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Large area low cost thermal neutron detectors for nuclear security

John McMillan March 2009

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PNL - Leeds detectors

(Polytechnic of North London - University of Leeds)

Layered ZnS-^{6}LiF scintillators with wavelength shifter readout

Pulse-counting neutron discrimination

PNL- Leeds detectors

Built for studying rare fission events
"superheavy elements in nature"

Rival groups had claimed positive results with ^{3}He tubes

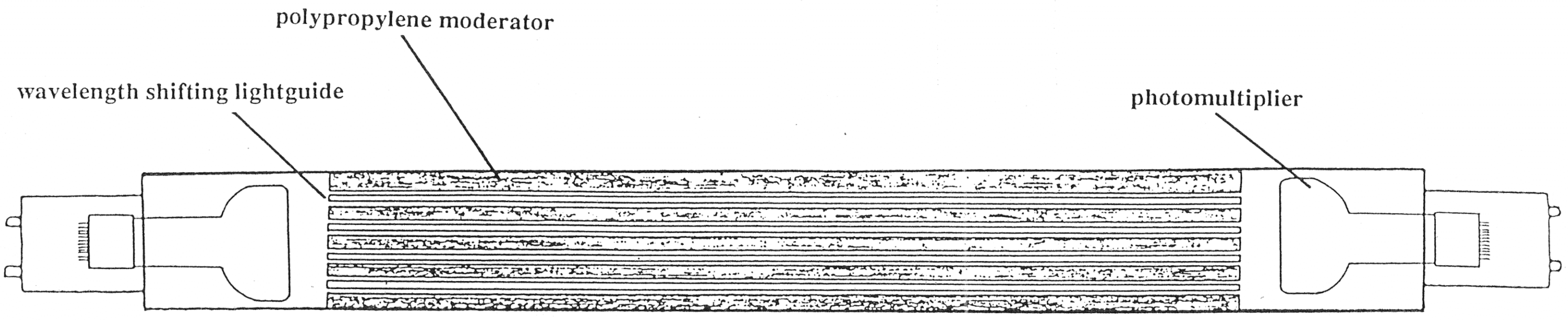
Low cost alternative based on previous work by Hornyak, Stedman, ...
Barton & Caines

8 detectors formed a neutron multiplicity detector

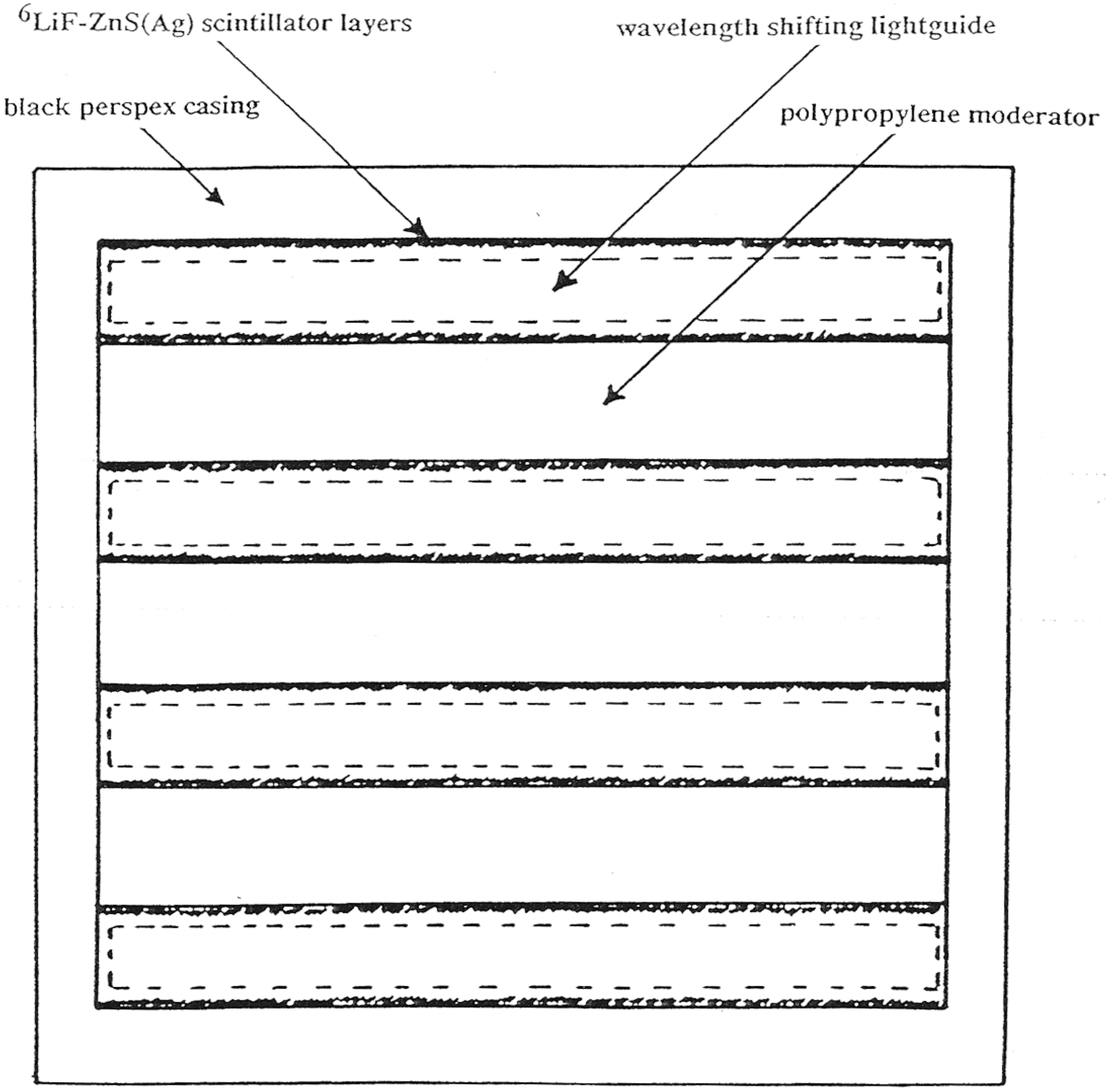
Intended for low background underground sites with harsh environments

Detectors now at the University of Sheffield or Boulby Mine

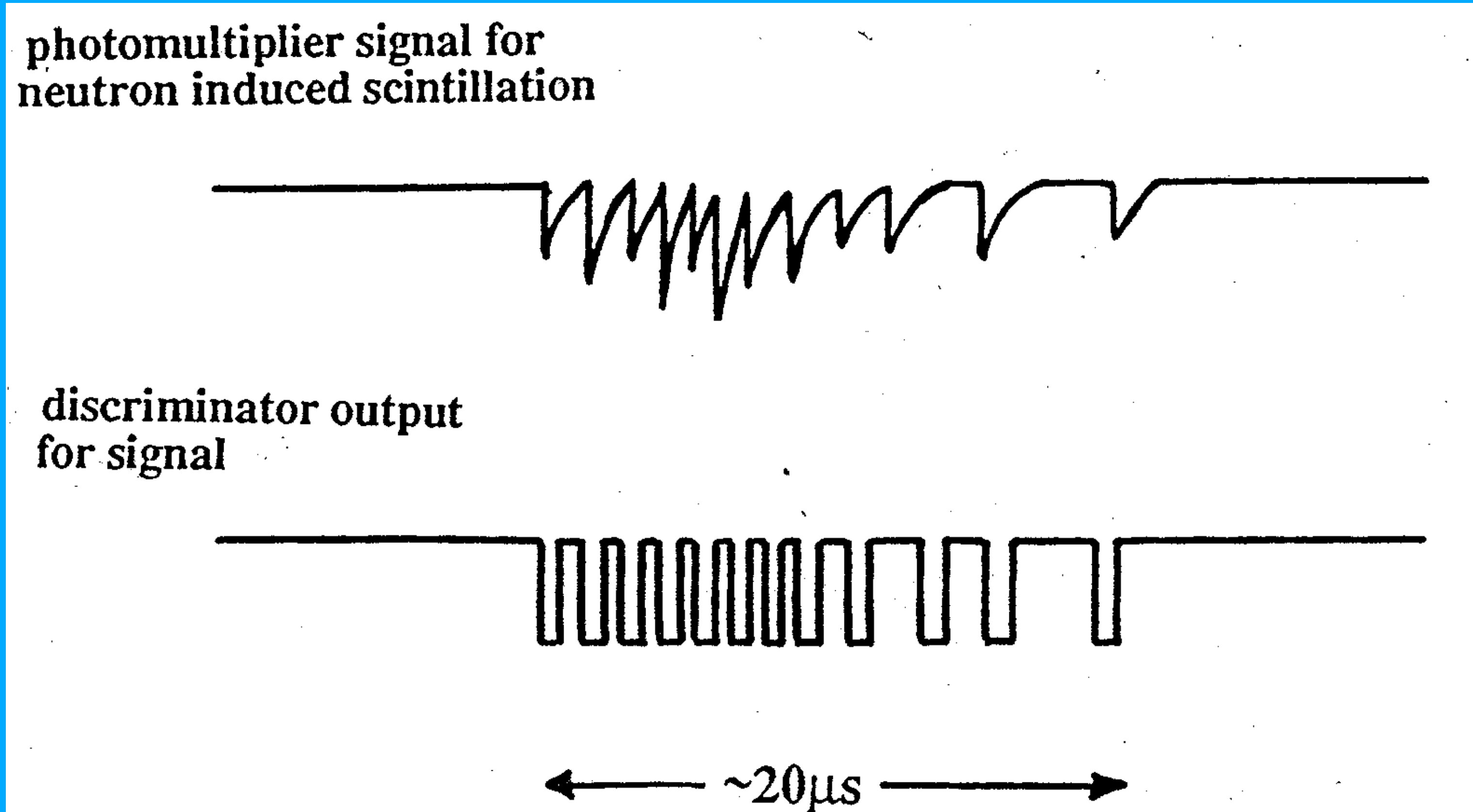
Detector design



Detector design



Pulse counting discrimination



Pulses in time gate counted

Caines P.J., M Phil Thesis, University of London, 1972

Davidson P.L. Rutherford Laboratory Report RL-77-106A, 1977

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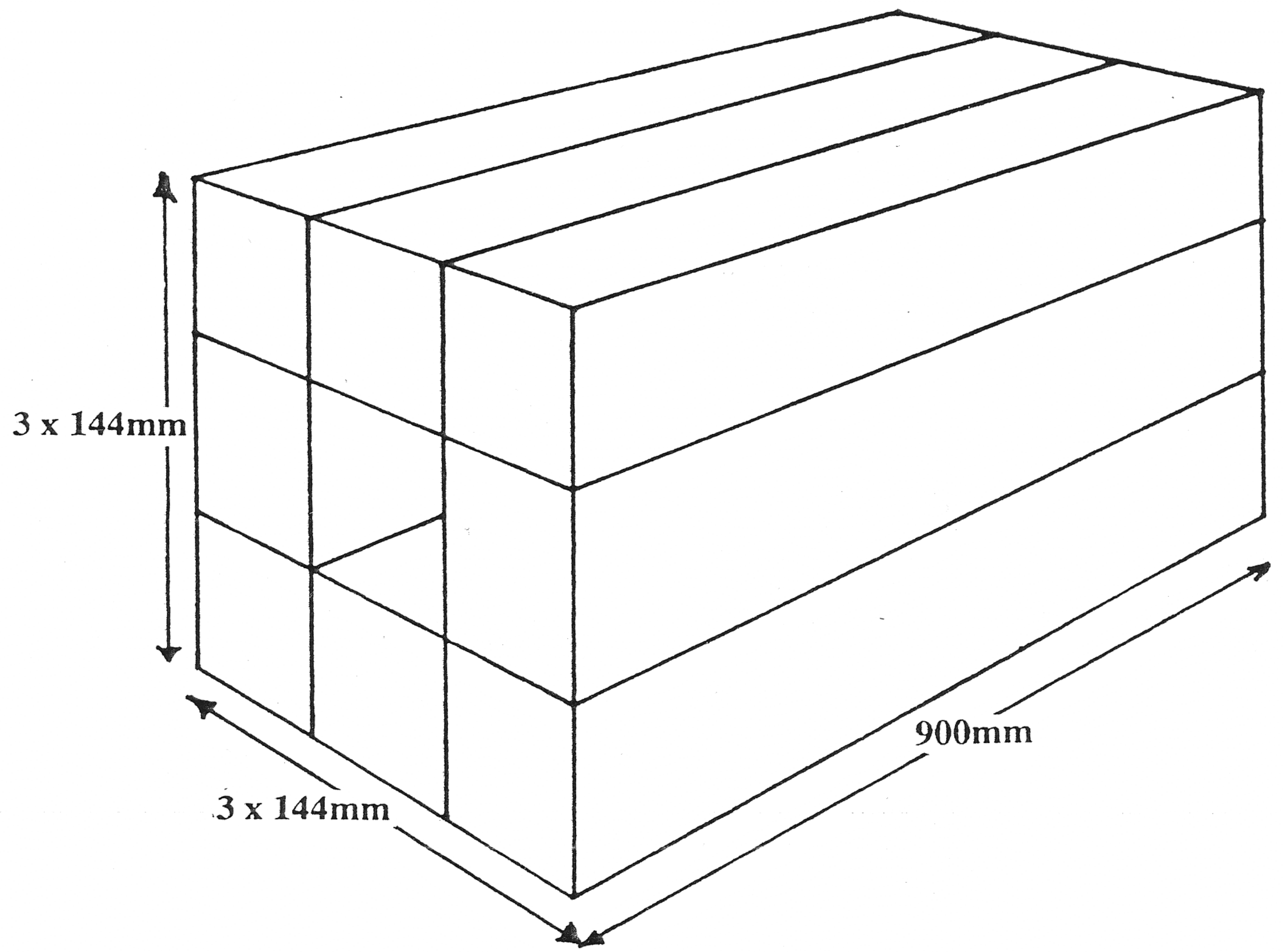
Stack of 8 with cavity



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Features of the PNL-Leeds detectors

Active volume 90 x 14.4 x 14.4cm

37% efficient for ^{252}Cf fission neutrons

(8 detectors surrounding source)

Totally insensitive to gammas and muons

Robust, stable operation over many years over a range of temperatures in harsh environments

Woodhead Railway Tunnel, Yorkshire
Holborn Underground station, London
Boulby Potash mine, Yorkshire (1km depth)

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PNL-Leeds detectors described in

"A novel neutron multiplicity detector using lithium fluoride and zinc sulphide scintillator"

Barton, J.C., Hatton, C.J. & McMillan, J.E.

J. Phys. G: Nucl. Part. Phys. 17 p1885-1899 (1991).

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Thermal Neutron Detectors for Security Applications

large-area, square metres needed for portals

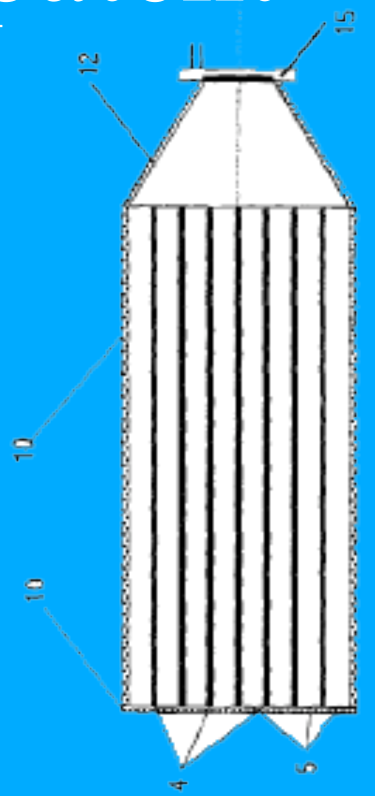
cost <$30,000 per square metre
(figure from ^{3}He, but price is rising, availability falling!!)

unambiguous, good signal-to-noise ratio, high efficiency, low background

real-time signal discrimination
(not compute-intensive post processed)

deployable
- reasonably robust
- stable over many years in harsh environments
- transportable
- minimal health & safety implications

SAIC patent



(12) **United States Patent**
Polichar et al.

(10) **Patent No.: US 7,244,947 B2**
(45) **Date of Patent: Jul. 17, 2007**

(54) **NEUTRON DETECTOR WITH LAYERED THERMAL-NEUTRON SCINTILLATOR AND DUAL FUNCTION LIGHT GUIDE AND THERMALIZING MEDIA**

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(73) Assignee: **Science Applications International Corporation**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 246 days.

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G01T 3/00 (2006.01)

(52) **U.S. Cl.** **250/390.01**; 250/367; 250/370.05; 250/370.11

(58) **Field of Classification Search** 250/390.01, 250/370.05, 370.11, 367
See application file for complete search history.

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Barton, John C., Hatton, Christopher J., and McMillan, John E., "A novel neutron multiplicity detector using lithium fluoride and zinc sulphide scintillator," Journal of Physics G: Nuclear and Particle Physics, vol. 17, 1991, pp. 1885-1899.

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Primary Examiner—Albert Gagliardi
(74) *Attorney, Agent, or Firm*—Banner & Witcoff, Ltd.

(57) **ABSTRACT**

A broad spectrum neutron detector has a thermal neutron sensitive scintillator film interleaved with a hydrogenous thermalizing media. The neutron detector has negligible sensitivity to gamma rays and produces a strong and unambiguous signal for virtually all neutrons that interact with the hydrogenous volume. The interleaving of the layers of thermal neutron sensitive phosphors helps ensure that all parts of the thermalizing volume are highly sensitive.

11 Claims, 3 Drawing Sheets

Invalid. All 11 claims are published prior art.

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Improvements to existing design

Scintillator: problems with ZnS

- opacity
- long decay time
- poor pulse height discrimination
  - => charge or photon counting discriminators
- trace contamination with U, Th, Radon progeny

But thin layered scintillator gives gamma immunity

Replace ZnS with another powdered inorganic scint eg CsI

or an organic scintillator eg polystyrene, PVT

But ZnS is the brightest low cost scintillator…

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Improvements to existing design II

Choice of capture material

^{6}LiF is a controlled material and increasingly expensive

Can we make worse (but very much cheaper) detectors using boron compounds?

Capture cross-section higher - but releases less energy

Can probably use natural rather than isotopically enriched material.

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Usable thermal neutron capture reactions

$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{3}\mathrm{H} + {}^{1}\mathrm{H} + 0.764\mathrm{MeV}$$

$$^{6}\mathrm{Li} + \mathrm{n} \rightarrow {}^{4}\mathrm{He} + {}^{3}\mathrm{H} + 4.8\mathrm{MeV}$$

$$^{10}\mathrm{B} + \mathrm{n} \rightarrow {}^{7}\mathrm{Li} + {}^{4}\mathrm{He} + 2.3\mathrm{MeV} + 0.48\mathrm{MeV}(\gamma)$$

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nuclide	% natural abundance	thermal cross-section
^{3}He	0.00014	5333 barns
^{6}Li	7.50	940 barns
^{10}B	19.80	3842 barns

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Geometric improvements

PNL-Leeds detectors were optimized for volume configuration (maximum efficiency, lowest background…)

Security applications need to optimize effective area per unit cost

$$\frac{efficiency \times area}{price}$$

Smaller or less efficient detectors can still win if they are very much cheaper!

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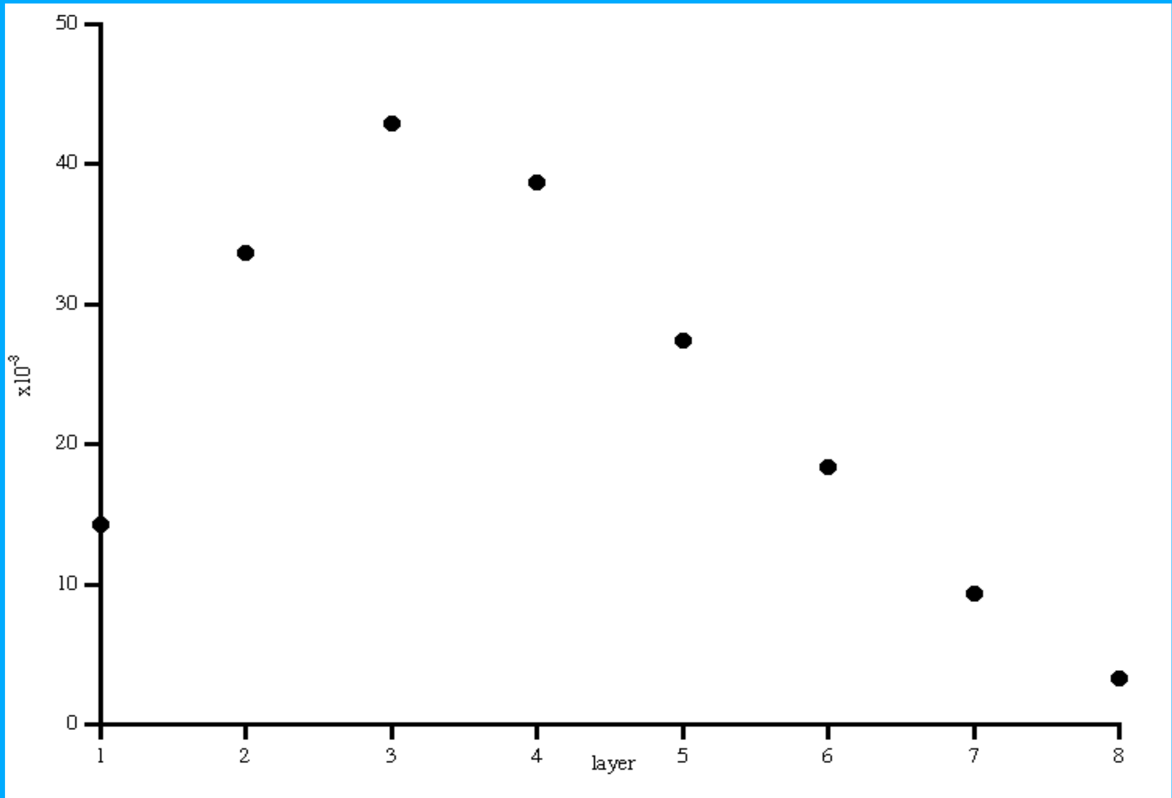
Geometric optimization



MCNPX simulations

Four best layers Contribute ~76% of the efficiency

Can re-deploy the other four to double the area.

Optical optimization

Redesign optical configuration for planar detector

New waveshifting materials and techniques

Use low cost (5cm) photomultipliers

Improved production of layers

Capture compound + Scintillator + Binder

~ 100 ± 10 microns

Minimize wastage, avoid aggressive solvents…

Original detectors used spreading technique

Consider spray painting, powder coating, serigraphy, ink-jet systems…

Neutron discrimination

Original pulse counting system used hard-wired TTL

Replace with Digital Signal Processing (DSP), PICs etc

Depends on choice of capture compound, scintillator, waveshifter and optical collection.

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Possible developments

Large arrays of thermal neutron detectors

Available online at www.sciencedirect.com
ScienceDirect

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 584 (2008) 383–400

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Passive neutron detection for interdiction of nuclear material at borders

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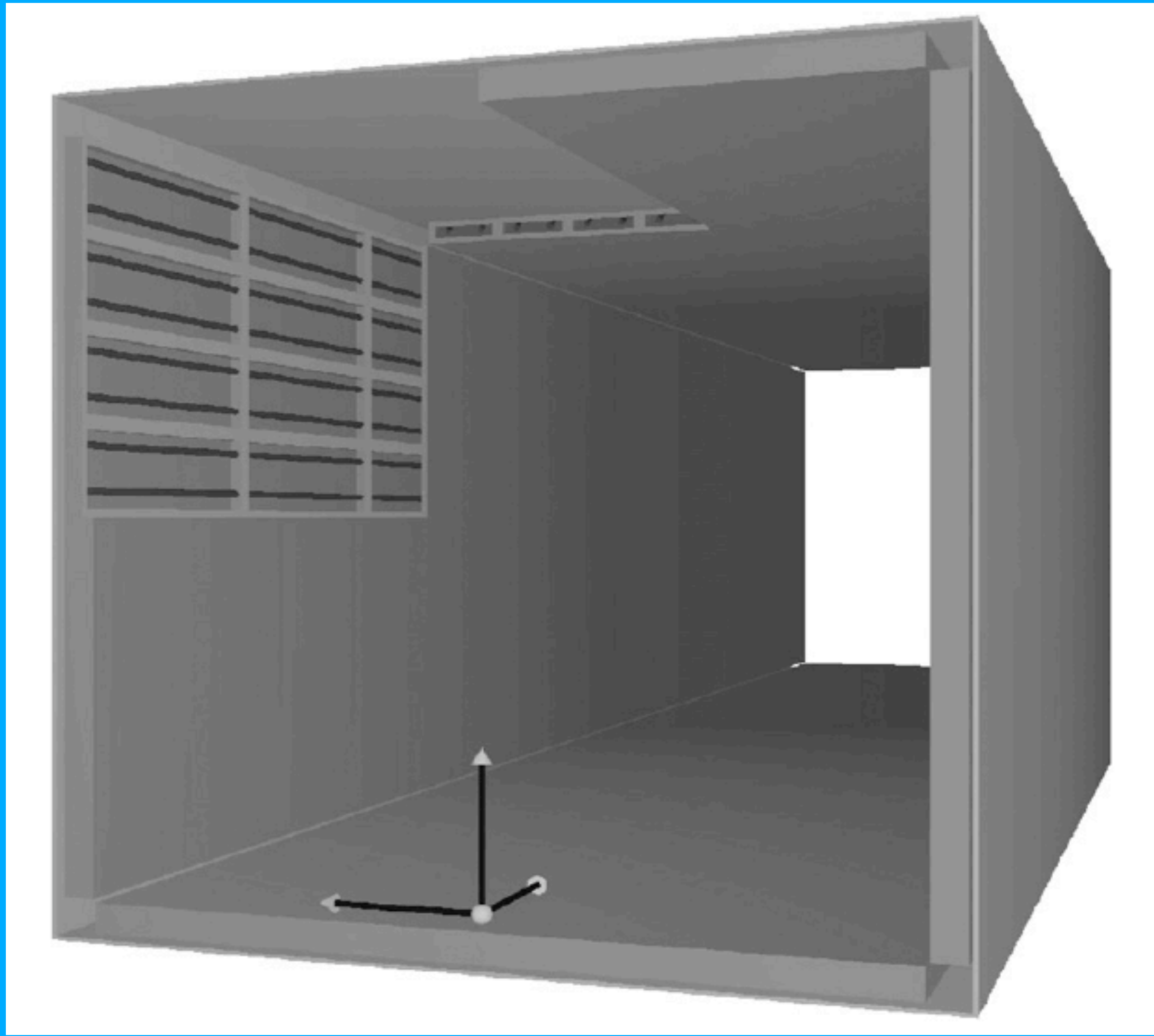
Neutron box counter

640 ^{3}He tubes
Surround truck
or ISO container.

13% efficient.

Simulations indicate
detection of 25kg
HEU at 3sigma
in 180s



Directional neutron detectors

A.J.Peurrung et al. PNNL

IEEE Trans NS-44(3):543–550, 1997

PNNL-11995, 1998

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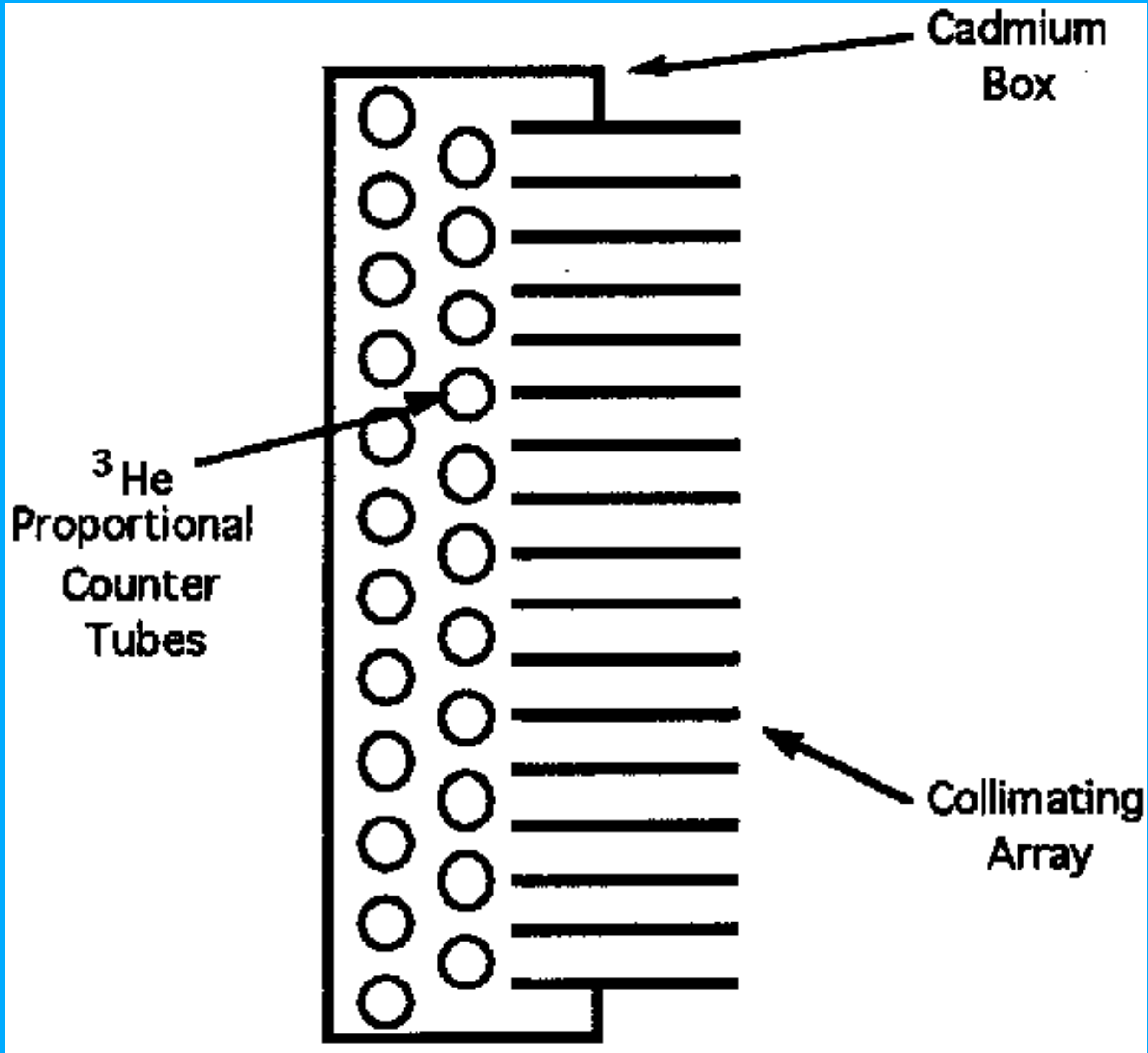
Directional neutron detectors



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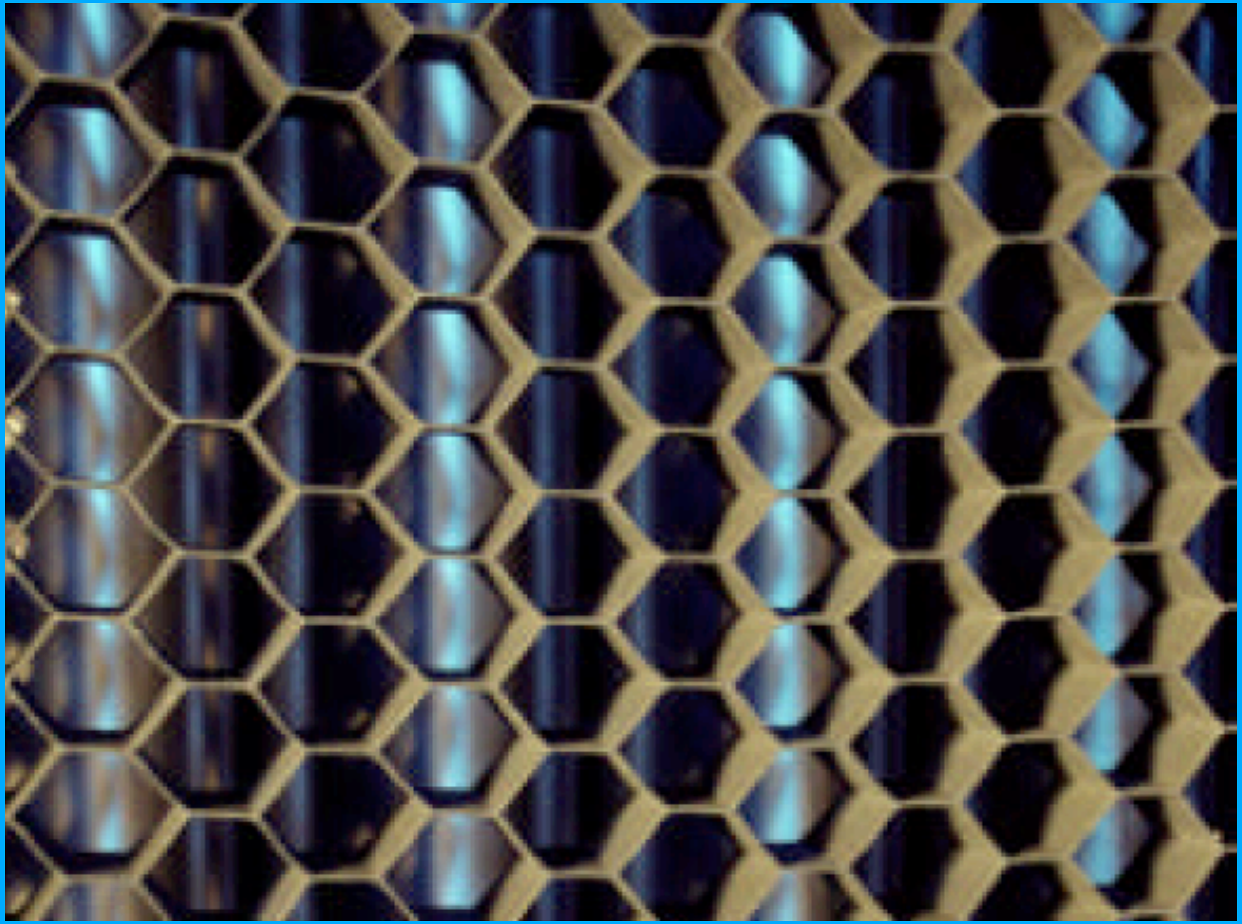
Directional neutron detectors

1sq m ^{3}He tubes

Boron collimators

Angular acceptance ~ 30^o

Reliable detection up to 100m range



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Current status

New planar geometry

New materials and construction techniques

Working towards 1sq m

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Dick Lacey – HOSDB

Questions?

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