Boron Concentration measurements in tissues by charged particles spectrometry

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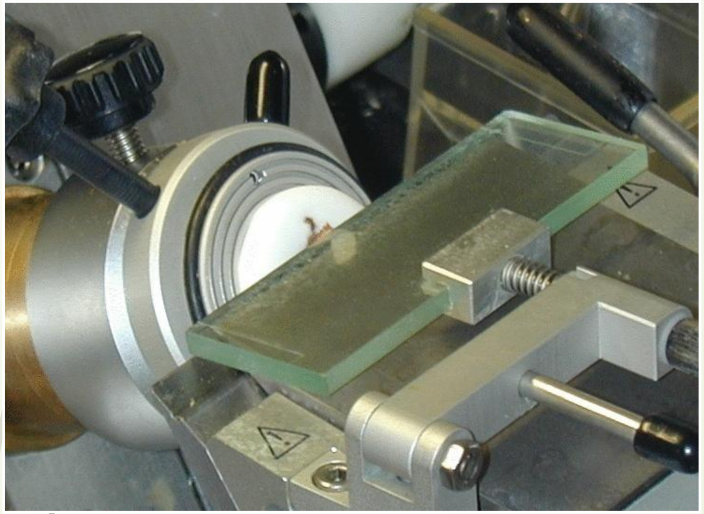
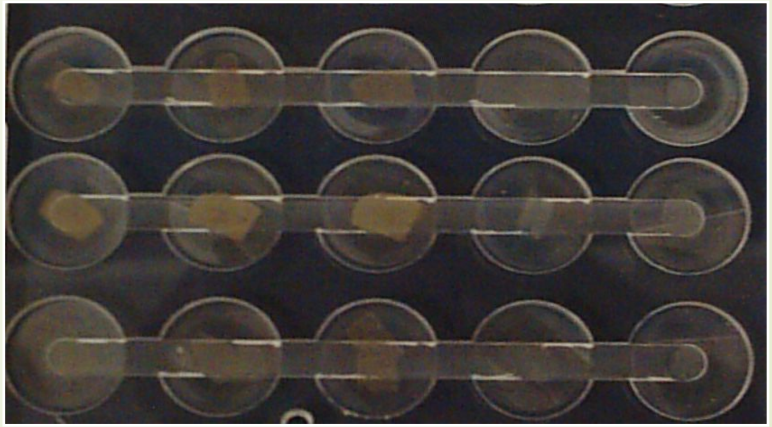
The samples

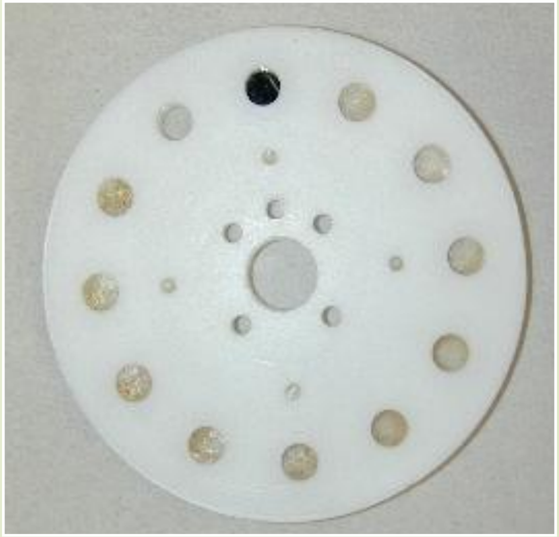
Biopsies taken from treated animals or from patients are divided into smaller samples of about 1 cm3 and frozen in liquid nitrogen. Then, 70-µm-thick sections are produced with a Leica cryostat at a temperature of -20 C and deposited on 100-µm-thick Mylar disks

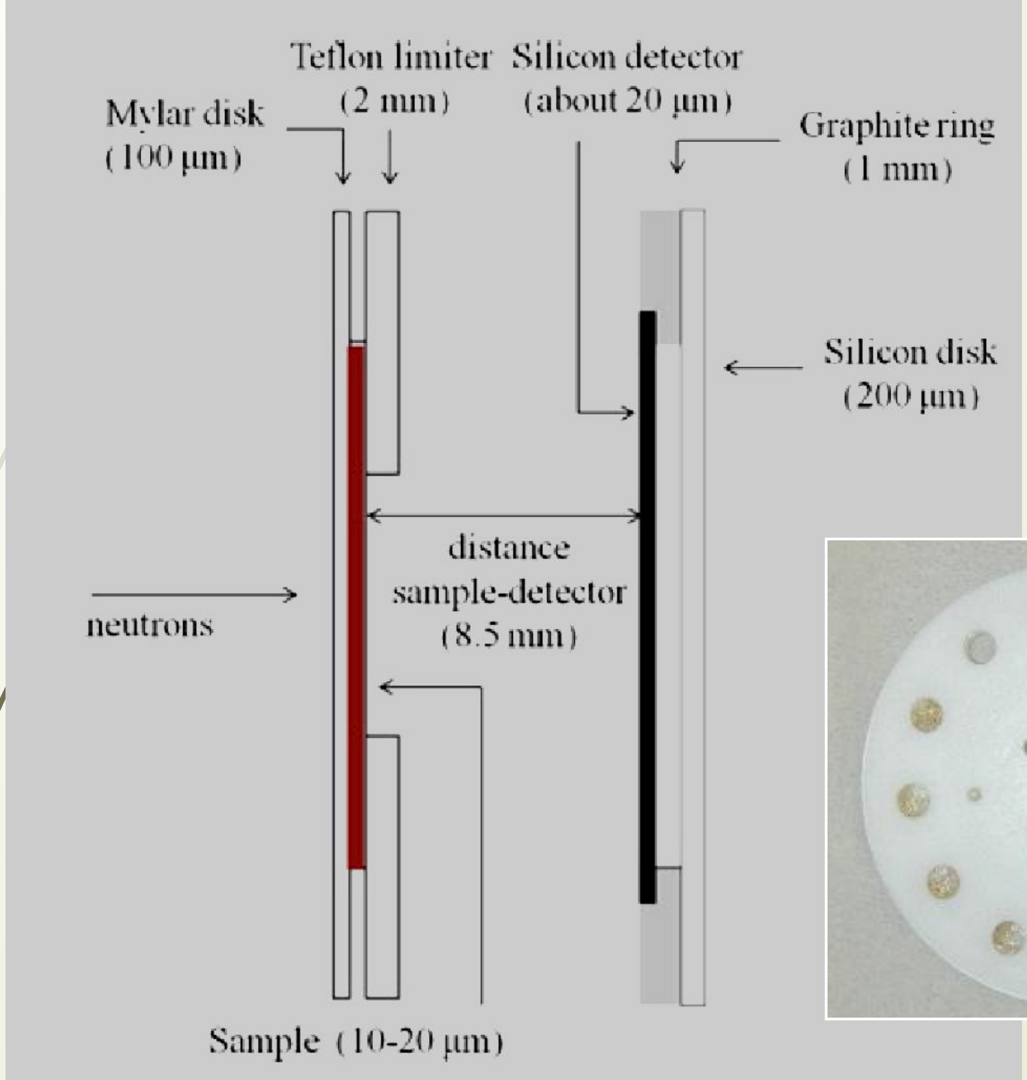


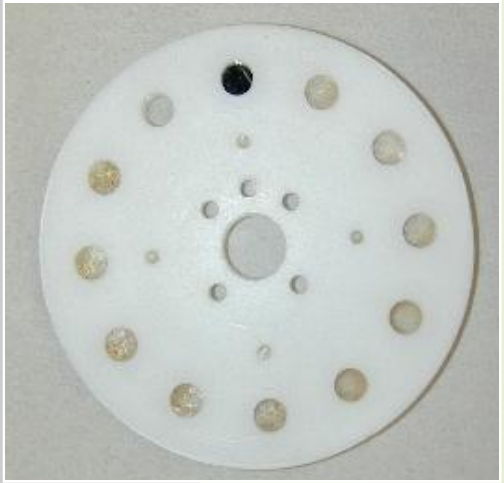
Sequential slices are cut in this order:

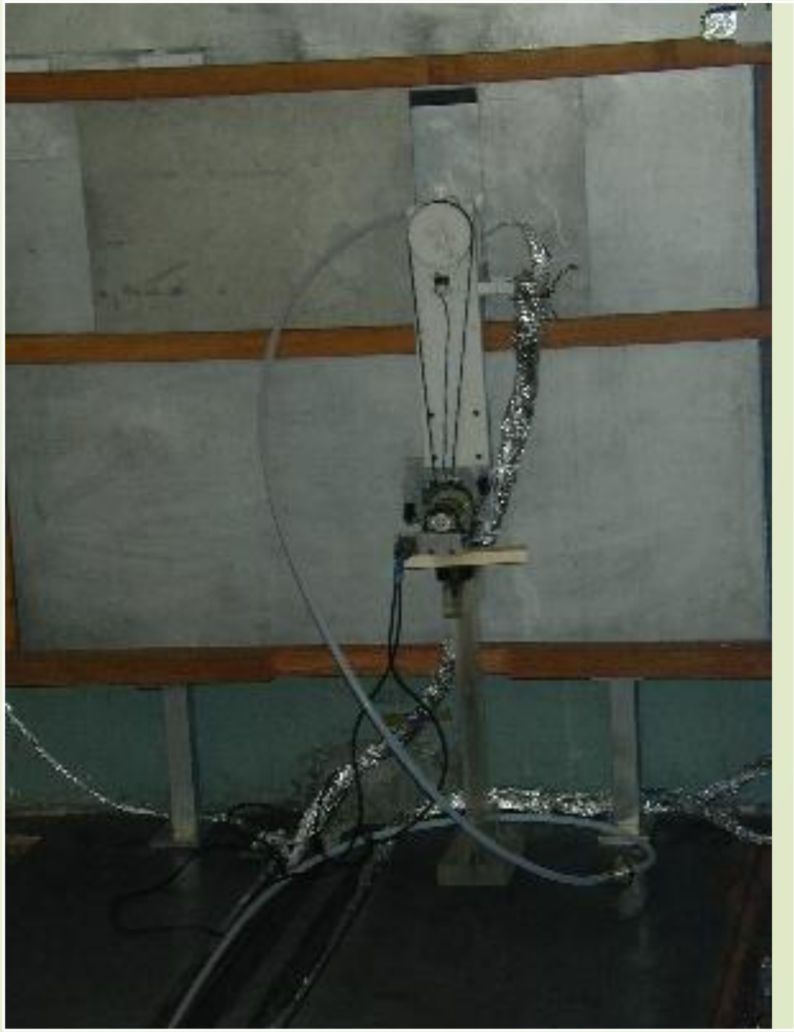
- 70 µm for spectrometry -> mylar disks
- 10 µm for histology
- 70 µm for autoradiography -> sensitive film





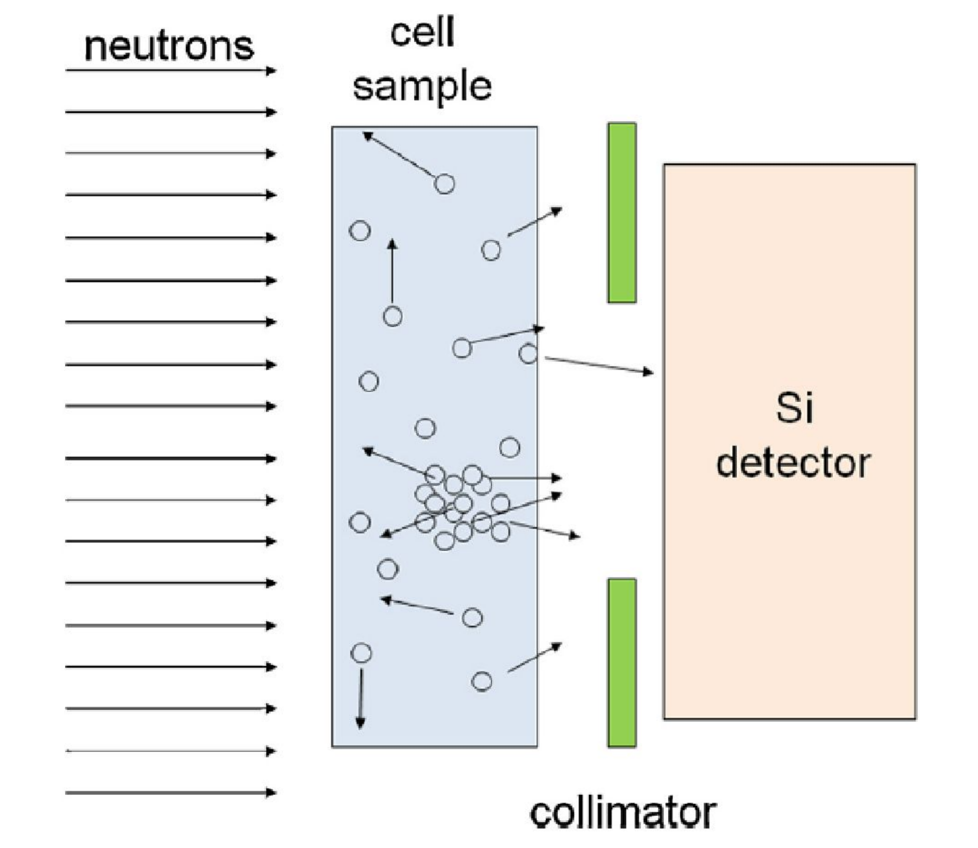

Teflon limiter
(2 mm)
Silicon detector
(about 20 µm)
Mylar disk
(100 µm)
Graphite ring
(1 mm)
Silicon disk
(200 µm)
distance
sample-detector
(8.5 mm)
neutrons
Sample (10-20 µm)





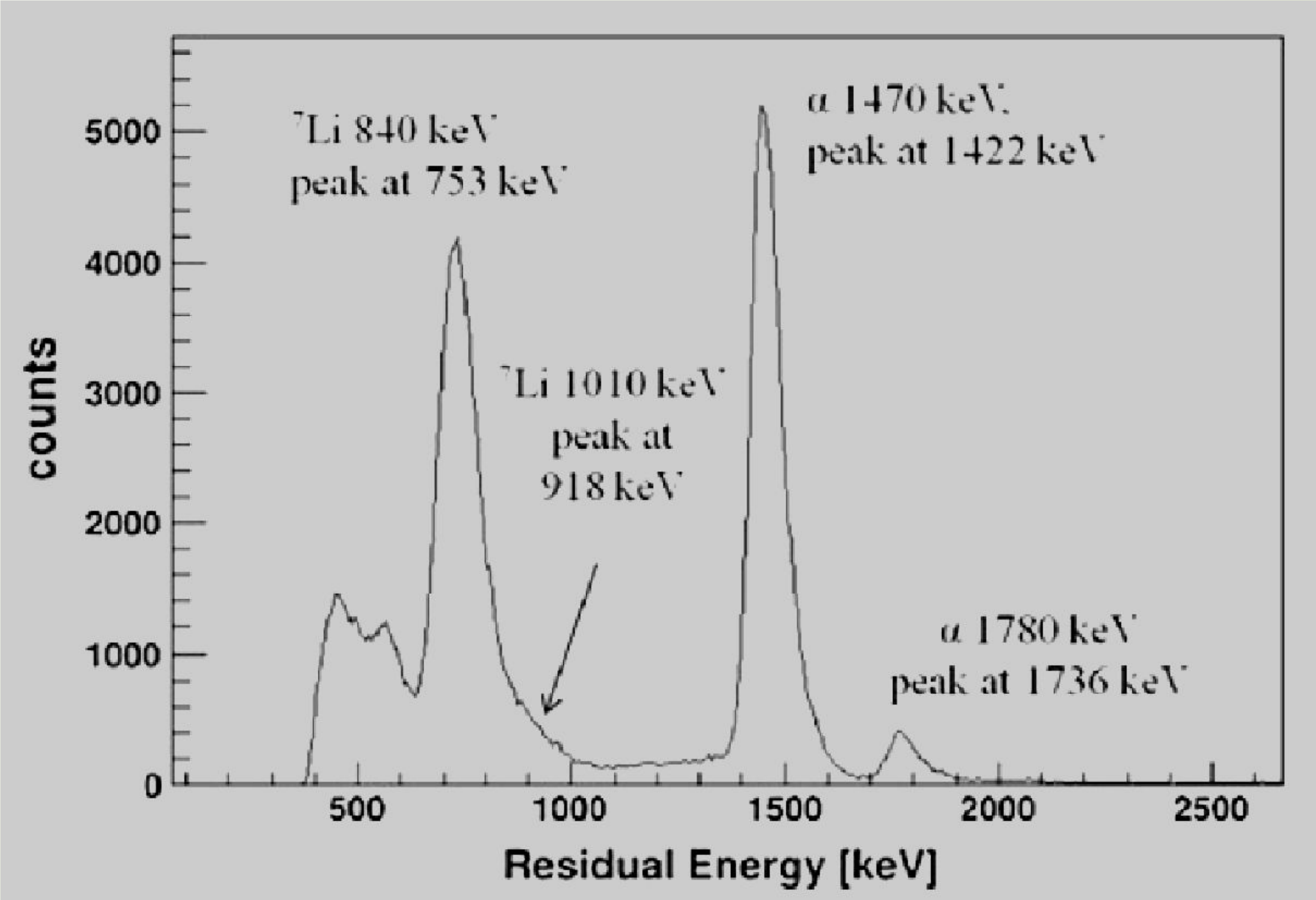
Principal reactions with positive Q-values that contribute to charged particle emission in biological tissue, during thermal neutron irradiation

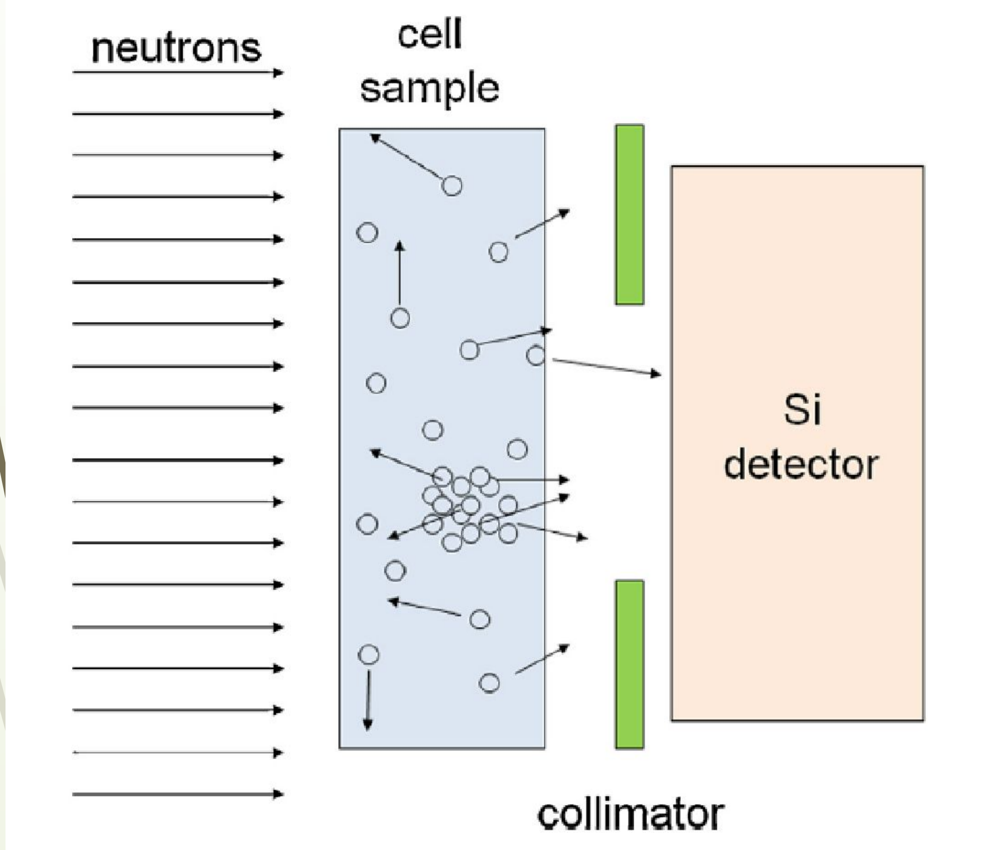
Reaction	Thermal microscopic cross section (barn)	Q-value (keV)	Isotopic abundance (%)	Elemental p weight of lu
$^{14}N(n,p)^{14}C$	1.8	630	99.634	3.1
$^{17}O(n,\alpha)^{14}C$	0.24	1,800	0.038	74.9
$^{32}S(n,p)^{33}P$	0.002	530	95.02	0.3
$^{32}S(n,\alpha)^{29}Si$	0.007	1,500	95.02	0.3
$^{33}S(n,\alpha)^{30}Si$	0.2	3,500	0.75	0.3
$^{35}Cl(n,p)^{35}S$	0.4	620	75.77	0.3
$^{40}K(n,p)^{40}Ar$	4.0	930	0.012	0.2
$^{10}B(n,\alpha)^{7}Li$	3,837	2,790	19.9	<0.5 ppm

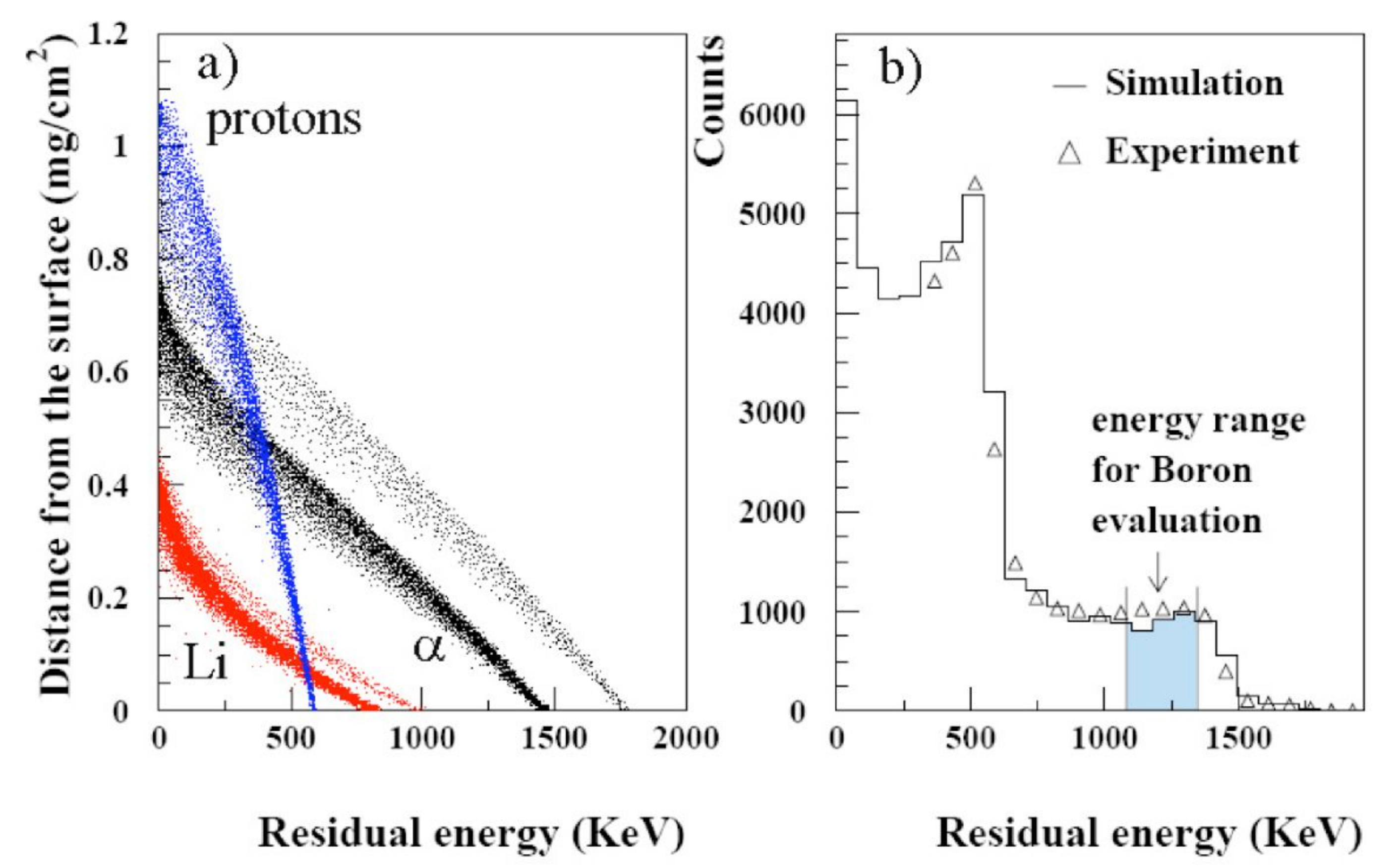


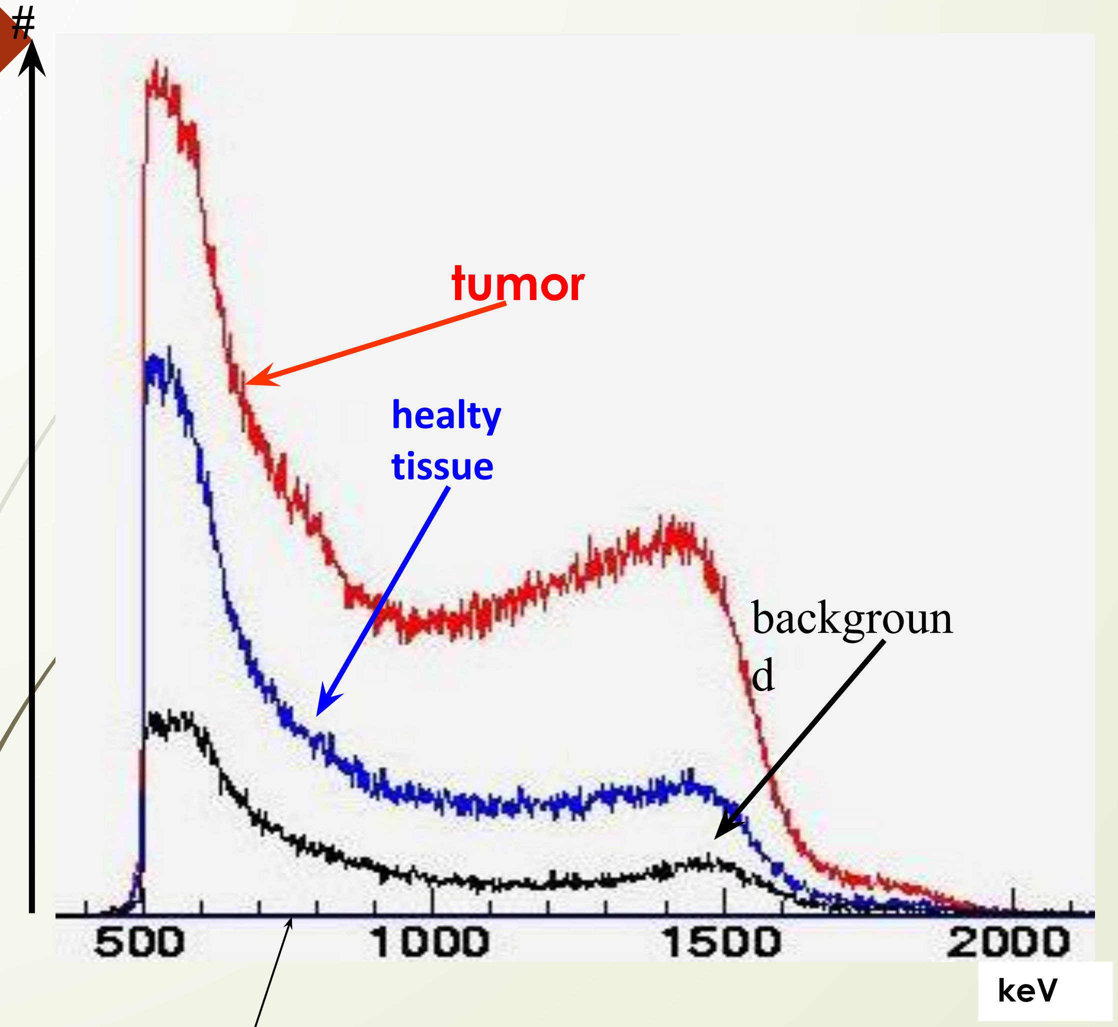
Boron standard

Boron implanted in Silicon




neutrons
cell
sample
Si
detector
collimator

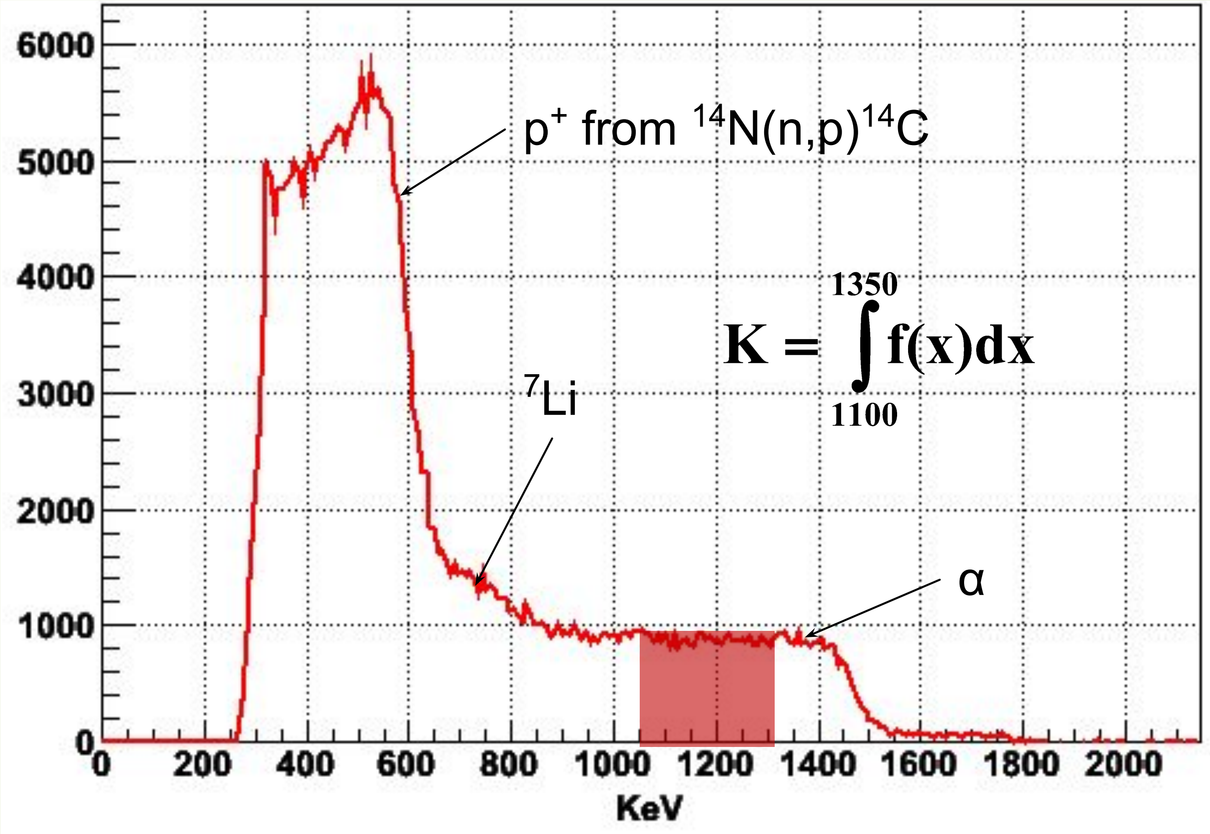

a)
protons
Li
α
Distance from the surface (mg/cm²)
Residual energy (KeV)
b)
Simulation
Experiment
energy range
for Boron
evaluation
Counts
Residual energy (KeV)



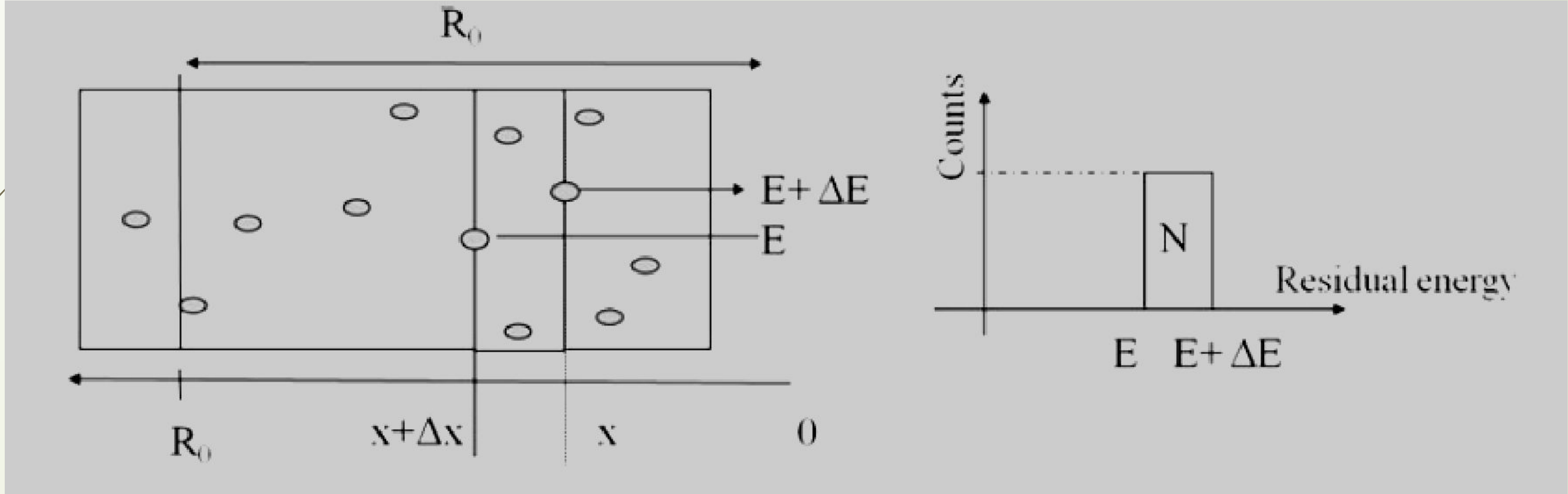
For every measurement, the following spectra are collected:

- Calibration sample: a superficial boron implantation on silicon
- Background: a mylar disk without tissue
- 10 tissue samples

The calibration sample made up of a ^{10}B implantation in Si is used to calibrate the experimental spectra in energy.

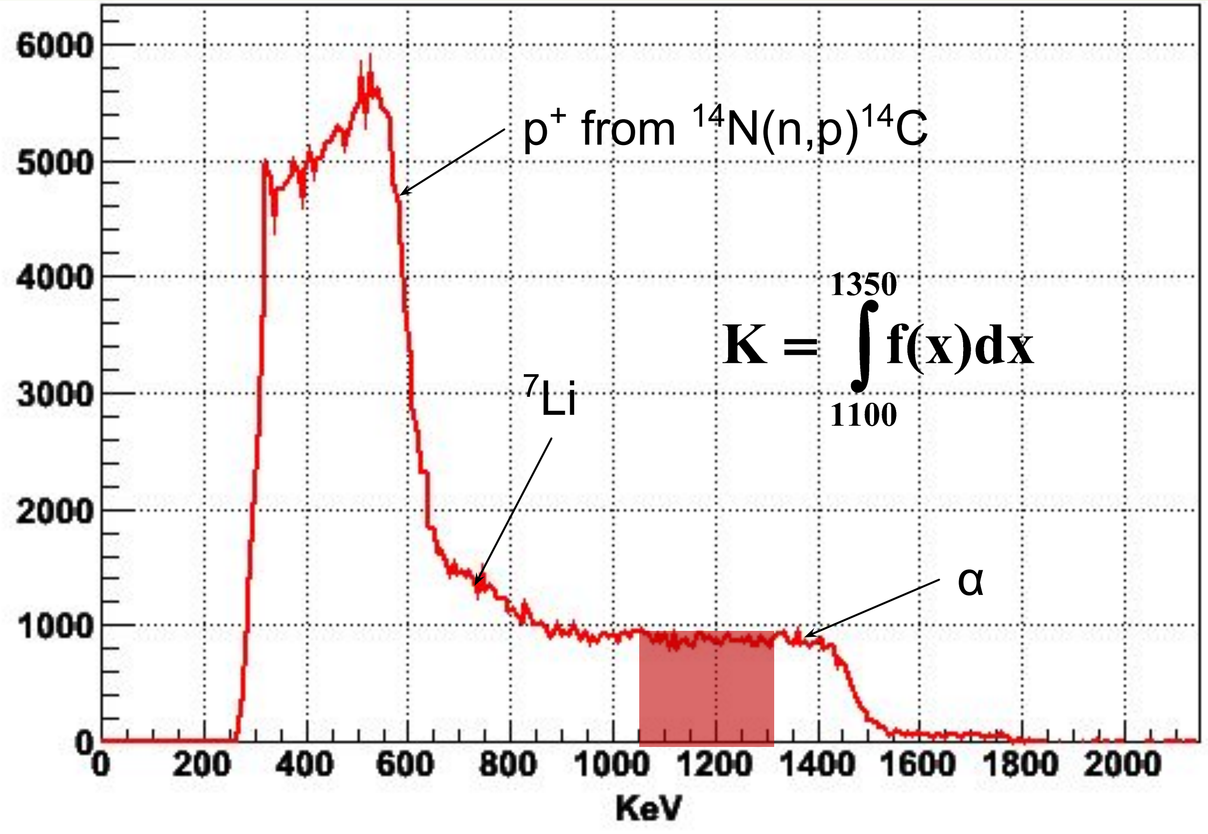


6000
5000
4000
3000
2000
1000
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
KeV
p+ from 14N(n,p)14C
7Li
α
$K = \int_{1100}^{1350} f(x)dx$



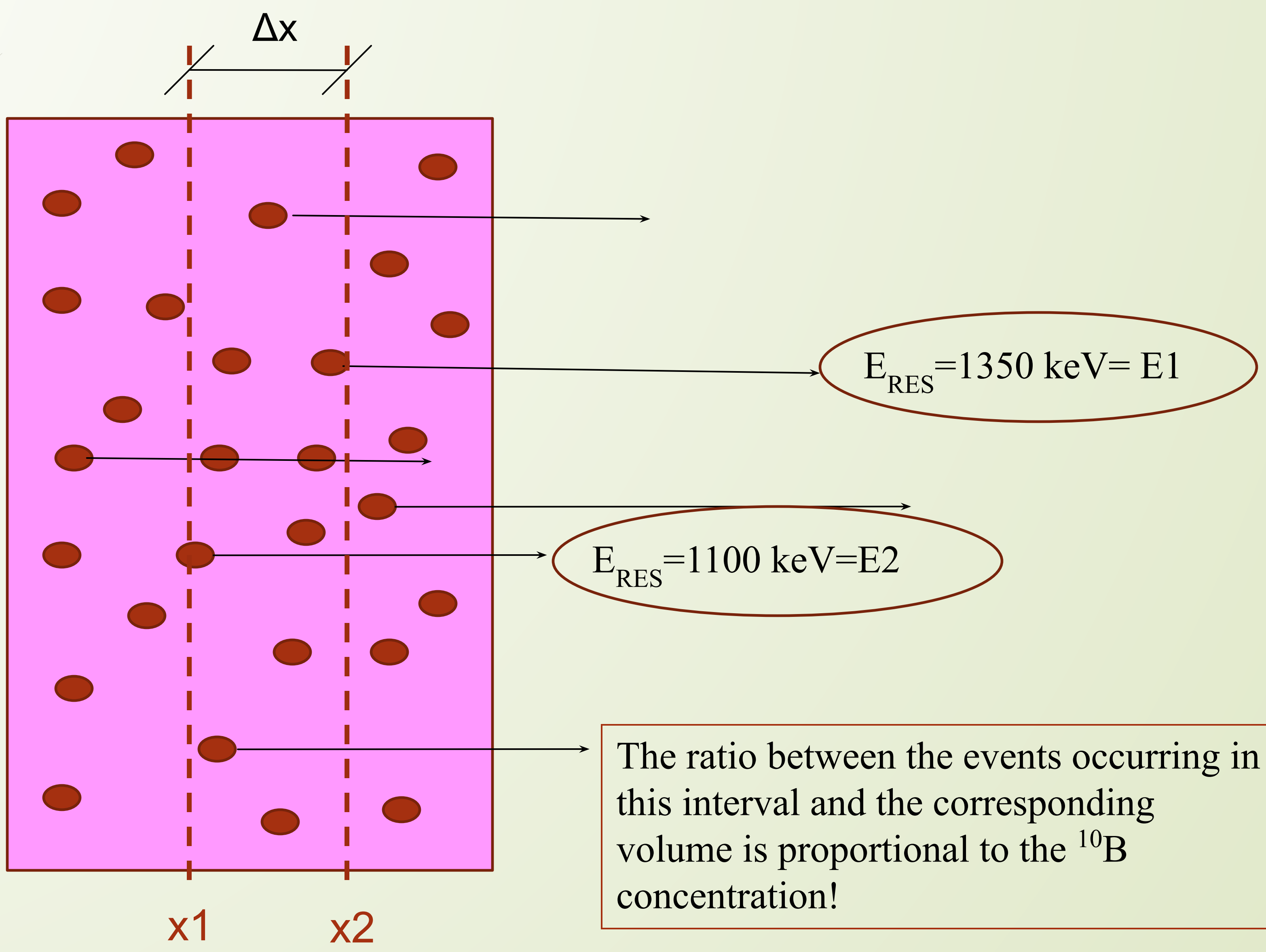
R0
E+ ΔE
E
R0
x+Δx
x
0
Counts
N
Residual energy
E
E+ ΔE

α contribution to the spectra the highlighted zone represents the particles that arrived at the detector with RESIDUAL ENERGY BETWEEN 1100 and 1350 keV.



$$K = \int_{1100}^{1350} f(x)dx$$

Using the residual energy as a function of the distance covered in lung tissue, the Δx from which the K particles came, can be calculated.



The ratio between the events occurring in this interval and the corresponding volume is proportional to the ^{10}B concentration!

$$\mathrm{conc_F} = \frac{K_\mathrm{d}}{\eta \cdot \sigma \cdot \phi \cdot S_\mathrm{d}} \cdot \frac{\Delta E_\mathrm{d}}{\Delta(\rho_\mathrm{d} x_\mathrm{d})} \cdot \frac{A_\mathrm{W}}{N_\mathrm{A}} \cdot \boxed{\frac{m_\mathrm{td}}{m_\mathrm{tf}}}$$

0.23 measured

Where:
K is the number of events in the interval ΔE;
ΔE/Δ(ρx) is the α stopping power in dry tissue;
η is the efficiency of the detection system;
σ is the cross section of the thermal n reaction on ^{10}B;
φ is the thermal neutron flux;
S is the surface of the sample seen by the detector;
A_w is the atomic weight of ^{10}B;
N_A is the Avogadro number.

$$\mathrm{conc_F} = \frac{K_\mathrm{d}}{\eta \cdot \sigma \cdot \phi \cdot S_\mathrm{d}} \cdot \boxed{\frac{\Delta E_\mathrm{d}}{\Delta(\rho_\mathrm{d} x_\mathrm{d})}} \cdot \frac{A_\mathrm{W}}{N_\mathrm{A}} \cdot \frac{m_\mathrm{td}}{m_\mathrm{tf}}$$

measured in the actual tissue

Where:
K is the number of events in the interval ΔE;
ΔE/Δ(ρx) is the α stopping power in dry tissue;
η is the efficiency of the detection system;
σ is the cross section of the thermal n reaction on ^{10}B;
φ is the thermal neutron flux;
S is the surface of the sample seen by the detector;
A_w is the atomic weight of ^{10}B;
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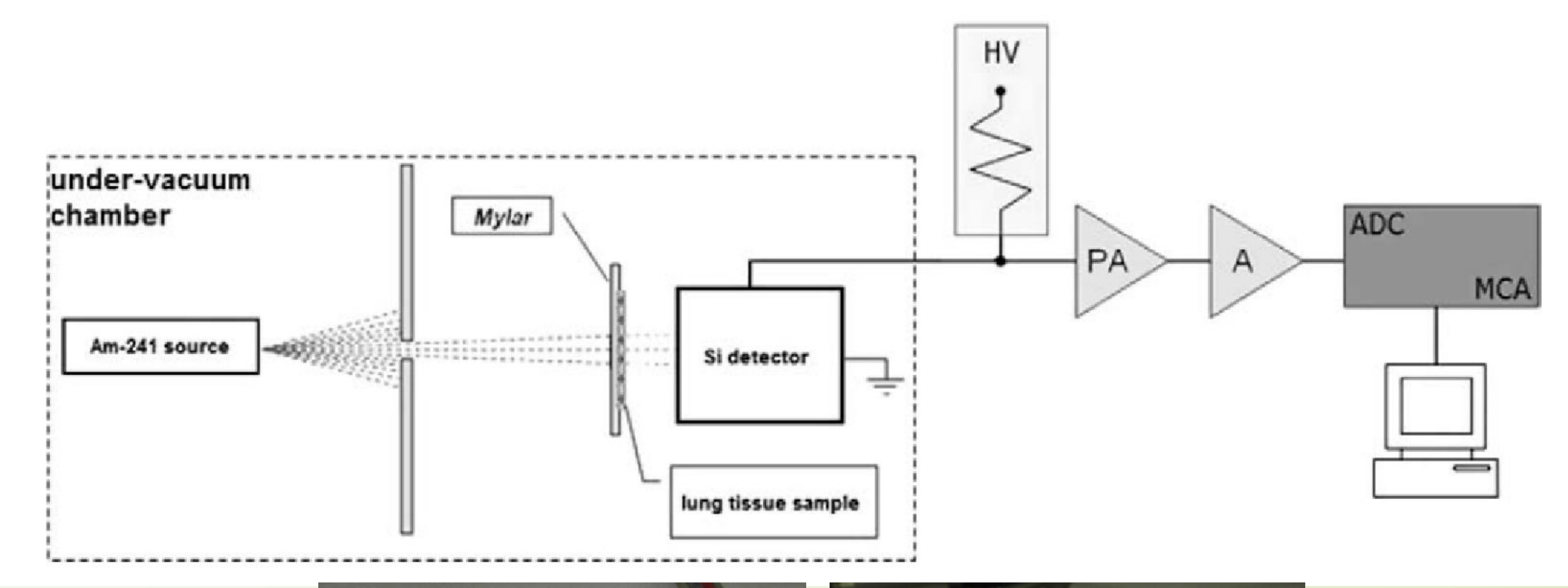
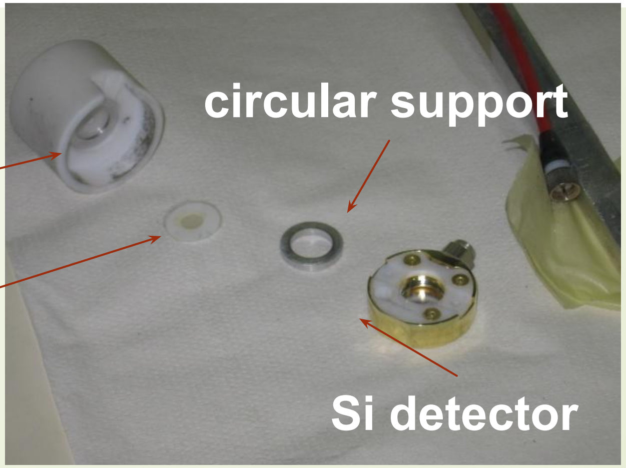
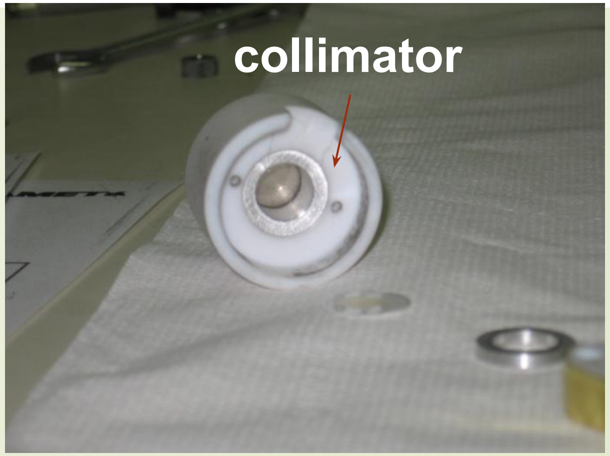
$$\mathrm{conc_F} = \frac{K_\mathrm{d}}{\eta \cdot \sigma \cdot \phi \cdot S_\mathrm{d}} \cdot \boxed{\frac{\Delta E_\mathrm{d}}{\Delta(\rho_\mathrm{d} x_\mathrm{d})}} \cdot \frac{A_\mathrm{W}}{N_\mathrm{A}} \cdot \frac{m_\mathrm{td}}{m_\mathrm{tf}}$$

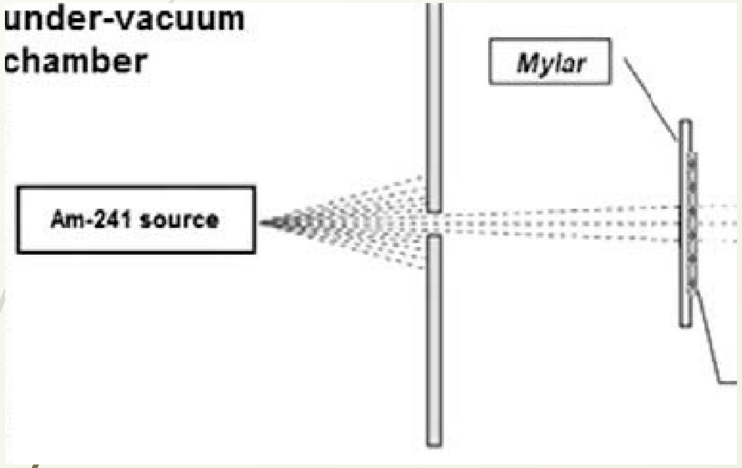


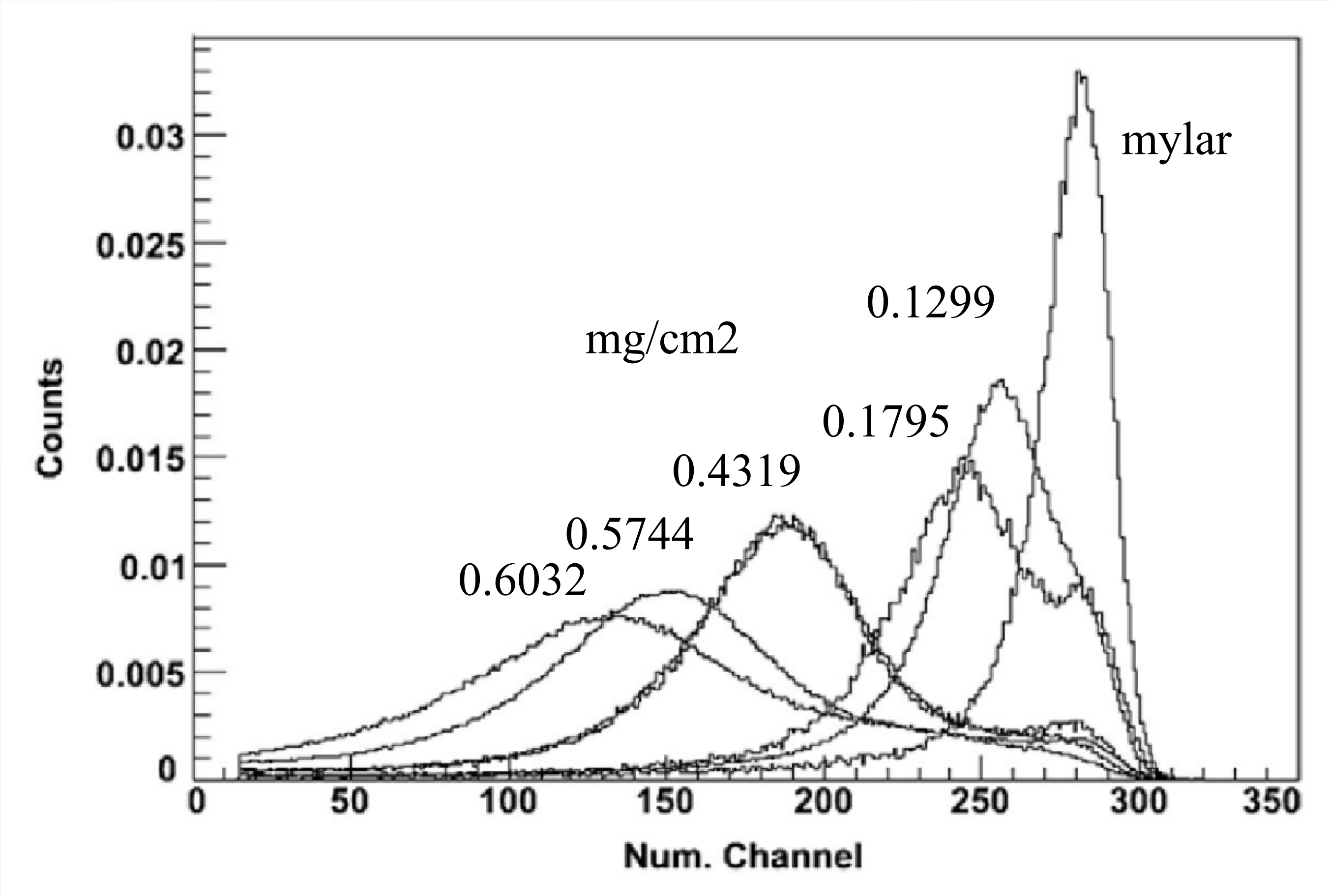
source

support for the sample (mylar)

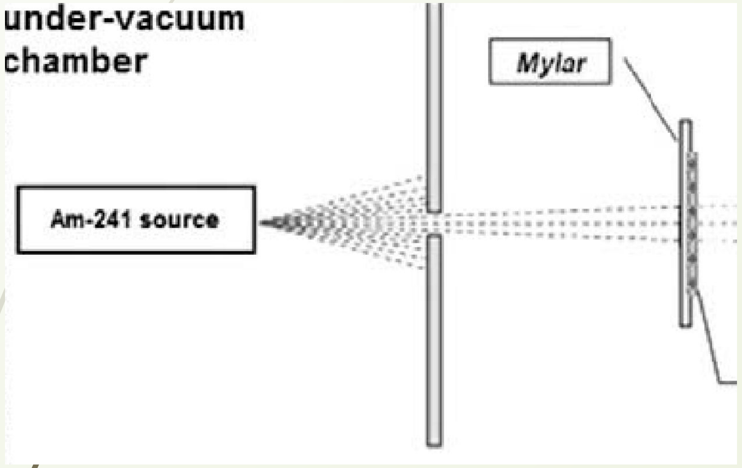


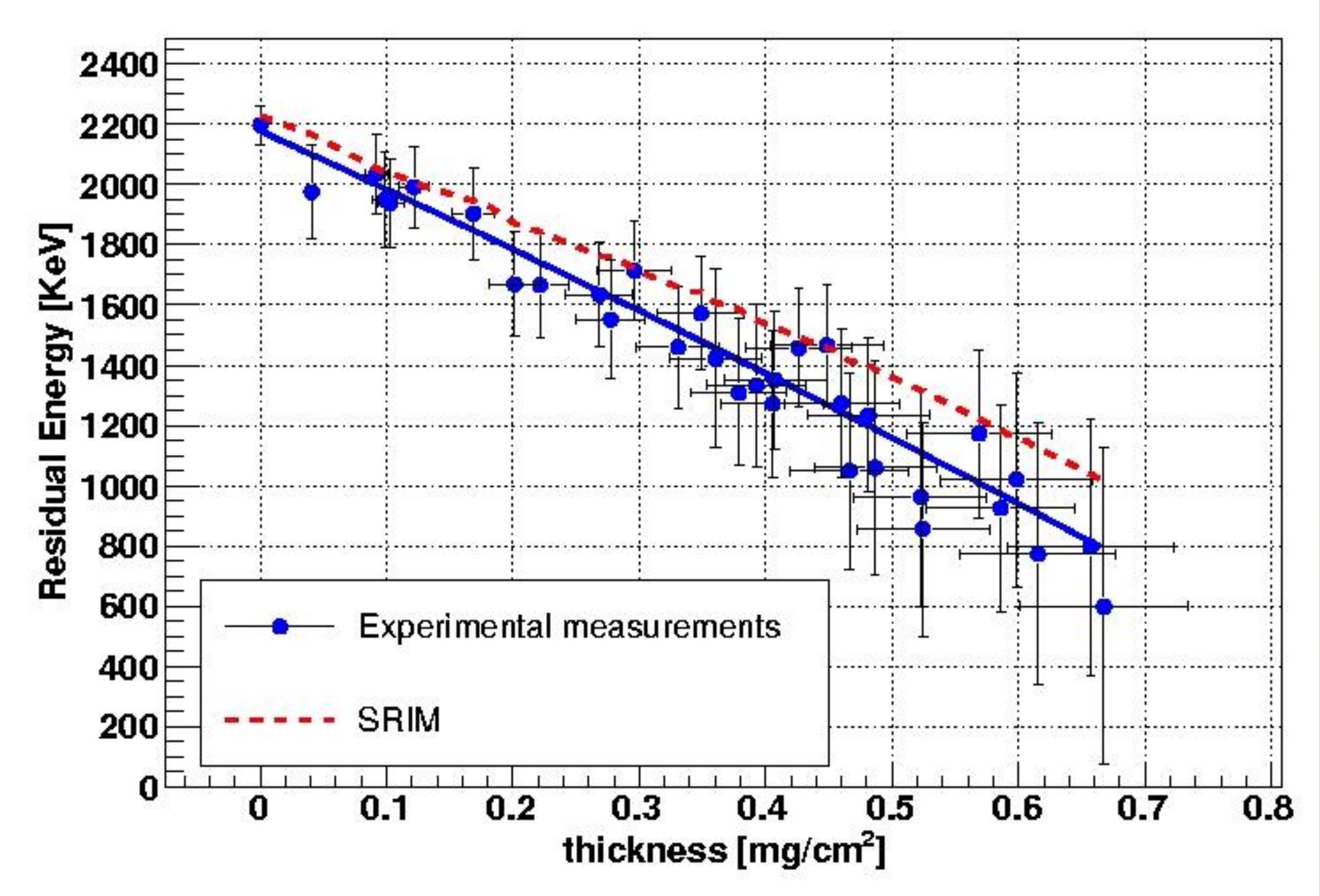



under-vacuum
chamber
Mylar
Am-241 source


mylar
0.1299
mg/cm2
0.1795
0.4319
0.5744
0.6032
Counts
Num. Channel
0
0.005
0.01
0.015
0.02
0.025
0.03
0
50
100
150
200
250
300
350

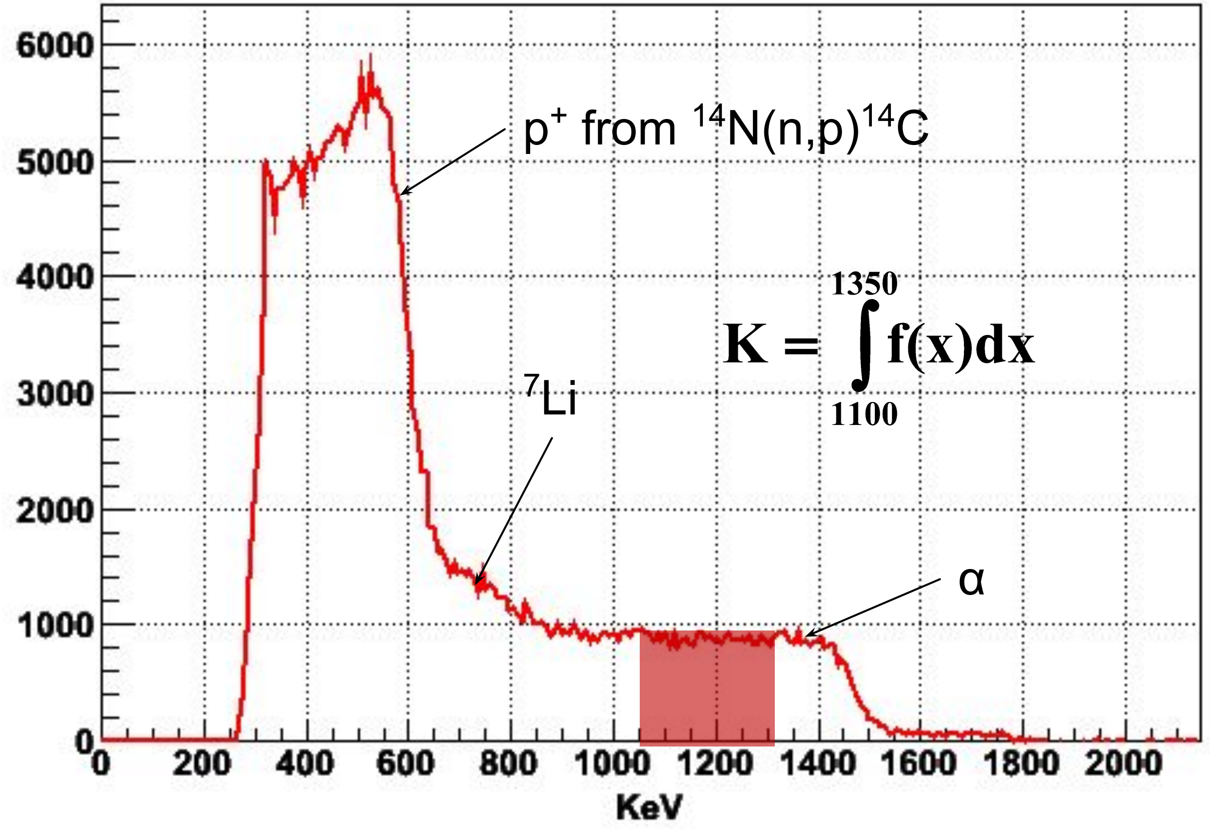
The residual energy as a function of the tissue thickness was obtained by experimental measurements using a ^{241}Am source and by MC methods using SRIM. The boron concentration obtained with these two curves differ by 5%.





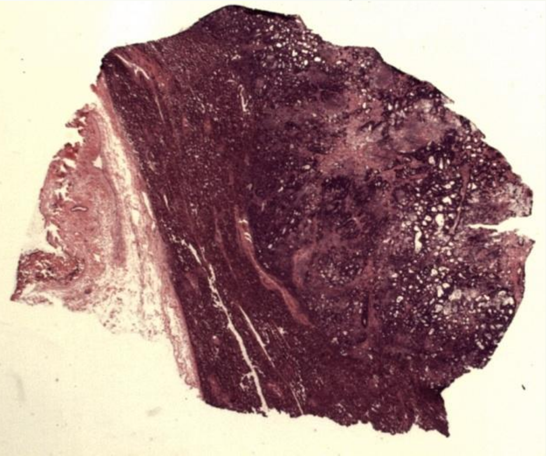
$$\frac{\Delta E_d}{\Delta(\rho_d x_d)}$$

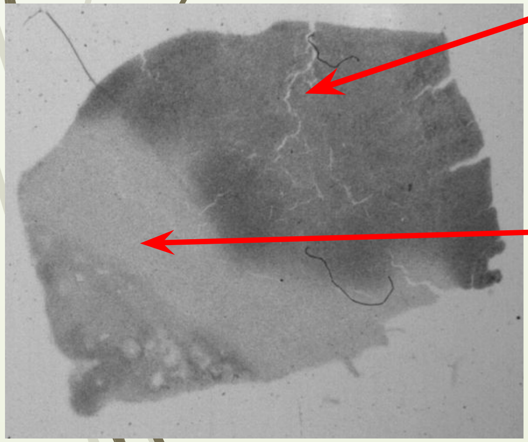
$$E_{res}\,[\mathrm{keV}] = 2183(\pm 50) - 1997(\pm 178) \cdot \Delta(\rho x)[\mathrm{mg/cm^2}]$$



$$\mathrm{conc_F} = \frac{K_\mathrm{d}}{\eta \cdot \sigma \cdot \phi \cdot S_\mathrm{d}} \cdot \frac{\Delta E_\mathrm{d}}{\Delta(\rho_\mathrm{d} x_\mathrm{d})} \cdot \frac{A_\mathrm{W}}{N_\mathrm{A}} \cdot \frac{m_\mathrm{td}}{m_\mathrm{tf}}$$

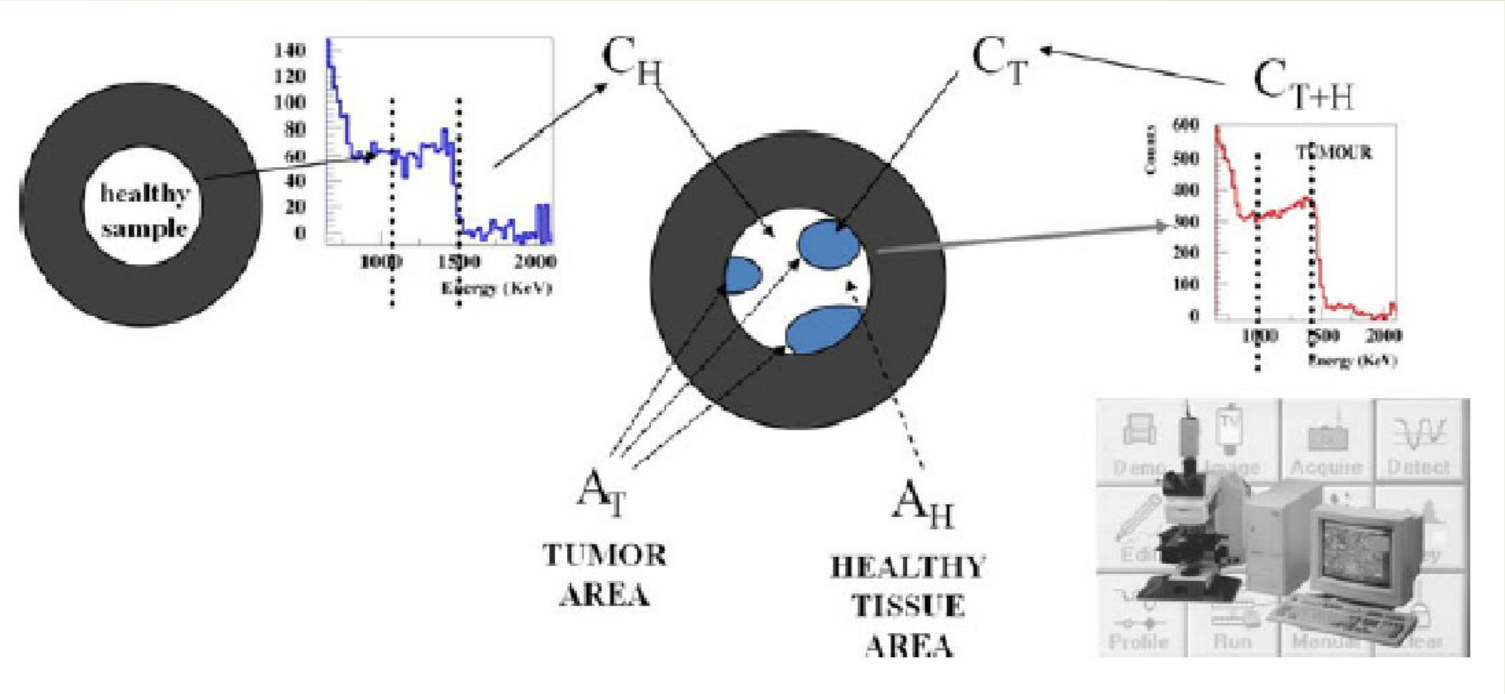
$$\mathrm{conc_F} = \frac{K_\mathrm{d}}{\eta \cdot \sigma \cdot \phi \cdot S_\mathrm{d}} \cdot \frac{\Delta E_\mathrm{d}}{\Delta(\rho_\mathrm{d} x_\mathrm{d})} \cdot \frac{A_\mathrm{W}}{N_\mathrm{A}} \cdot \frac{m_\mathrm{td}}{m_\mathrm{tf}}$$





TUMOUR

HEALTHY TISSUE



$$ppm_T = \frac{ppm_H}{\alpha}\left[\frac{ppm_M}{ppm_H} - \left(1 - \frac{V_T}{V_{tot}}\right)\right]$$

Thank you