ICNST 2024

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TENIS: THERMAL NEUTRON IMAGING SYSTEM

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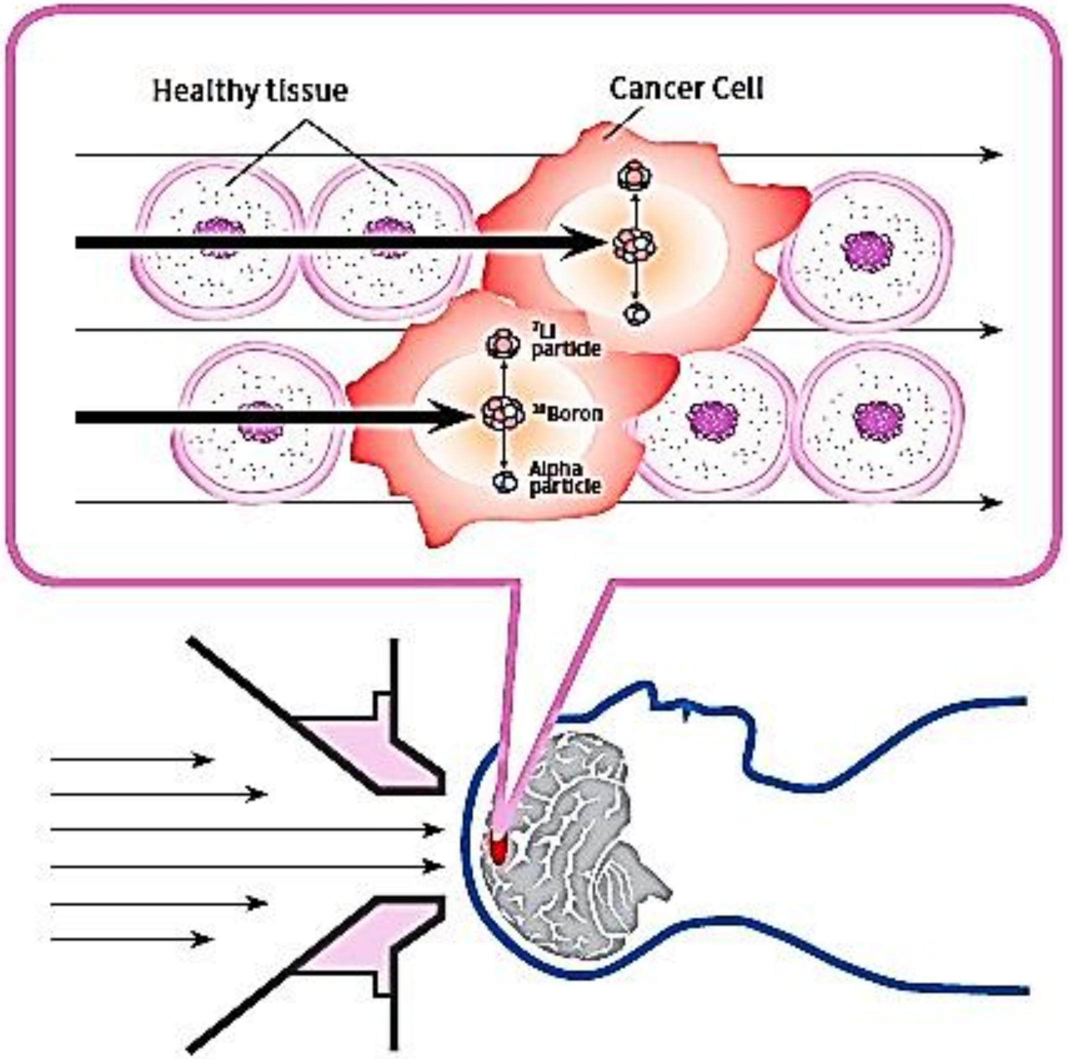
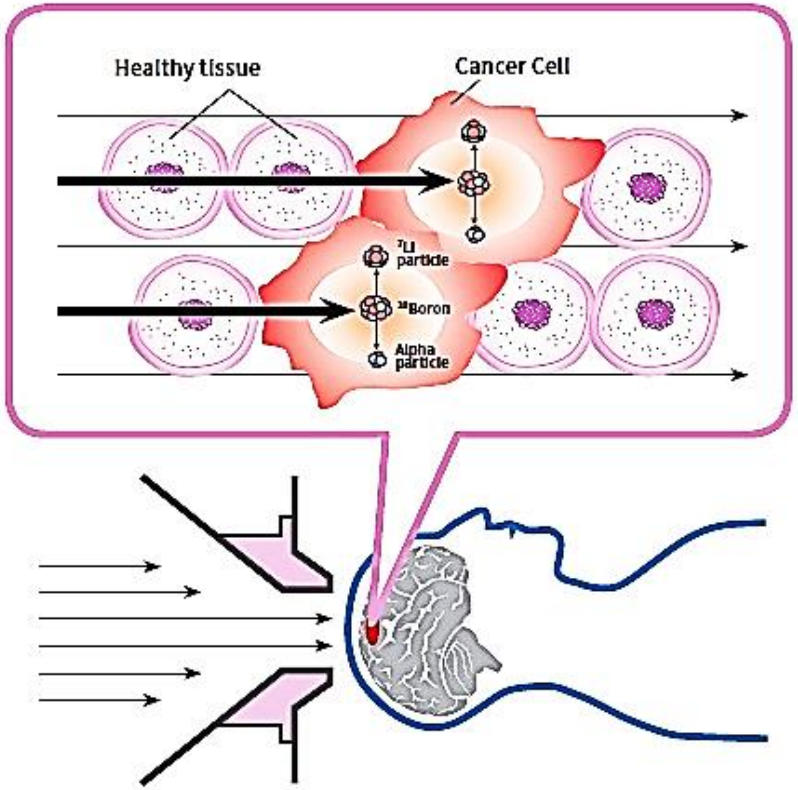
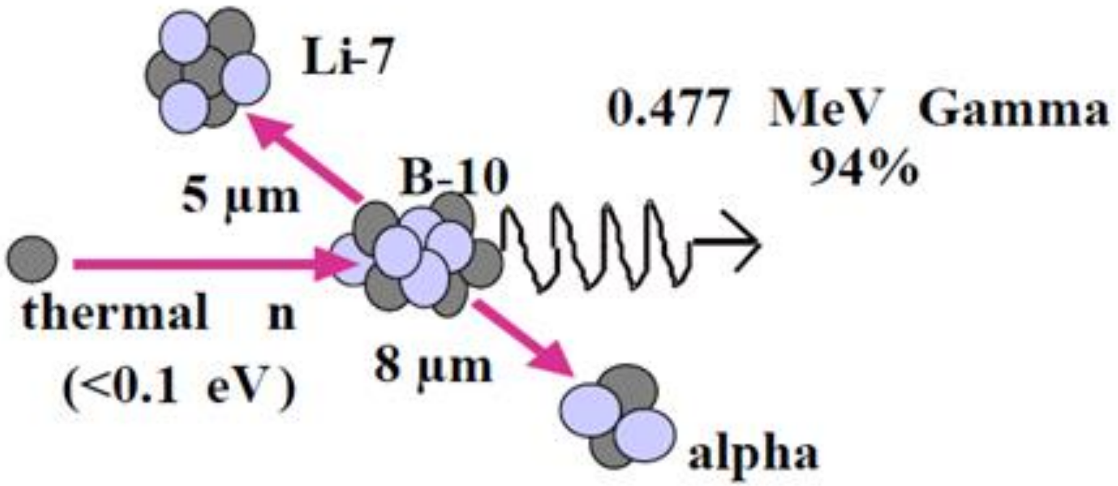
BNCT (BORON NEUTRON CAPTURE THERAPY)



BNCT (BORON NEUTRON CAPTURE THERAPY)





BCNT IN UNIVERSITY OF BIRMINGHAM

C.N. Culbertson, **S. Green**, A.J. Mason, D. Picton, G. Baugh, R.P. Hugtenburg, Z. Yin, **M.C. Scott**, and J.M. Nelson, Applied Radiation and Isotopes, 61 (2004) 733-738.

In-phantom characterisation studies at the Birmingham Accelerator-Generated epIthermal Neutron Source (BAGINS) BNCT facility.

Dynamitron (Proton accelerator) (Ep=2.8 MeV) (I=1mA)

$$p + {}^{7}Li \rightarrow {}^{7}Be + n \quad (Q = -1.646\ MeV)$$

RESEARCH BACKGROUND

- In 2015, a research visit to the University of Birmingham, UK, to find a solution for a pre-clinical quality assurance (pre-QA) in BNCT: Thermal and epithermal neutron fluxes, boron dose, etc.

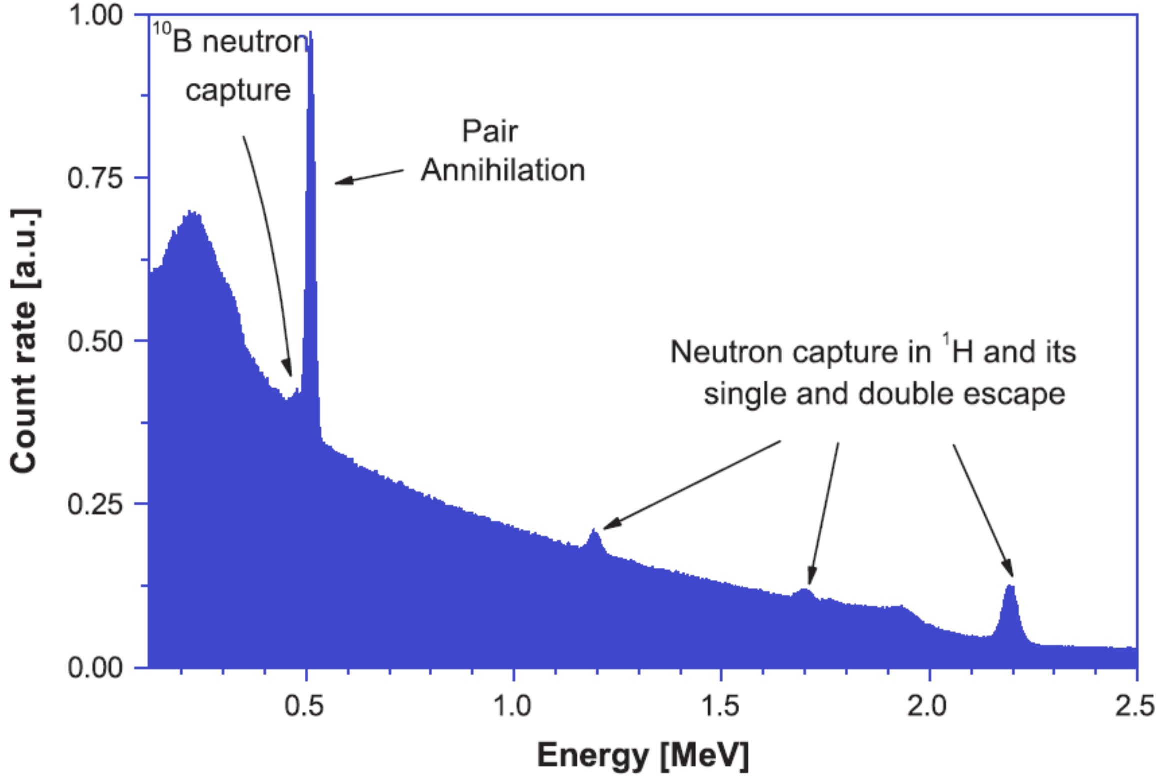
Techniques already incorporated

- Gold wire and foil activations, TLDs, etc.
- Miniature detectors (Lithium-glass scintillator)
- Boron dose monitoring using SPECT

BORON DOSE MONITORING

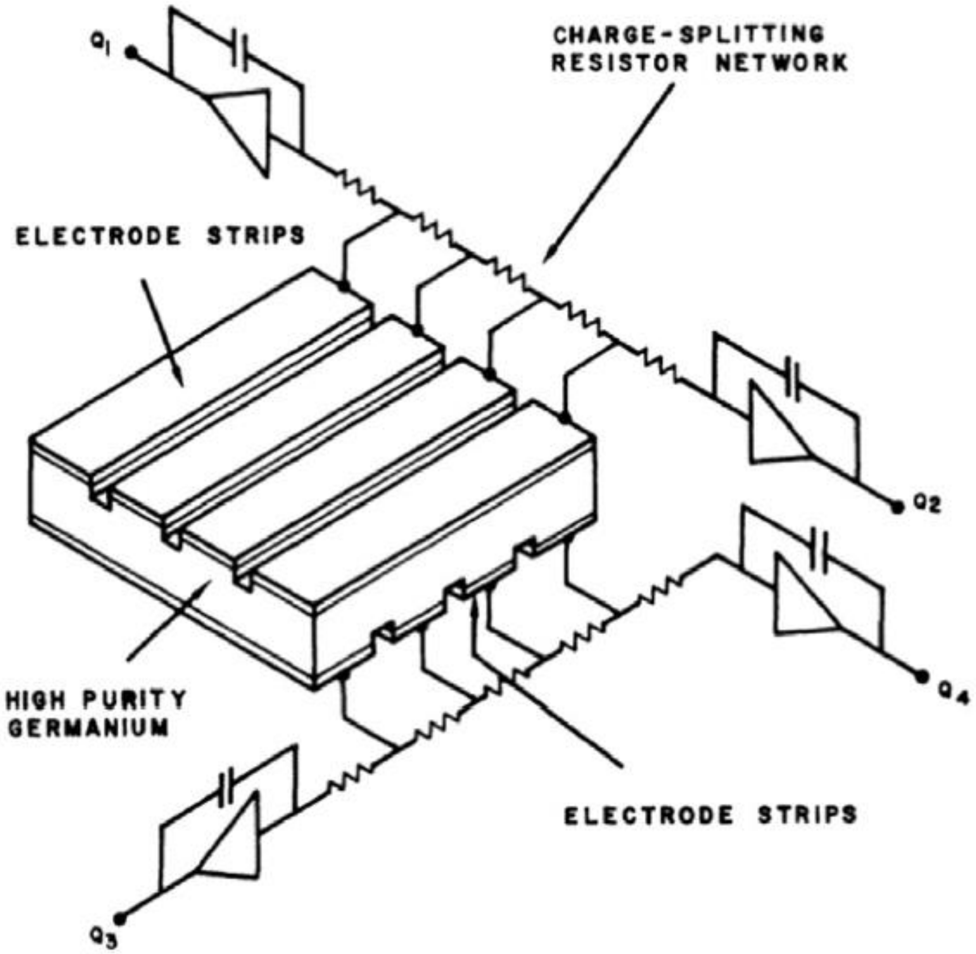
Using **$LaBr_3$ scintillator** to detect **478 keV** gamma-rays.

- Minsky et al., 2009. Experimental feasibility studies on a SPECT tomograph for BNCT dosimetry. Applied Radiation and Isotopes, 67(7-8), pp.S179-S182.
- Minsky et al., 2011. First tomographic image of neutron capture rate in a BNCT facility. Applied Radiation and Isotopes, 69(12), pp.1858-1861.



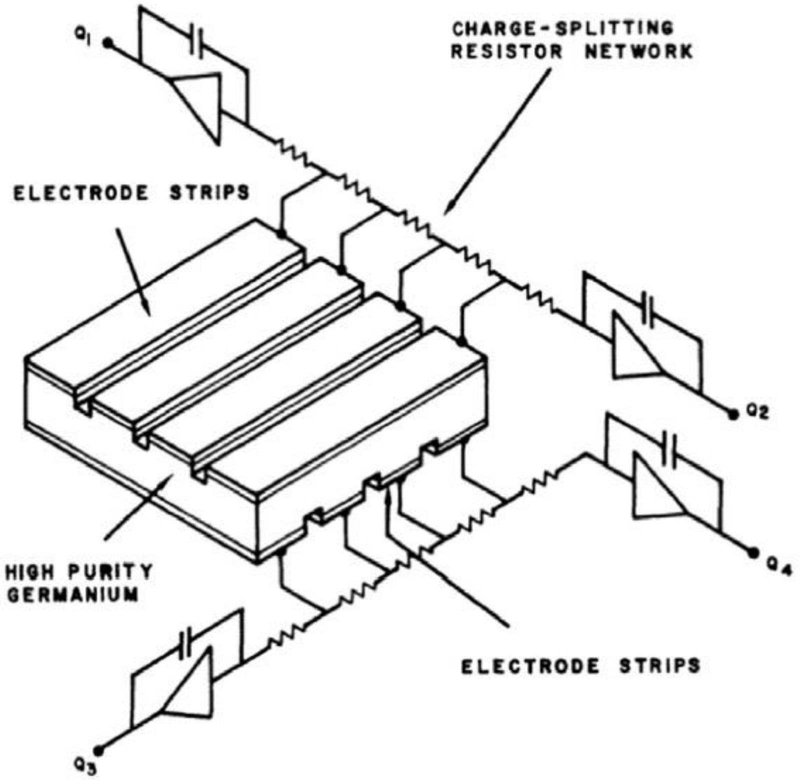
Gamma ray spectrum shows very prominent ^{1}H neutron capture and pair annihilation peaks and a weak ^{10}B neutron capture peak.

IDEA OF TENIS

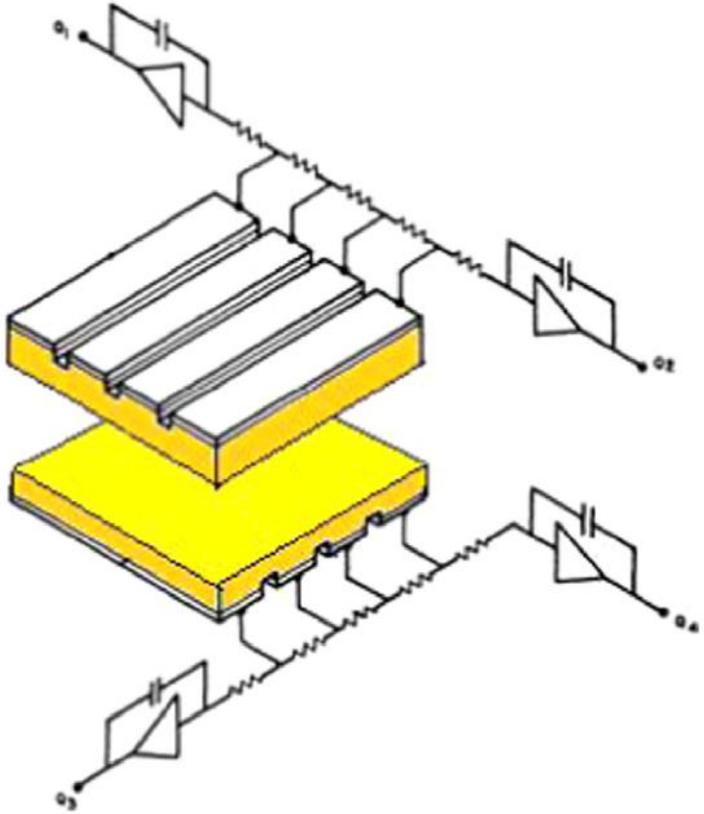


The orthogonal-strip position-sensitive detector

IDEA OF TENIS

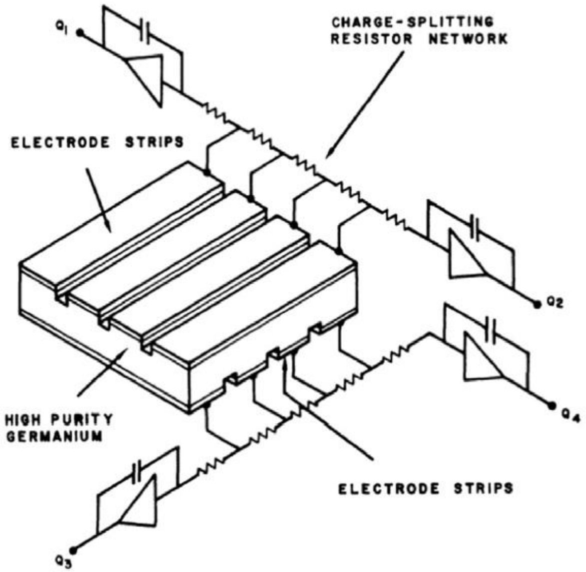


The orthogonal-strip position-sensitive detector

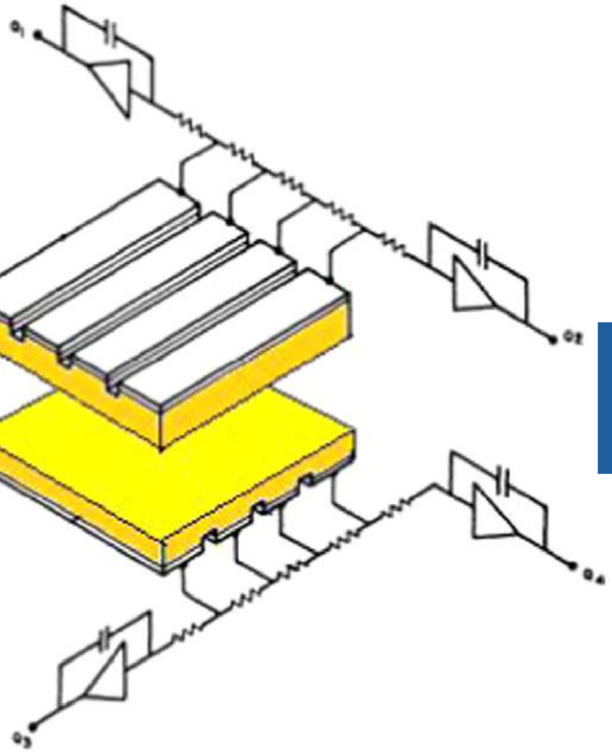


Modified orthogonal-strip position-sensitive detector.

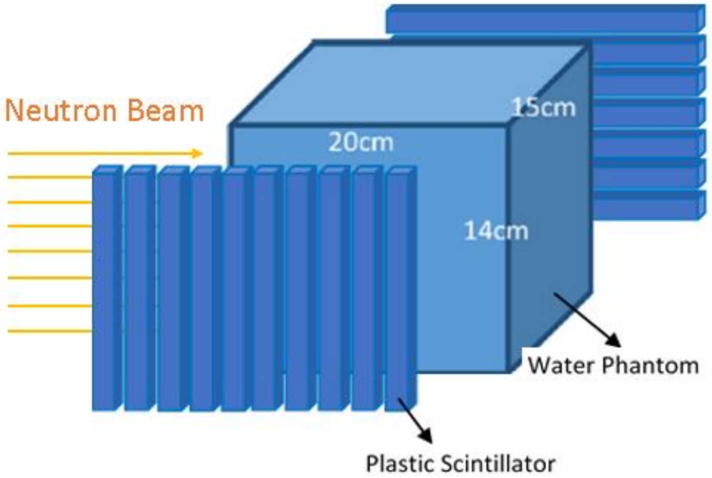
IDEA OF TENIS



The orthogonal-strip position-sensitive detector

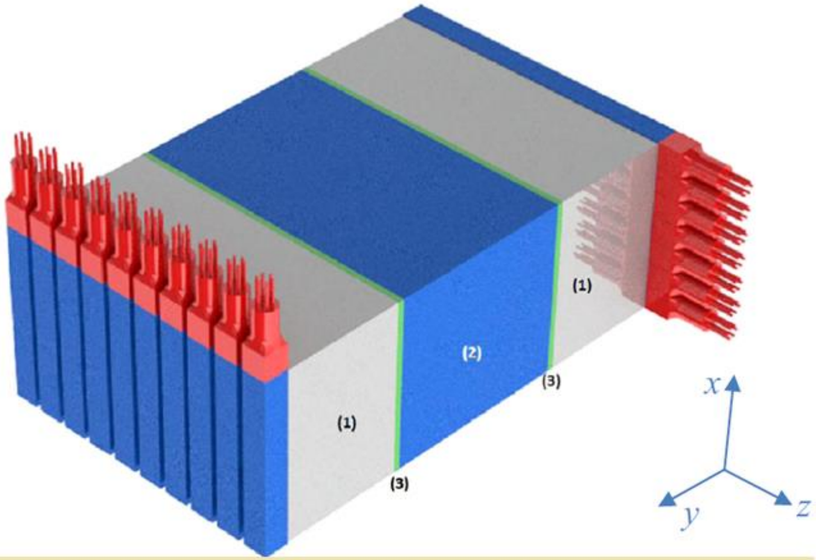


Modified orthogonal-strip position-sensitive detector.

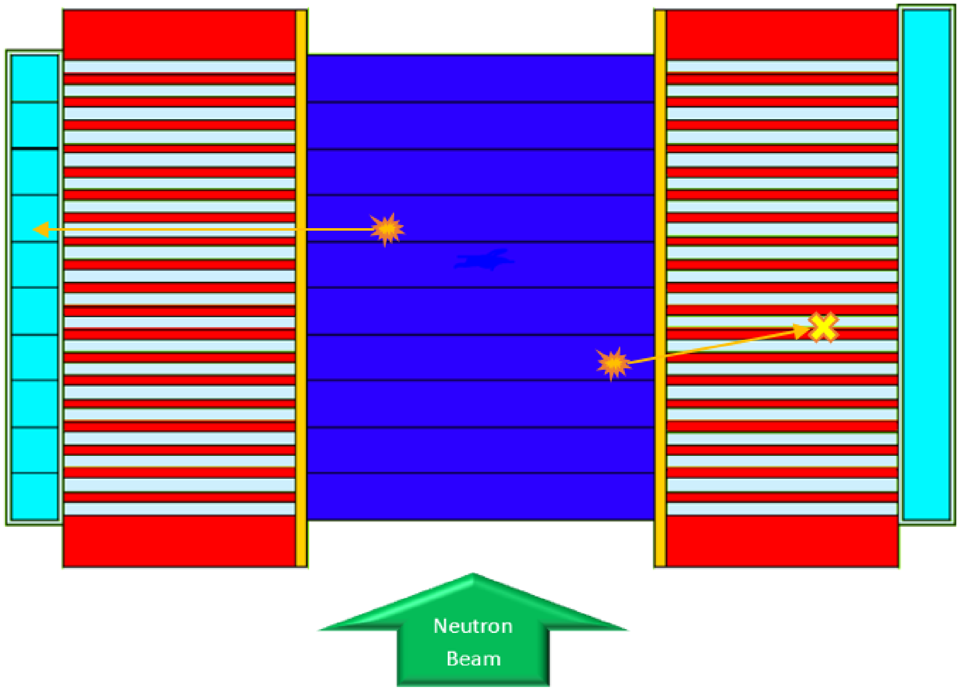


IDEA OF TENIS (CONT'D)

$H(n_{th}, \gamma)D$ ($E\gamma$= 2.22 MeV)



(a) Two sets of orthogonal plastic scintillators to be placed around the water phantom. (b) The detection system consists of horizontal and vertical scintillators, thick lead collimator blocks (1), rectangular water phantom (2), thin cadmium sheets (3) and 17 PMTs.

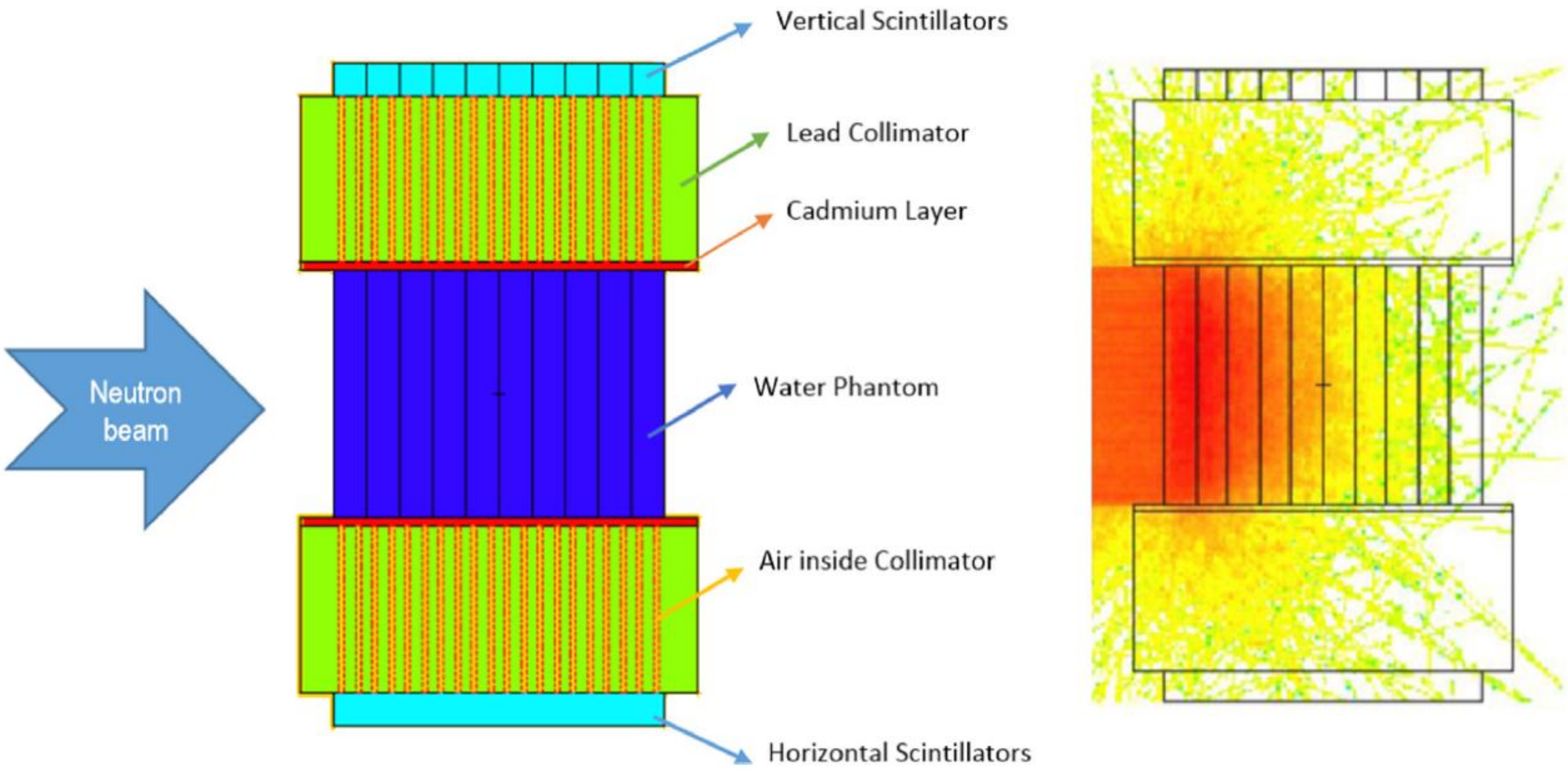


SIMULATION STUDIES

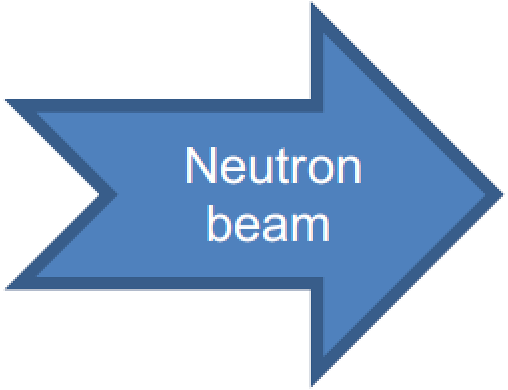
Stage 1:

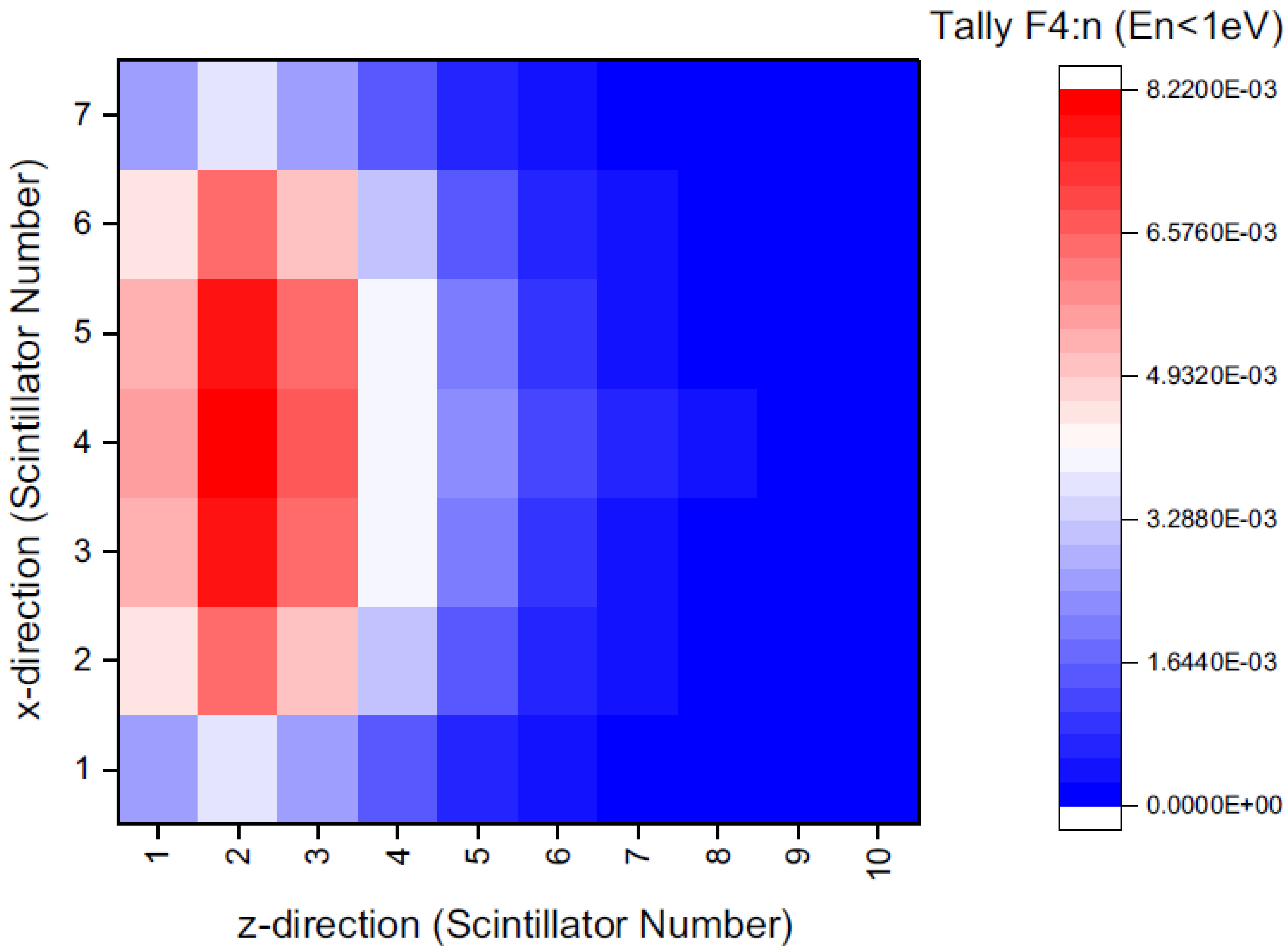
A 1200-line MCNPX input file to model TENIS and extract 17 scintillator responses.

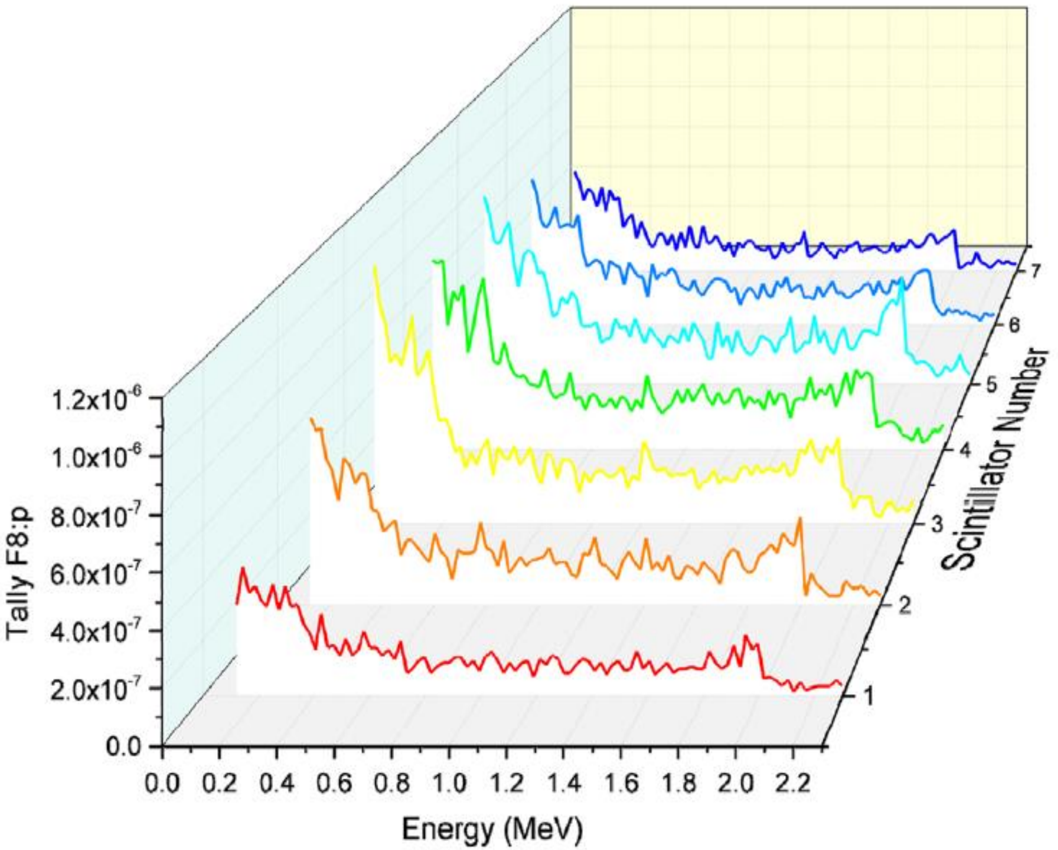
MCNPX pulse-height tally was assumed as the scintillator responses (Ignoring scintillation light production and transport!!)



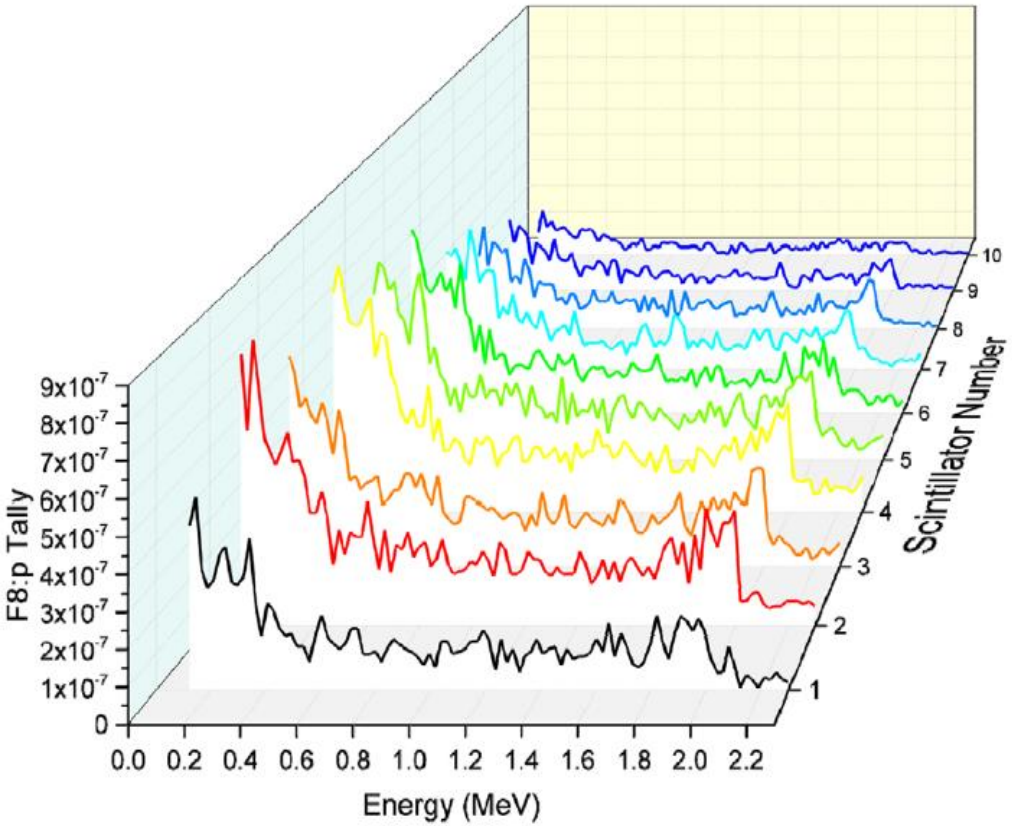
(Left) The MCNP-generated plot of the proposed thermal neutron imaging system (top view). (Right) The MCNPX mesh tally plot of neutron flux.


Neutron
beam


Tally F4:n (En<1eV)
8.2200E-03
6.5760E-03
4.9320E-03
3.2880E-03
1.6440E-03
0.0000E+00
x-direction (Scintillator Number)
z-direction (Scintillator Number)
1
2
3
4
5
6
7
8
9
10

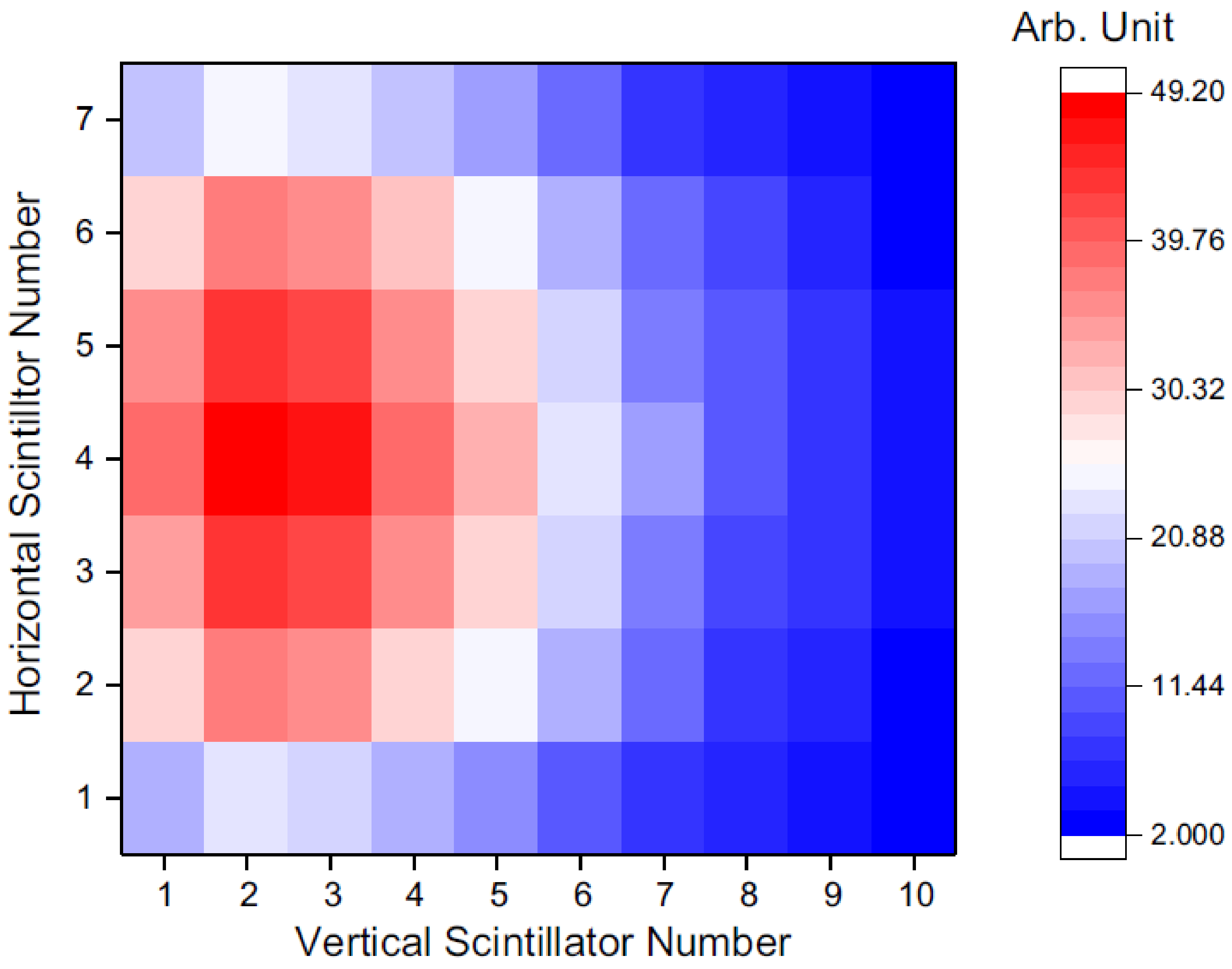


Tally F8:p
1.2x10-6
1.0x10-6
8.0x10-7
6.0x10-7
4.0x10-7
2.0x10-7
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
Energy (MeV)
Scintillator Number
1 2 3 4 5 6 7



F8:p Tally
9x10-7
8x10-7
7x10-7
6x10-7
5x10-7
4x10-7
3x10-7
2x10-7
1x10-7
0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
Energy (MeV)
Scintillator Number
1 2 3 4 5 6 7 8 9 10

Horizontal Scintillators: Typical F8 Values	Vertical Scintillators: Typical F8 Values									
	17.29	21.62	20.80	17.53	14.59	10.59	7.13	4.86	3.61	2.02
1.12	19.36	24.21	23.30	19.63	16.34	11.86	7.99	5.44	4.04	2.26
1.74	30.08	37.62	36.19	30.50	25.39	18.43	12.41	8.46	6.28	3.51
2.04	35.27	44.10	42.43	35.76	29.76	21.60	14.55	9.91	7.36	4.12
2.27	39.25	49.08	47.22	39.79	33.12	24.04	16.19	11.03	7.97	4.59
2.03	35.10	43.89	42.22	35.59	29.62	21.50	14.47	9.87	7.33	4.10
1.69	29.22	36.54	35.15	29.63	24.66	17.90	12.05	8.21	6.10	3.41
1.06	18.33	22.92	22.05	18.58	15.47	11.23	7.56	5.15	3.83	2.14
	Evaluated Values									


Arb. Unit
49.20
39.76
30.32
20.88
11.44
2.000
Horizontal Scintilltor Number
1
2
3
4
5
6
7
Vertical Scintillator Number
1
2
3
4
5
6
7
8
9
10

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Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

A plastic scintillator-based 2D thermal neutron mapping system for use in BNCT studies

N. Ghal-Eh [a,*], S. Green [b,c]

SIMULATION STUDIES (CONT'D)

For long rectangular scintillators, the light transport is a necessary part of the simulation.

In case of small cylindrical scintillator (where diameter equals length) without special painting/covering exposed to isotropic gamma-ray source, GEB can be used as an alternative to broadening caused by light transport.

Stage 2:

The deposition energy data of the MCNPX code (ptrac output) were used as input for the PHOTRACK (A home-made light transport code)

SIMULATION STUDIES (CONT'D)

Stage 3:

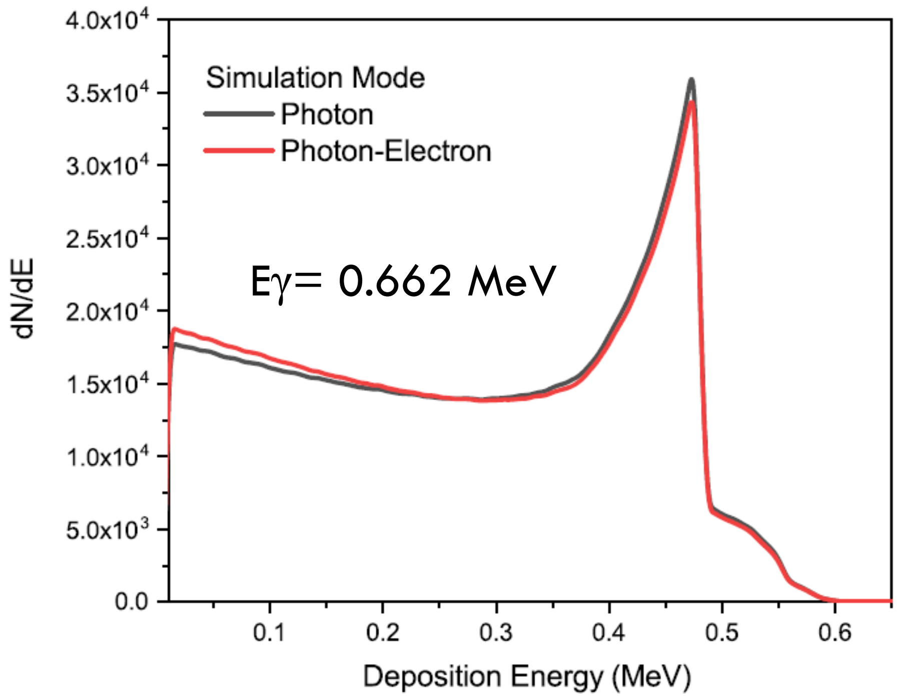
FLUKA was used for the simulations. It can model both radiation and the scintillation light produced as a result of radiation interaction.

The results of scintillation light transport with FLUKA was published for the first time in Iran.

SIMULATION IN P-E MODE

Deposition energy response (PTRAC size)

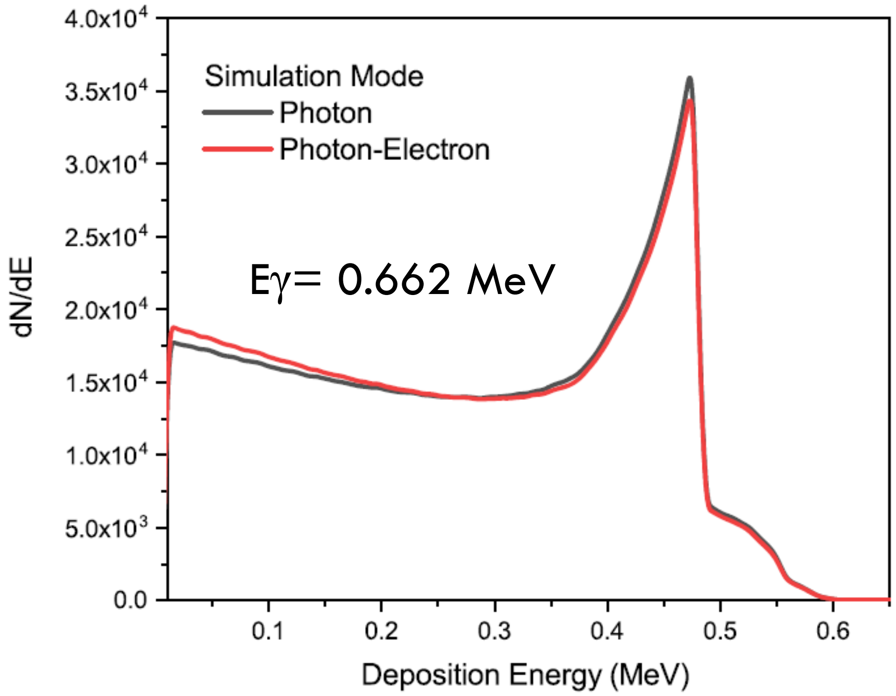
photon mode **(~900MB)**



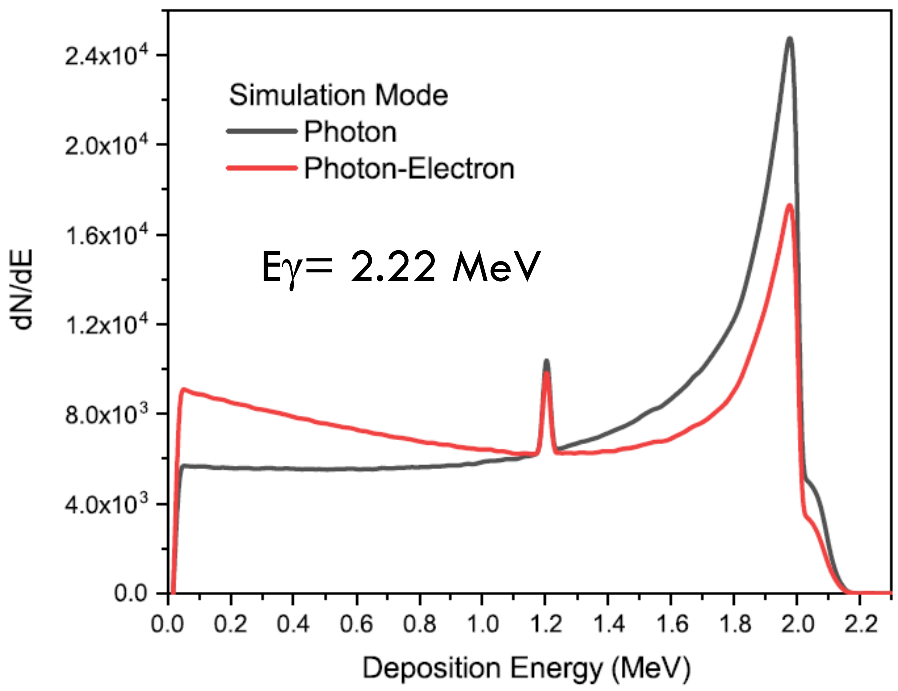
SIMULATION IN P-E MODE

Deposition energy response (PTRAC size)

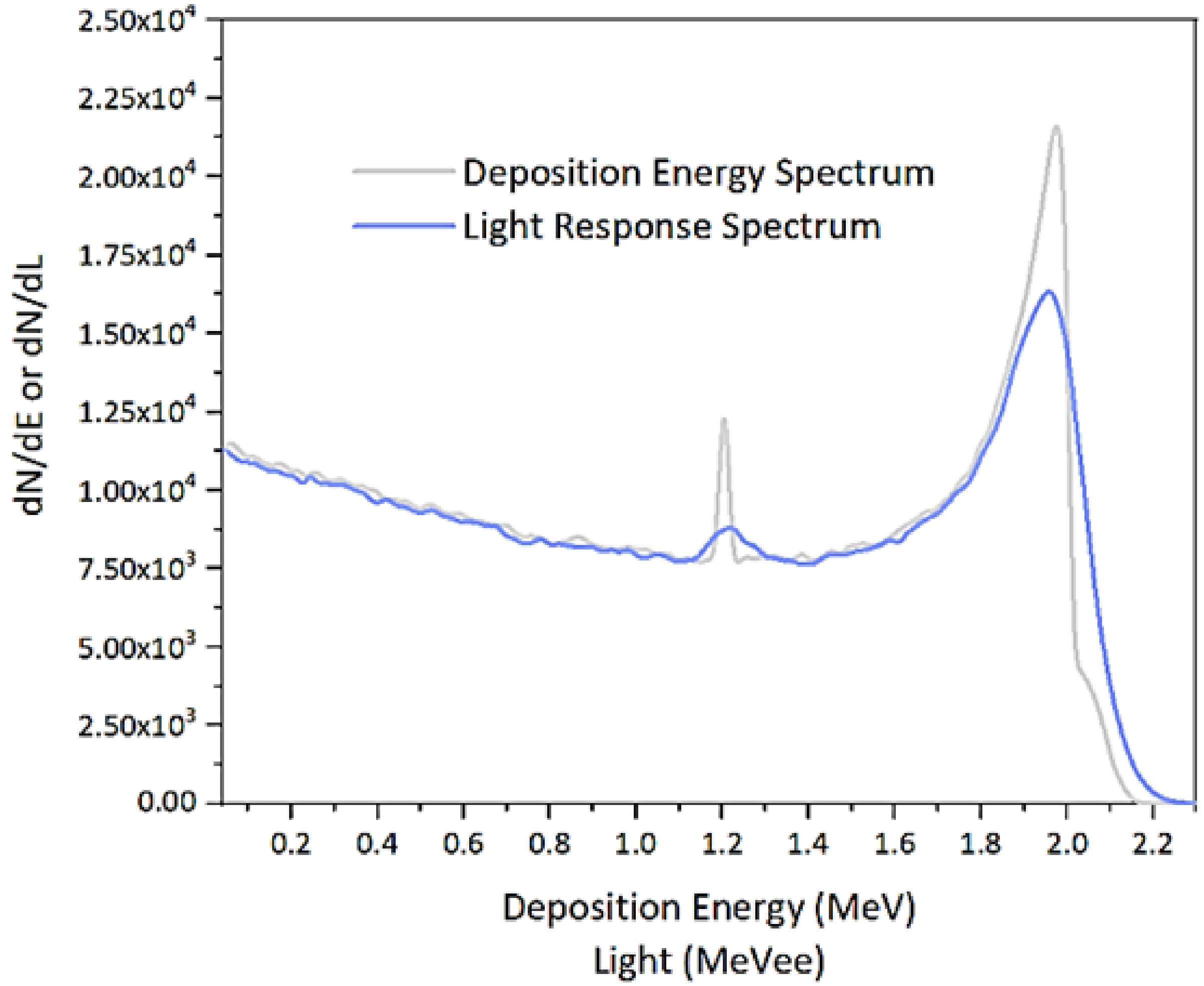
photon mode **(~900MB)**



photon-electron mode **(~4GB)**

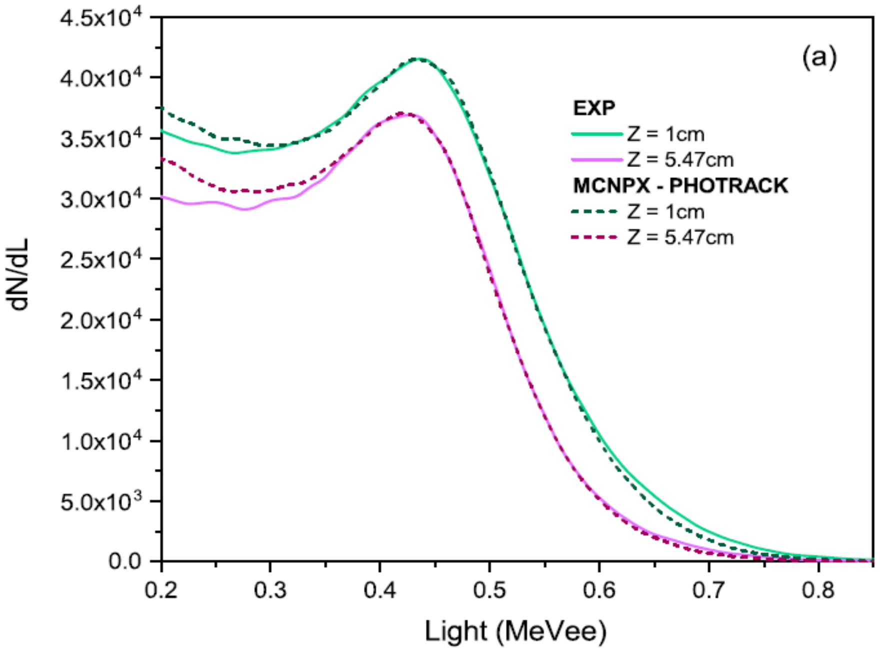


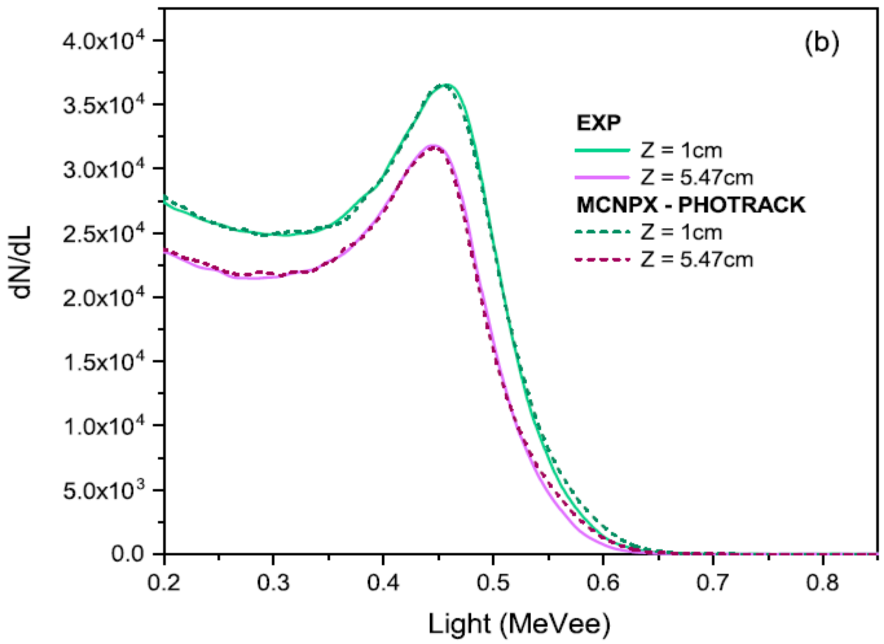
LIGHT TRANSPORT INCORPORATION



$2 \times 2 \times 20\ \mathrm{cm}^3$ NE102 scintillator
2.22 MeV photon beam

VERIFICATION OF PHOTRACK CODE





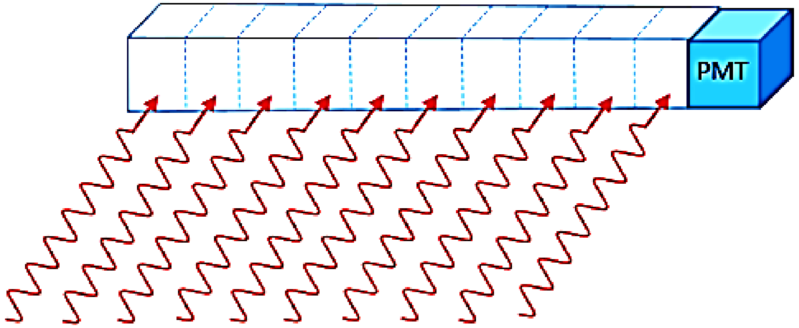
Polished surface

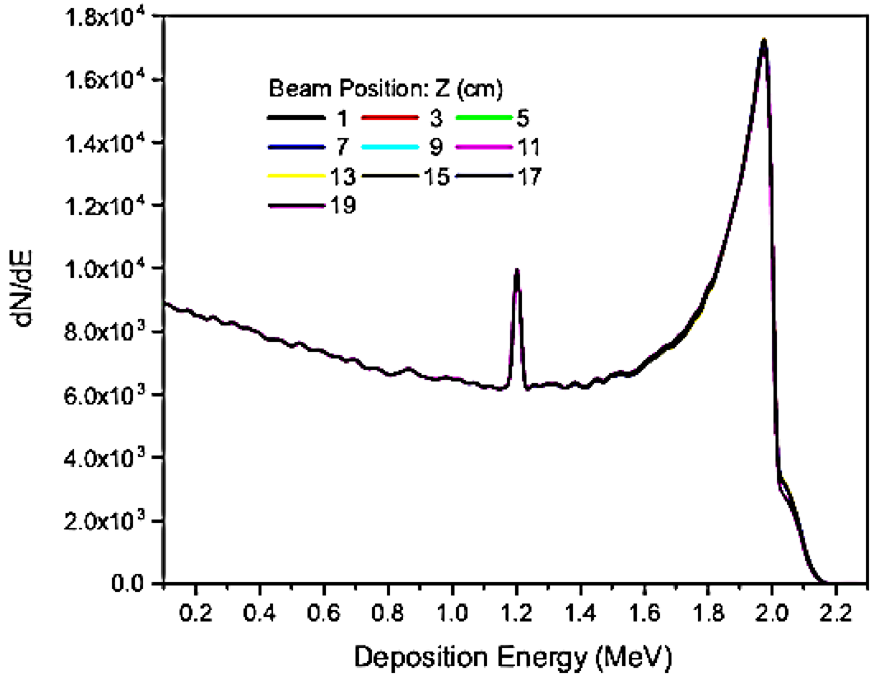
Painted surface

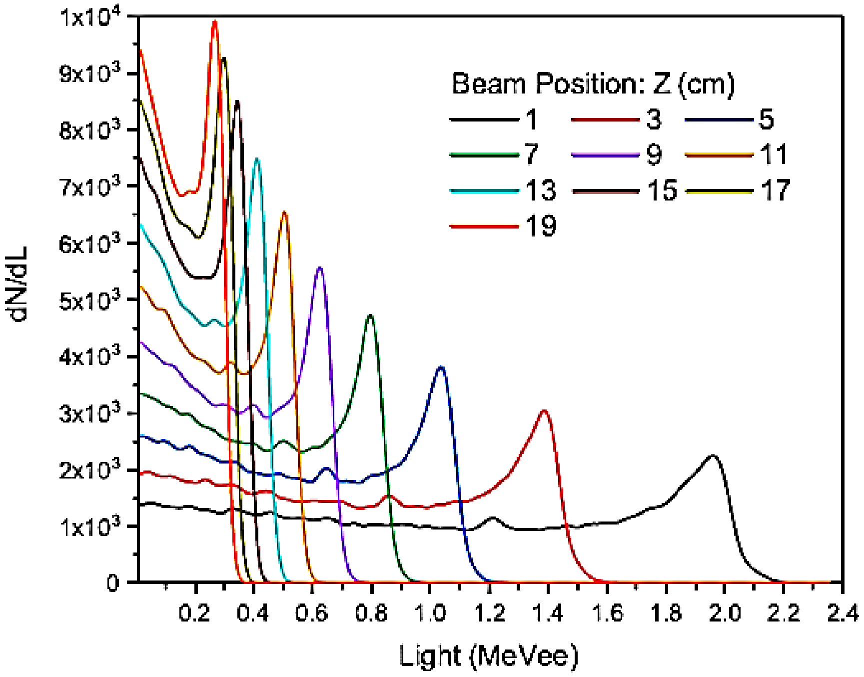
4.16 x 4.16 x 5.47 cm^3 and collimated Cs-137 source

LONGITUDINAL RESPONSE

- Fully-painted surface

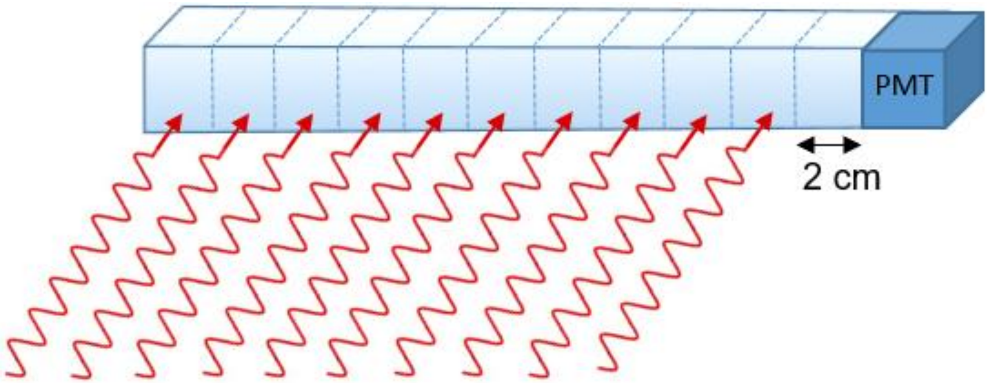


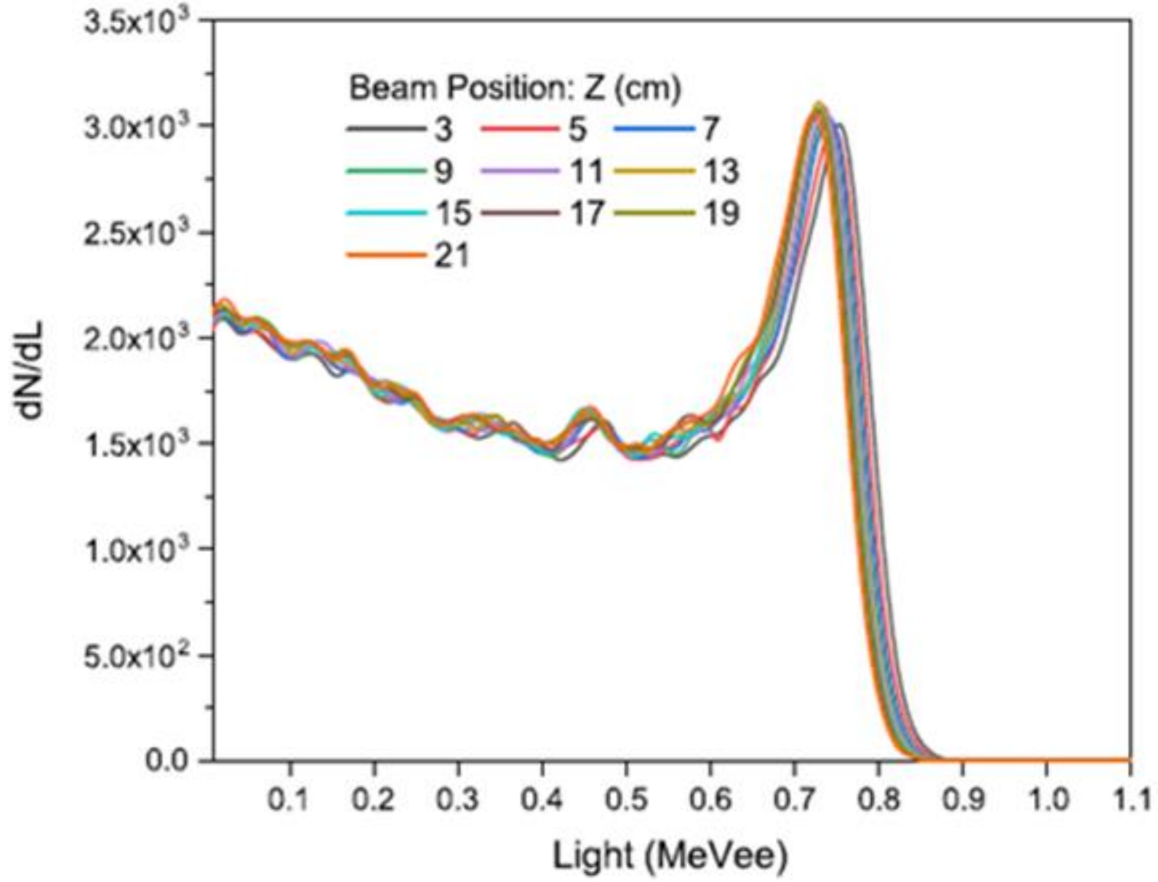




RESPONSE UNIFORMITY

- Fully-polished surface
- 2×2×22 cm^3 plastic scintillator





Nuclear Inst. and Methods in Physics Research, A 944 (2019) 162574

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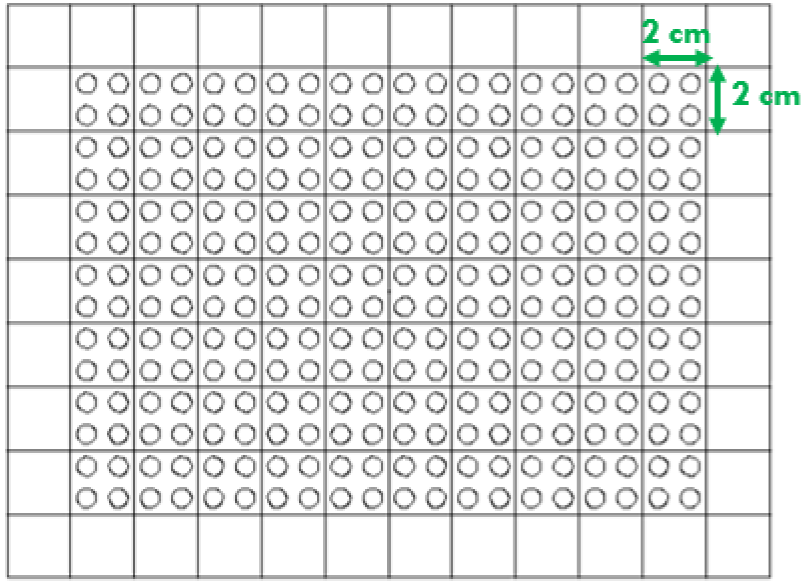
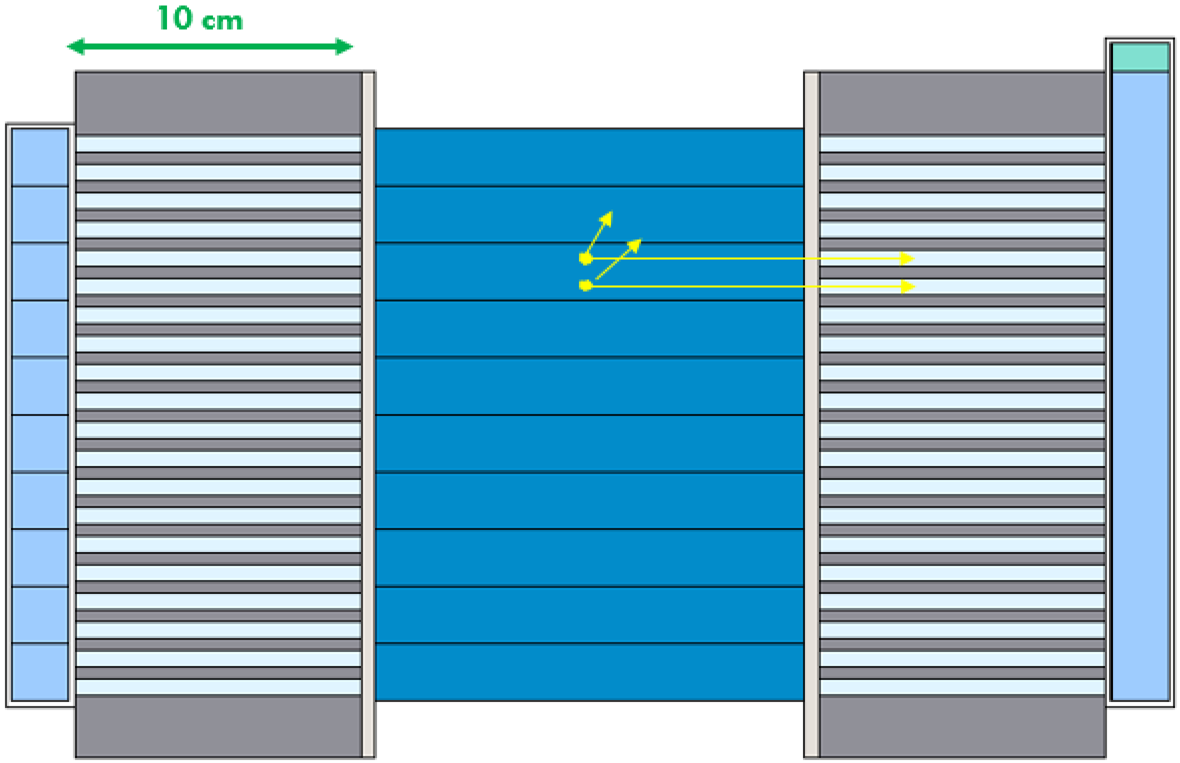
journal homepage: www.elsevier.com/locate/nima

Longitudinal response uniformity of a rectangular-shaped plastic scintillator when exposed to mono-energetic gamma-rays

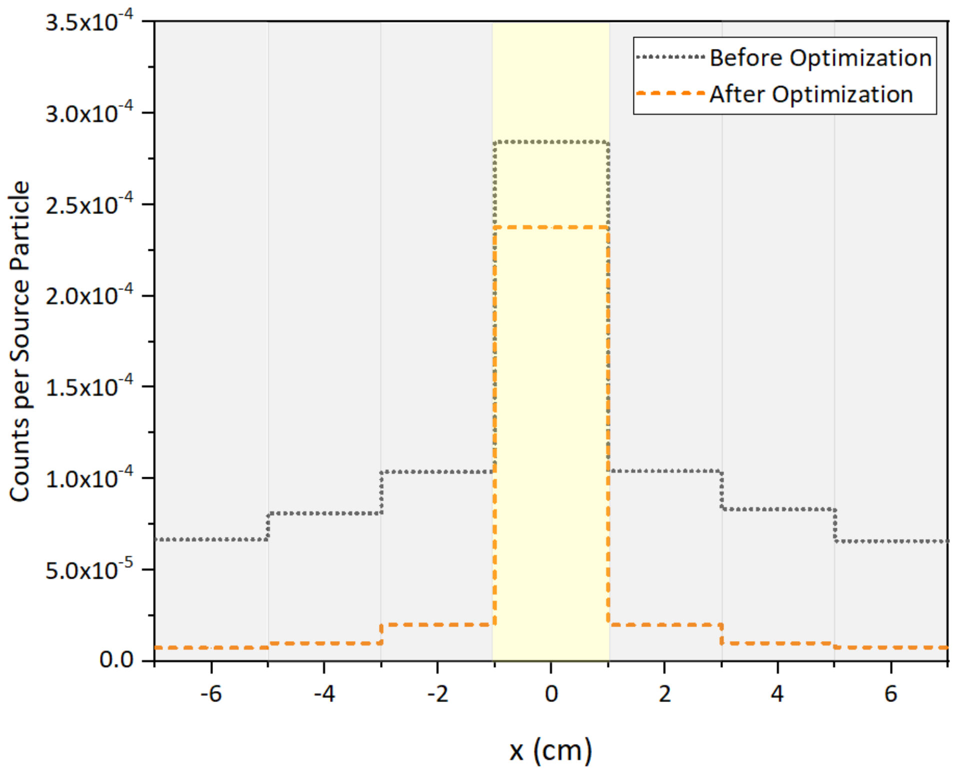
H. Yazdandoust [a], N. Ghal-Eh [b,c,*], M.M. Firoozabadi [a]

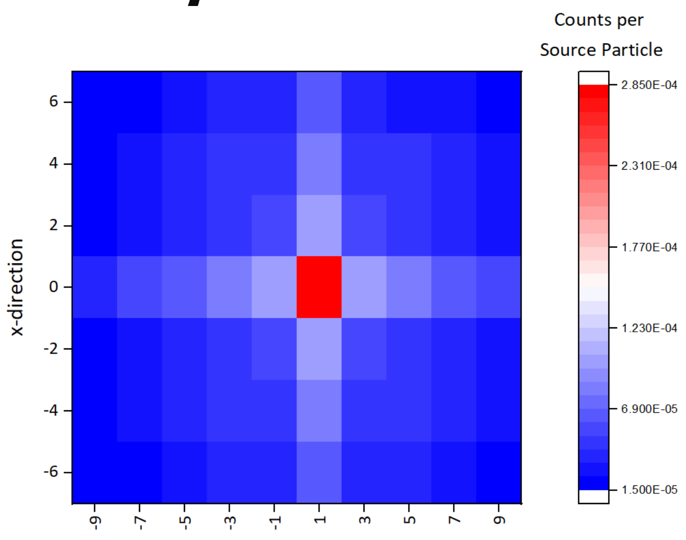
COLLIMATOR MODIFICATION

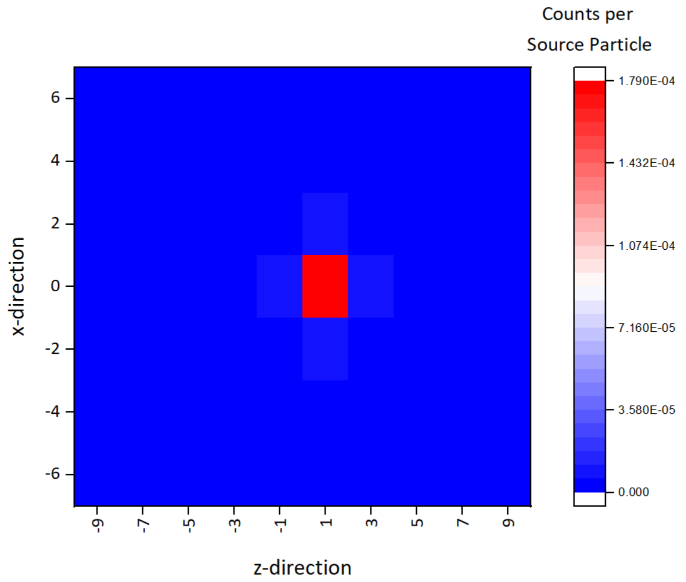




COLLIMATOR MODIFICATION (CONT'D)







10/20-cm thick collimator with four/one circular hole of 0.6/1.2 cm diameter in each of its 2×2 cm² spatial unit

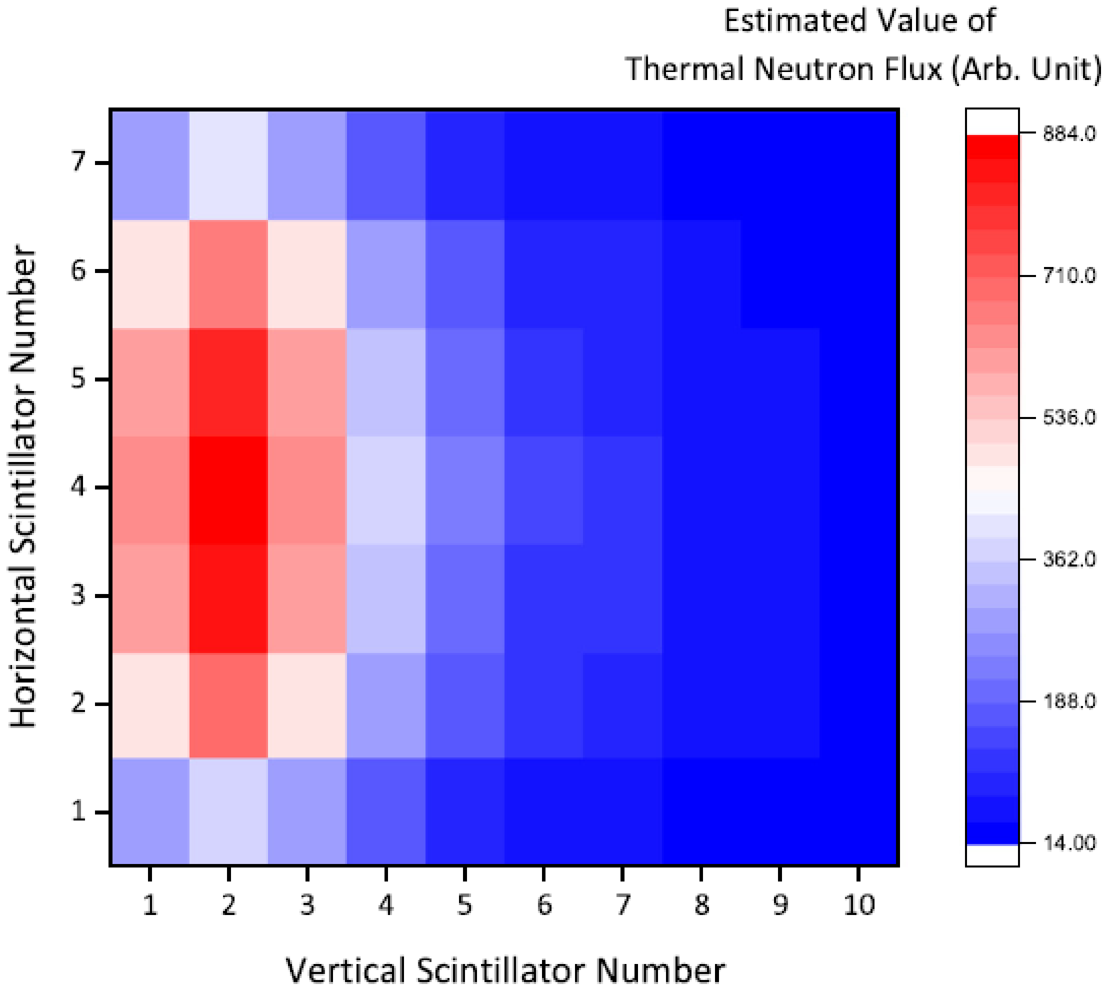
IMPROVING IMAGE RECONSTRUCTION

Modified multiplication algorithm

$$Flux_{est}\ (i,j) = \left(-a + b\sqrt{\frac{R_{Vrt}(j)}{R_{Vrt}\ (Max)}}\right)^2 \times R_{Hrz}(i)$$

a = 0.23 and b = 1.23

$$\chi^2 = \sum_{i=1}^{N}\sum_{j=1}^{M}\left(Flux_{Est}\left(R_{Hrz}(i), R_{Vrt}(j)\right) - Flux(i,j)\right)^2$$



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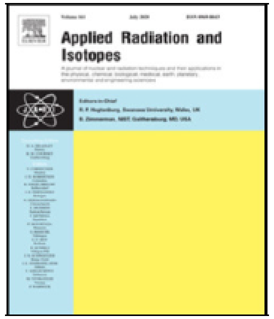
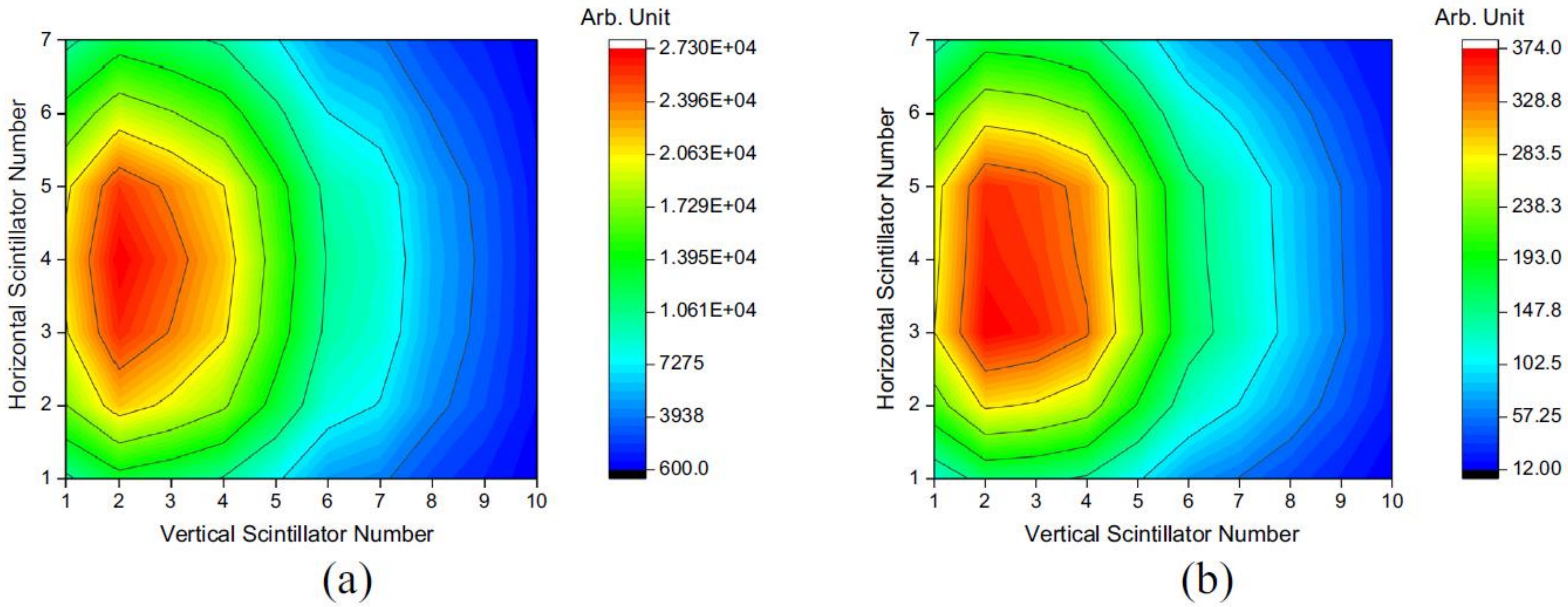


TENIS — ThErmal Neutron Imaging System for use in BNCT

H. Yazdandoust [a], N. Ghal-Eh [b,*], M.M. Firoozabadi [a]

AN IMPORTANT QUESTION

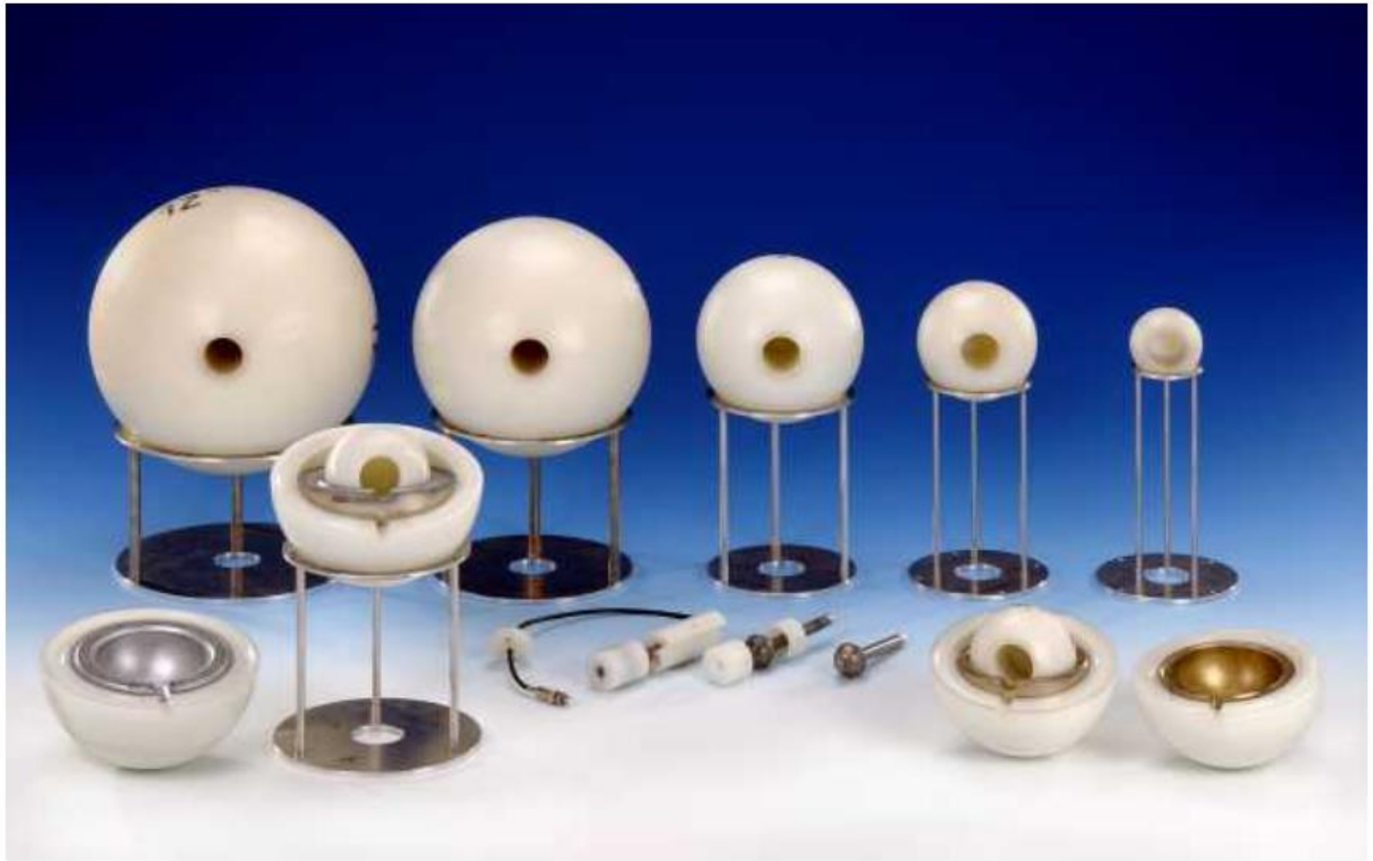
Can TENIS sense the neutron energy?



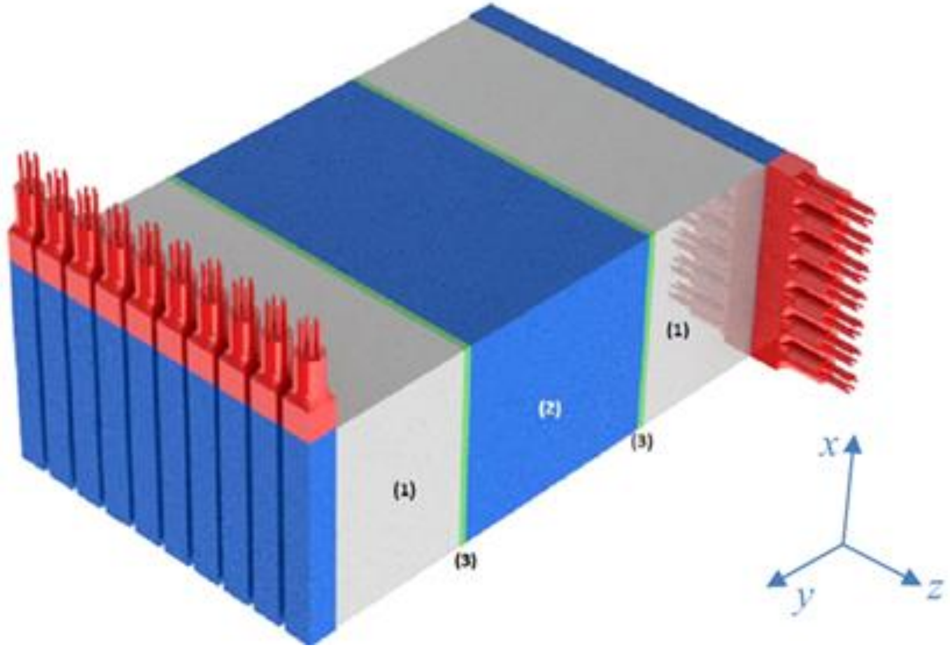
A 2D contour plot version of thermal neutron reconstructed image for an incident rectangular beam of different energies: (a) 1 keV and (b) 10 keV.

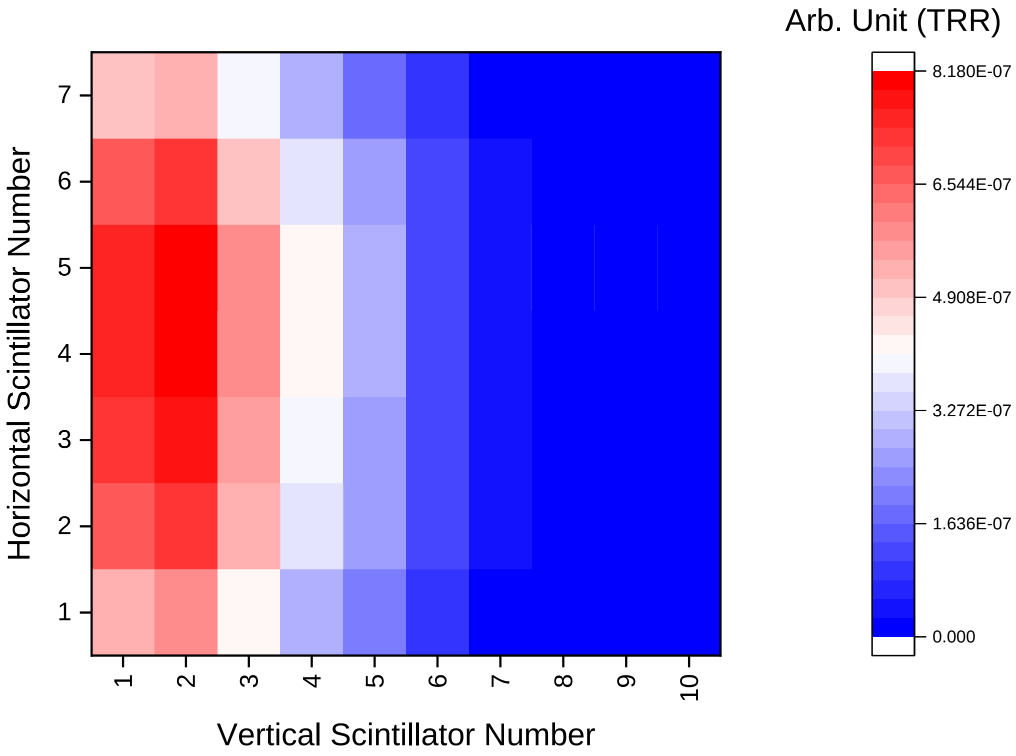
TENIS VS. BONNER SPHERES

Our studies confirm that the 70-pixel images of TENIS are equivalent to 70 Bonner spheres.



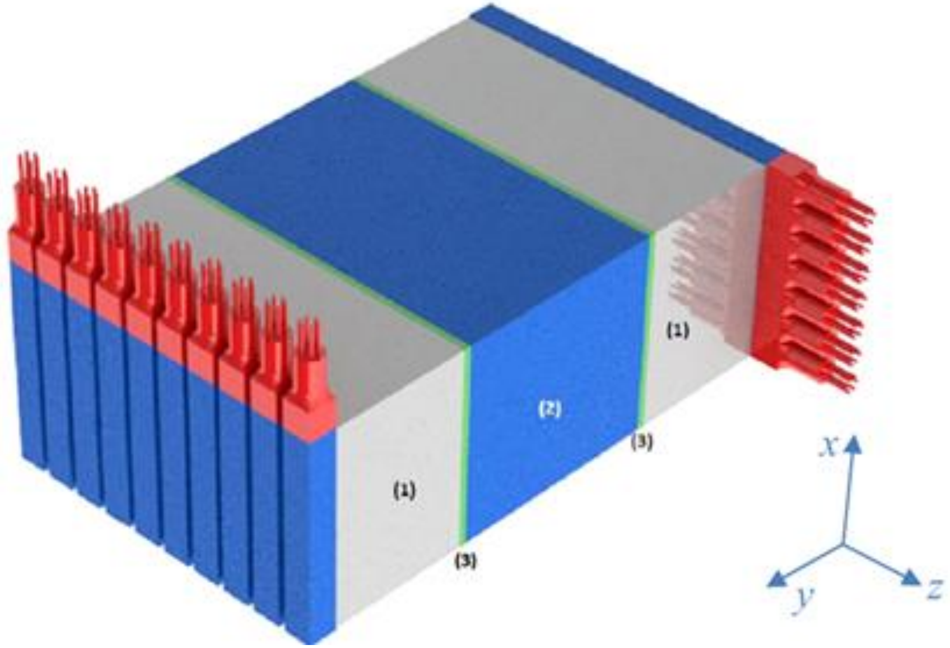
RESPONSE MATRIX

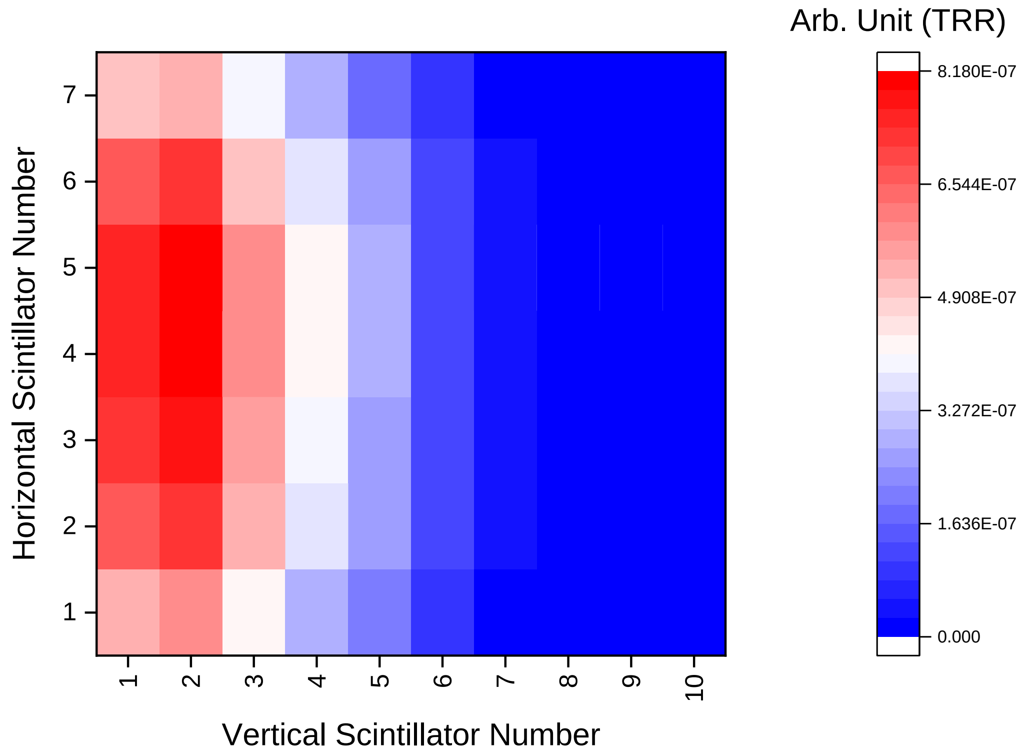




55 mono-energetic neutron energies from 10^{-11} MeV to 14.92 MeV with equi-lethargy intervals

RESPONSE MATRIX

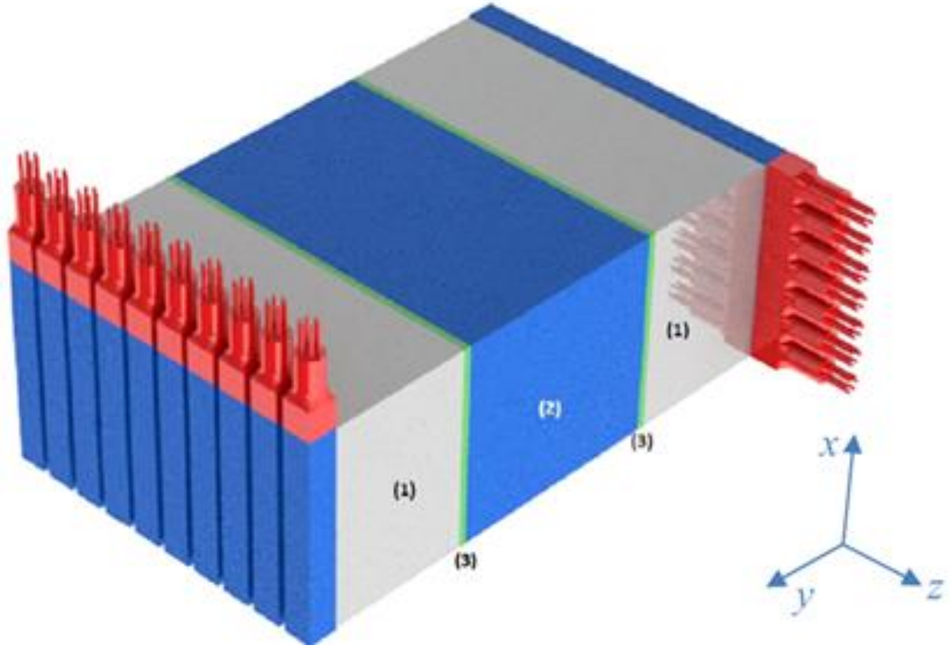


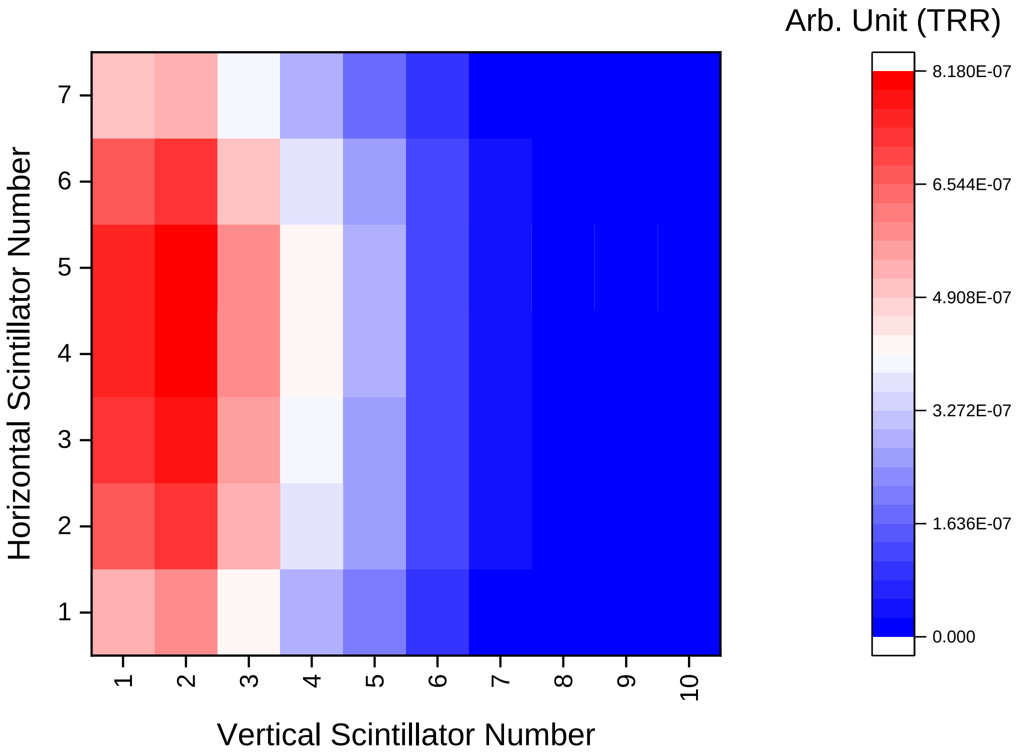


55 mono-energetic neutron energies from 10^{-11} MeV to 14.92 MeV with equi-lethargy intervals

70 Bonner spheres
55 Neutron energies

RESPONSE MATRIX

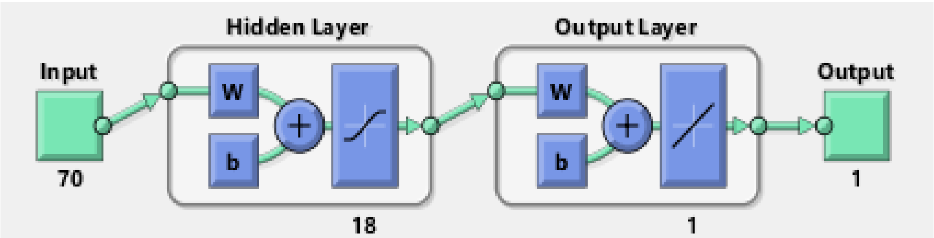


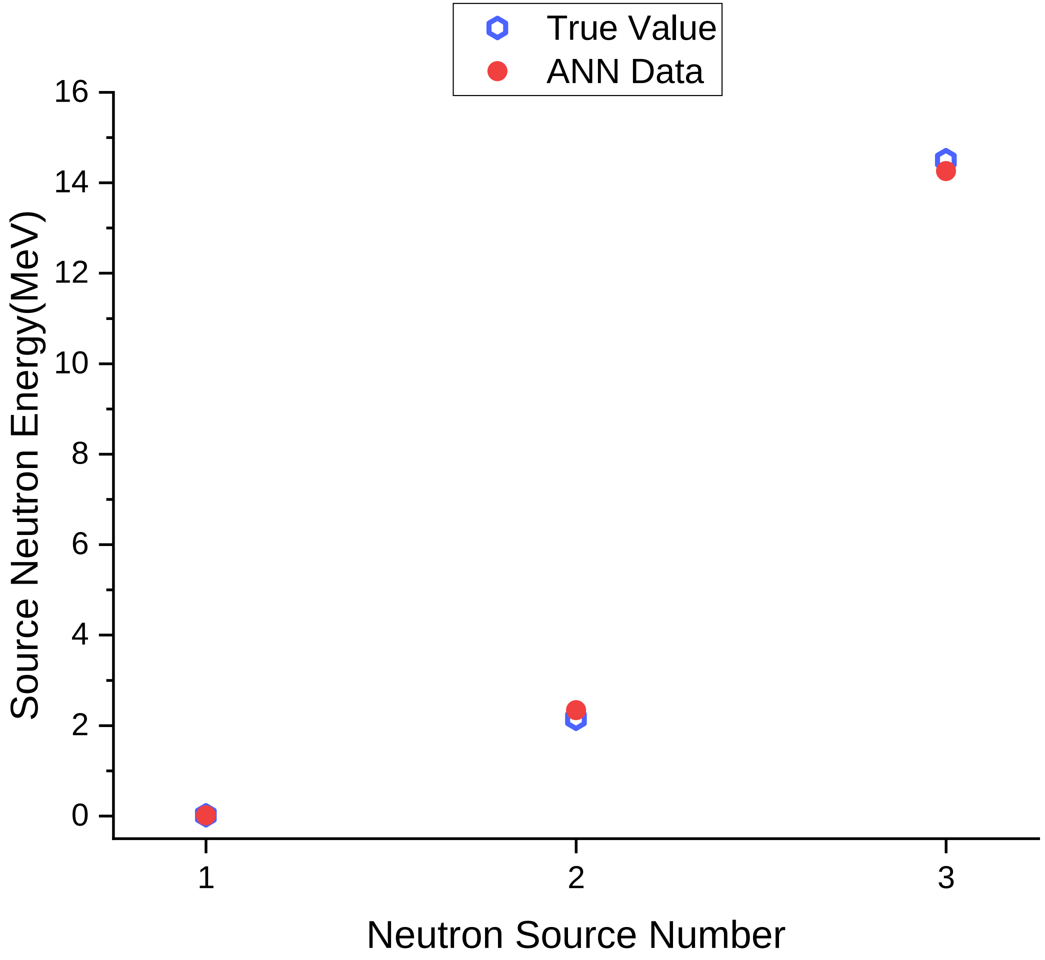


55 mono-energetic neutron energies from 10-11 MeV to 14.92 MeV with equi-lethargy intervals → 70 Bonner spheres 55 Neutron energies → Response Matrix Dimension: 70 × 55

UNFOLDING WITH MATLAB'S ANN

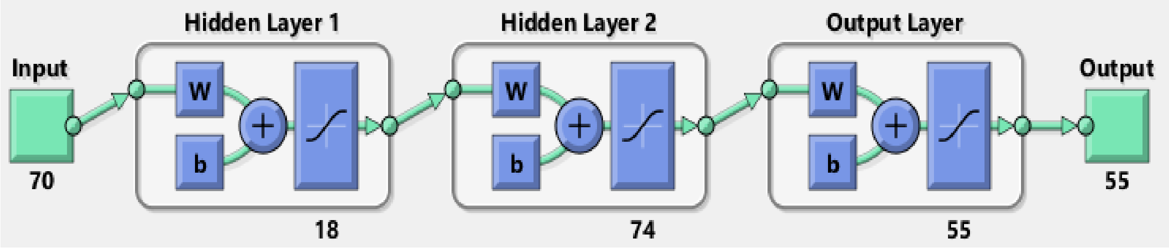
The results of ANN unfolding for unknown mono-energetic neutron sources (**0.015**, **2.15**, and **14.5MeV**)

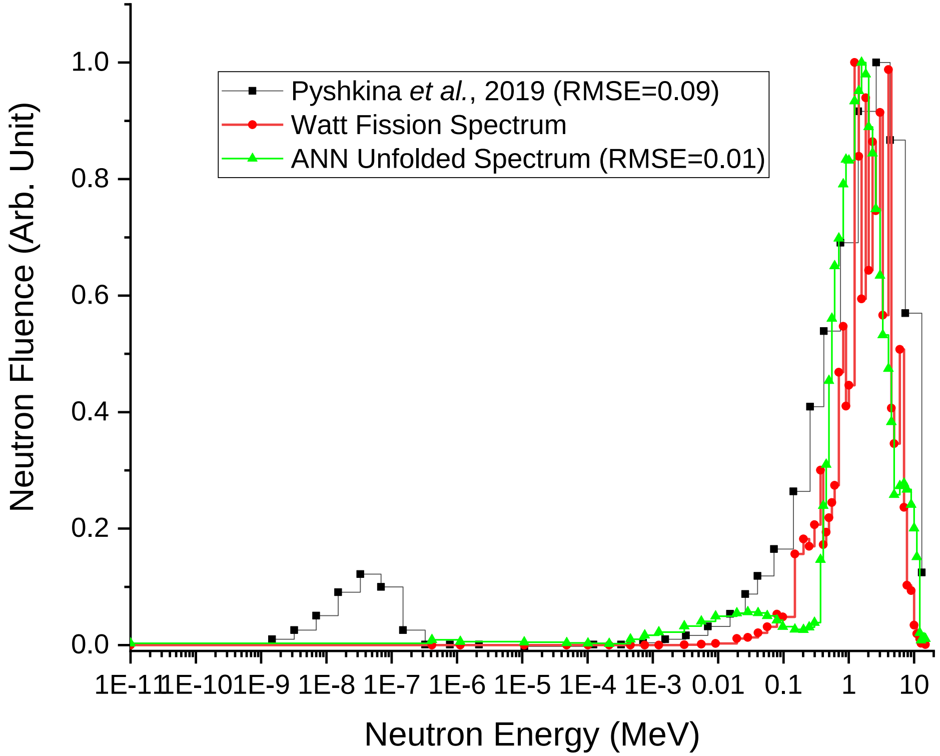




UNFOLDING WITH MATLAB'S ANN (CONT'D)

Comparison of the ^{252}Cf spectra: ANN-unfolded, Pyshkina *et al.*'s, and the Watt fission spectrum data





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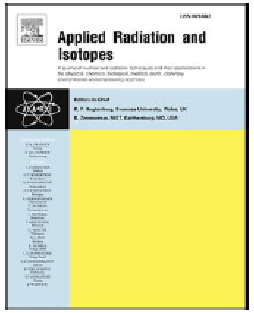


Neutron spectroscopy with TENIS using an artificial neural network

S. Bagherzadeh-Atashchi [a], N. Ghal-Eh [a,*], F. Rahmani [b], R. Izadi-Najafabadi [a], S.V. Bedenko [c]

TENIS FOR EPITHERMAL NEUTRON SPECTROSCOPY

TRR Reactor (Tehran)

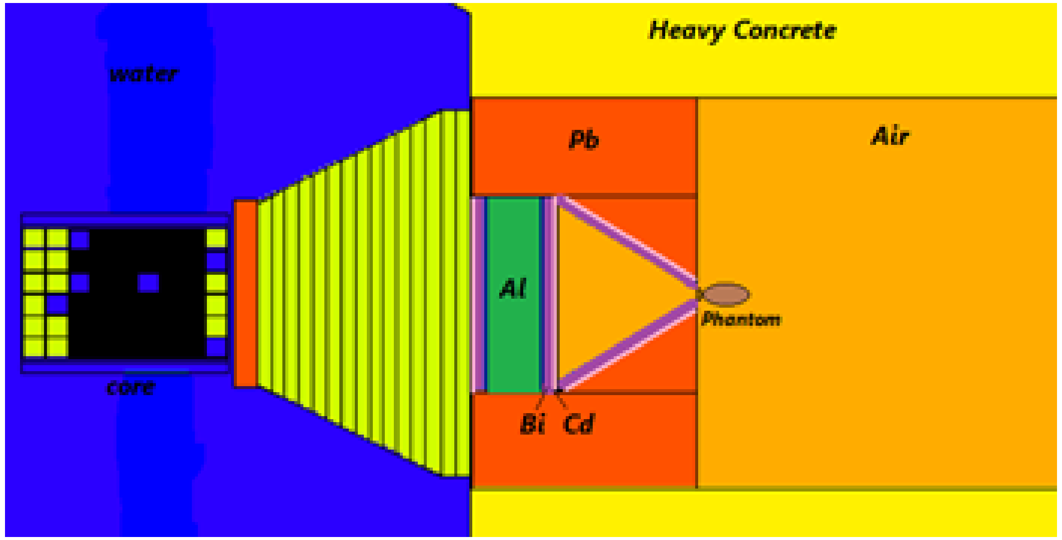
- 5MW
- Pool-type, Light water
- Core lattice is a 6×9 array containing standard and control fuel elements

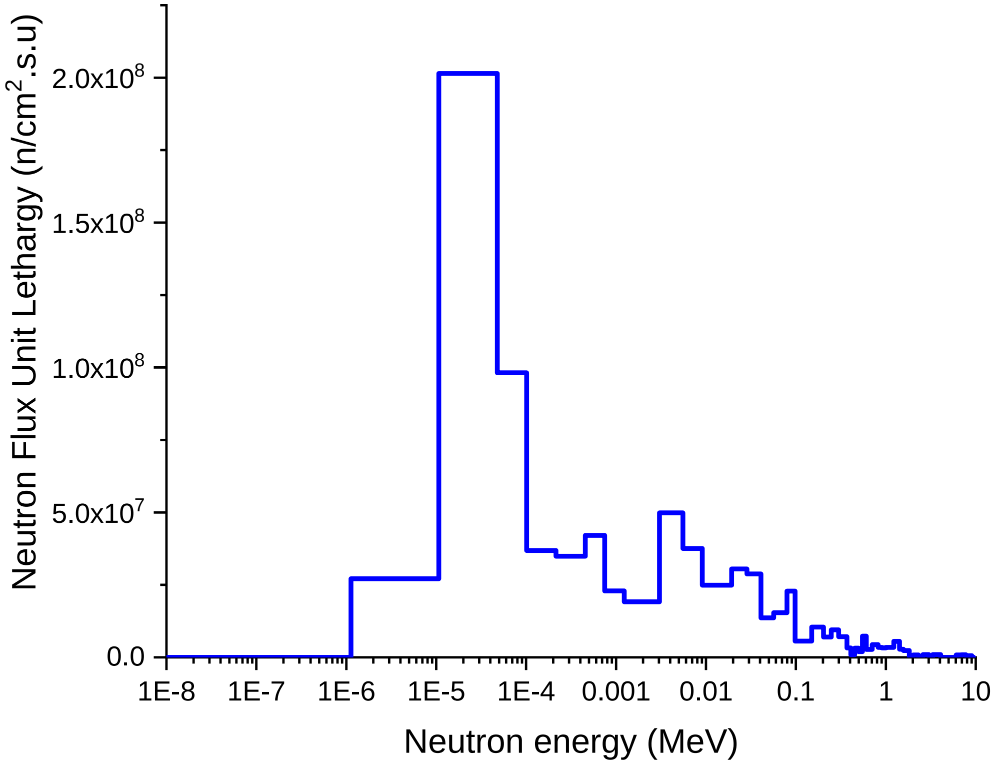
IRT-T Reactor (Tomsk)

- 6MW
- Pool-type, Light water
- Core lattice is a 7×8 array containing 6-tube and 8-tube fuel assemblies

BSA DESIGNS FOR TRR AND IRT-T REACTORS

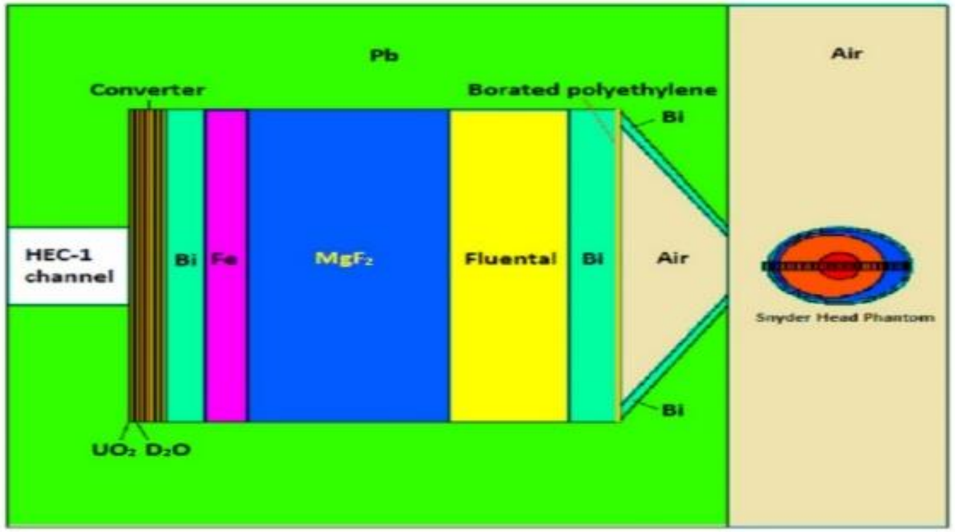
BNCT beam line of TRR

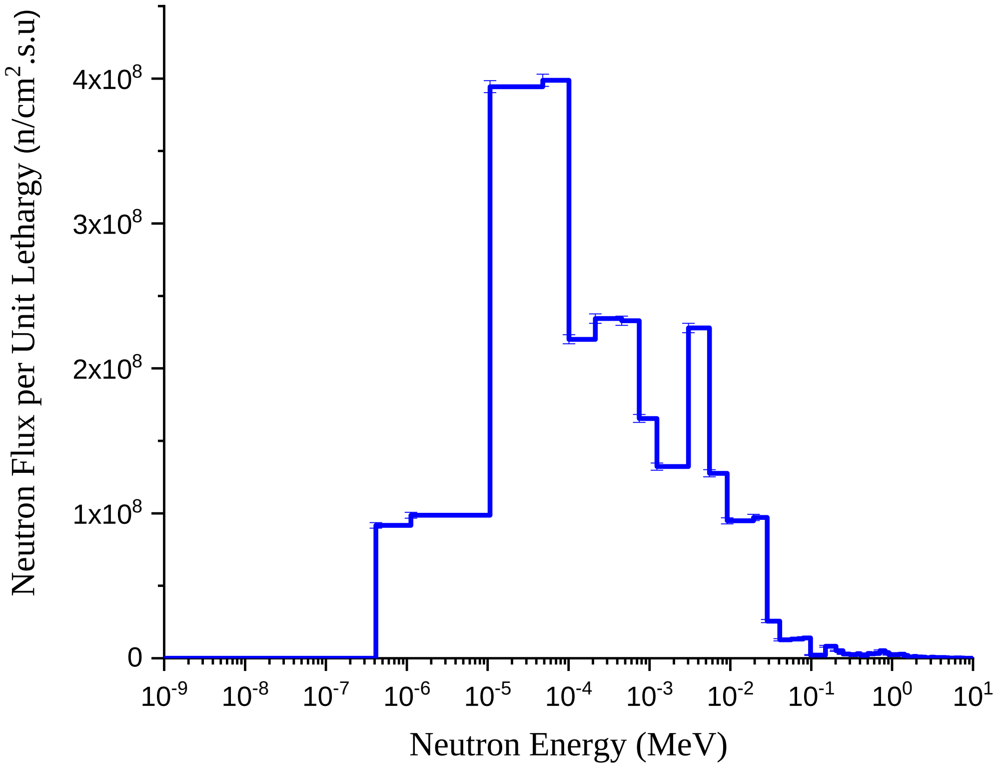




BSA DESIGNS FOR TRR AND IRT-T REACTORS (CONT'D)

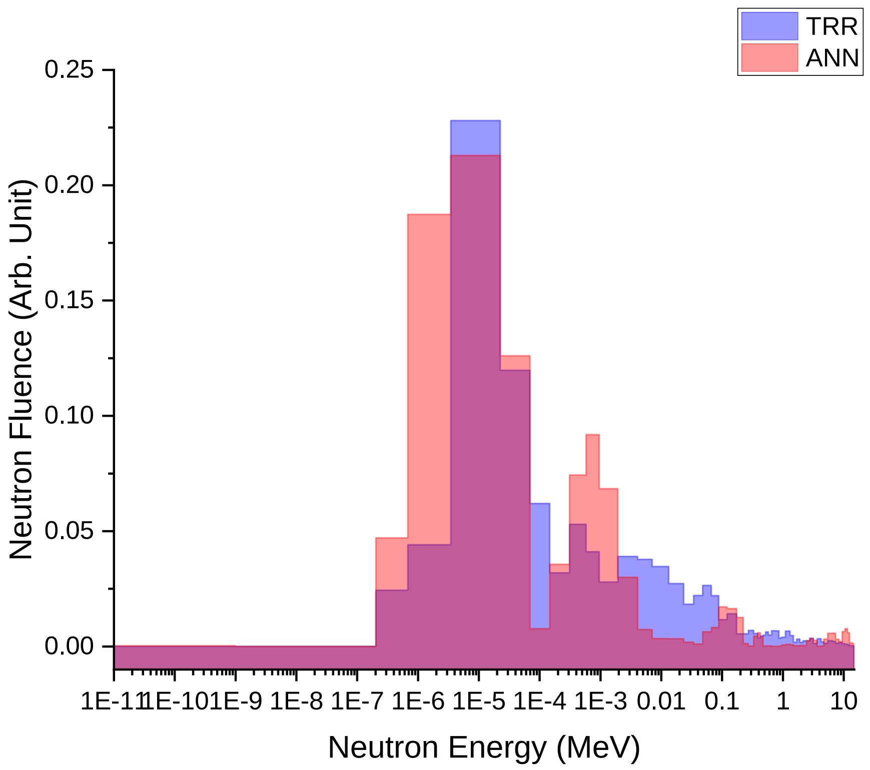
BNCT beam line of IRT-T



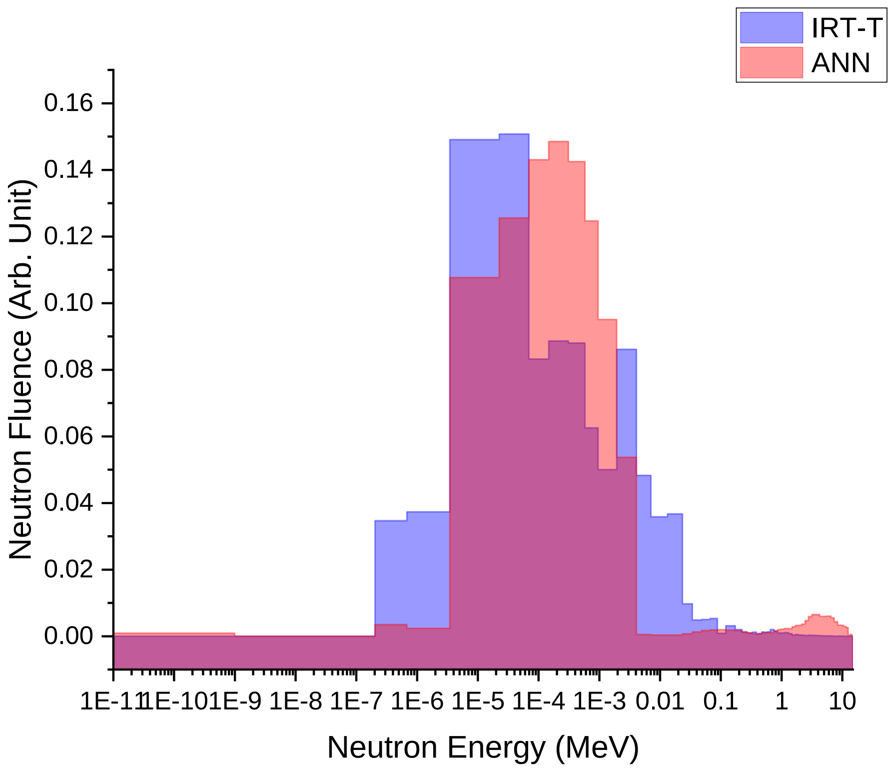


TENIS UNFOLDED SPECTRA

Unfolded neutron spectrum for TRR BNCT spectra



Unfolded neutron spectrum for IRT-T BNCT spectra



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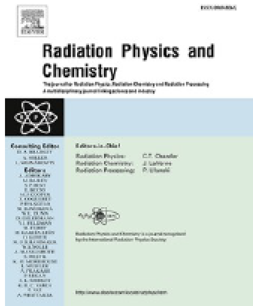

Design of beam line for BNCT applications in HEC-1 channel of IRT-T research reactor

S. Bagherzadeh-Atashchi [a], N. Ghal-Eh [a,*], F. Rahmani [b], R. Izadi-Najafabadi [a], S.V. Bedenko [c]

WHAT'S NEXT?

Measurements

For preliminary experimental investigation, with one horizontal and one vertical scintillators.

THANK YOU ALL!