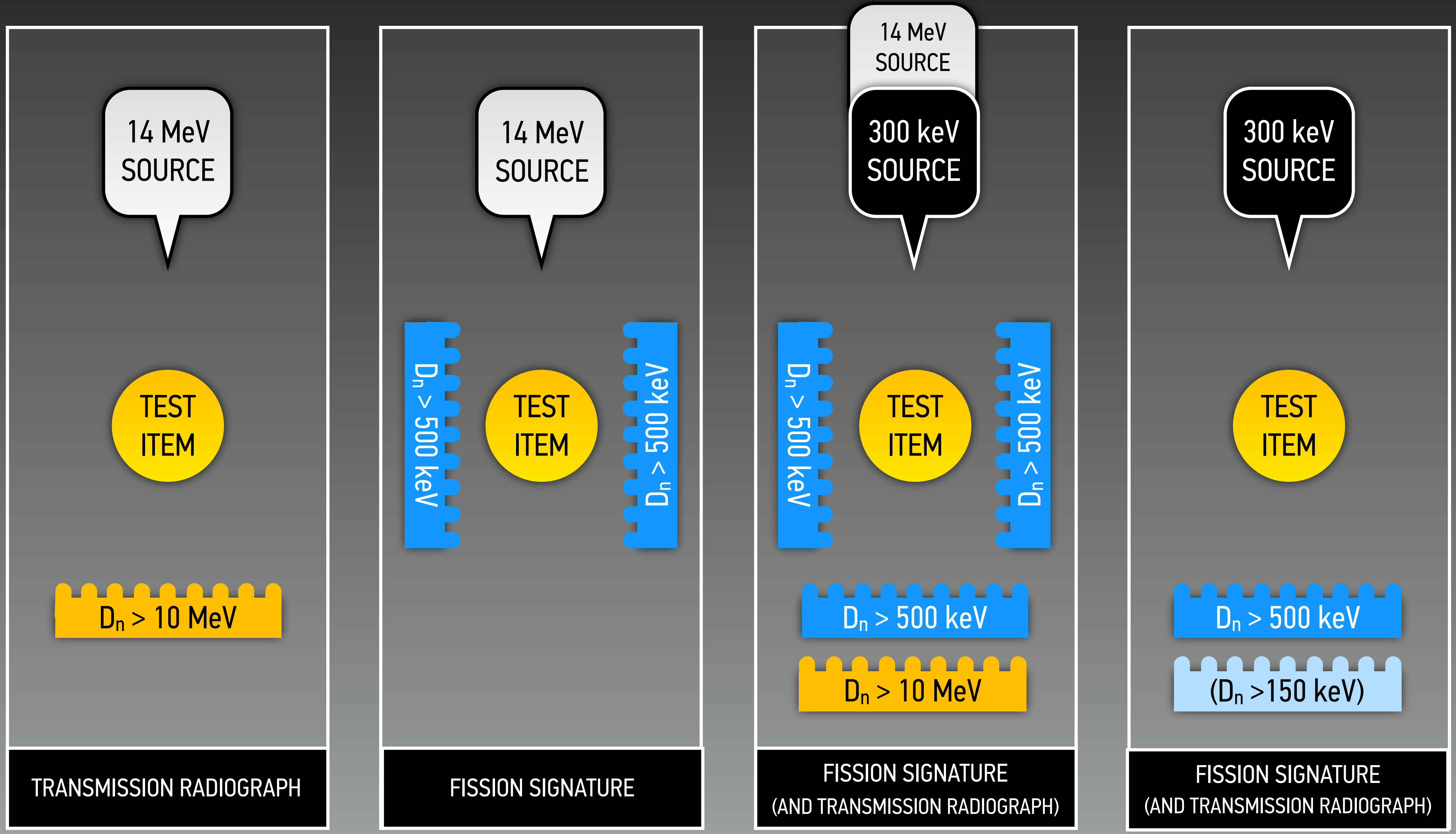
POSSIBLE IMPLEMENTATIONS

"ONE-COLOR" AND "TWO-COLOR" SETUPS FOR ACTIVE NEUTRON INTERROGATION



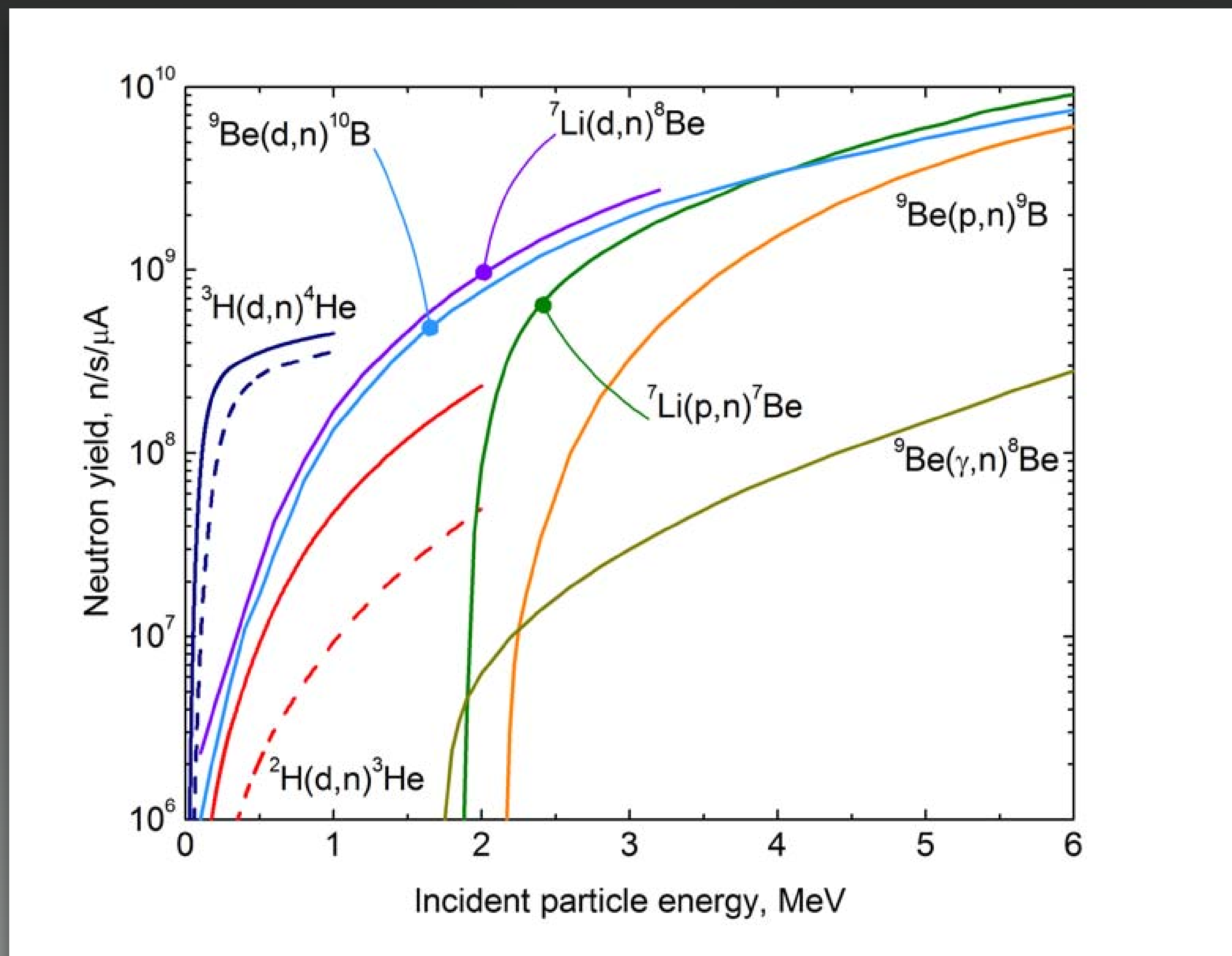
POSSIBLE IMPLEMENTATIONS

“ONE-COLOR” AND “TWO-COLOR” SETUPS FOR ACTIVE NEUTRON INTERROGATION



A STRONG 300-keV NEUTRON SOURCE

TOTAL NEUTRON YIELD CURVES FOR SELECTED (THRESHOLD) REACTIONS



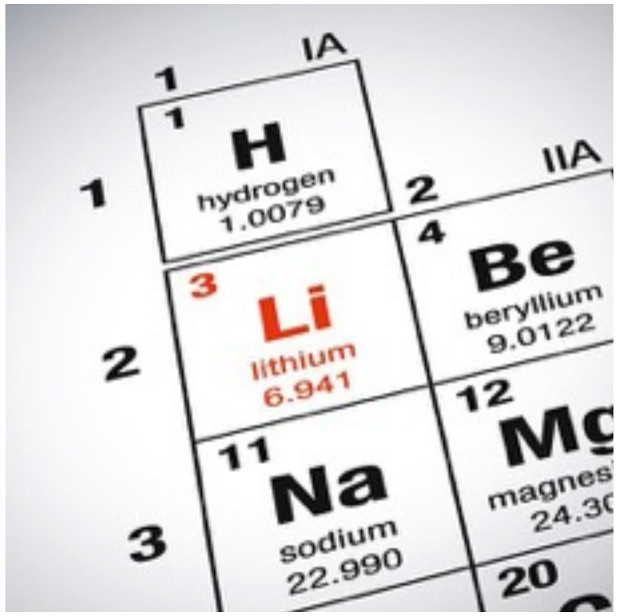
David L. Chichester, *Production and Applications of Neutrons Using Particle Accelerators*
INL/EXT-09-17312, Idaho National Laboratory, November 2009

OPEN-SOURCE
MONTE CARLO SIMULATIONS

SimLiT + GEANT 4

MODELING APPROACH

SIMLIT AND GEANT 4

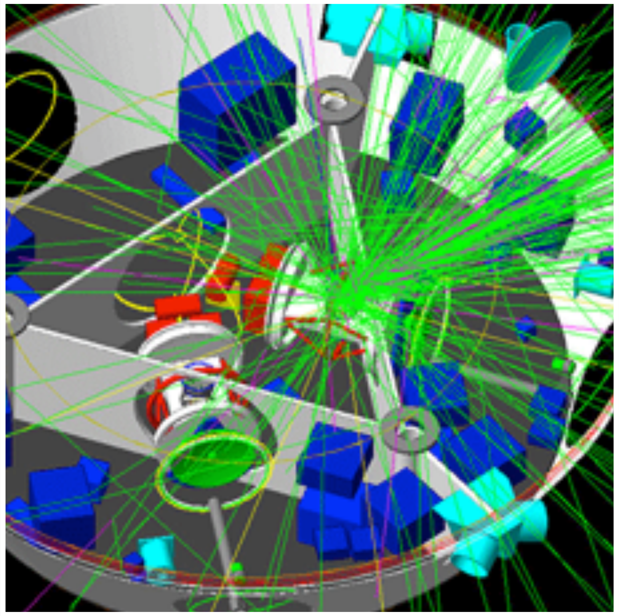


SimLiT (shrek.phys.huji.ac.il/SimLiT)

Dedicated Monte Carlo code to simulate neutrons from ^{7}Li(p,n) reaction

Ability to couple to Geant 4

Open source (designed as a C++ class)



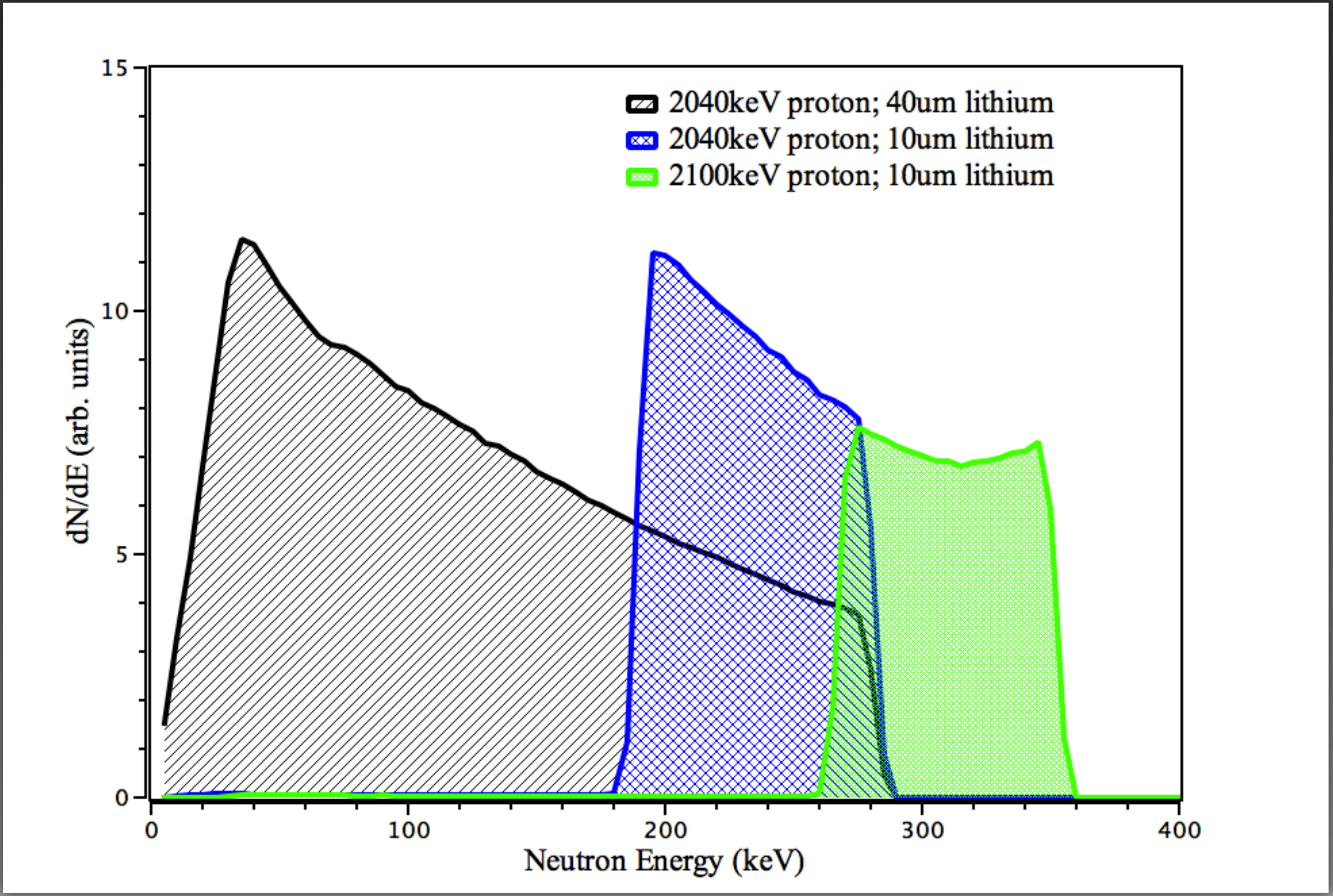
Geant 4 (geant4.cern.ch)

A Monte Carlo simulation toolkit for the simulation of the passage of particles through matter; used in many scientific fields

Open source (C++)

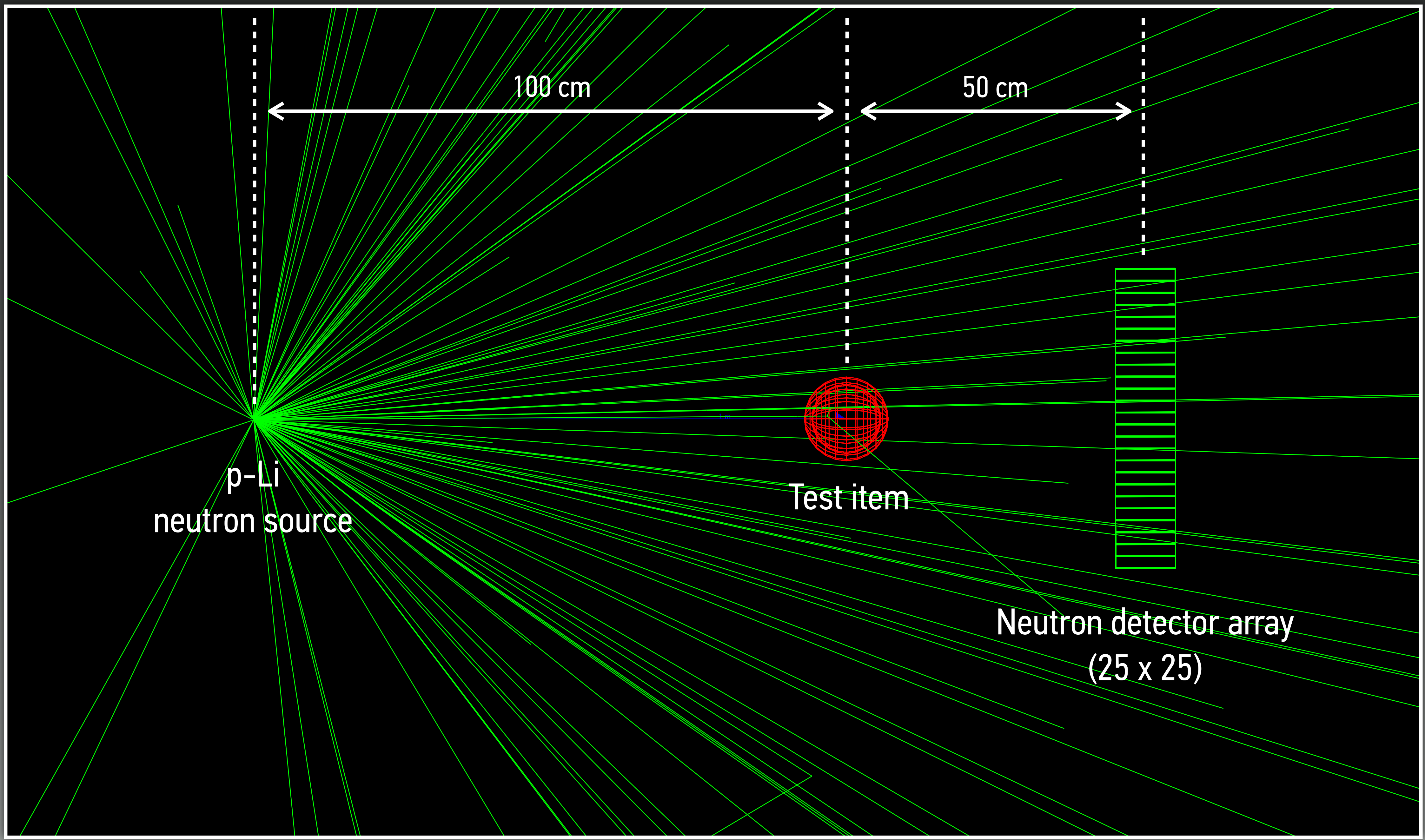
SIMULATED p-Li NEUTRON SOURCE

SPECTRUM CAN BE TAILORED BY ADJUSTING THE INCIDENT PROTON ENERGY AND THE THICKNESS OF THE LITHIUM TARGET



SIMPLIFIED EXPERIMENTAL SETUP

NEUTRON SOURCE, TEST ITEM, AND DETECTOR ARRAY



NOTIONAL TEST ITEMS

Based on: Steve Fetter, Valery A. Frolov, Marvin Miller, Robert Mozley, Oleg F. Prilutsky, Stanislav N. Rodionov, Roald Z. Sagdeev
"Detecting nuclear warheads," *Science & Global Security,* 1 (3–4), 1990, pp. 225–253

Fetter et al.'s Uranium Item (12 kg weapon-grade HEU)

Reference item
14.0 cm OD
12 kg of HEU; 93% U-235

Modified isotopics

Modified diameter
15.0 cm OD
(same mass)

Fetter et al.'s Plutonium Item (4 kg weapon-grade Pu)

Reference item
10.0 cm OD
4 kg of WPu; 93% Pu-239

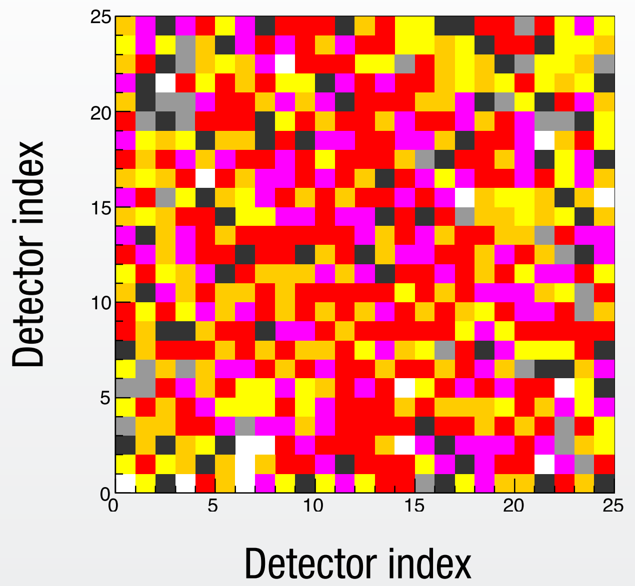
Modified isotopics

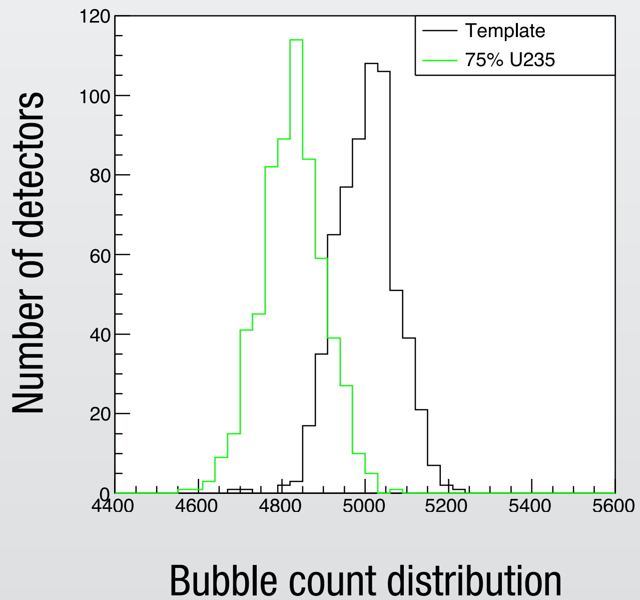
Modified diameter
11.0 cm OD
(same mass)

RESULTS

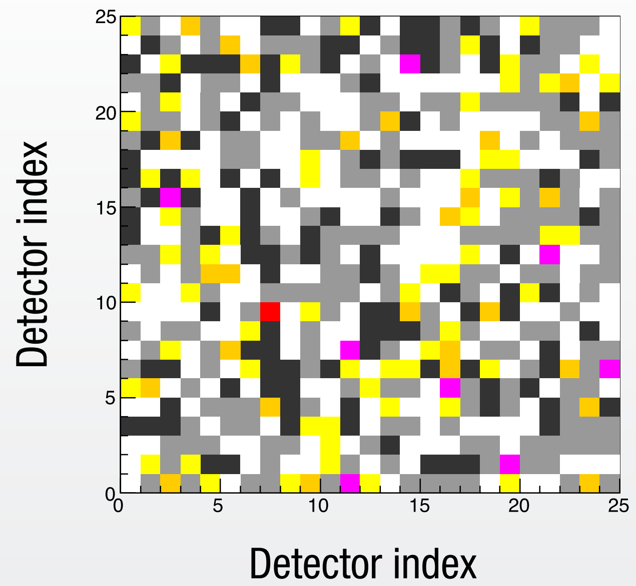
300-keV DRIVEN FISSION SIGNATURES

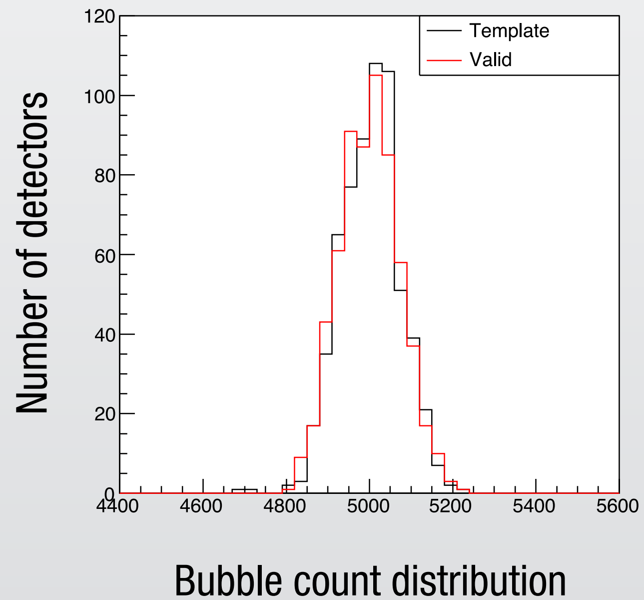
Invalid item (75% U-235)



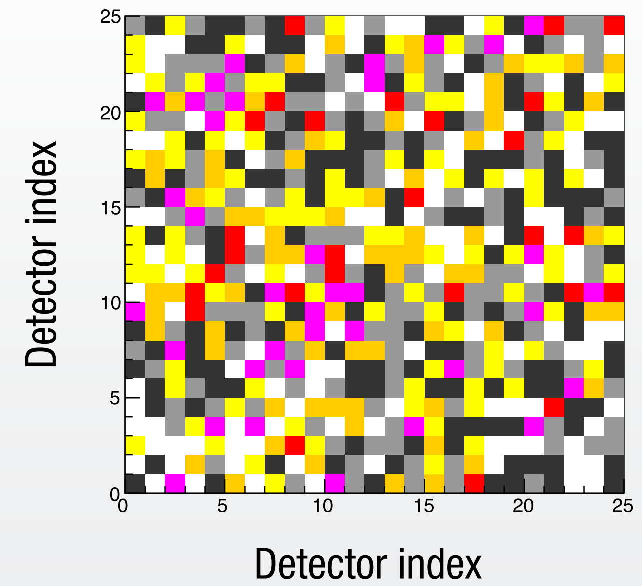


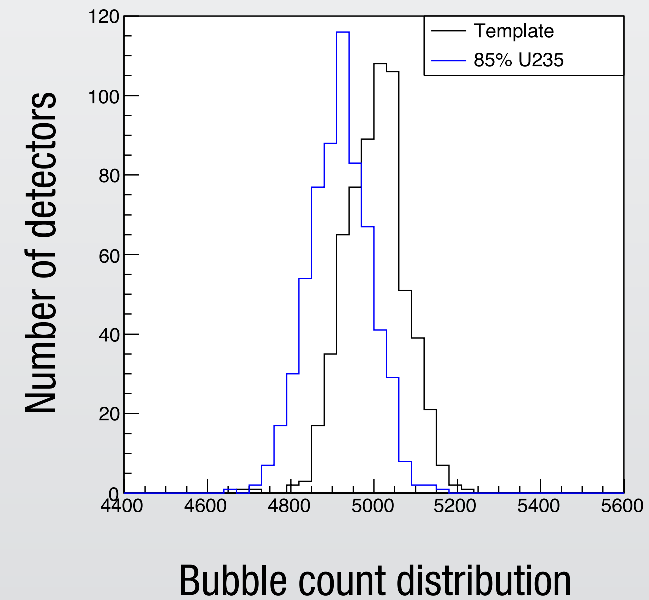
Valid item (93% U-235)





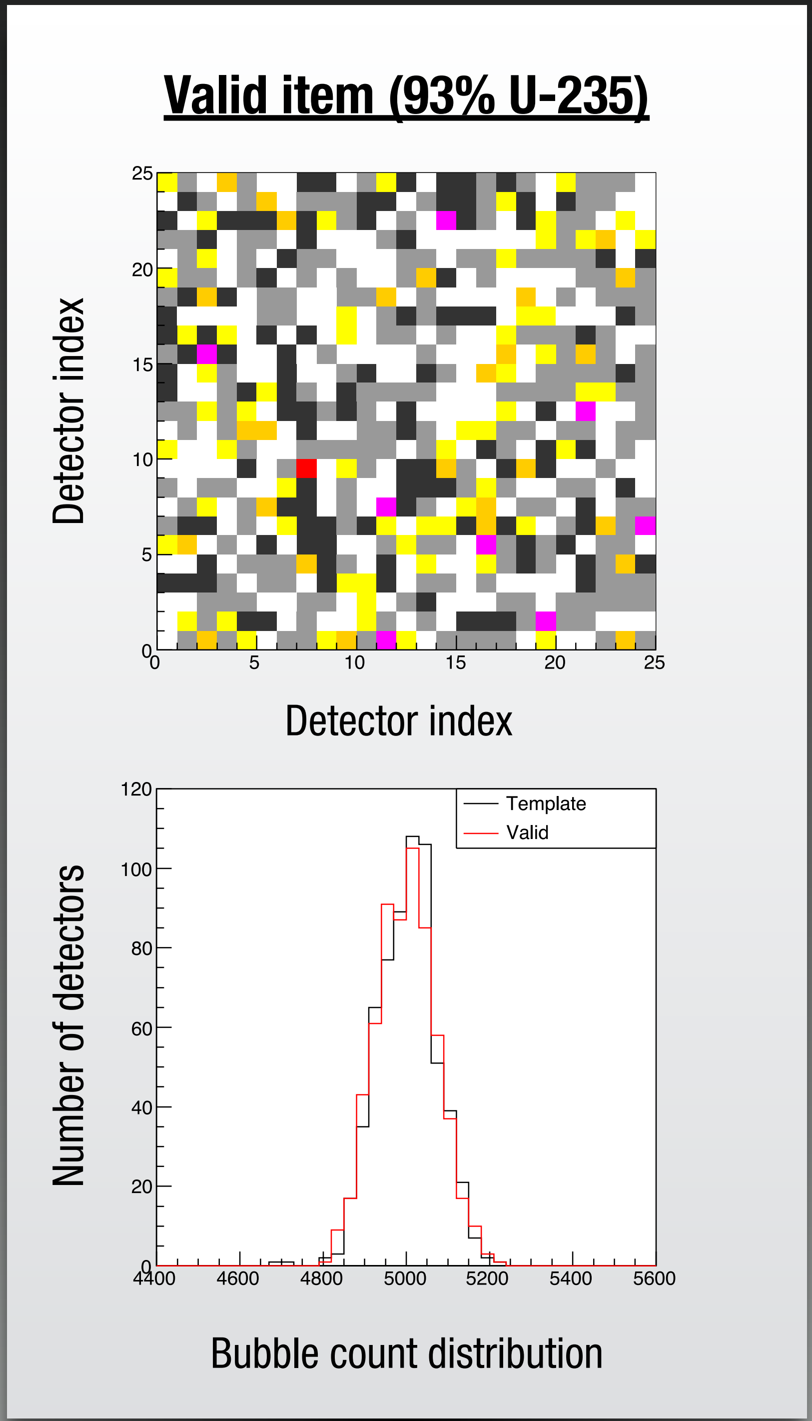
Invalid item (85% U-235)

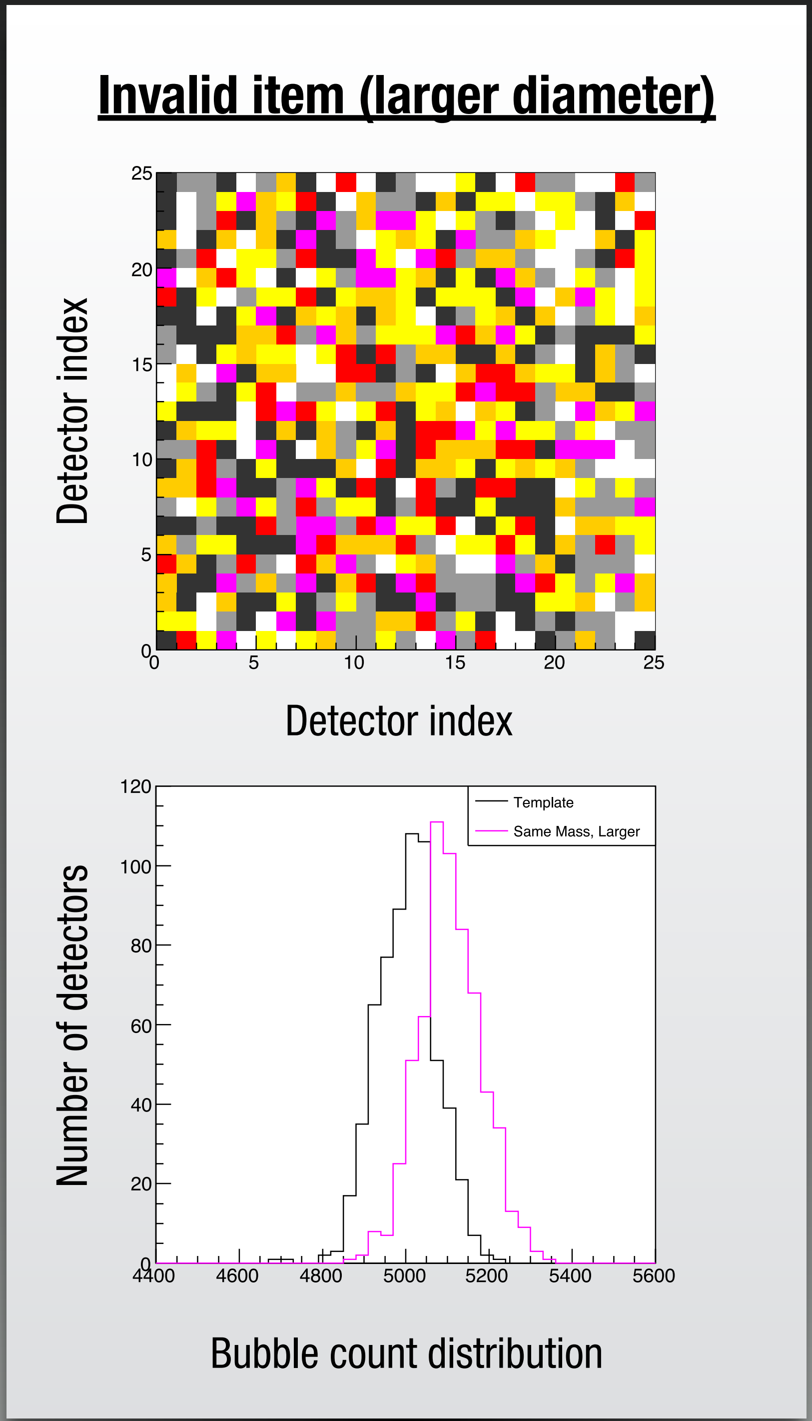




Small deviation from N_{max} Significant deviation from N_{max} (1.5, 2.0, 2.5, 3 Sigma)

300-keV DRIVEN FISSION SIGNATURES

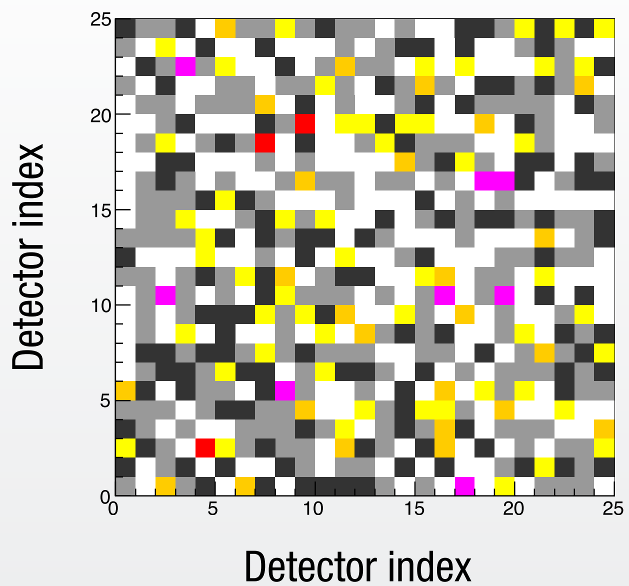


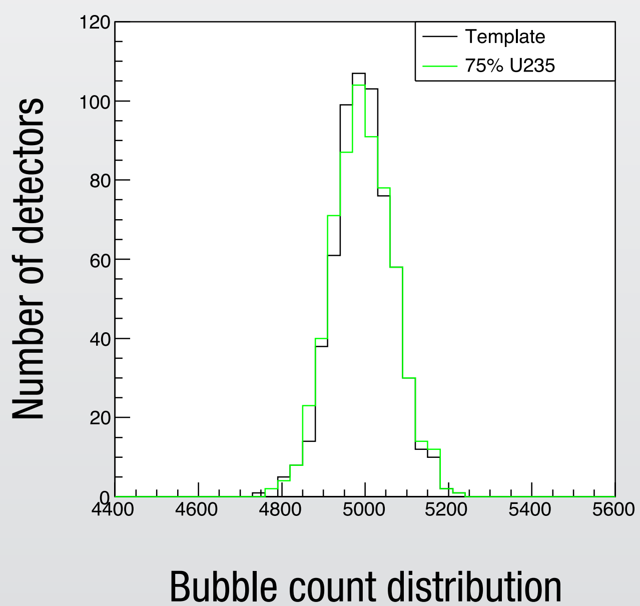


Small deviation from N_{max} Significant deviation from N_{max} (1.5, 2.0, 2.5, 3 Sigma)

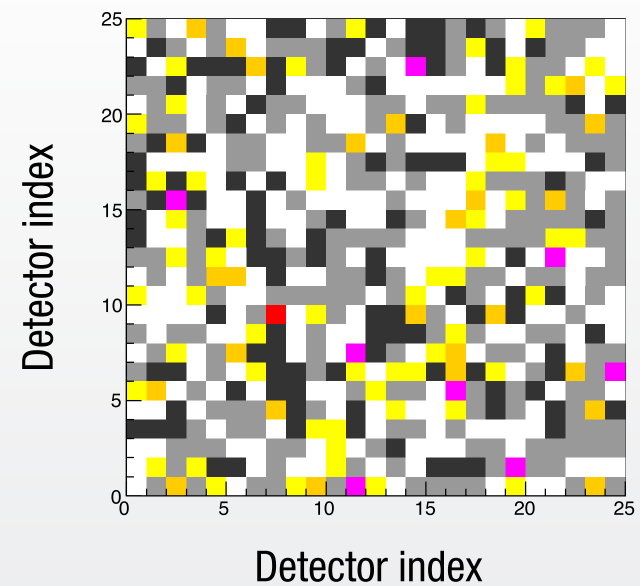
“TRANSMISSION RADIOGRAPH”

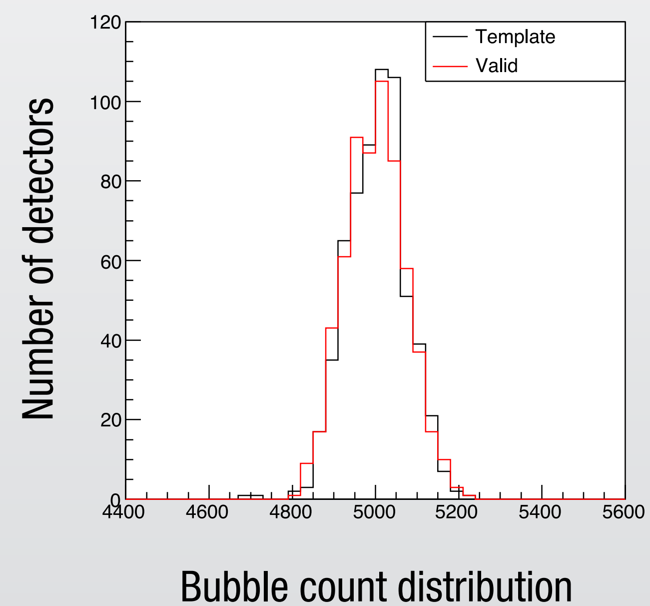
Invalid item (75% U-235)



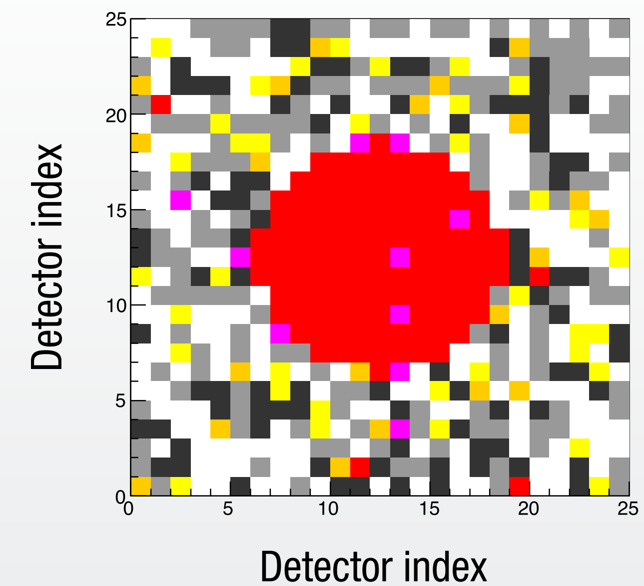


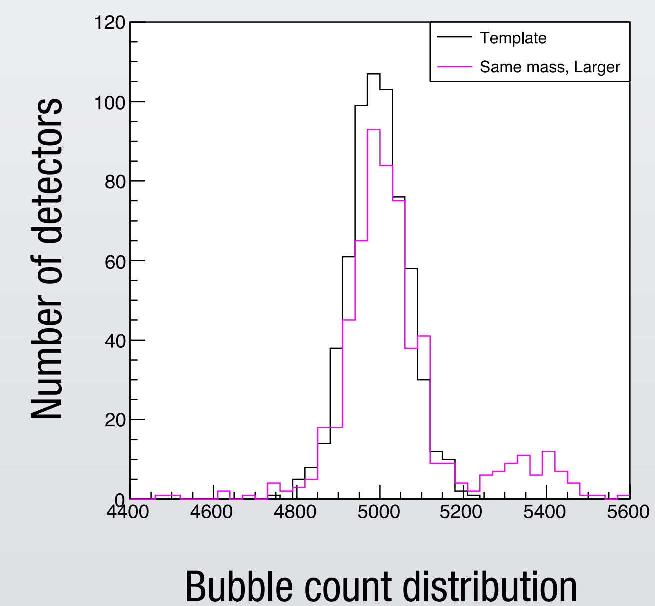
Valid item (93% U-235)





Invalid item (larger diameter)





Small deviation from N_{max} Significant deviation from N_{max} (1.5, 2.0, 2.5, 3 Sigma)

ASSESSING THE RESULTS

USING THE KOLMOGOROV-SMIRNOV STATISTICAL TEST AS A PASS/FAIL CRITERION

Uranium Item

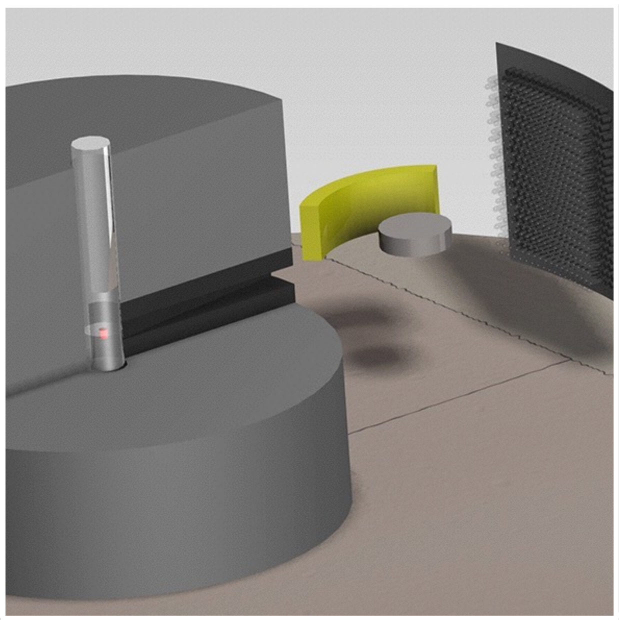
	Radiograph	Fission signature
Valid item	0.988	0.987
75% U-235	0.872	0
85% U-235	0.986	0
Larger diameter	3.738E–05	0

Plutonium Item

	Radiograph	Fission signature
Valid item	0.998	0.986
59% Pu-239	0.822	0
75% Pu-239	0.999	0
Larger diameter	0.112	0

As expected, radiography (here: using 300-keV neutrons) is not very sensitive to isotopic changes
Fission signature is *very* clear for uranium and plutonium items

CONCLUSION AND OUTLOOK



“ONE-COLOR” SETUP

Neutron transmission radiography using high-energy (14 MeV) neutrons is effective in detecting geometric and elemental differences

Distinguishing isotopic differences can be more challenging because relevant 14-MeV fission cross sections can be similar for some elements (esp. for Pu-239 vs Pu-240)

“TWO-COLOR” SETUP

Fission signatures triggered by ~ 300-keV neutrons are extremely sensitive to isotopic differences (and also to differences in geometry)

Combine with 14-MeV (and ~150-keV) transmission radiography

Needed for experimental demonstration: Intense 2-MeV proton source