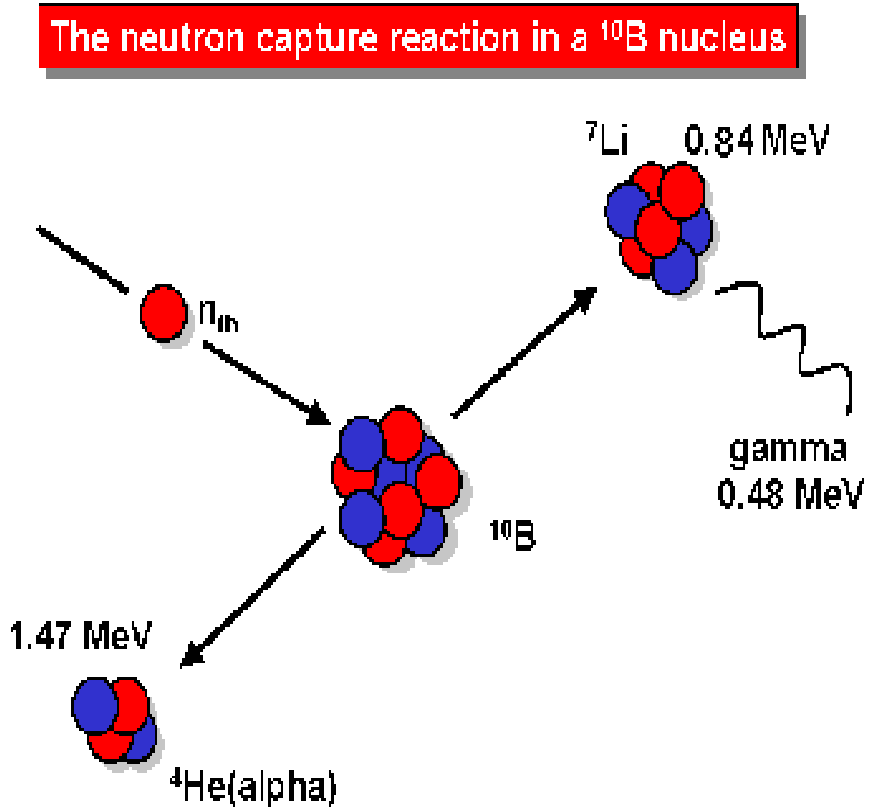
Neutron filter design for BNCT

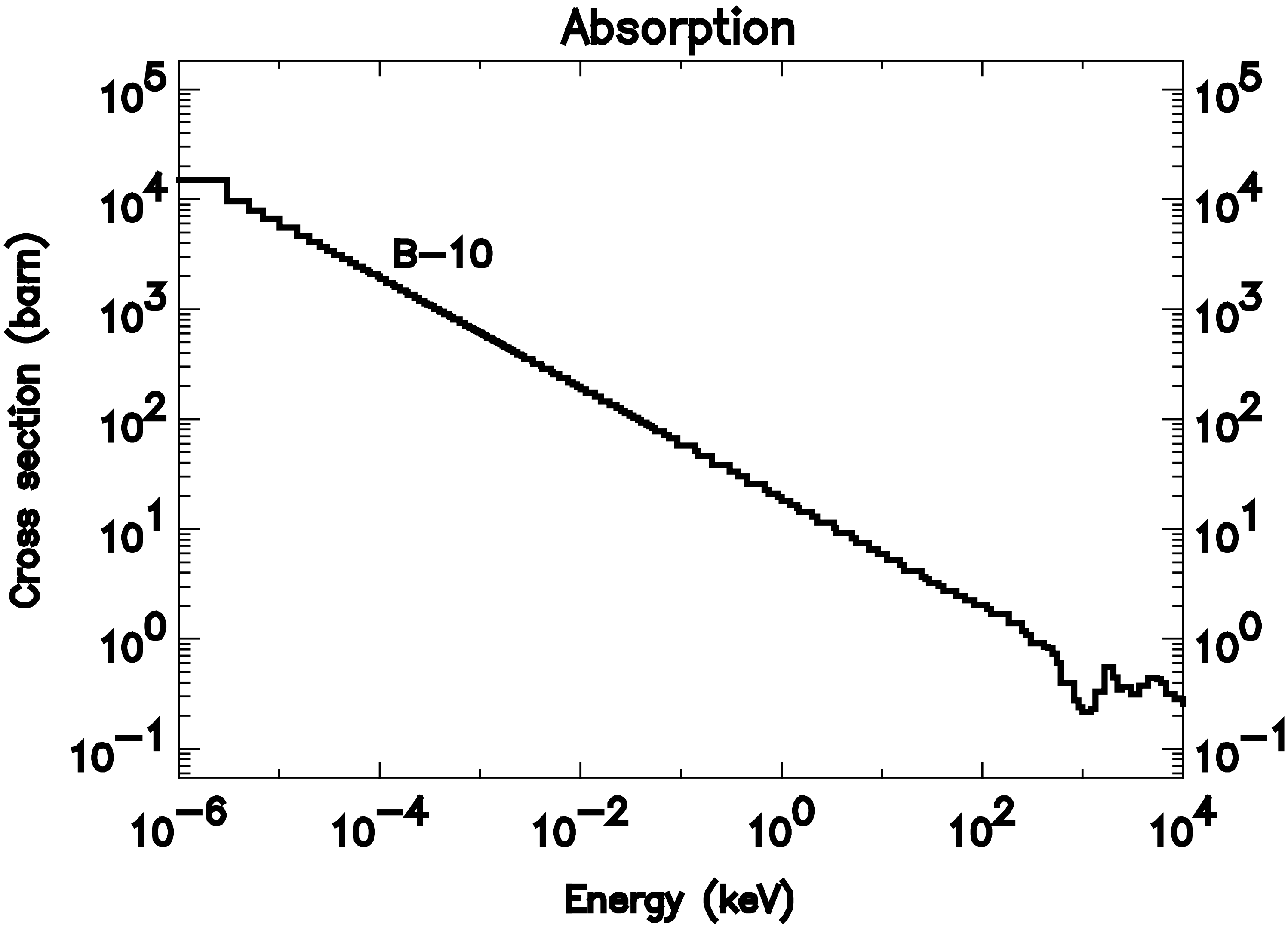
Jan Leen Kloosterman
Interfaculty Reactor Institute
Delft University of Technology

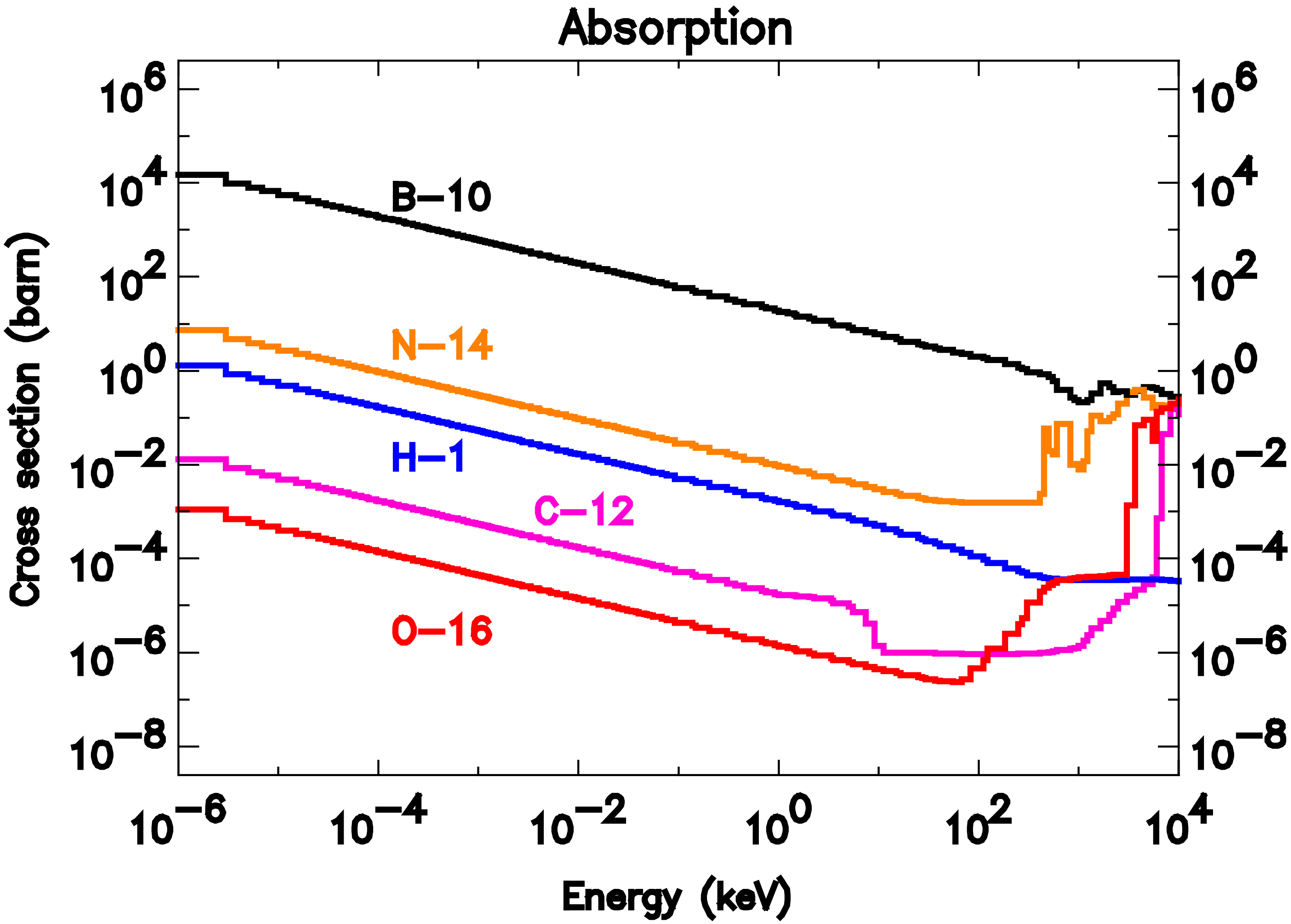
Boron Neutron Capture Therapy



BNCT is a form of radiotherapy for treating certain types of malignant tumours.

BNCT is based on the ability of the isotope ^{10}B to capture low energy neutrons to produce two highly energetic particles. If the reaction occurs next to or within each cancer cell, only the cancer cells are destroyed.


Absorption
Cross section (barn)
B-10
Energy (keV)
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}



Absorption
Cross section (barn)
Energy (keV)
B-10
N-14
H-1
C-12
O-16

History of BNCT

1936 G.L.Locher (USA) proposes neutron capture reactions should be applied to radiation therapy:

"In particular, there exist the possibilities of introducing small quantities of strong neutron absorbers into the region where it is desired to liberate ionization energy (a simple illustration would be the injection of a soluble non-toxic compound of boron, lithium, gadolinium, or gold into a superficial cancer, followed by bombardment with slow neutrons)".

1951-61 (USA) First trials of BNCT- effective failure.

1968 – 1980's Professor Hatanaka (Japan) – impressive results.

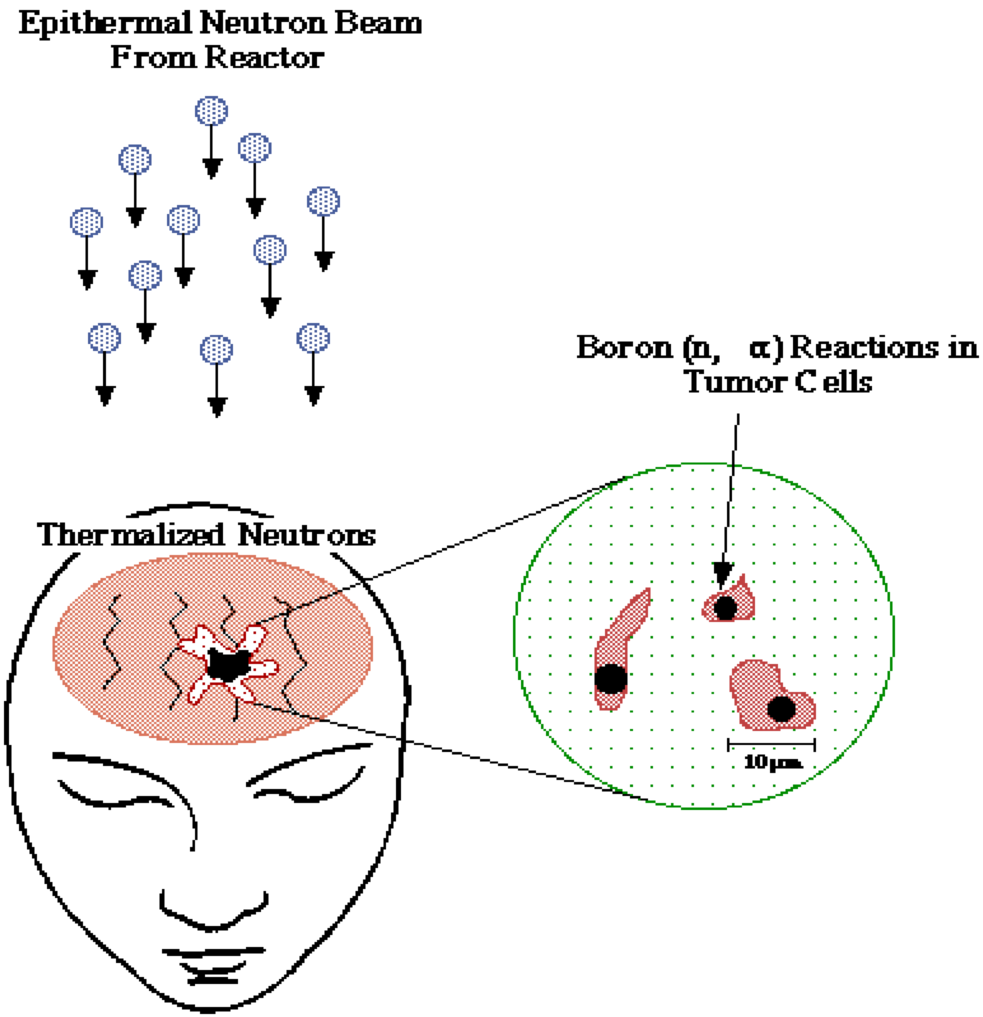
late 1980's Re-start of US and European efforts

1994 New US trials at Brookhaven and MIT

1997 Start of first European trial (Petten)

1999 Finnish BNCT consortium

Epithermal neutron beams



Current developments in beam design

- **Kim and Kim, "Conceptual design of a <u>Cf-based</u> epithermal neutron beam for BNCT using a subcritical multiplying assembly", *Nucl. Techn.* 124 (1998).**

- **Kiger III, Sakamoto, and Harling, "Neutronic design of a <u>fission converter-based</u> epithermal neutron beam for neutron capture therapy", *Nucl. Sci. Eng.* 131 (1999).**

- **Powell, Ludewig, Todosow, and Reich, "Target and filter concepts for <u>accelerator-driven</u> BNCT applications", *Nucl. Techn.* 125 (1999).**

- **Verbeke, Vujic, and Leung, "Neutron beam optimization for BNCT using the <u>D-D and D-T</u> High-Energy neutron sources", *Nucl. Techn.* 129 (2000).**

- **Kobayashi, Sakurai, Kanda, Fujita, and Ono, "The remodeling and basic characteristics of the heavy water neutron irradiation facility of the Kyoto university <u>research reactor</u>, mainly for NCT", *Nucl. Techn.* 131 (2000).**

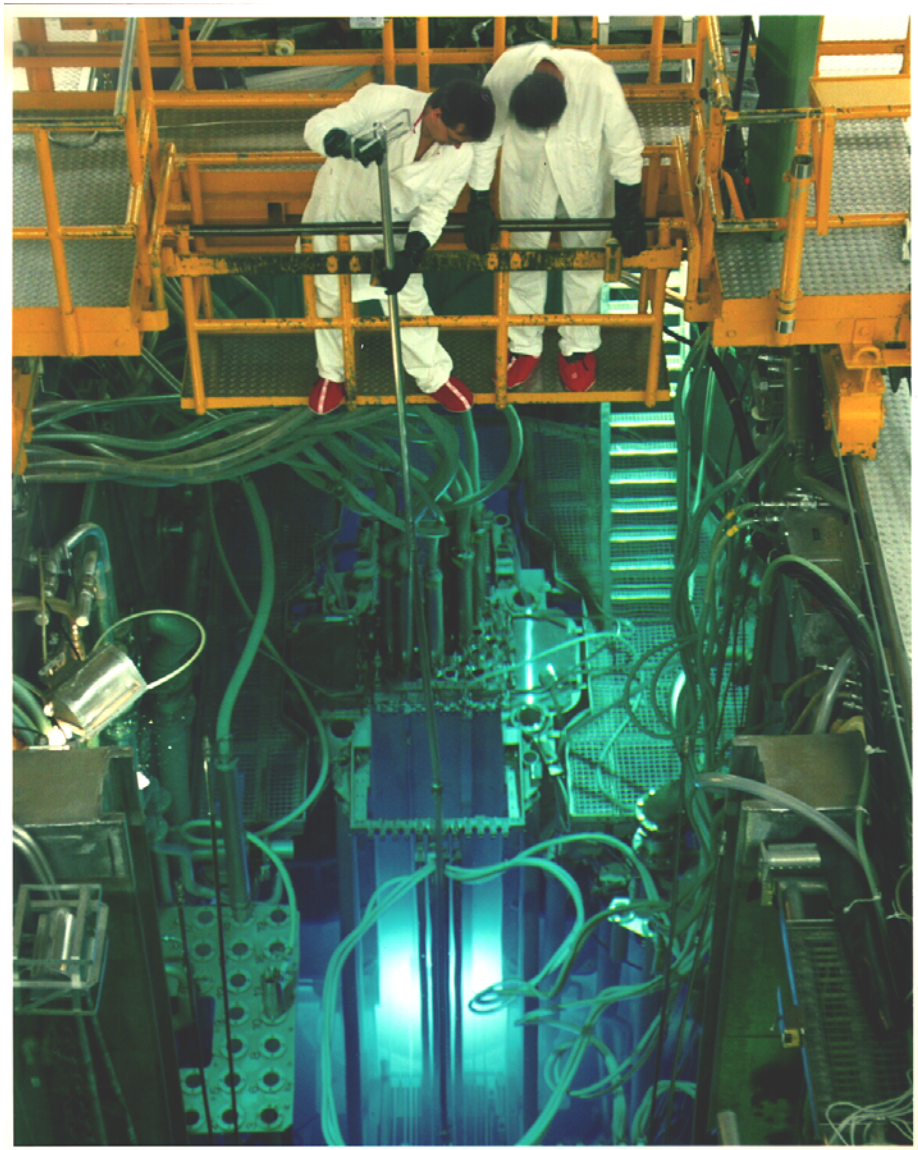
- **Maucec, "Conceptual design of a clinical BNCT beam in an adjacent dry cell of the Jozef Stefan institute <u>TRIGA reactor</u>", *Nucl. Techn.* 132 (2000).**

European BNCT group

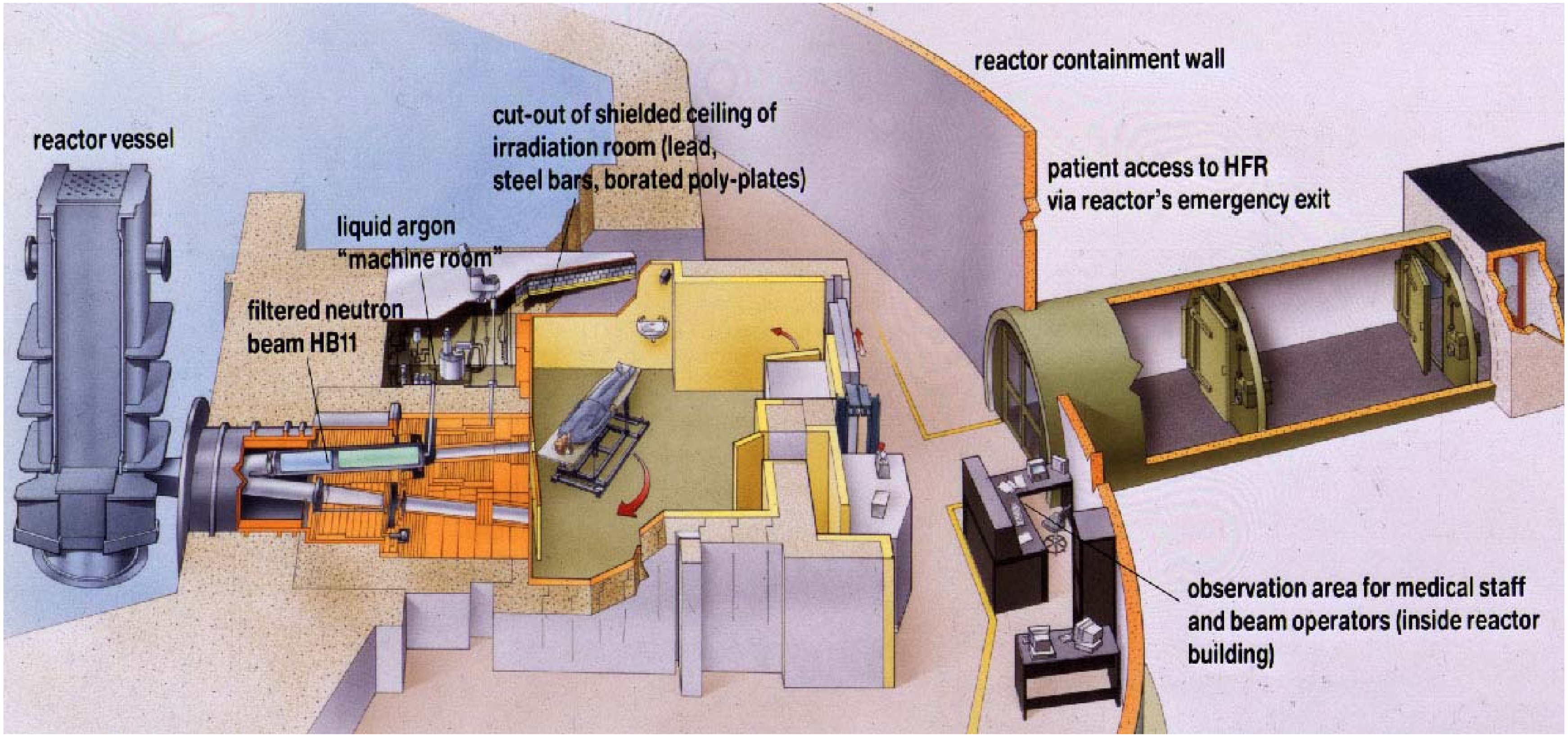
Phase I Clinical Trial - Participating Centres		
University of Essen	D	Prinicipal Clinical Investigator/Study Coordinator
University of Bremen	D	EU Project Coordinator
University Hospital Graz	A	Neurosurgery/patients
University Hospital Munich	D	Neurosurgery/patients
University Hospital Lausanne	CH	Neurosurgery/patients
University Hospital Nice	FR	Neurosurgery/patients
Central Hospital Bremen	D	Neurosurgery/patients
Vrije Universiteit Ziekenhuis Amsterdam	NL	Neurosurgery/patients – care of patients
JRC Petten	CEC	Facility Management - Technical support – Treatment Planning
ECN Petten	NL	Facility Operation – Dosimetry - Boron measurements

Petten High Flux Reactor

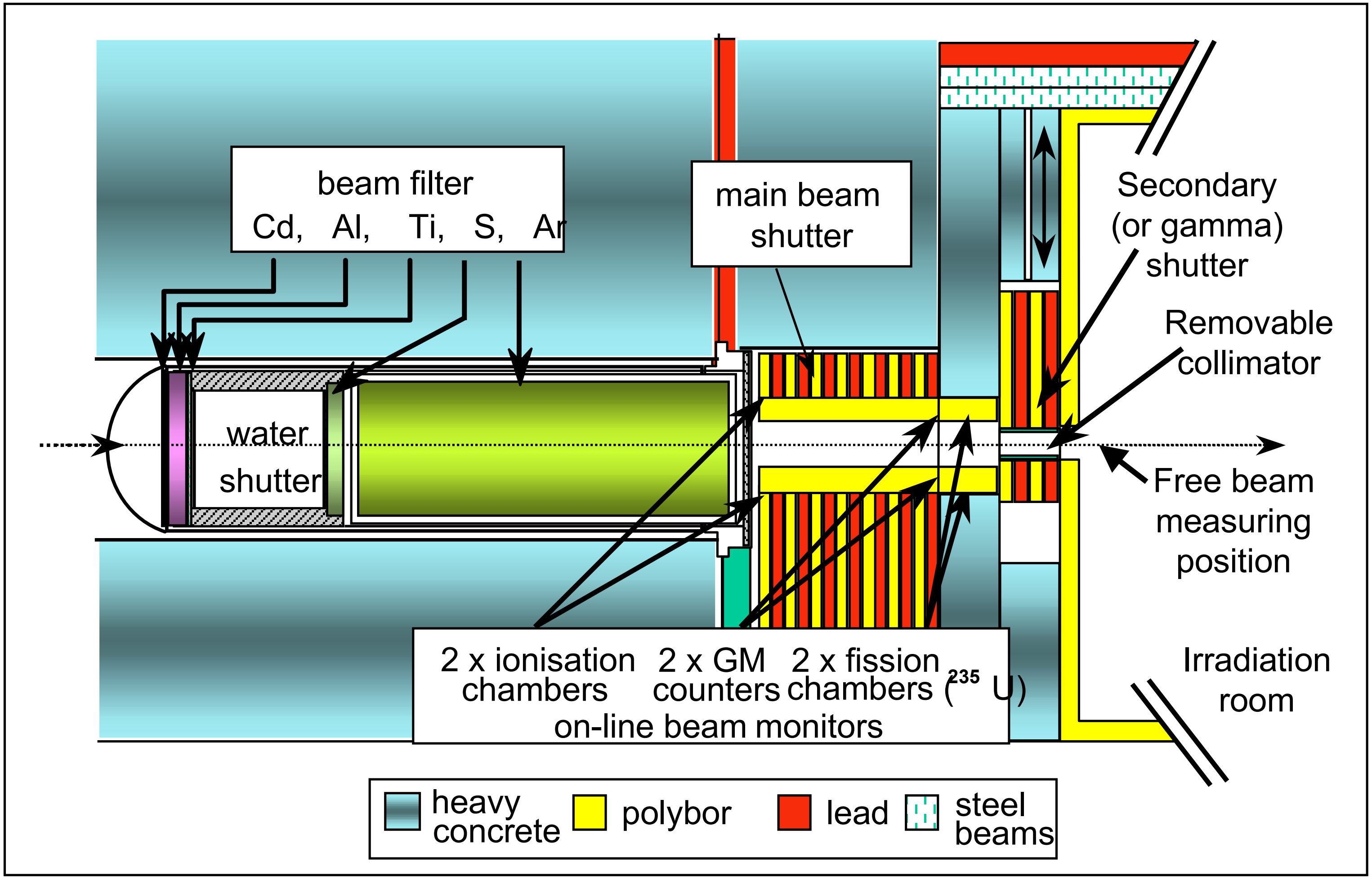
Petten High Flux Reactor



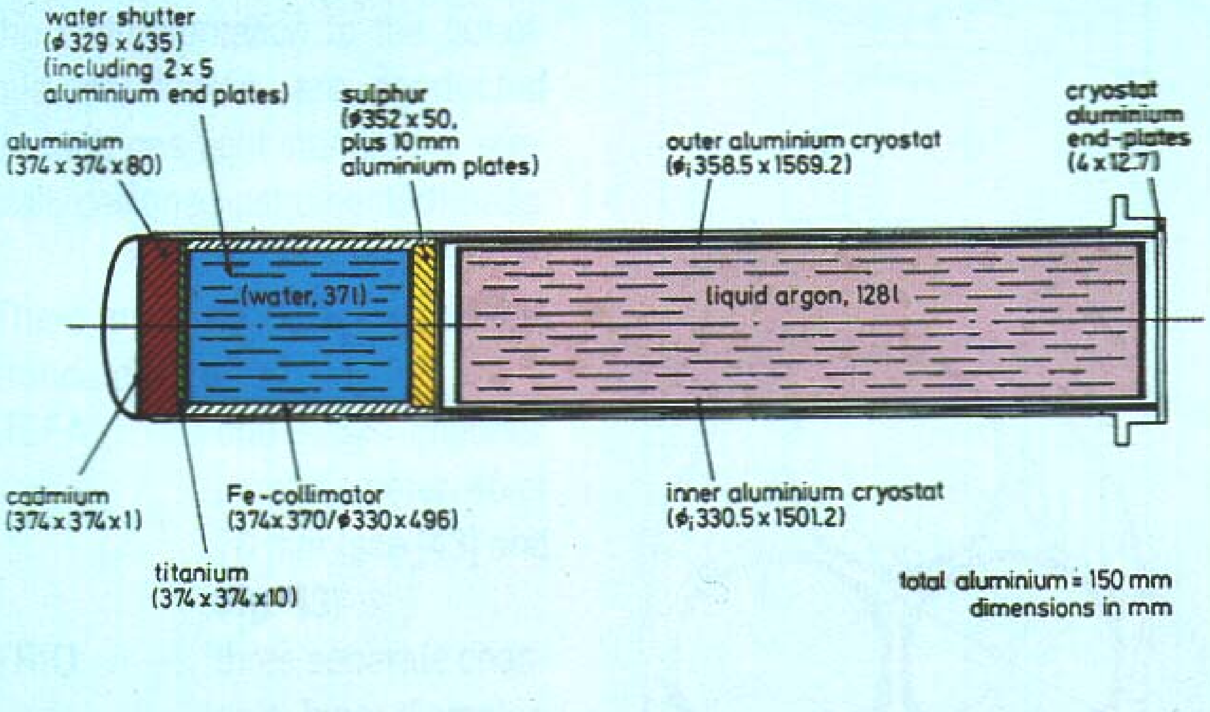
BNCT facility at the Petten HFR



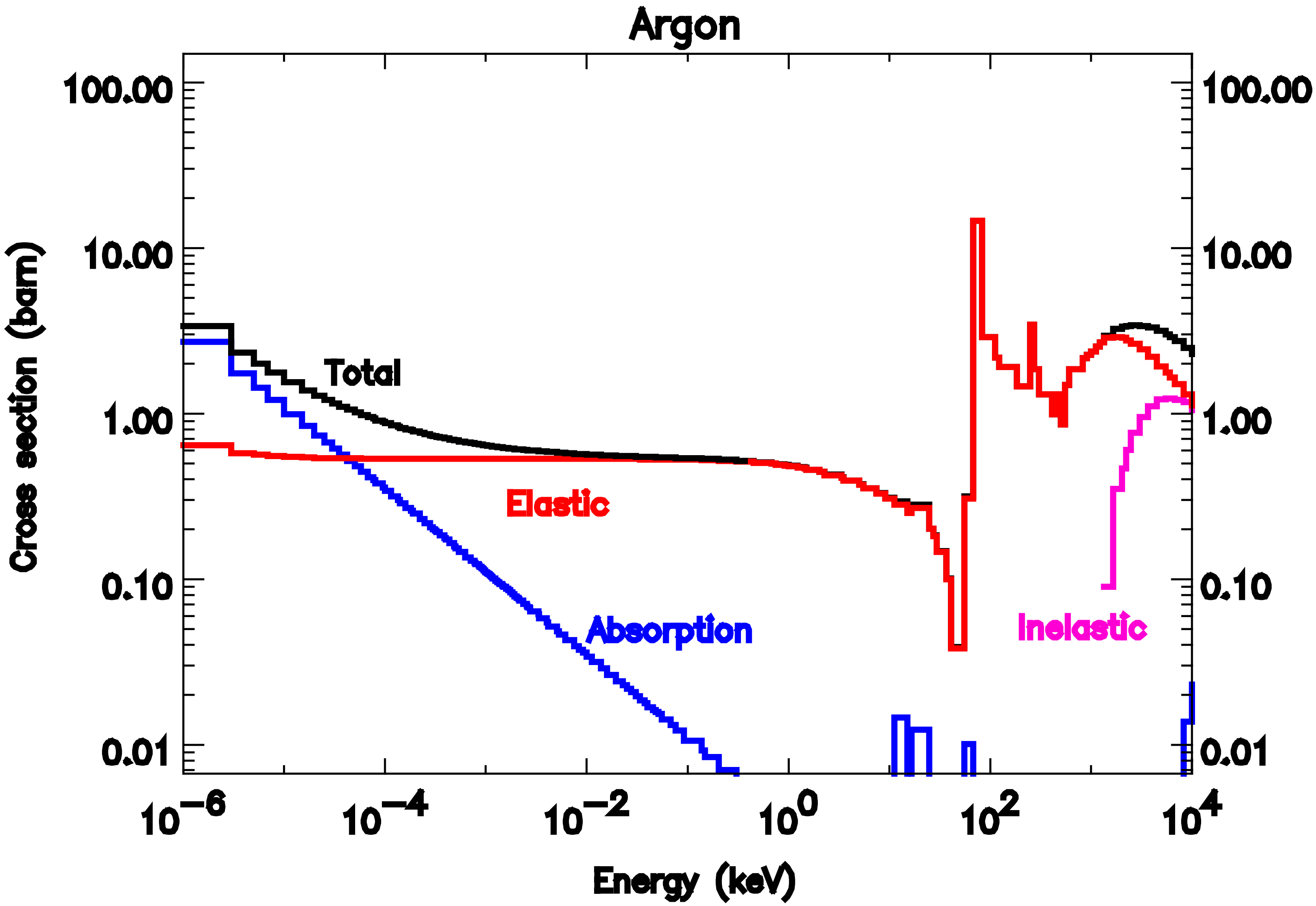
Current neutron filter design

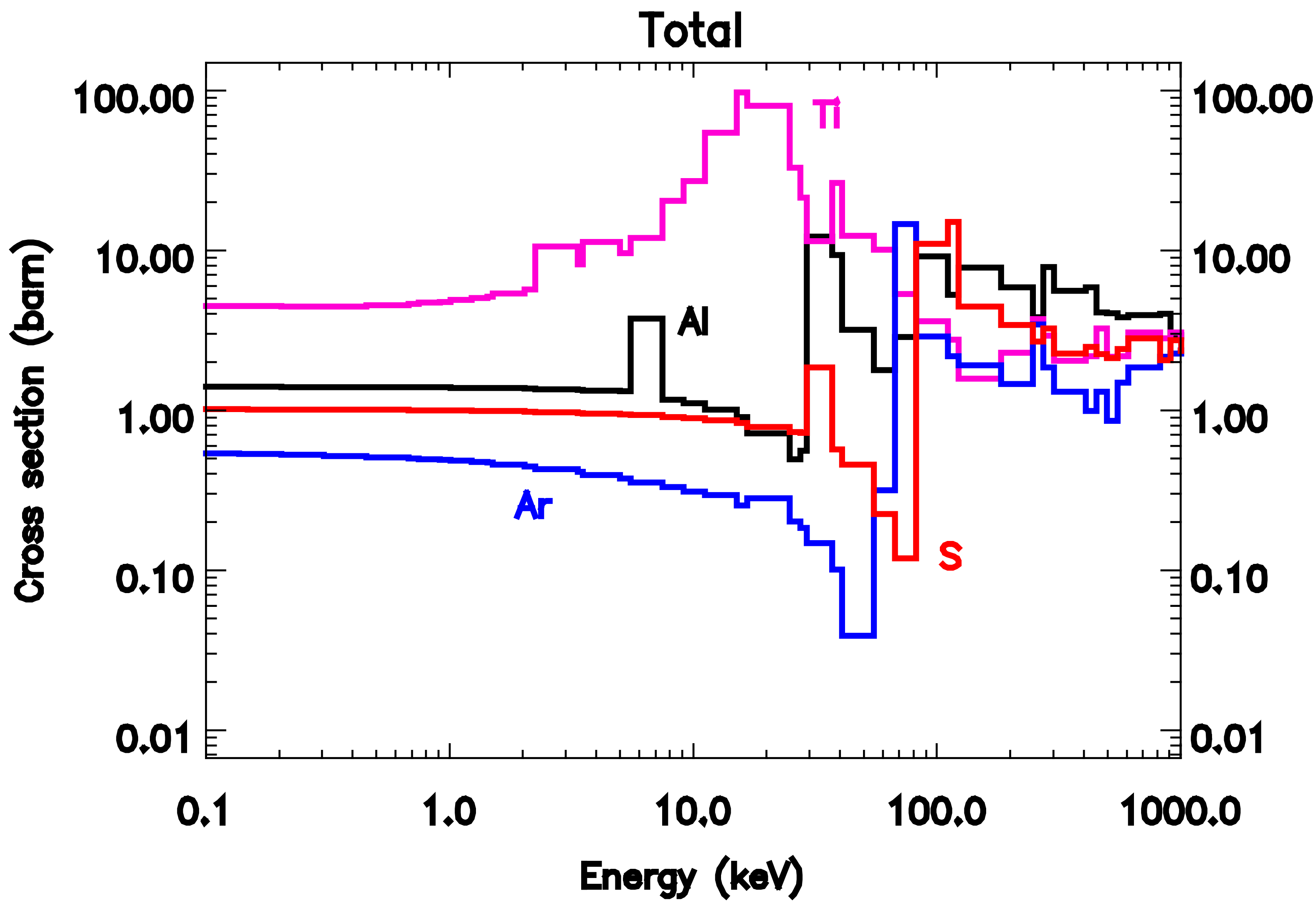


Current neutron filter design



Petten BNCT Project : The HB11 filter configuration


Argon
100.00
10.00
1.00
0.10
0.01
100.00
10.00
1.00
0.10
0.01
Cross section (barn)
Total
Elastic
Absorption
Inelastic
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Energy (keV)


Total
100.00
10.00
1.00
0.10
0.01
Cross section (barn)
0.1
1.0
10.0
100.0
1000.0
Energy (keV)
Ti
Al
Ar
S

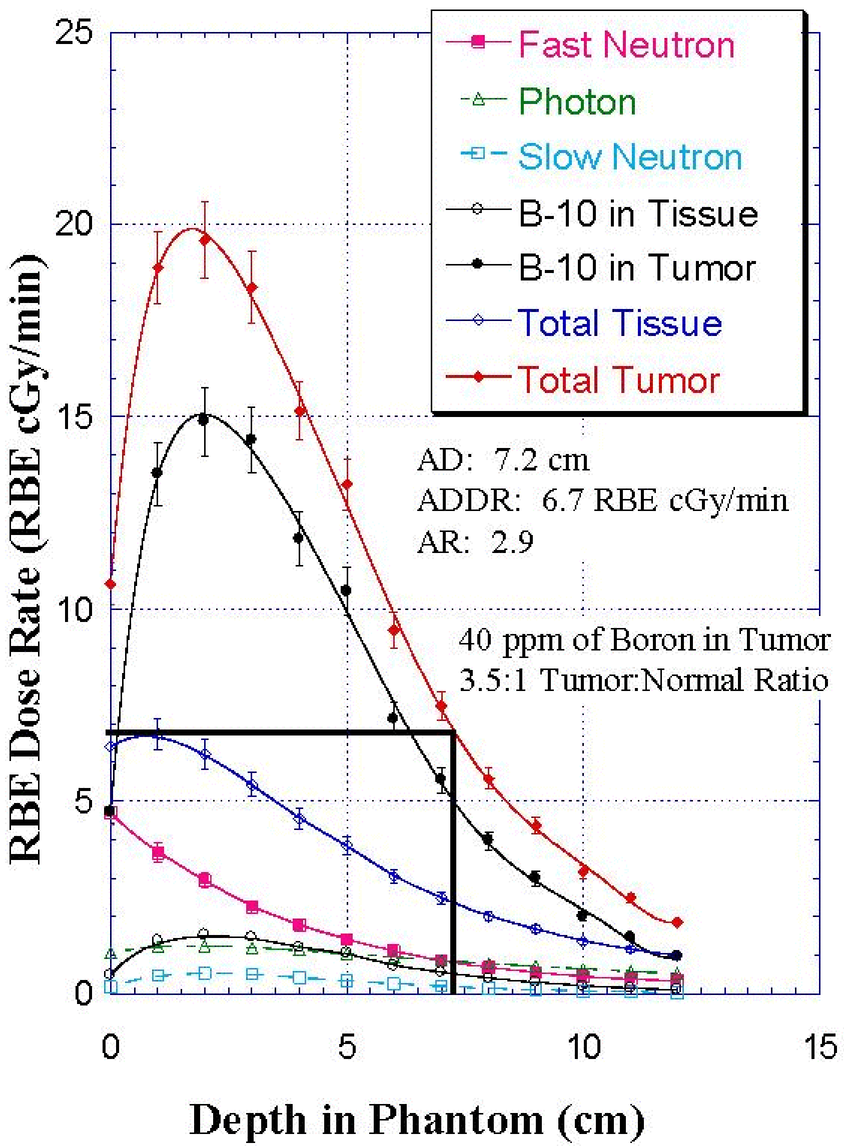
In-phantom Figures of Merit (FOM)

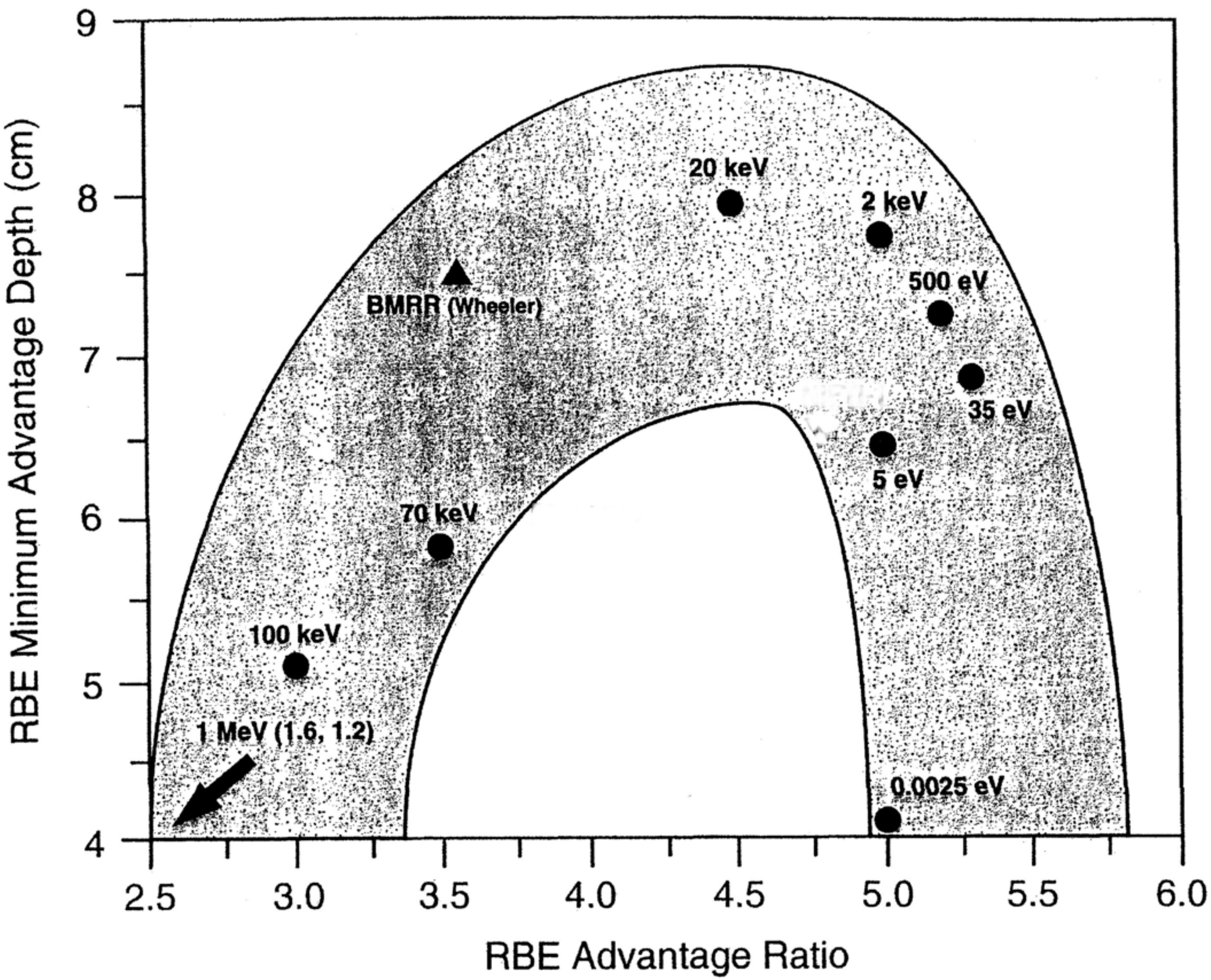
- **Advantage Depth (AD): Depth in the tissue at which the dose to the tumor equals the maximum dose delivered to the normal tissue.**

- **Advantage Ratio (AR): Ratio of the dose to the tumor and the dose to the normal tissue integrated from the body surface to the Advantage Depth.**

- **Advantage Depth Dose Rate (ADDR): Dose rate to the tumor at the Advantage Depth (AD).**

MITR-II M67 Beam





RBE Minimum Advantage Depth (cm)
9
8
7
6
5
4
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
RBE Advantage Ratio
20 keV
2 keV
500 eV
35 eV
5 eV
70 keV
100 keV
1 MeV (1.6, 1.2)
0.0025 eV
BMRR (Wheeler)

In-air Figures of Merit (FOM)

- **Epithermal neutron flux Φ_{epi} (n.cm^{-2}.s^{-1}).**

- **Ratio of the fast neutron dose rate to the epithermal neutron flux $\check{D}_{fn}/\Phi_{epi}$ (Gy.cm^2/n).**

- **Ratio of the gamma dose rate to the epithermal neutron flux $\check{D}_{\gamma}/\Phi_{epi}$ (Gy.cm^2/n).**

Beam characteristics

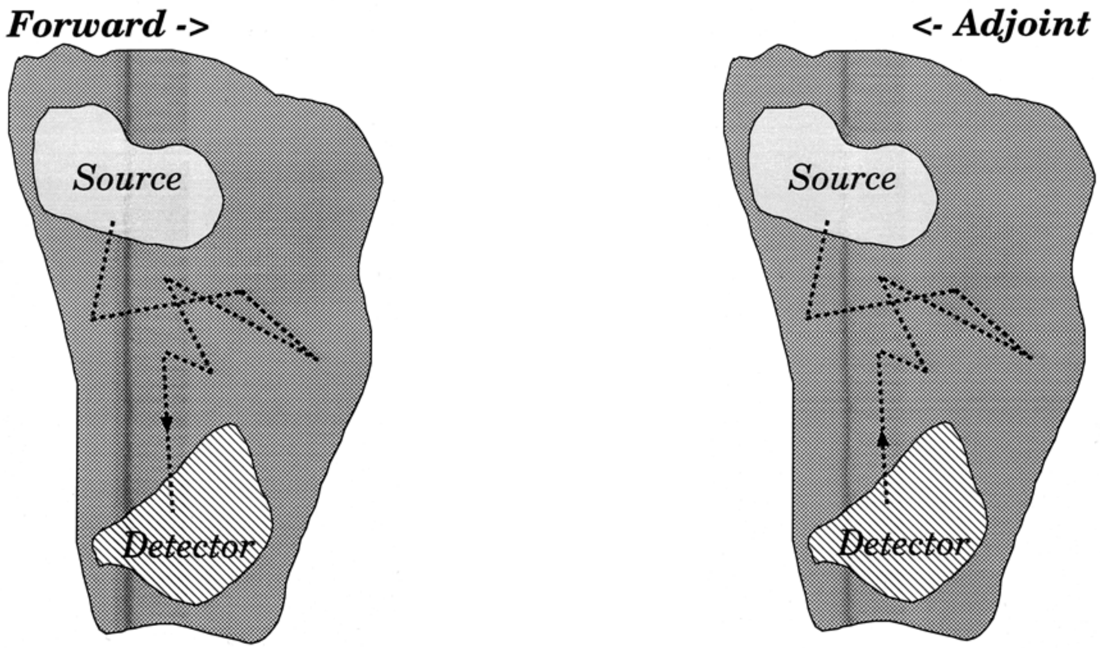
Facility	Power (MW)	Φ_{epi} ($cm^{-2}.s^{-1}$)	$\check{D}_{fn}/\Phi_{epi}$ ($Gy.cm^2/n$)	$\check{D}_{\gamma}/\Phi_{epi}$ ($Gy.cm^2/n$)
HFR	45	3.3E8	8.6E-13	1.0E-12
BMRR	3	1.8E9	4.3E-13	1.3E-13
BMRR (FCB)	3	1.2E10	2.8E-13	1.0E-13
MITR-II	5	2.1E8	8.6E-13	1.3E-12
MITR (FCB)	5	1.7E10	1.3E-13	1.0E-13

Criteria neutron filter materials

- **Material should not undergo phase changes.**
- **Material should not decompose or emit toxic substances.**
- **Material should not accumulate high long-term activity.**
- **Material should not contain impurities or moisture.**
- **Low cost of material, component fabrication and maintenance.**

Calculation techniques

•**Midway Monte Carlo technique.**



•**Differential sampling in Monte Carlo codes.**