

**FEASIBILITY OF ^{10}B LOCALISATION
BY NEUTRON & GAMMA DETECTION
DURING BORON NEUTRON
CAPTURE THERAPY (BNCT)**

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UNIVERSITY OF
SURREY

RADIOTHERAPY

without BNCT

BNCT

Modern trends:

IMRT (intensity modulated)

IGRT (image guided)

RESPIRATORY GATING

etc

**Control beam shape
timing.**

**Once in the body, beam
can't discriminate
what to hit (diseased
tissues) from what to miss
(healthy tissues)**

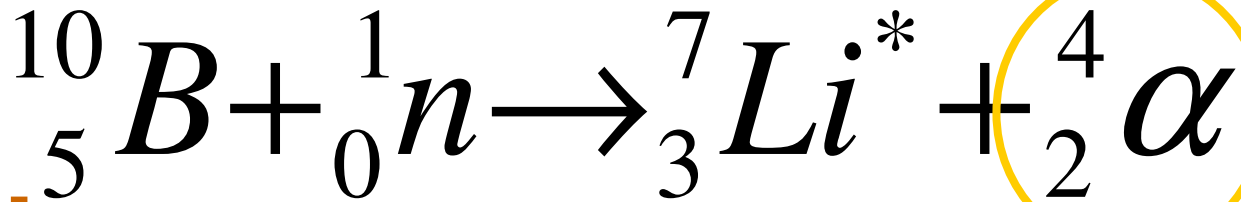
**Biochemical
targeting**

**BEYOND
GEOMETRIC
TARGETING**

**inject ^{10}B tumour-seeking
compound as agent into the
body:**

IF ^{10}B in tissue → HIT

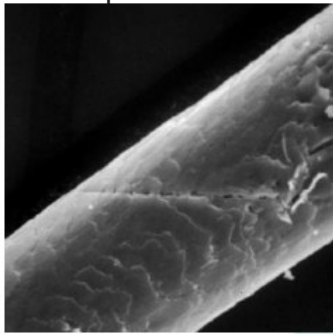
IF ^{10}B not there → MISS



HIGH LET



478 keV γ

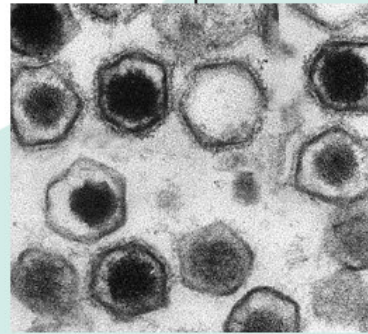


Human hair (80 μ m)



Red blood cells (7 μ m)

Credit: D Marshall & D Gregory/Wellcome Photo Library



Icosahedral virus particles (150nm)

Biomedical Electron Microscopy Unit, Newcastle University.



The Royal Society & The Royal Academy of Engineering: Nanoscience & nanotechnologies 2004

IF ${}^{10}B$ in tissue \rightarrow HIT

IF ${}^{10}B$ not there \rightarrow MISS

THE IDEAL	Tumour	Other tissues
^{10}B (%)	100	0

WE ARE NOT THERE YET

THE NEED FOR

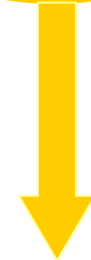
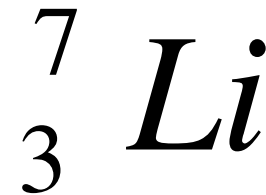
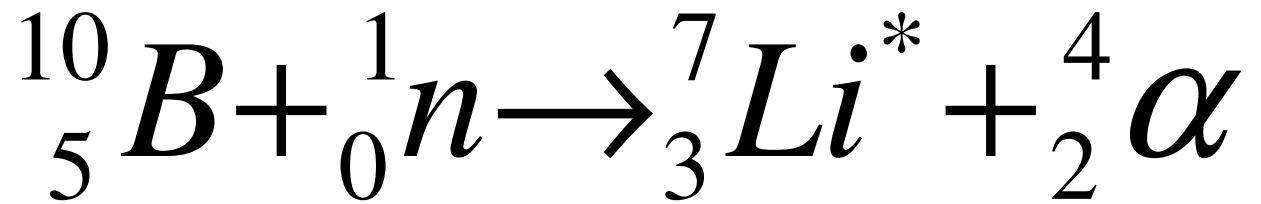
IN VIVO

**MAPPING OF ^{10}B
DISTRIBUTION**

Inject ^{10}B **tumour-seeking** compound as agent into the body:

IF ^{10}B in tissue → HIT

IF ^{10}B not there → MISS



MEASURE



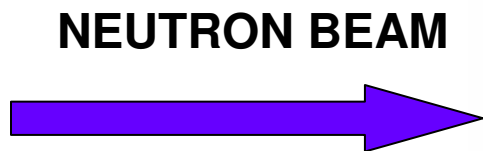
DETERMINE

**THE NEED FOR
IN VIVO
MAPPING OF ${}^{10}B$
DISTRIBUTION**

Proposed Spyrou NM 1999 J Radioanal Nucl Chem **239** 59

Reported Verbakel W *et al* 2001 Phys Med Bio **46** 687

Valda A *et al* 2005 Brazilian J Phys **35** 785



**DETECTORS
WOULD ALMOST
CERTAINLY
PRODUCE *SOME*
READING...
IF WE HAVEN'T
DAMAGED THEM**



**NEUTRON
SPECTROMETER**

NEUTRON BEAM

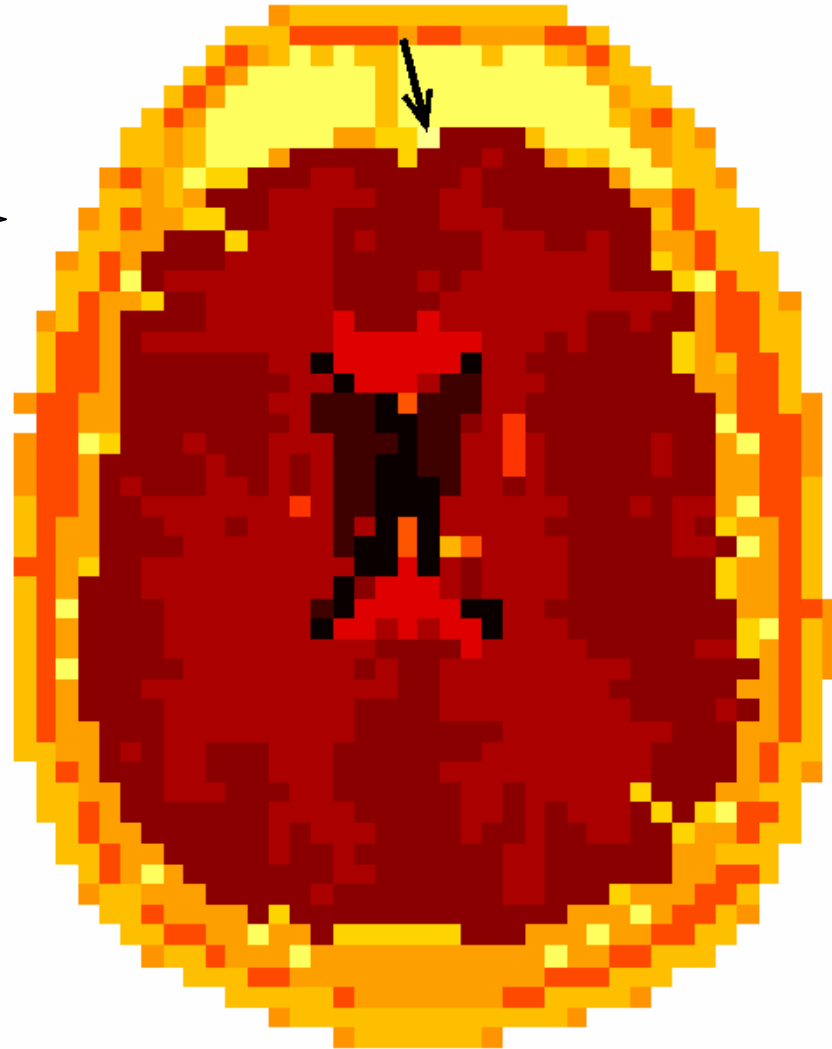


Q1. What gamma spectrum do we expect?

Q2. What neutron spectrum do we expect?

Q3. How do each change with varying ^{10}B distributions?

GAMMA-RAY SPECTROMETER



GAMMA-RAY SPECTROMETER

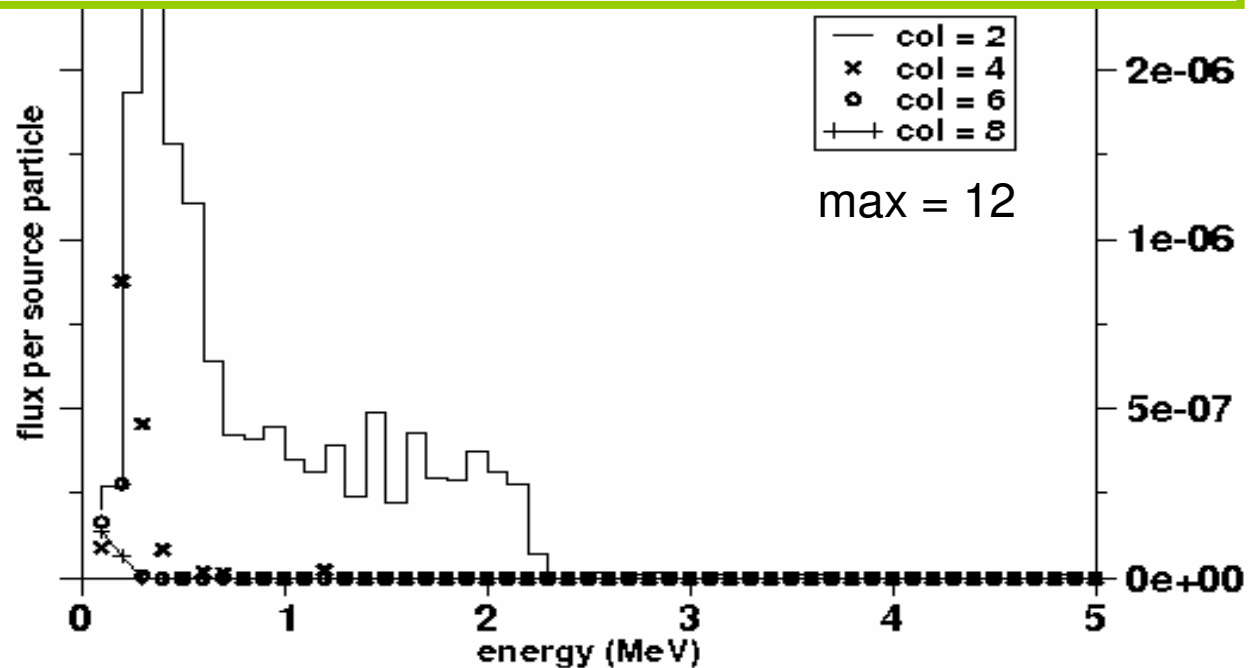
NEUTRON SPECTROMETER



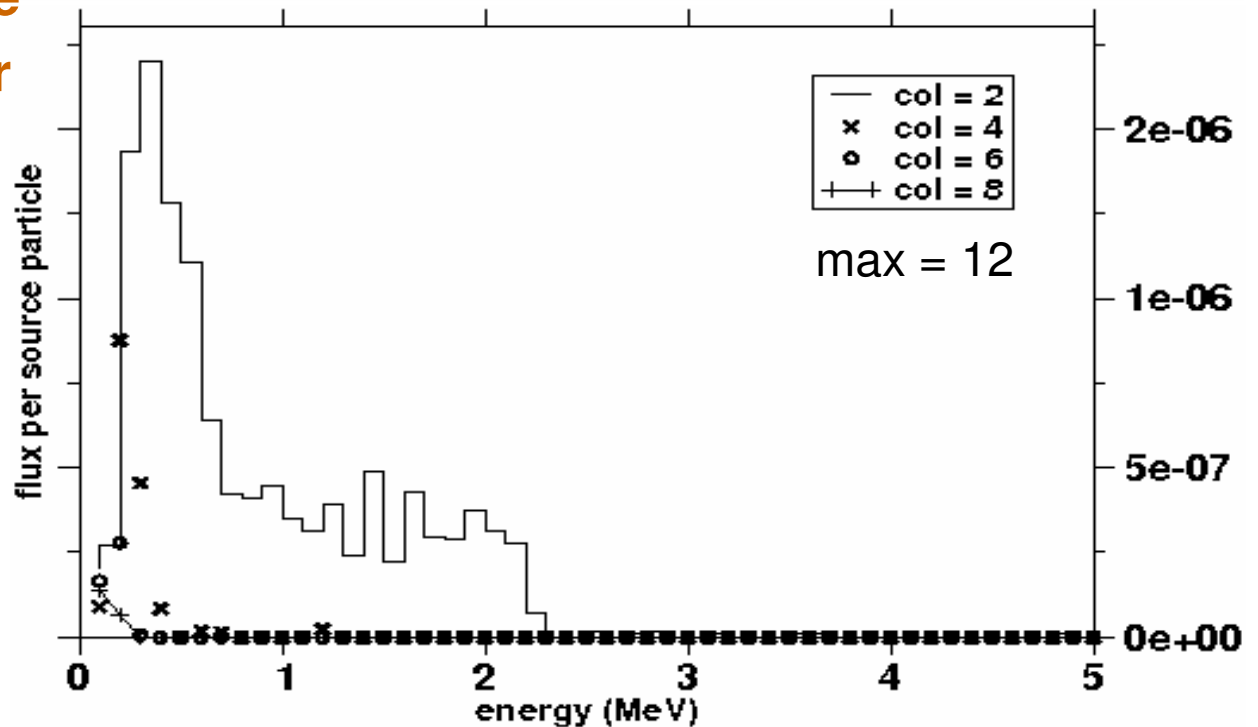
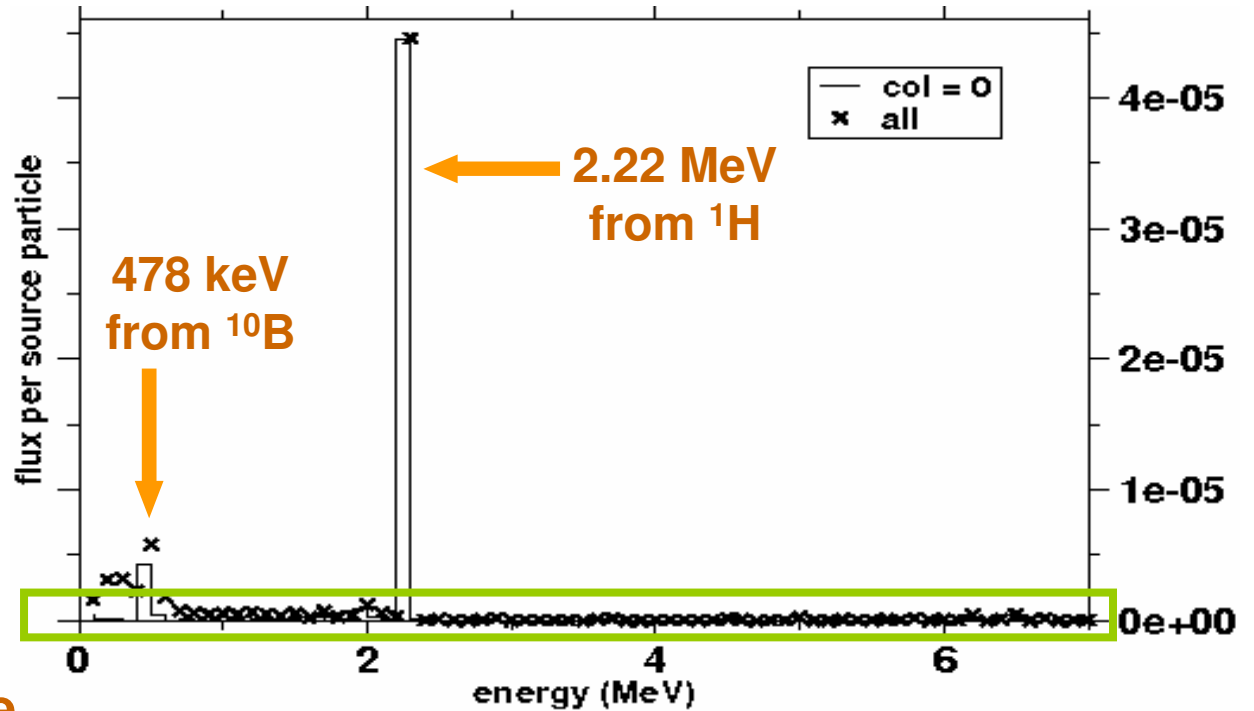
Thermal Neutron Capture Gammas — Target Nucleus ^1H

Target Nucleus= ^1H
 Strongest transition $E_\gamma=2223.25\pm 0.00$ keV $\%I_\gamma=100.00\pm 0.00$

E_γ (keV)	ΔE_γ (keV)	$I_\gamma/I_\gamma(\text{max})$ (%)	$\Delta(I_\gamma/I_\gamma(\text{max}))$
2223.25	0.00	100.0	0.00



Non-zero counts elsewhere (Spectra are always nicer & cleaner in the textbooks)



Thermal Neutron Capture Gammas — Target Nucleus ^{10}B

Target Nucleus= ^{10}B
Strongest transition $E_{\gamma}=4444.00\pm 2.00$ keV % I_{γ} unknown

E_{γ} (keV)	ΔE_{γ} (keV)	$I_{\gamma}/I_{\gamma}(\text{max})$ (%)	$\Delta(I_{\gamma}/I_{\gamma}(\text{max}))$
2120.00	0.00	4.6	0.21
2295.00	2.00	15.3	4.67
2534.00	2.00	23.0	3.26
4444.00	2.00	100.0	6.53
4711.00	2.00	38.4	2.35
5019.00	0.00	3.0	0.14
6739.00	2.00	29.2	2.05
7006.00	2.00	83.0	6.00
8916.00	2.00	23.0	3.26
11447.00	2.00	9.	1.60

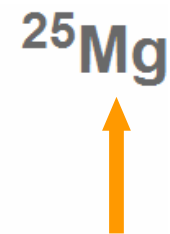
Thermal Neutron Capture Gammas — Target Nucleus ²⁵Mg

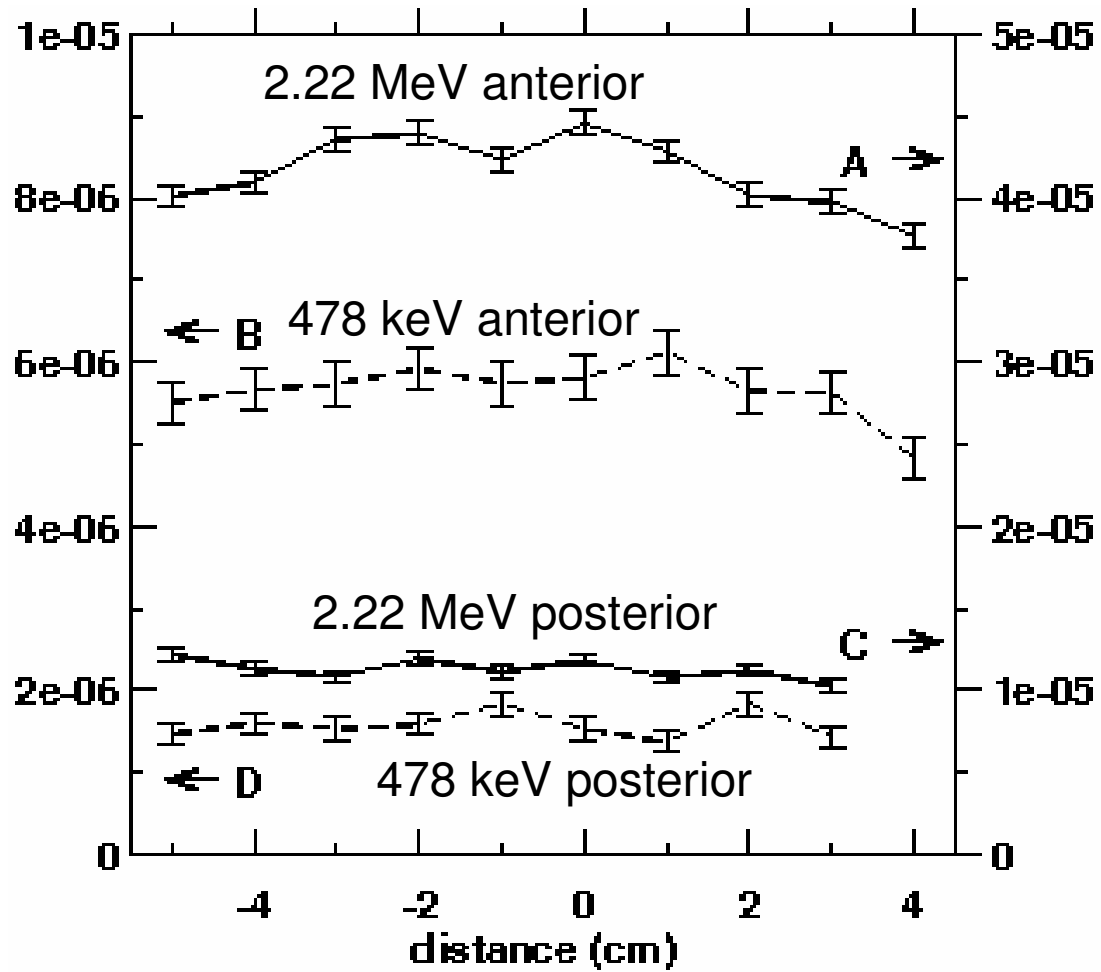
Target Nucleus=²⁵Mg
 Strongest transition E_γ=1808.68+-0.04 keV %I_γ=93.00+-3.73

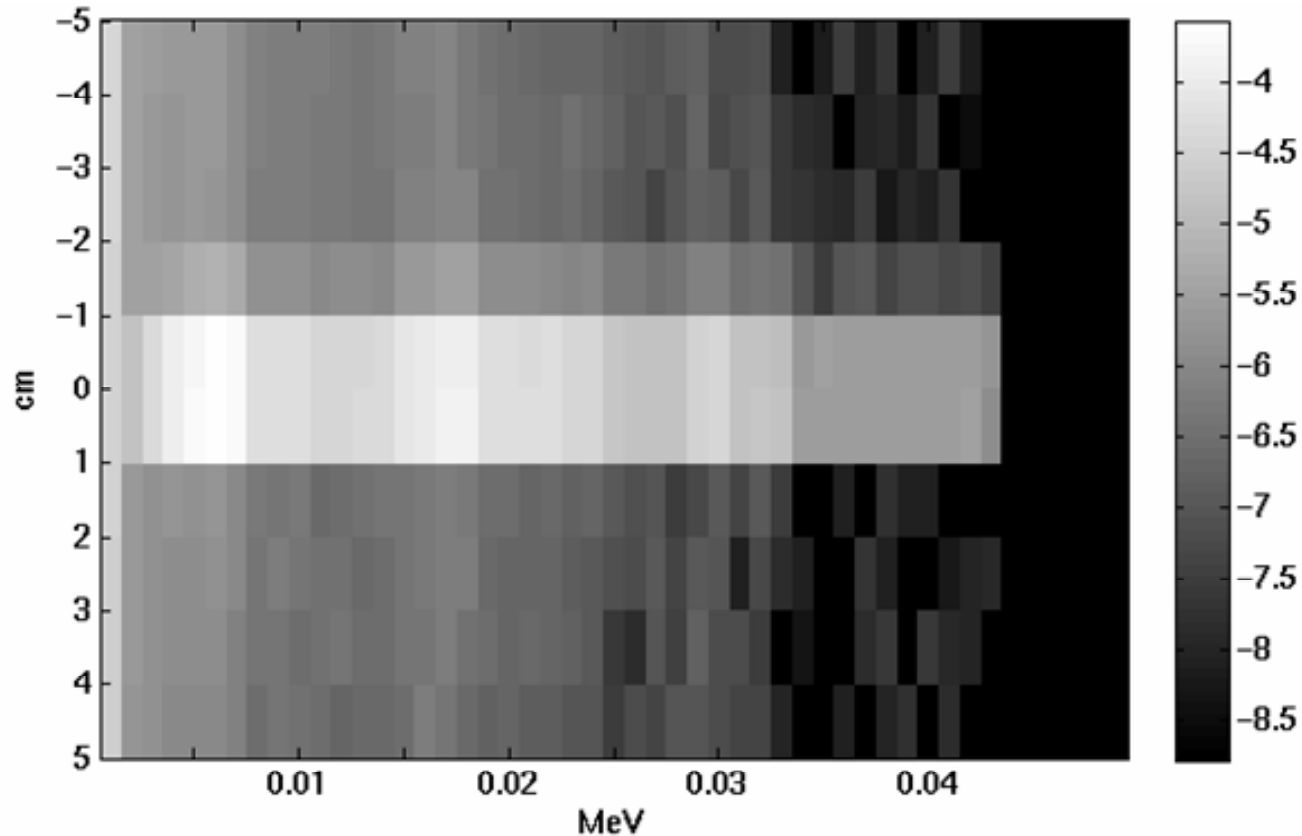
**ONE OF THE
 MAJOR
 ELEMENTS
 IN THE BODY**

E _γ (keV)	ΔE _γ (keV)	I _γ /I _γ (max) (%)	Δ(I _γ /I _γ (max))
287.50	.40	0.04	0.01
347.20	.12	0.06	0.01
374.43	.08	0.13	0.02
391.00	.00	0.02	0.00
409.40	.50	0.03	0.01
409.40	.50	0.03	0.01
411.30	.30	0.04	0.01
----- <i>MANY MORE</i> -----			
8153.54	0.05	16.0	1.06
8225.60	0.40	0.2	0.02
8316.40	0.80	0.1	0.02
8409.70	0.90	0.0	0.01
8502.20	0.30	0.3	0.04
8539.20	0.90	0.0	0.01
8552.20	0.30	0.3	0.03
8957.70	0.50	0.1	0.02
8996.50	0.90	0.0	0.01
9237.10	0.80	0.2	0.01
9282.68	0.06	2.4	0.16

**HIGHER THEN
 PEAK IN
 RADIOTHERAPY
 SPECTRA** →







The neutron spectra from 10 detectors, lined up 1 cm apart, placed perpendicular to the beam axis at the beam exit side of the head. The grayscale at each pixel denotes $\log_{10} N_{i,e}$ where $N_{i,e}$ is the flux per source particle detected in energy bin e by the i^{th} detector. A horizontal line profile drawn across the map would give the energy spectrum by the specific detector; a vertical line profile of the same map would give the detector-to-detector variation for the specific energy bin. Two peaks at 0.006 and 0.018 MeV are visible. By moving 1 cm perpendicularly away from the central axis of the beam, N dropped by two orders of magnitude. Data shown is from the simulation with one voxel of tumour containing 30 ppm ^{10}B .

**MCNPX SIMULATION
REPEATED WITH 11
DIFFERENT ¹⁰B
DISTRIBUTIONS:**

Q1. What gamma spectrum do we expect?

Q2. What neutron spectrum do we expect?

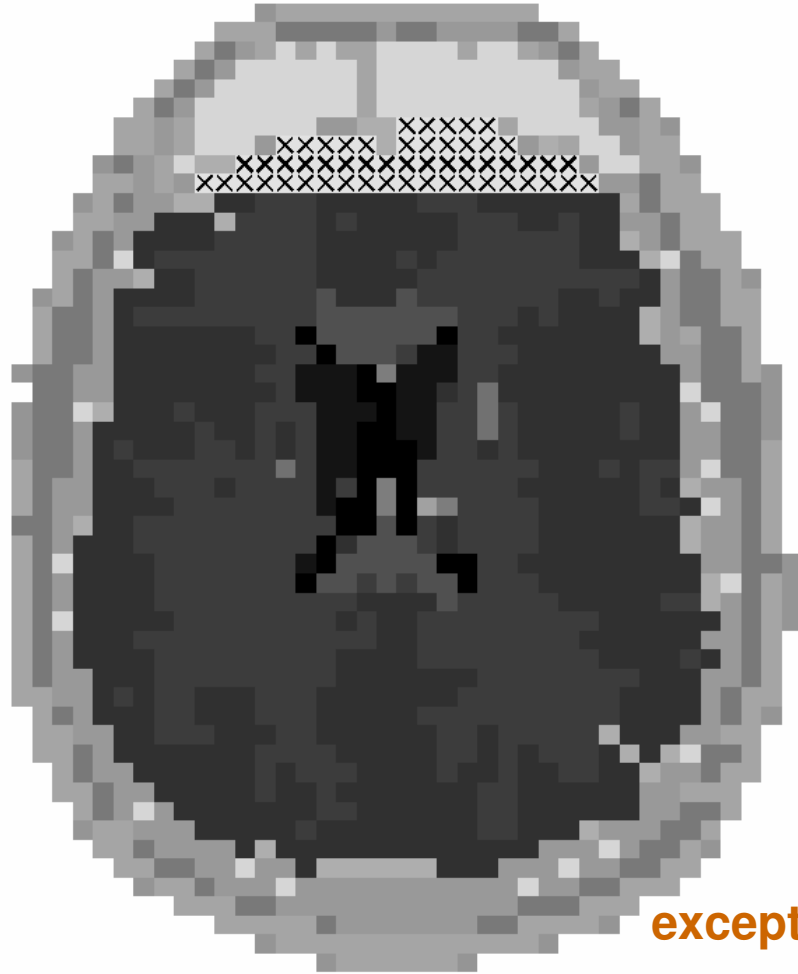
Q3. How do each change with varying ¹⁰B distributions?

except this

blood (ppm)	tissue (ppm)	tumour (ppm)	tumour (voxels)
15	10	0	0
15	10	20	1
15	10	30	1
15	10	40	1
15	10	30	5
15	10	50	149
15	10	30	149
15	10	50	88
15	10	30	88
15	10	50	1
0	0	0	0

1 voxel = 4 mm x 4 mm x 4 mm

**NO DETECTABLE DIFFERENCE
EVEN WITH A PERFECT
DETECTOR**

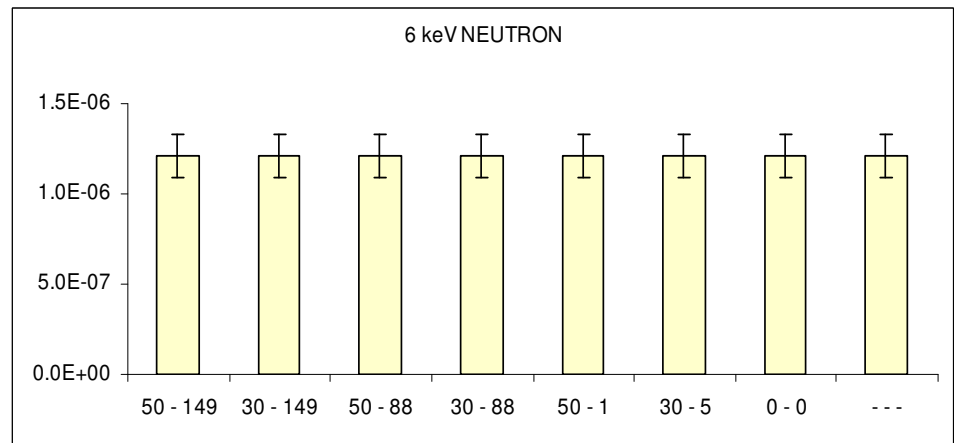
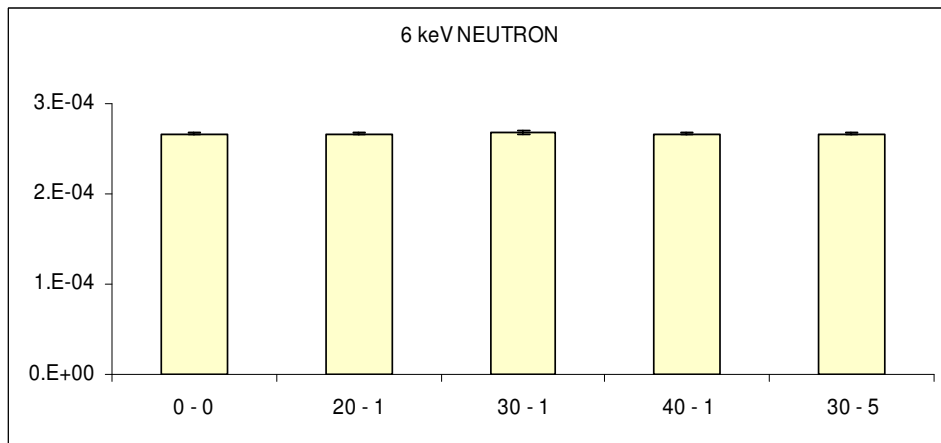
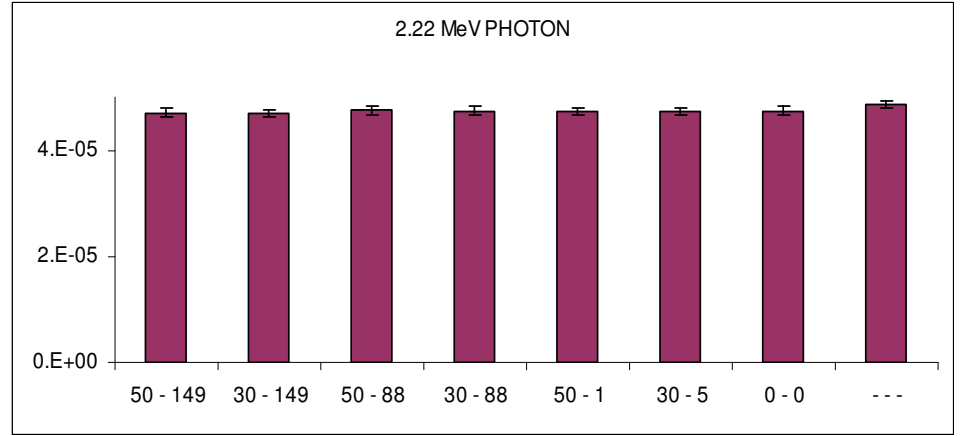
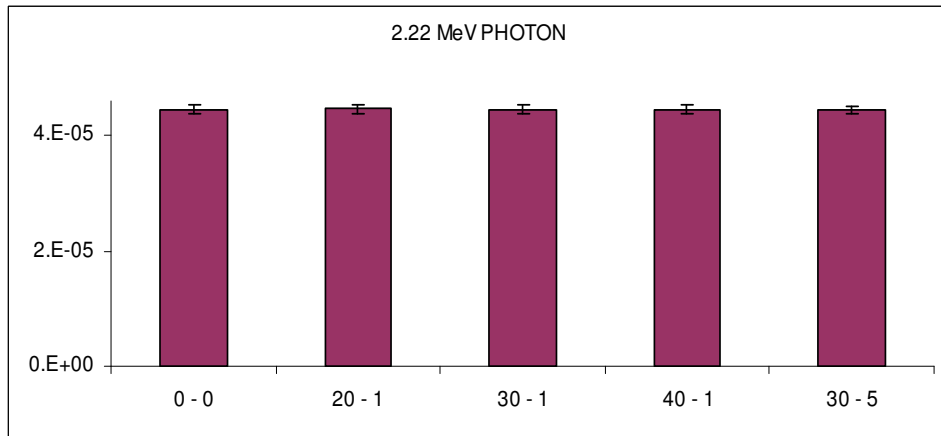
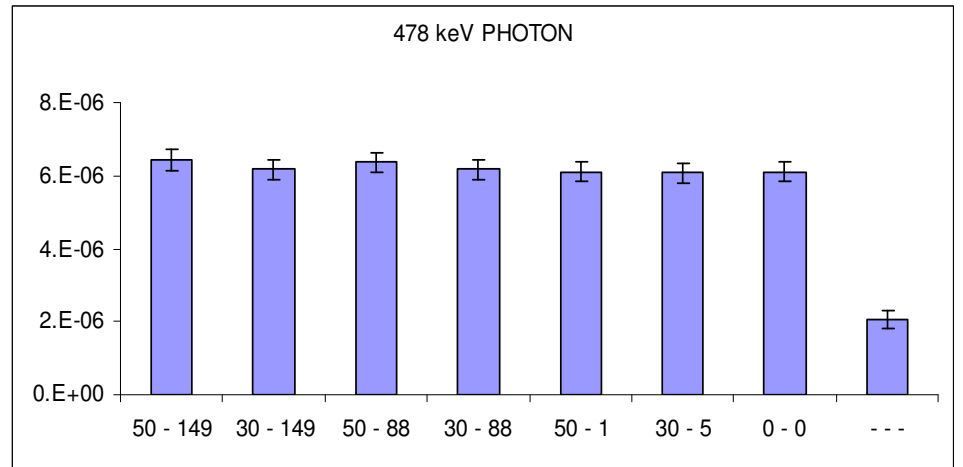
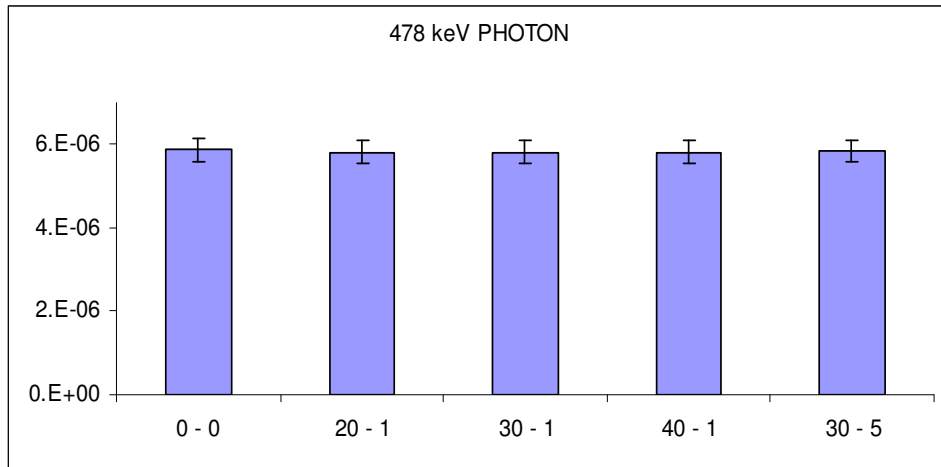


except this

blood (ppm)	tissue (ppm)	tumour (ppm)	tumour (voxels)
15	10	0	0
15	10	20	1
15	10	30	1
15	10	40	1
15	10	30	5
15	10	50	149
15	10	30	149
15	10	50	88
15	10	30	88
15	10	50	1
0	0	0	0

1 voxel = 4 mm x 4 mm x 4 mm

**NO DETECTABLE DIFFERENCE
EVEN WITH A PERFECT
DETECTOR**



BEHIND THE SCENES

TFC CHANGED FROM DEFAULT TO 478 keV and 2.22 MeV BINS

F4:P CELL-AVERAGED FLUX	F5:P POINT-DETECTOR FLUX
LESS EFFICIENT INDEED <i>FOM</i> > 10 ³ LOWER NO UNSAMPLED REGIONS IN LARGE SCORE TAIL OF EMPIRICAL HISTORY SCORE <i>PDF</i>	DETERMINISTIC ESTIMATOR <i>FAILED</i> PDF SLOPE TEST VOV TESTS EXCLUSION TO AVOID ZERO-RADIUS SINGULARITY

SUMMARY

NEUTRON BEAM



blood (ppm)	tissue (ppm)	tumour (ppm)	tumour (voxels)
15	10	0	0
15	10	20	1
15	10	30	1
15	10	40	1
15	10	30	5
15	10	50	149
15	10	30	149
15	10	50	88
15	10	30	88
15	10	50	1

GAMMA-RAY SPECTROMETER

NO DIFFERENCE



NEUTRON SPECTROMETER

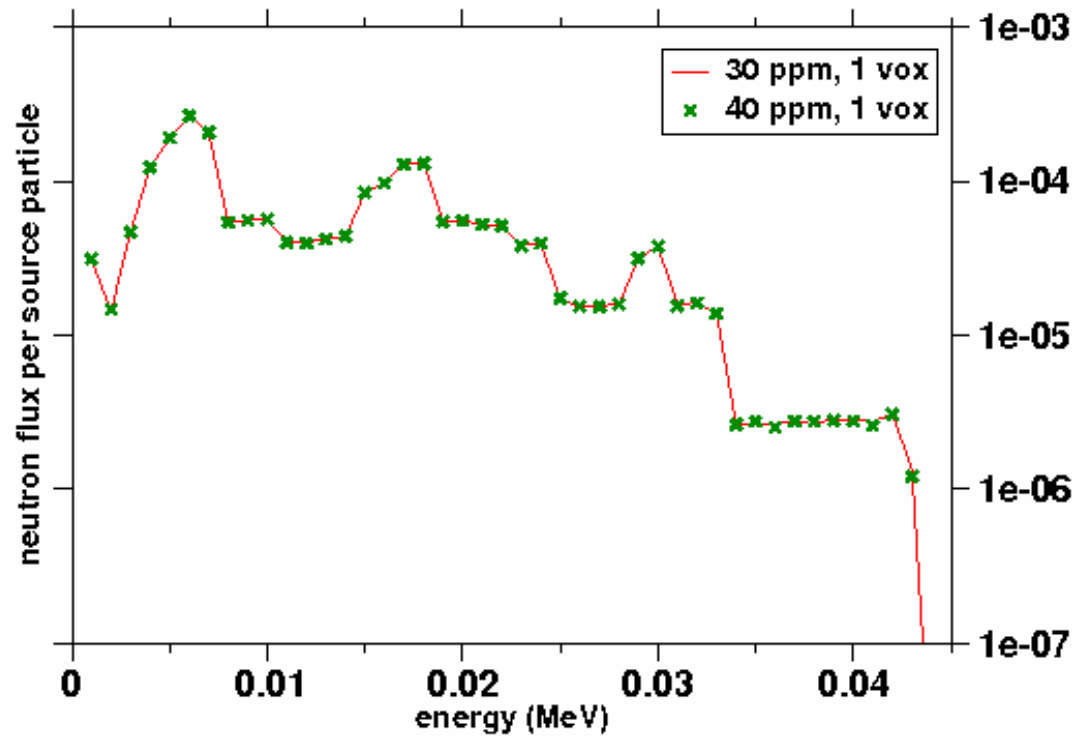
NO DIFFERENCE

GAMMA-RAY SPECTROMETER

NO DIFFERENCE

blood (ppm)	tissue (ppm)	tumour (ppm)	voxels
15	10	0	0
15	10	20	1
15	10	30	1
15	10	40	1
15	10	30	5
15	10	50	149
15	10	30	149
15	10	50	88
15	10	30	88
15	10	50	1
-	-	-	-

1 voxel = 4 mm x 4 mm x 4 mm



Thermal Neutron Capture Gammas — Target Nucleus ^{23}Na

Target Nucleus= ^{23}Na
 Strongest transition $E_\gamma=472.23\pm 0.03$ keV $\%I_\gamma=92.20\pm 1.20$

	E_γ (keV)	ΔE_γ (keV)	$I_\gamma/I_\gamma(\text{max})$ (%)	$\Delta(I_\gamma/I_\gamma(\text{max}))$
	91.01	03	49.89	.26
5073.38	²⁷² 0.10	¹¹ 03	^{0 00} 0.4	^{0 00} 0.01
5112.85	0.11		0.5	0.02
5336.90	0.70		0.0	0.00
5445.33	0.12		0.1	0.01
5599.85	0.24		0.1	0.01
5612.12	0.03		0.1	0.02
5614.15	0.03		0.4	0.03
5617.30	0.02		4.3	0.12
5683.80	0.70		0.0	0.00
5703.20	0.30		0.0	0.01
5774.41	0.17		0.2	0.02
5784.40	0.50		0.0	0.01
6395.30	0.06		20.1	0.29
6486.16	0.14		0.4	0.02

Thermal Neutron Capture Gammas — Target Nucleus ^{25}Mg

Atomic Weights and Isotopic Compositions for Magnesium

<u>Isotope</u>	<u>Relative Atomic Mass</u>	<u>Isotopic Composition</u>	<u>Standard Atomic Weight</u>	<u>Notes</u>
12 Mg 24	23.985 041 90(20)	78.99(4)	24.3050(6)	
25	24.985 837 02(20)	10.00(1)		
26	25.982 593 04(21)	11.01(3)		
	409.40	.50	0.05	0.01
	411.30	.30	0.04	0.01
	8153.54	0.05	16.0	1.06
	8225.60	0.40	0.2	0.02
	8316.40	0.80	0.1	0.02
	8409.70	0.90	0.0	0.01
	8502.20	0.30	0.3	0.04
	8539.20	0.90	0.0	0.01
	8552.20	0.30	0.3	0.03
	8957.70	0.50	0.1	0.02
	8996.50	0.90	0.0	0.01
	9237.10	0.80	0.2	0.01
	9282.68	0.06	2.4	0.16