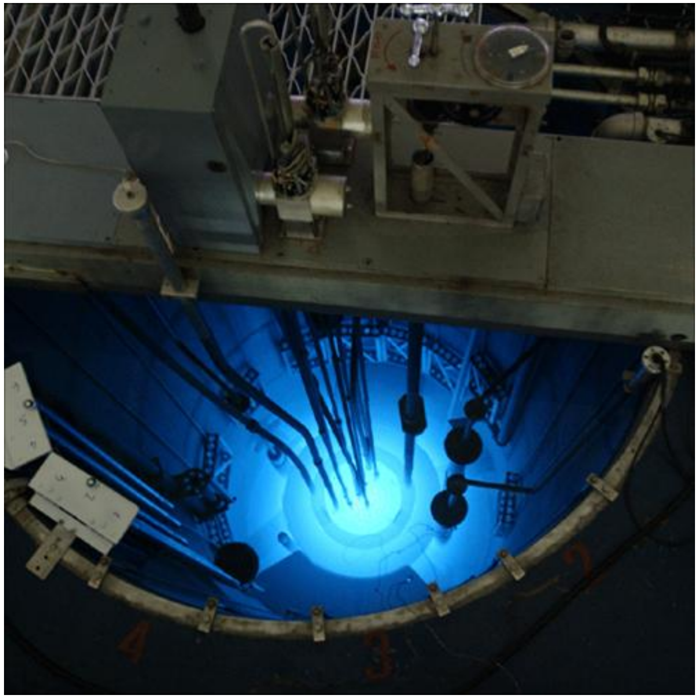
RESEARCH IN NEUTRON CAPTURE THERAPY AT UNIVERSITY OF PAVIA



Saverio Altieri

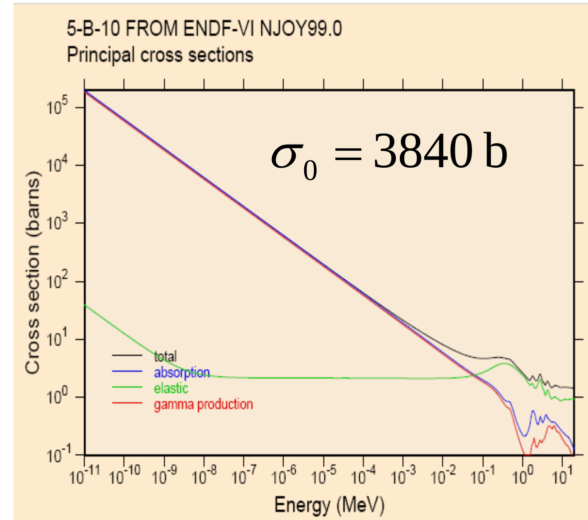
Department of Physics University of Pavia , Italy
and
National Institute of Nuclear Physics
(INFN) Section of Pavia, Italy

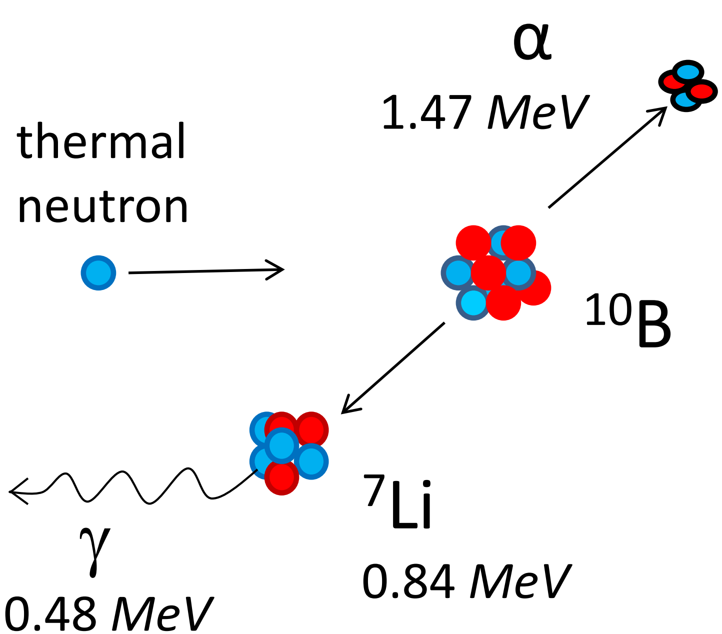
BNCT principle

$$Q_{value} = 2.79\ MeV$$

$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}Li + \alpha + 2.79\,MeV & 6.1\% \\ \left({}^{7}Li\right)^{*} + \alpha + 2.31\,MeV & 93.9\% \end{cases}$$

$$\downarrow \rightarrow {}^{7}Li + \gamma\,(0.478MeV)$$



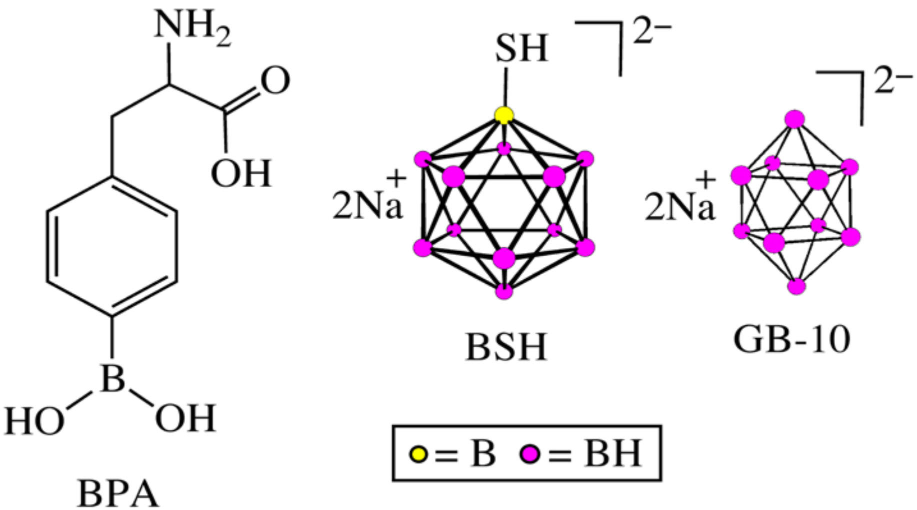


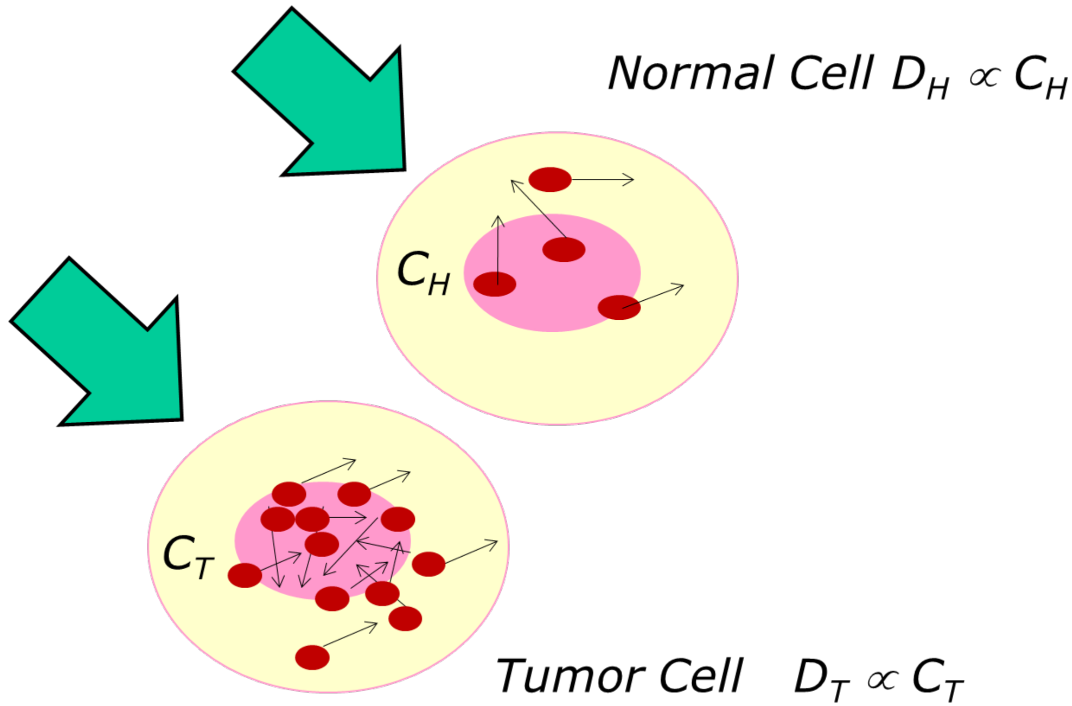
Range in tissues

$$R_\alpha \cong 8\mu m$$
$$R_{Li} \cong 5\mu m$$

shorter than
a cell diameter

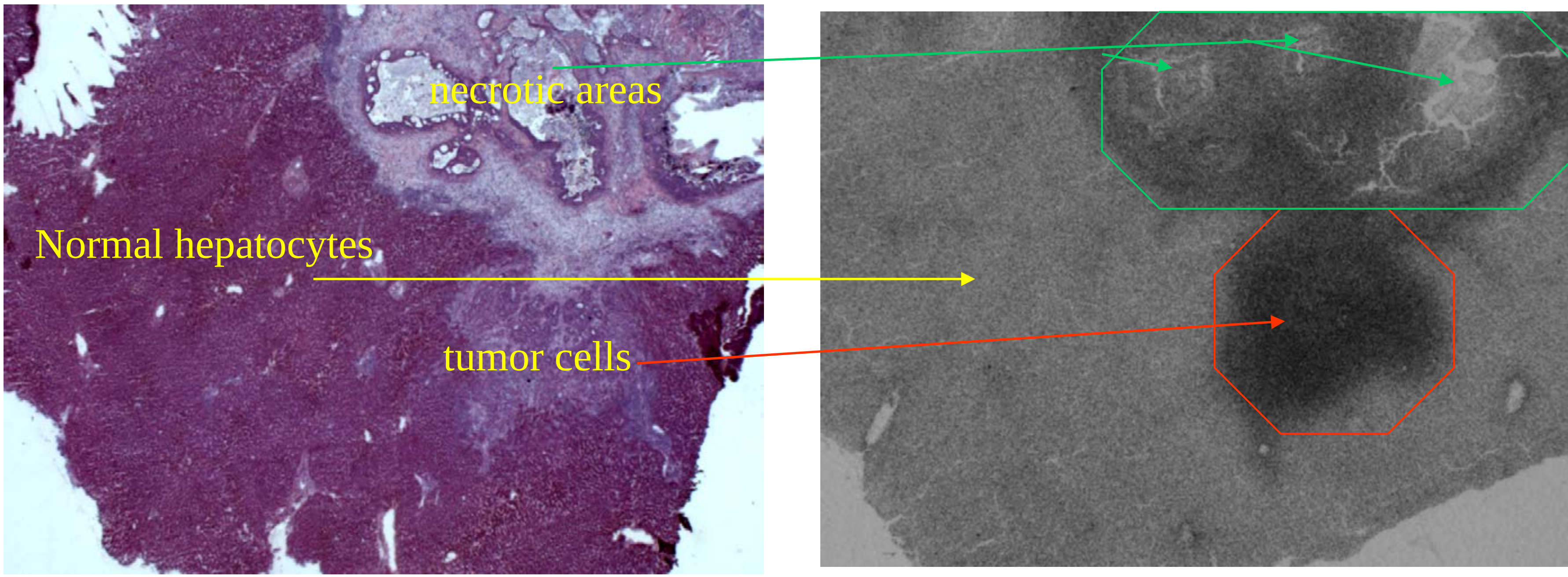
BNCT: selectivity at cellular level





BNCT: selectivity at cellular level

Some neutron autoradiography images of human liver with metastases



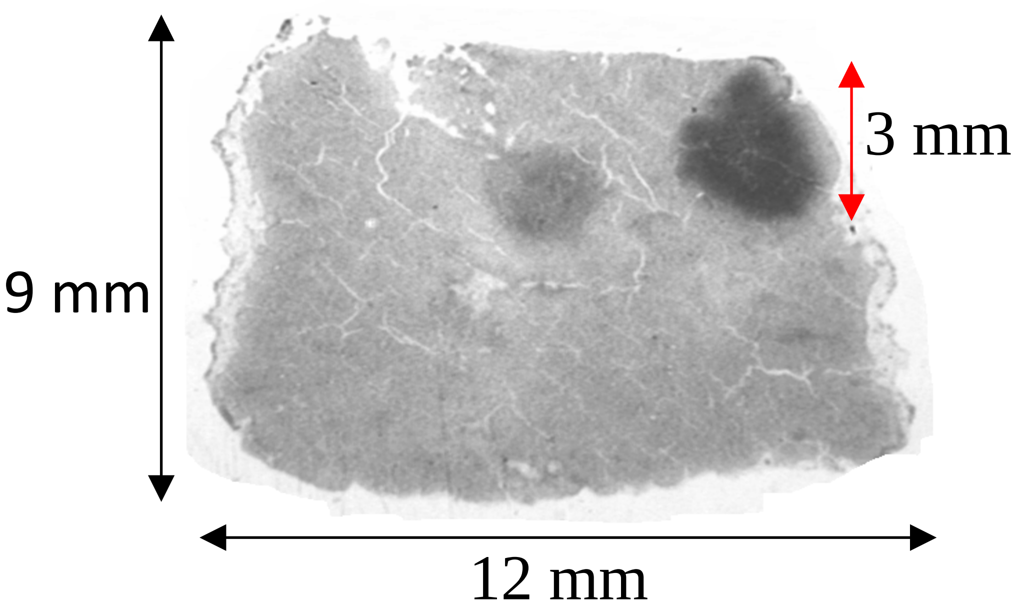
histological image — neutron autoradiography image

Neutron radiography shows how boron concentration changes depending on the tissue type

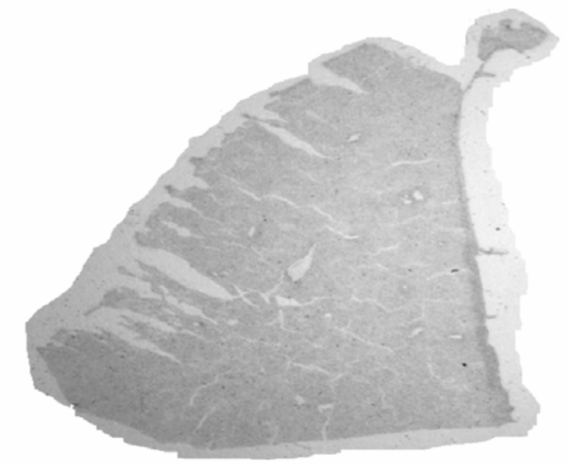
S. Altieri et. al Applied Radiation and Isotopes 66 (2008) 1850– 1855

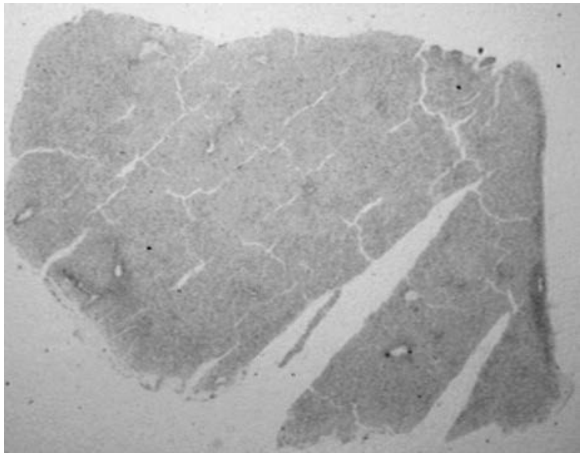
Some neutron autoradiography images of human liver with metastases

Liver with tumor



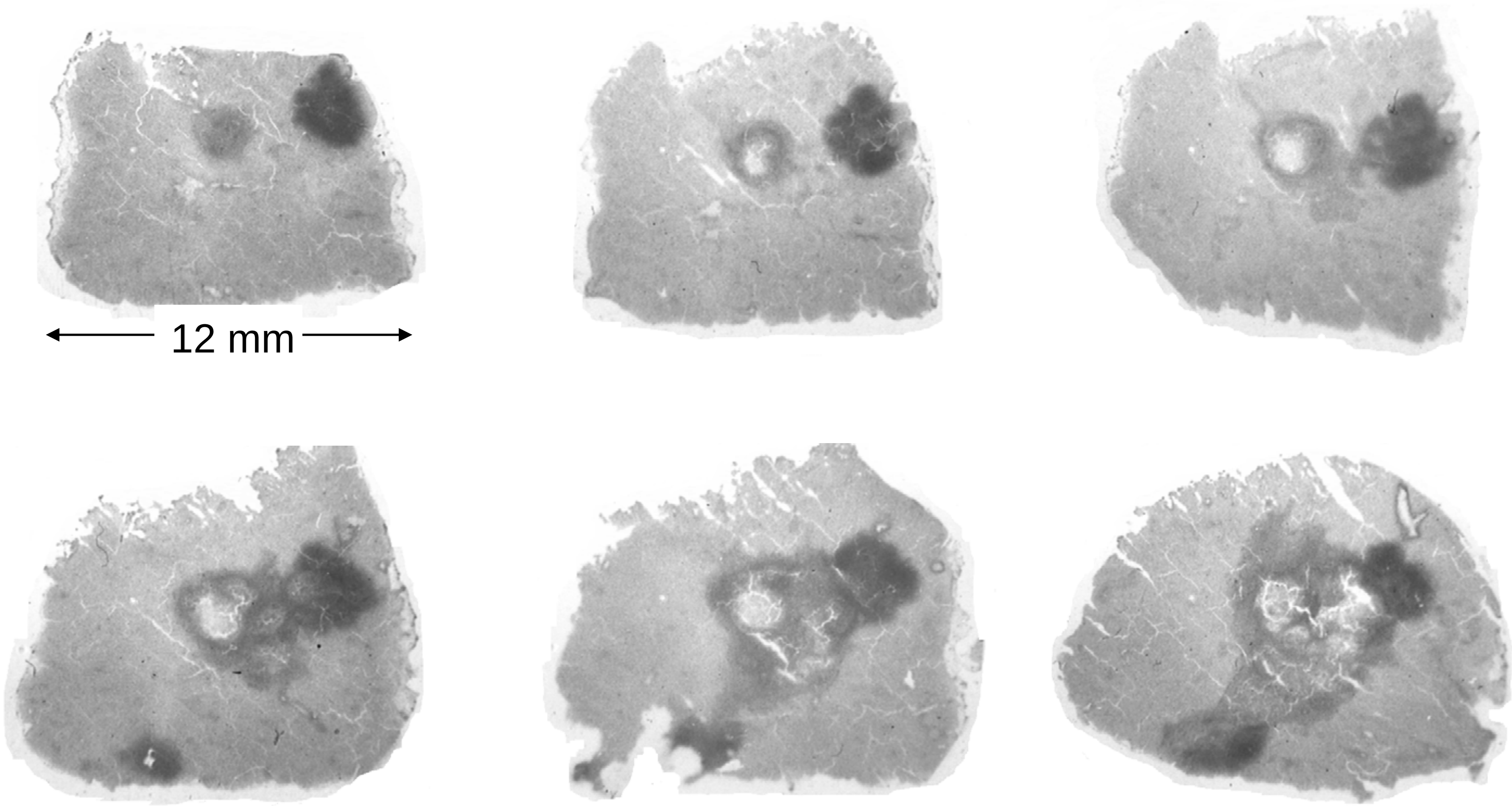
Healthy liver



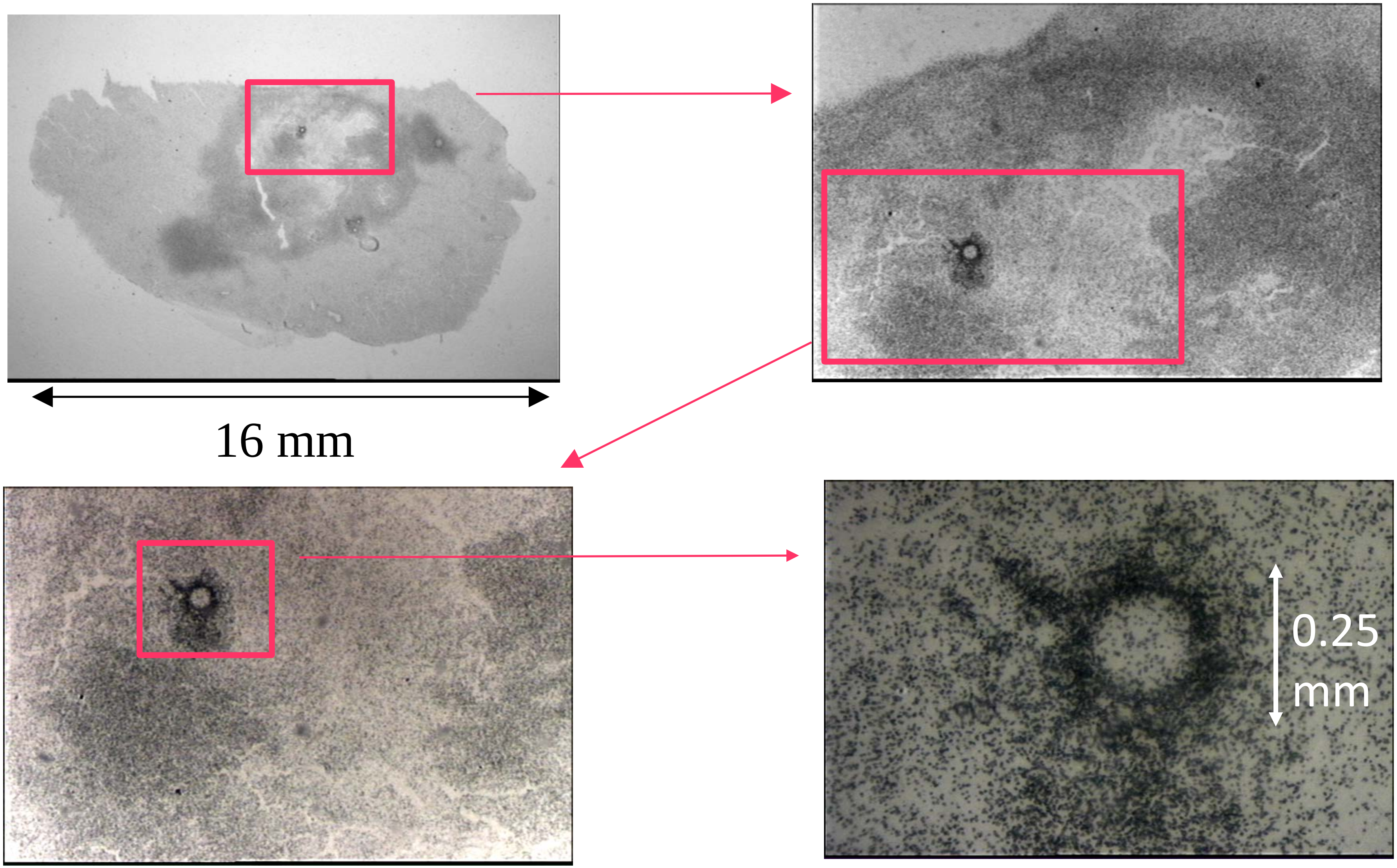


BNCT: selectivity at cellular level

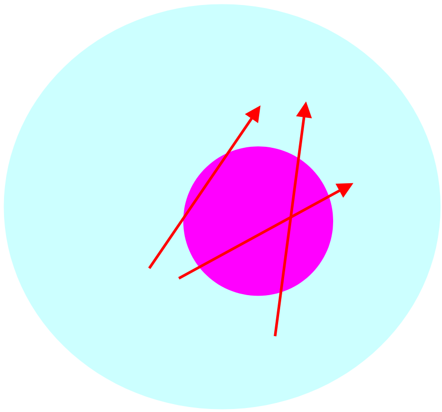
A sample sliced every 40 μm



BNCT: selectivity at cellular level



BNCT: Boron concentration



from 2 to 6 tracks in the nucleus → a letal lesion in the cell

Tumour cells with boron

$$[\Psi_n]_{th} = 10^{12} cm^{-2}$$

neutron fluence

10^9 athoms of ^{10}B in a cell

$\Updownarrow$

$30 \mu g \ ^{10}B / g$ of tissue

Boron concentration

$2 - 3 \ (n, \alpha)$ reactions in the cell with ^{10}B

number og reactions

BNCT: Absorbed dose ratio

$$[\Psi_n]_{th} = 10^{12} cm^{-2}$$

Tumour cells with boron

$$30\, ppm\ {}^{10}B$$

$${}^{10}B(n,\alpha)^{7}Li$$

Healthy cells without boron

$${}^{14}N(n,p)^{14}C$$

$${}^{1}H(n,n')p$$

$$\frac{D_{Tumour}}{D_{Healthy}} \cong 4$$

healthy cells with boron

$$\frac{C_T}{C_H} = 6 \Rightarrow \frac{D_T}{D_H} \cong 3.4$$

BNCT: Biologically weigthed dose

Dose from

p,γ | α, Li

$^{10}B(n,\alpha)^{7}Li$

Radiation Biological Efficacy
RBE

Compound Biological Efficacy
CBE

$$RBE_{rad.} = \frac{[D_X]_{eff.}}{[D_{rad.}]_{eff.}}$$

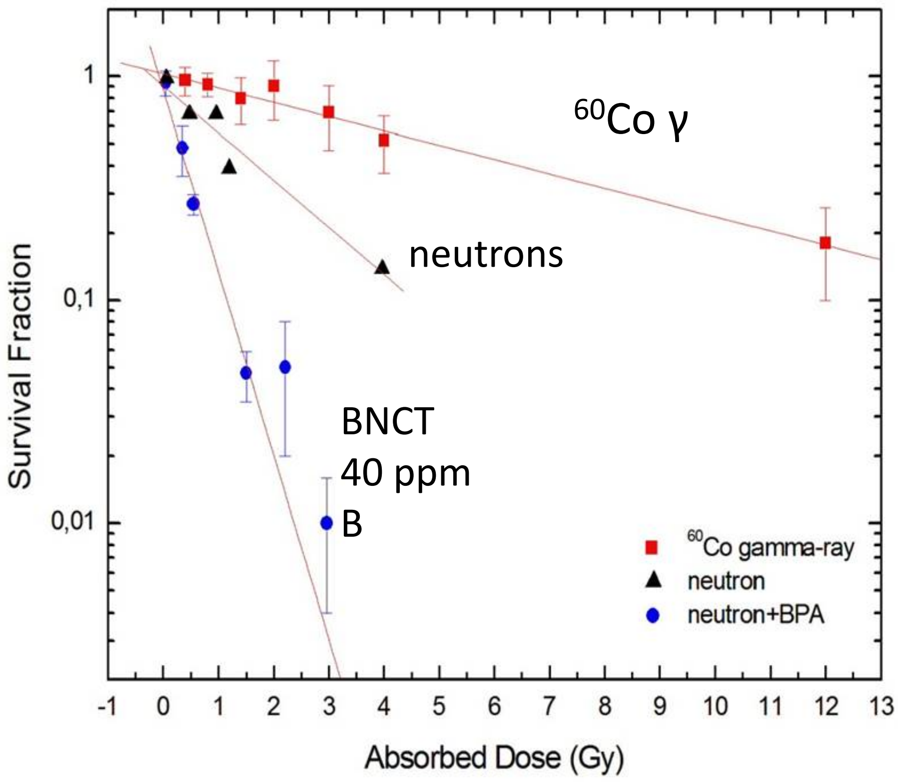
RBE of the neutron beam without boron
RBE of the neutron beam with boron

Biological weighted Dose Gy-eq

$$D_{bw} = D_\gamma + w_p D_p + w_c D_B$$

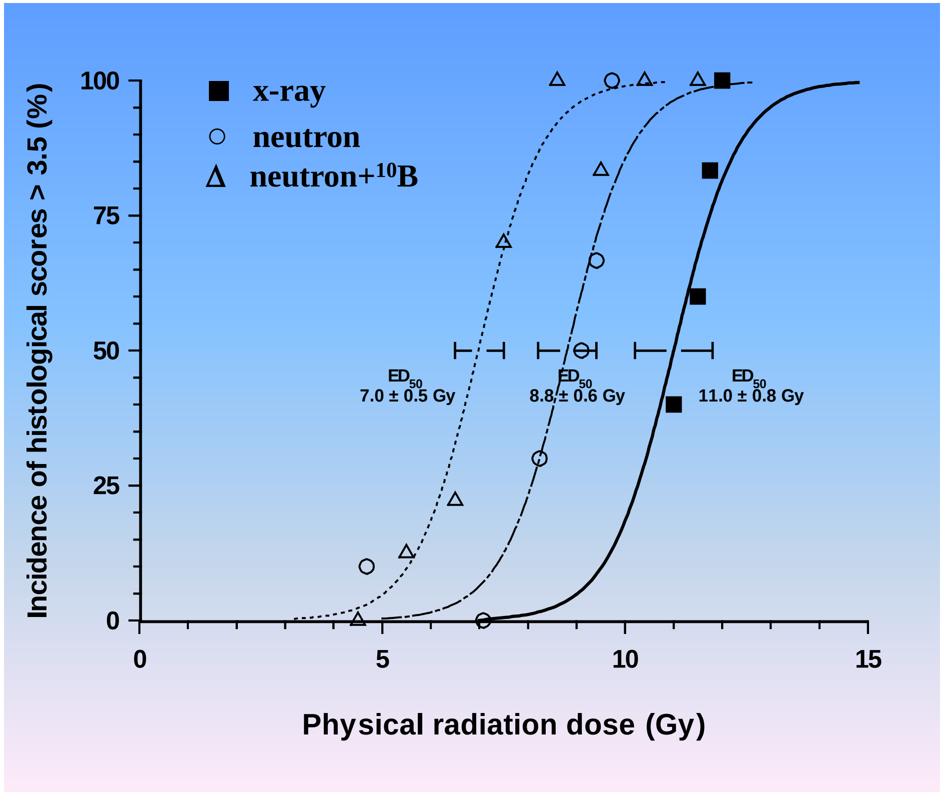
BNCT: Biologically weigthed dose

Survival curves of rat DHD cells



C.Ferrari et al. Rad Res 175 (2011)

Functional and histological changes in rat lung after irradiation



Kiger, *et al.*,

BNCT: Biologically weigthed dose

Biological Effectiveness Factors Used in Calculating Photon Equivalent Doses during BNCT at the Brookhaven Medical Research Reactor

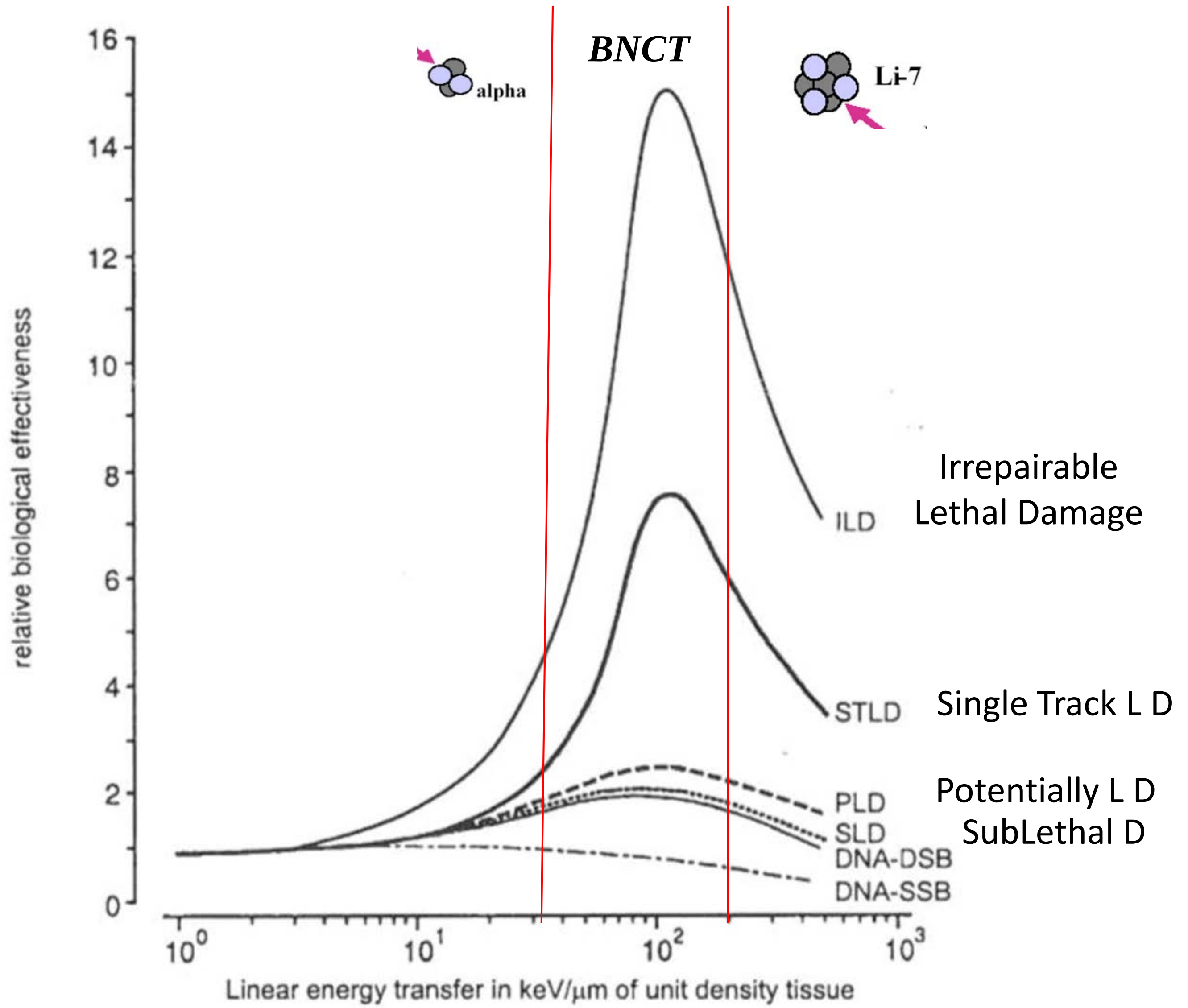
Dose component	Biological effectiveness factor (CBE or RBE)
$^{10}B(n,\alpha)^{7}Li$ reaction (BPA-fructose)	Tumor (9L rat gliosarcoma)[a] = 3.8 CNS (rat spinal cord)[b] = 1.3 Human skin (moist desquamation)[c] = 2.5
Beam protons $^{14}N(n,p)^{14}C$ and $^{1}H(n,n')p$	Tumor (9L rat gliosarcoma)[a] = 3.2 Dog brain[d] = 3.3 Dog skin[e] = 3.0

$$D_{bw} = D_{\gamma} + w_p D_p + w_{BPA} D_B$$

$$\frac{C_T}{C_H} = 6 \Rightarrow \frac{D_T}{D_H} \cong 3.4 \Rightarrow \frac{D_{Tbw}}{D_{Hbw}} \cong 8$$

New trends: Isoeffective dose evaluation

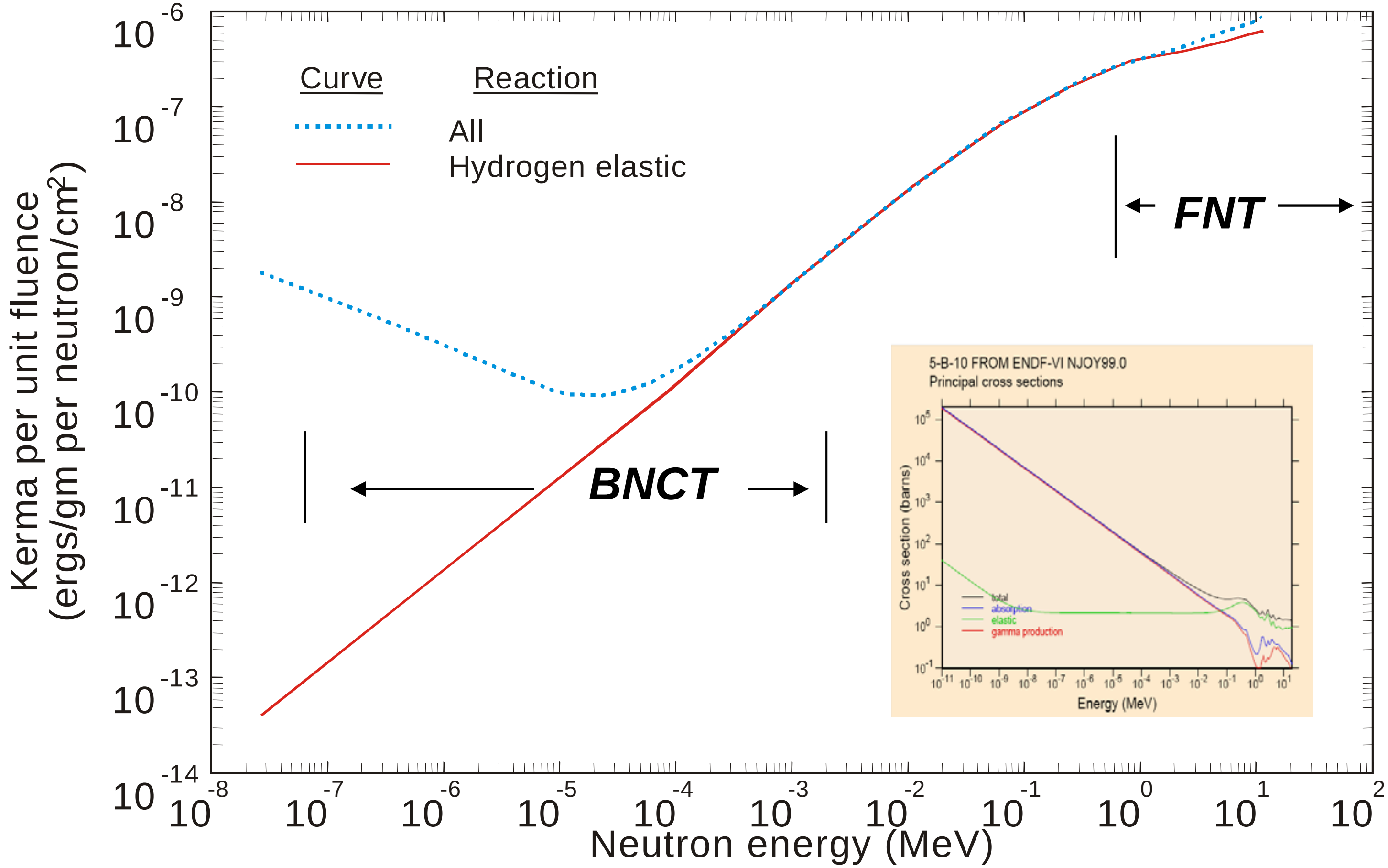
BNCT: an hadron therapy at cellular level



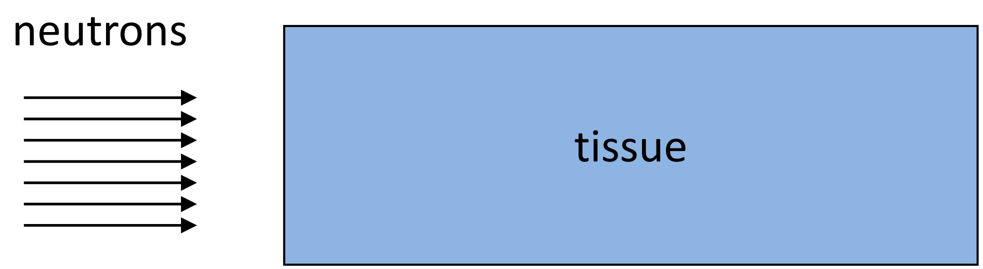
Barendsen GW, van Bree C, Franken NAP: Importance of cell proliferative state and potentilly lethal damage repair on radiation effectiveness: implications for combined tumor treatments (review). Int J Oncol 2001, 19:257-256, review.

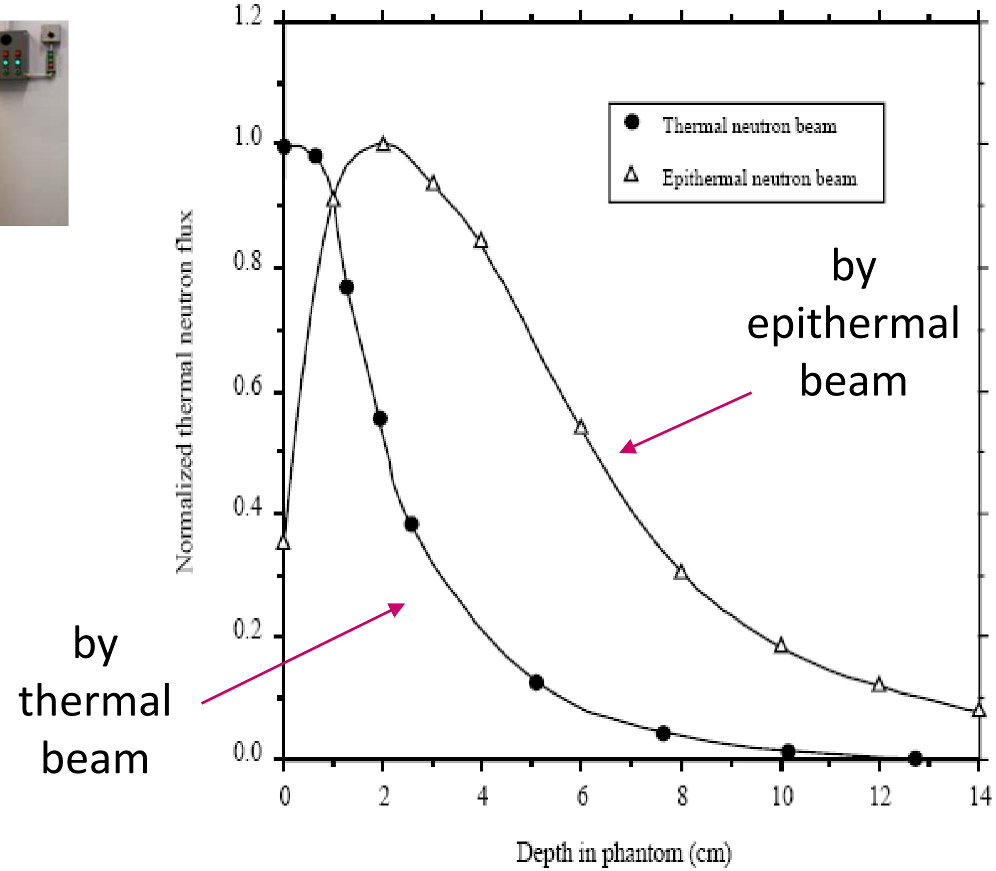
Neutron energy for BNCT

Neutron kerma in healthy tissue



Neutron beam: thermal or epithermal





Thermal neutron distribution inside the phantom

NEUTRON BEAM

THERMAL → Shallow tumours

EPITHERMAL → Deep seated tumours

Neutron beam: dose profile with epithermal

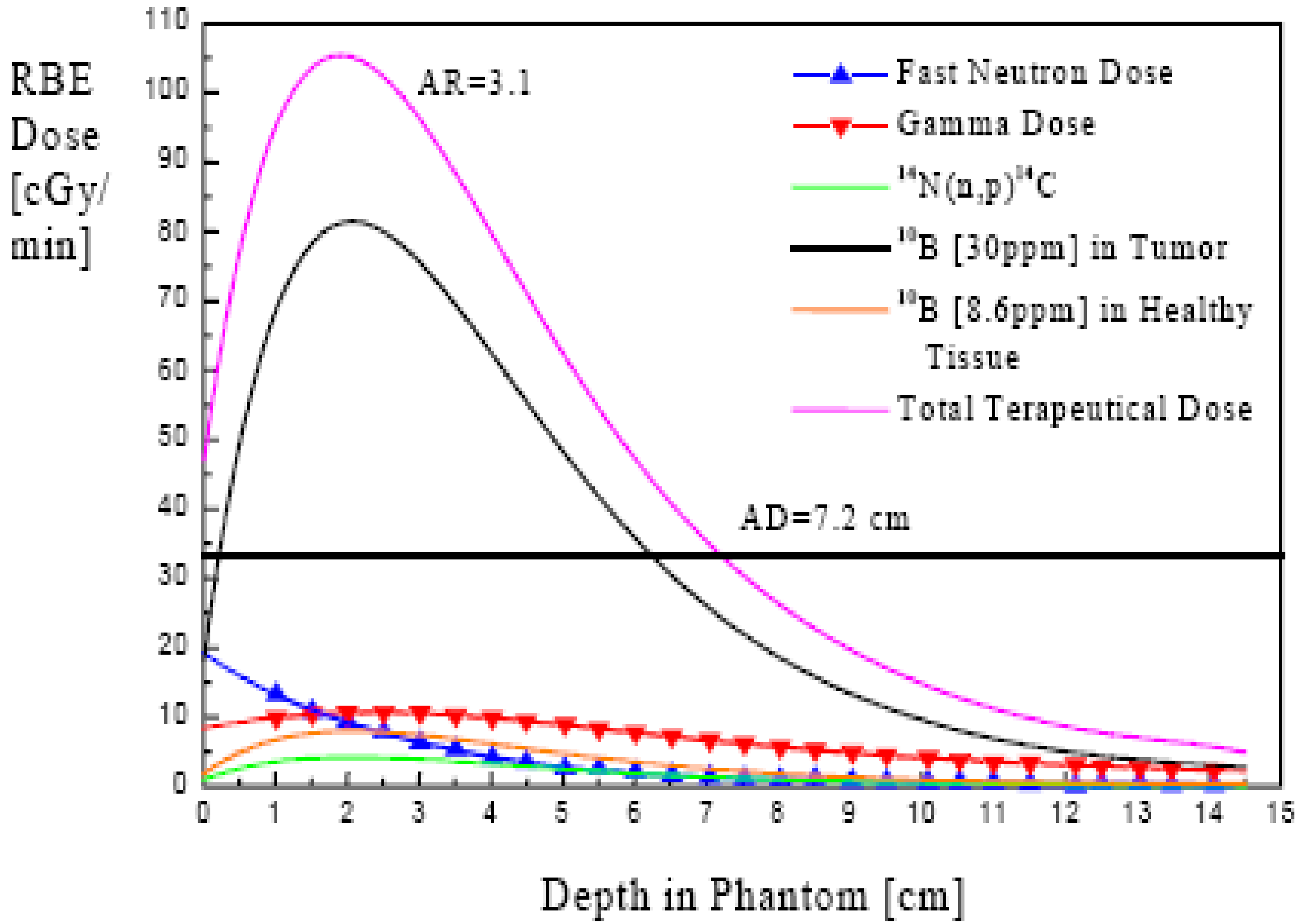
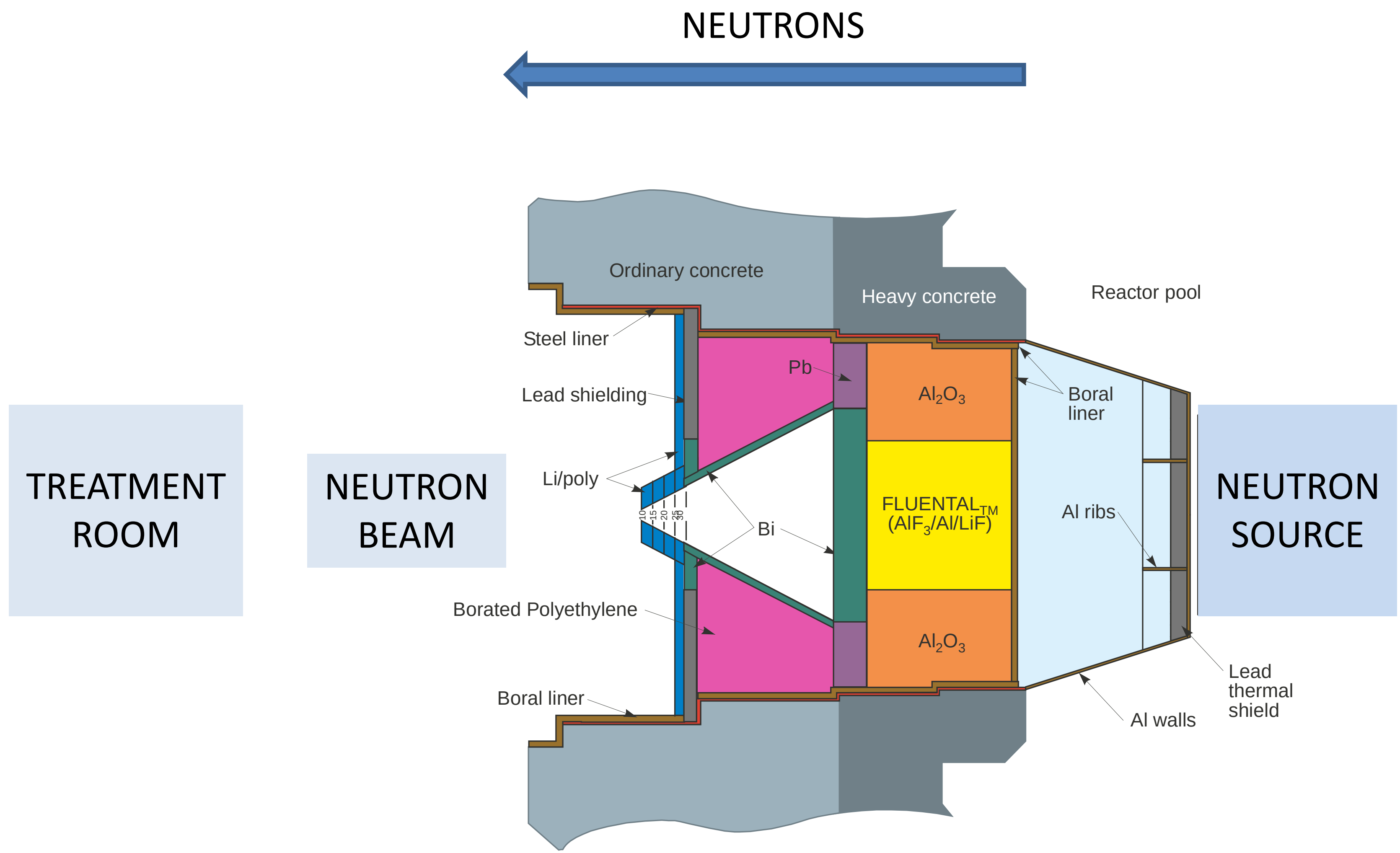


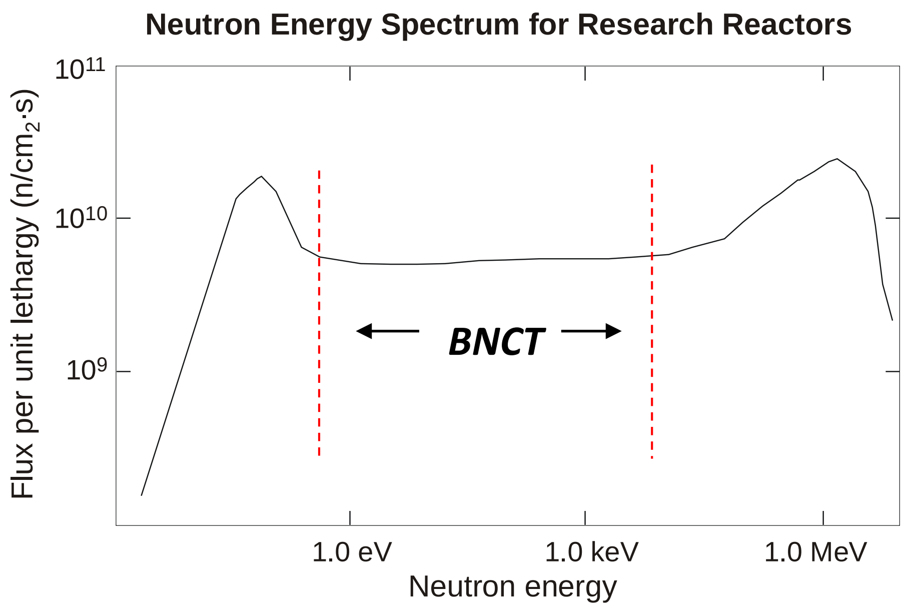
FIG 4. RBE dose in phantom.

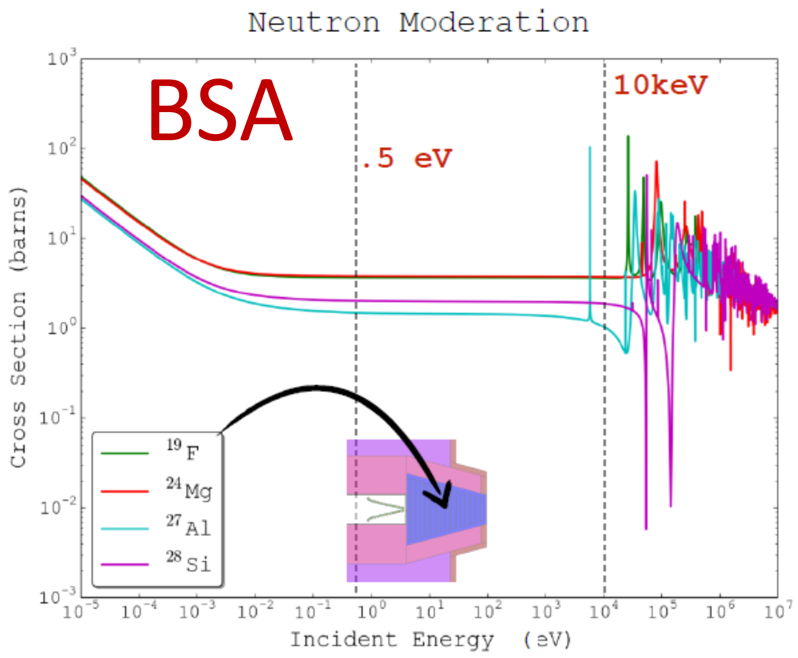
Neutron source: Beam Shaping Assembly (BSA)

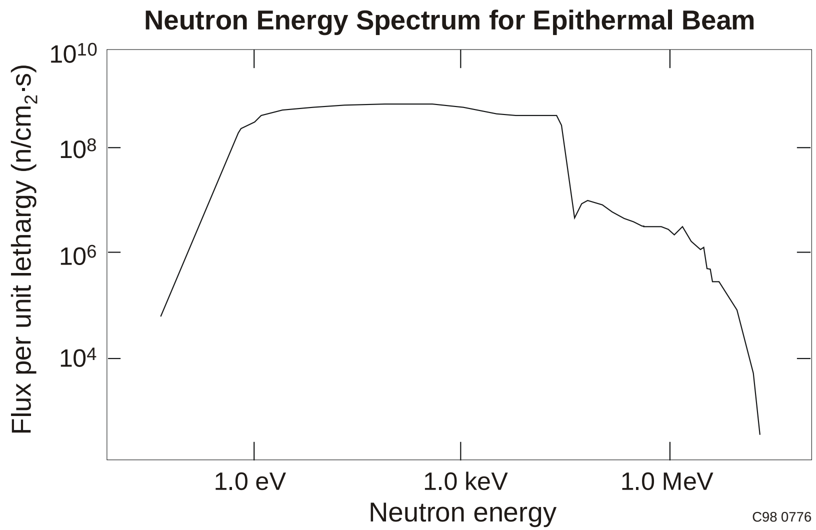


WSU Epithermal Filter

Neutron source: Beam Shaping Assembly (BSA)



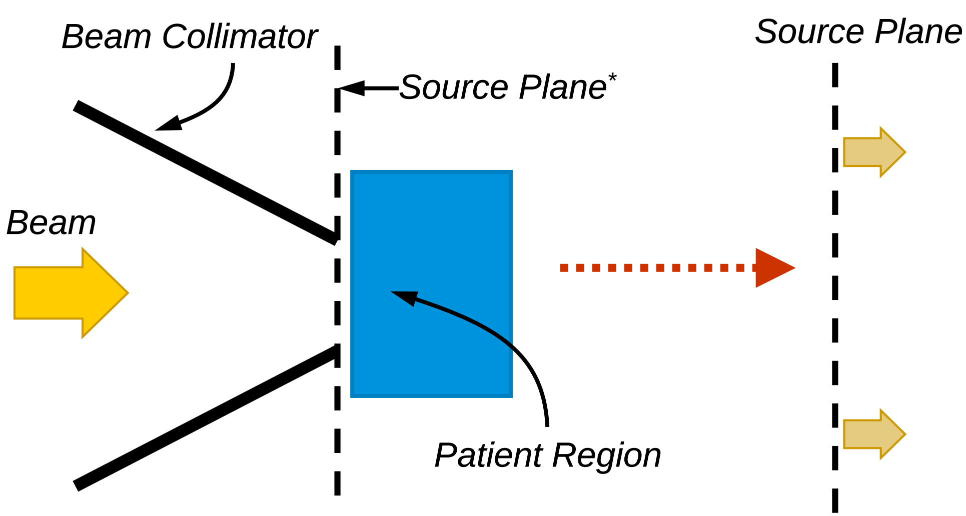




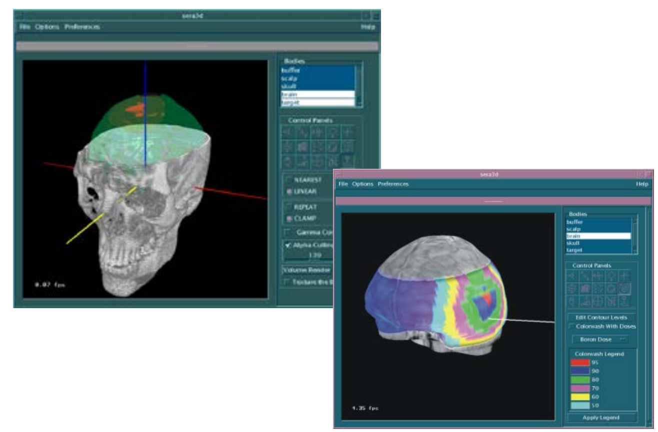
Treatment Planning System for BNCT

Basic Data Flow – BNCT Treatment Planning

Reactor or Accelerator and Beam Modeling DORT or MCNP (S_n) (M.C.) → Source Plane Flux $\Phi_s(E)$ → NCT-PLAN, SERA, JCDS, etc. → $\overline{\Phi}_n(x,y,z,E)$ $\overline{\Phi}_g(x,y,z,E)$ $D(x,y,z)$

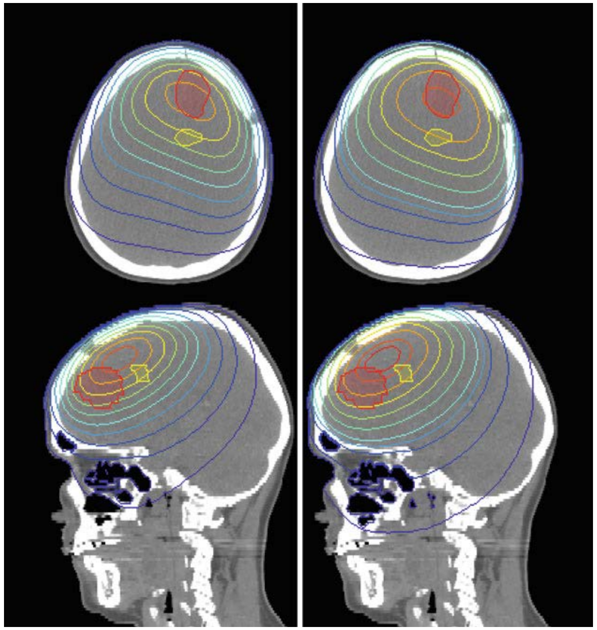


Detailed Treatment planning model and 3-D flux/dose calculation over full-range energy spectrum (many orders of magnitude in energy)

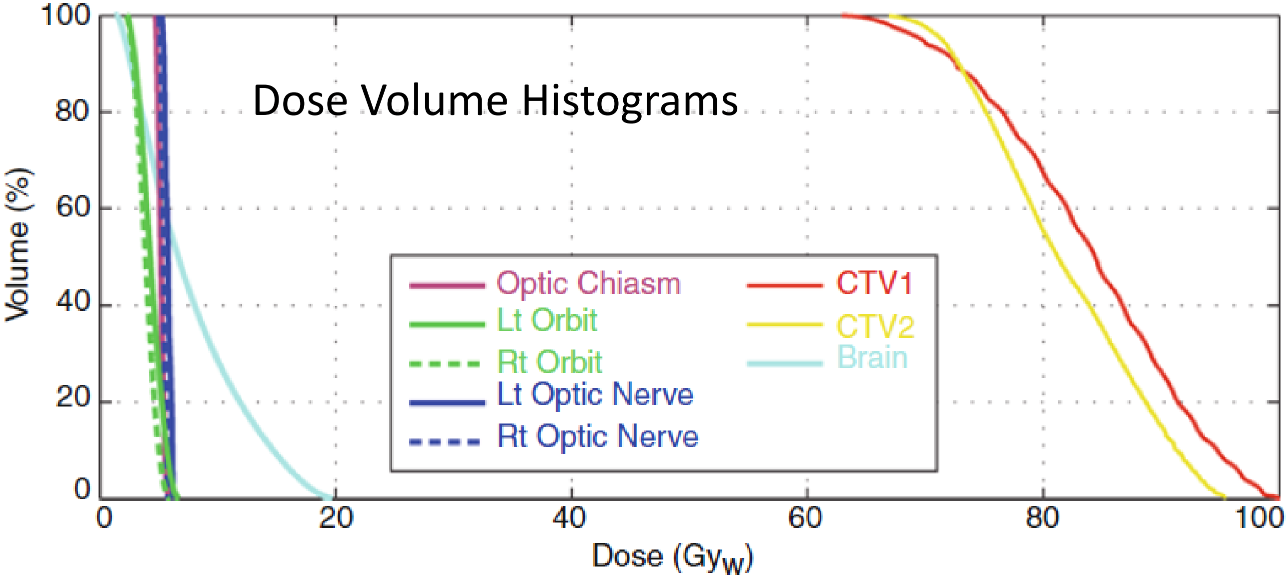


See Albritton and Kiger, ISNCT-13 for some considerations important for representation of the particle flux in the source plane.

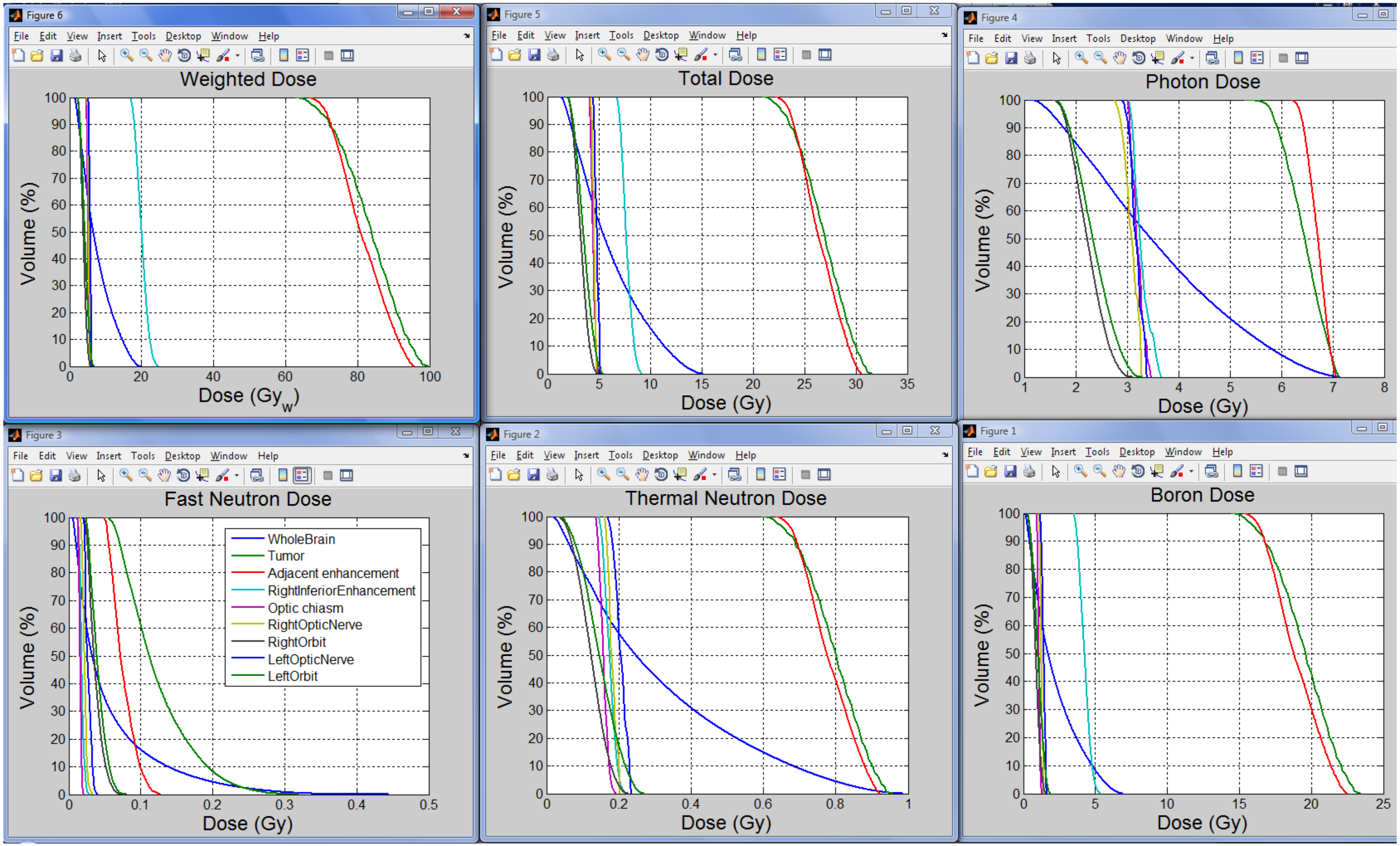
TPS for BNCT: isodoses and DVH



Isodose Distribution



TPS for BNCT: dose components

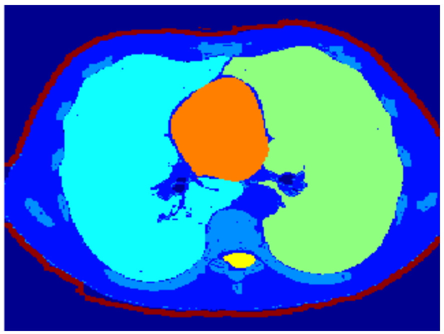


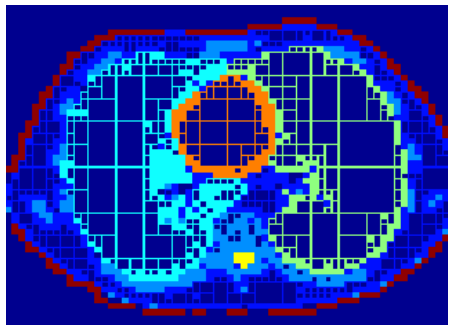
- ***Simplified reporting: DVHs & dose statistics available for all structures and all dose components***

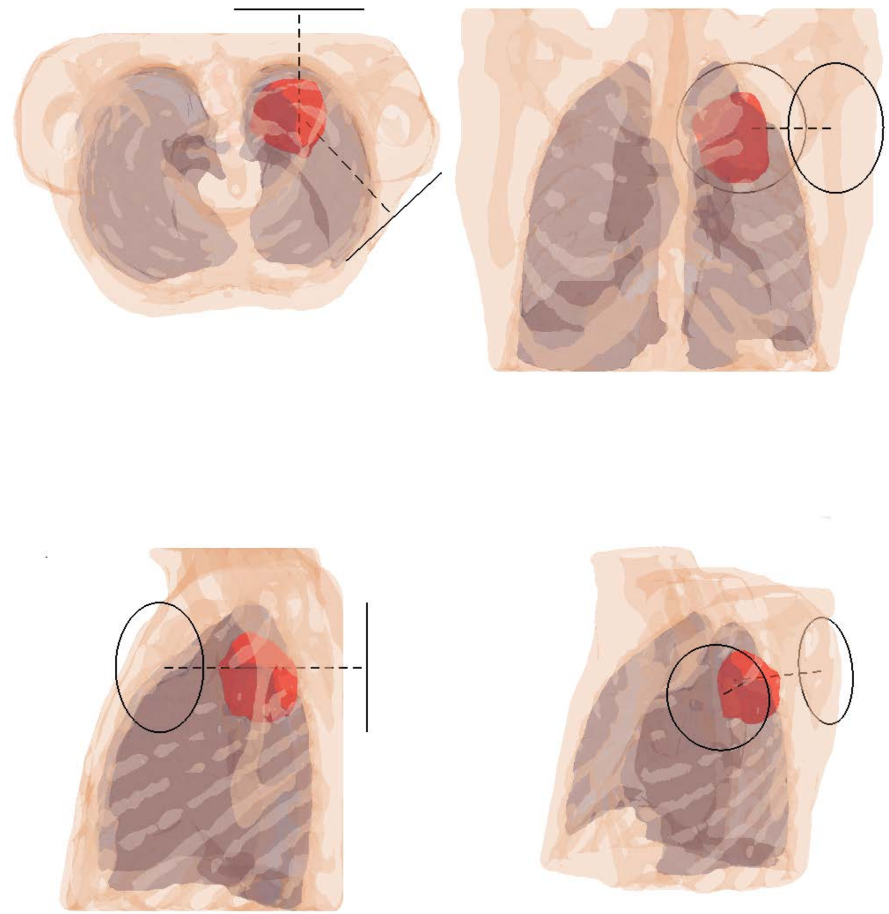
Courtesy of Stead Kiger
Harvard Medical School
Department of Radiation Oncology

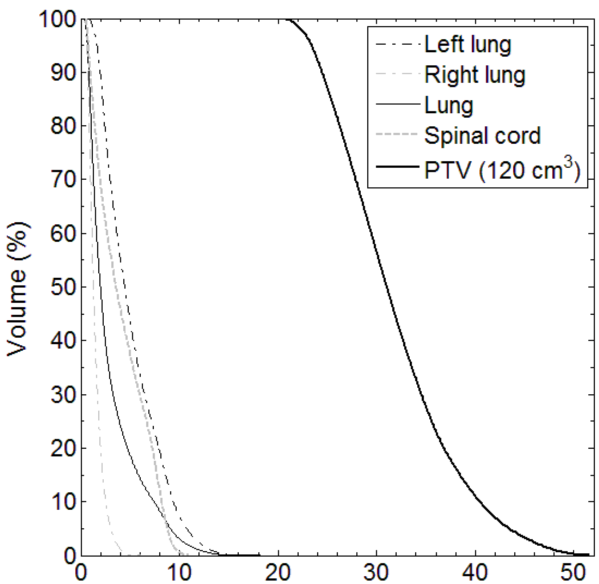
TPS for lung BNCT in patients

In collaboration with Computational Dosimetry and Treatment Planning group of CNEA (Argentina)







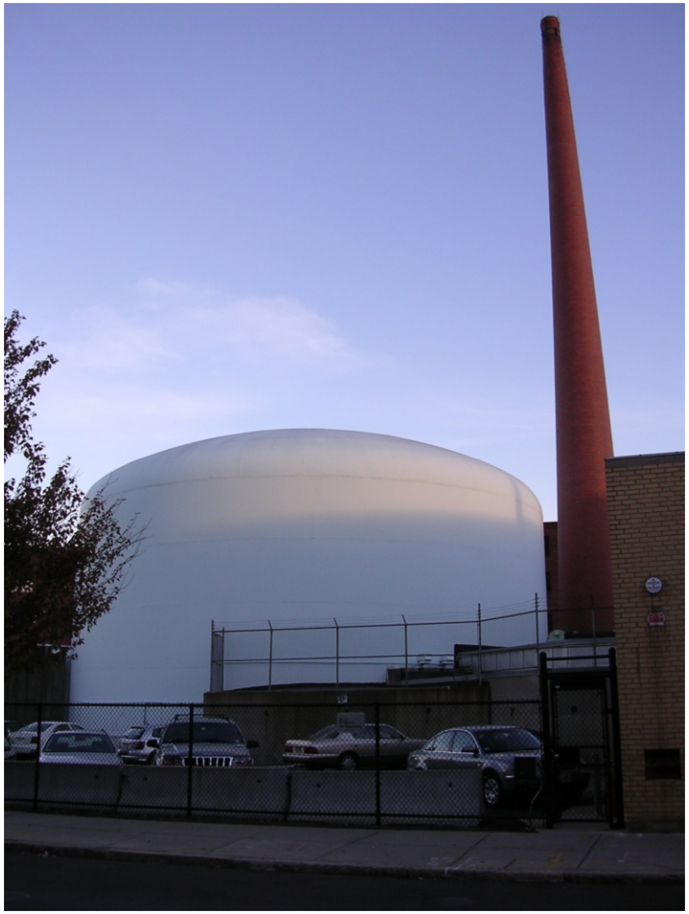


Neutron sources: nuclear reactors

$$\Psi_{th} \cong 10^{12} cm^{-2}$$

Reasonable Irradiation Time
20-40 min.

$$\Phi_{th} = 10^{9} cm^{-2} s^{-1}$$



Nuclear Reactors

IN THE PAST

BNCT in the World

- **Japan (Tsukuba-Osaka-Kyoto)**:
  - Brain tumours (glioma, meningioma)
  - Recurrent Head and neck
  - Melanoma
  - A few cases of
    - lung tumours,
    - pleura,
    - liver …
- **Finland (Helsinki)**
  - Brain tumours
  - Head and neck
- **USA**
  - Brain tumours
- **Argentina (Bariloche)**
  - Skin Melanoma
- **Taiwan (Tsing Hua)**
  - Recurrent Head and neck
- **Italy (Pavia)**
  - Liver metastases

JRR-4 reactor Tsukuba, Japan

Cross-Sectional View of Neutron Beam facility, JRR4.

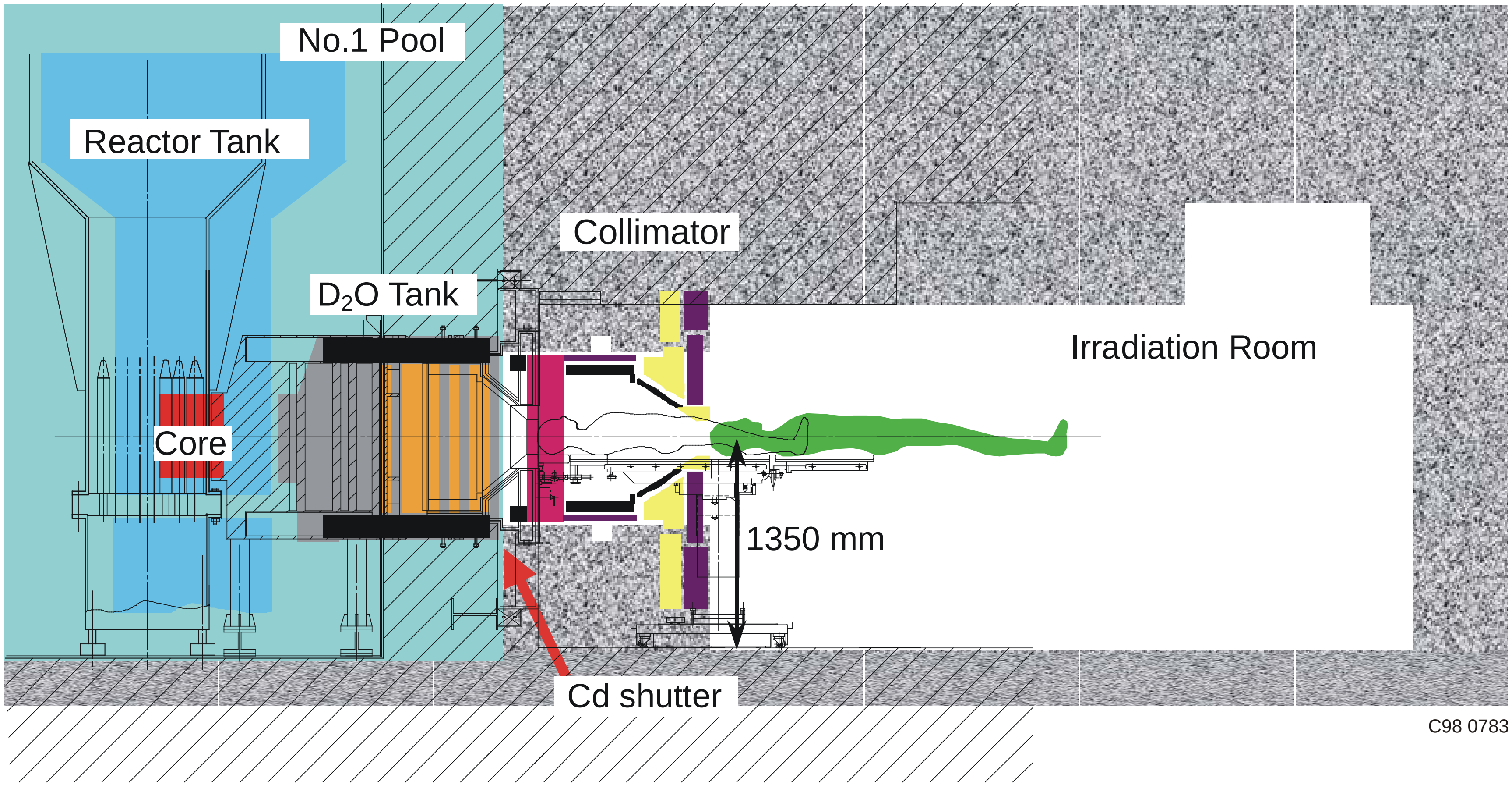
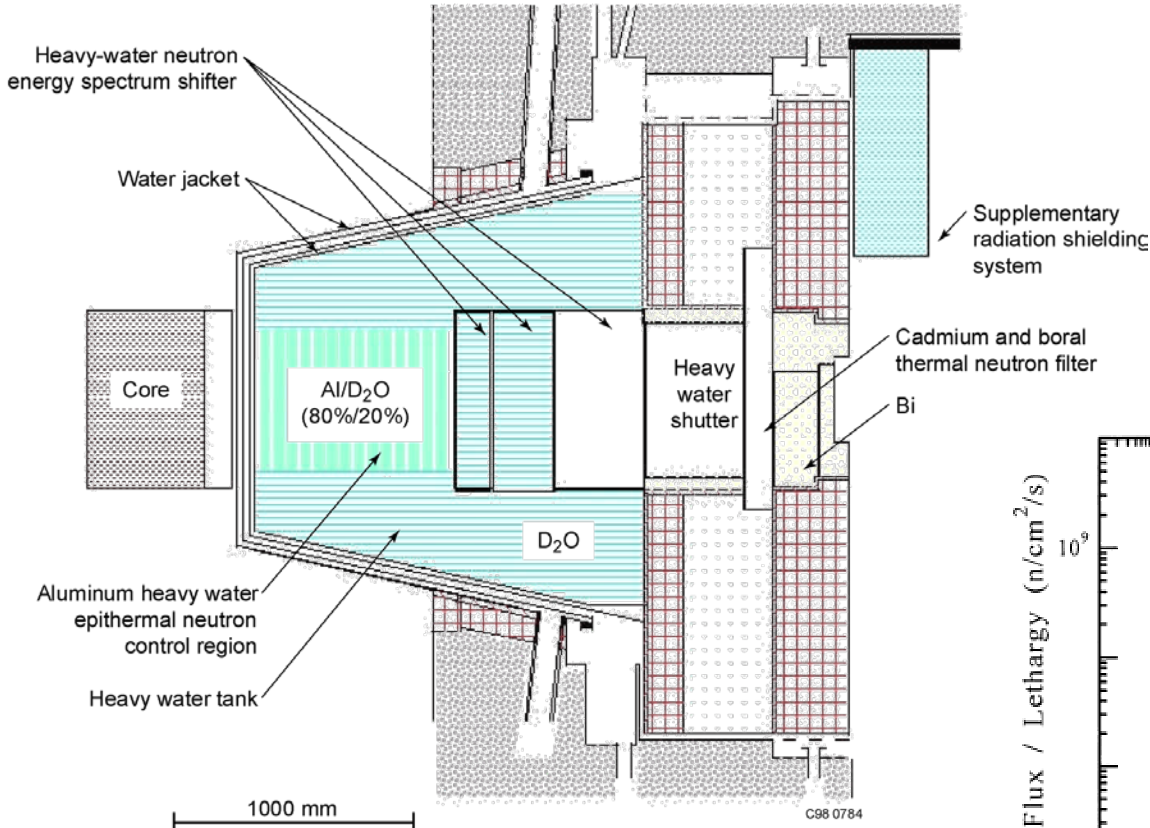
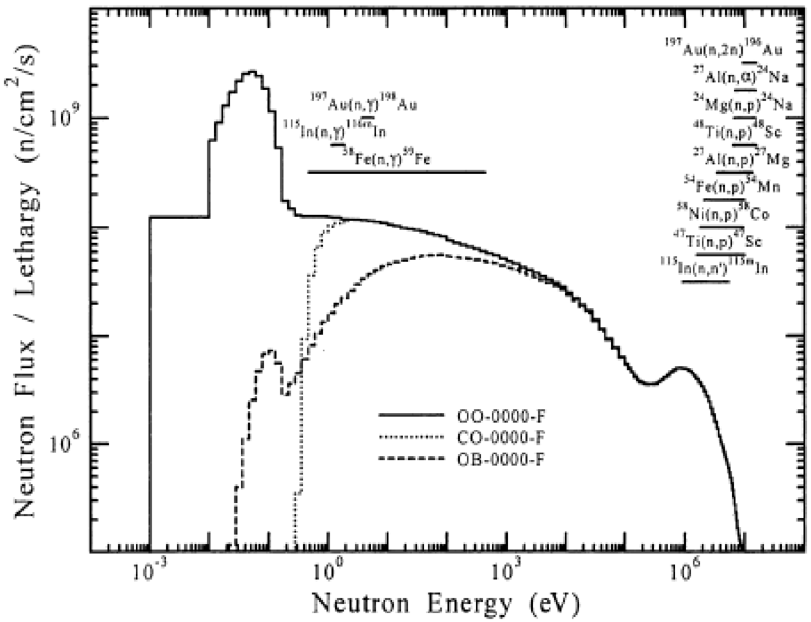


Illustration provided by the Japanese Atomic Energy Research Institute

Kyoto Research Reactor, Japan

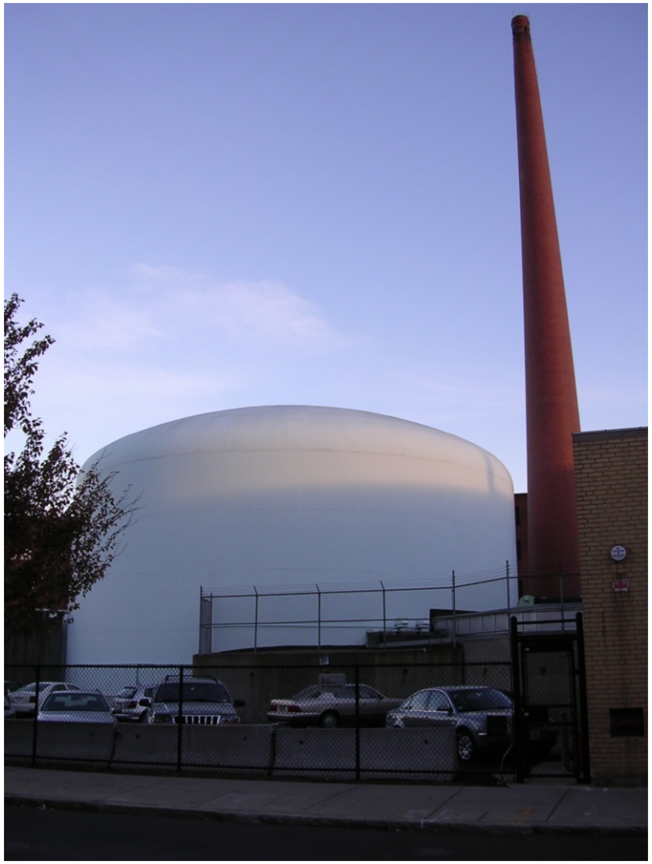


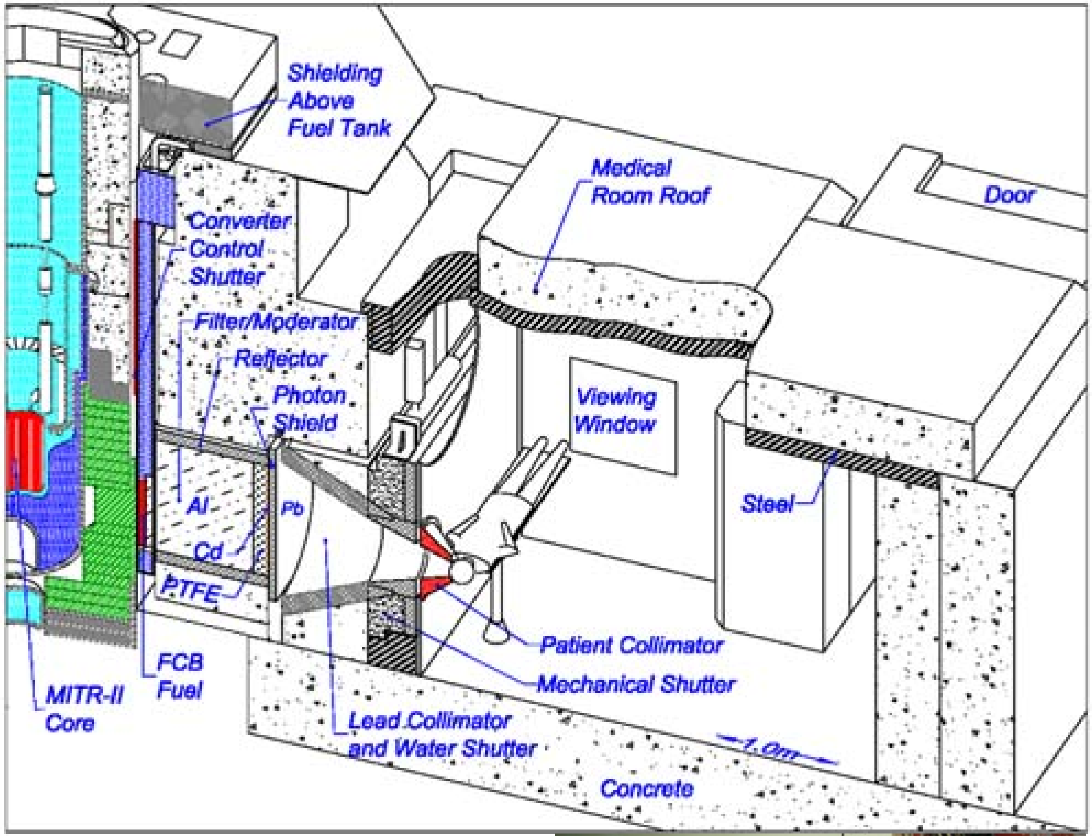


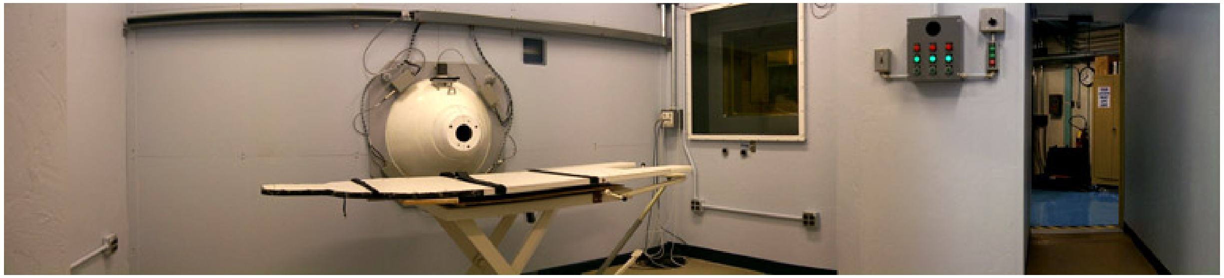
Cross Sectional View of Neutron Beam Facility, Kyoto Research Reactor

Illustration provided by T. Kobayashi, Kyoto University

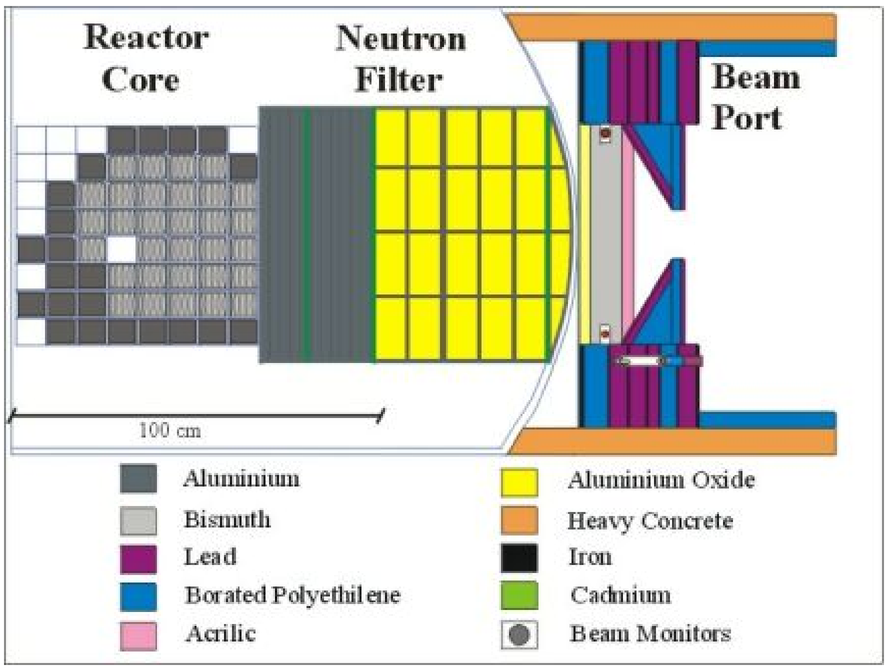
Harvard MIT reactor Boston, USA







RA-6 CNEA Bariloche Argentina



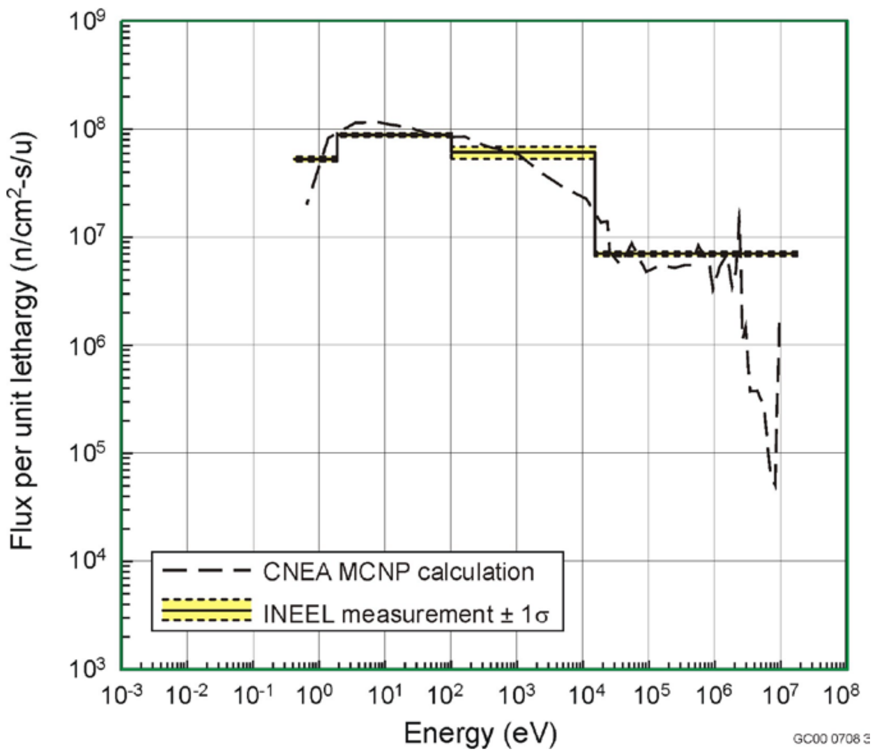
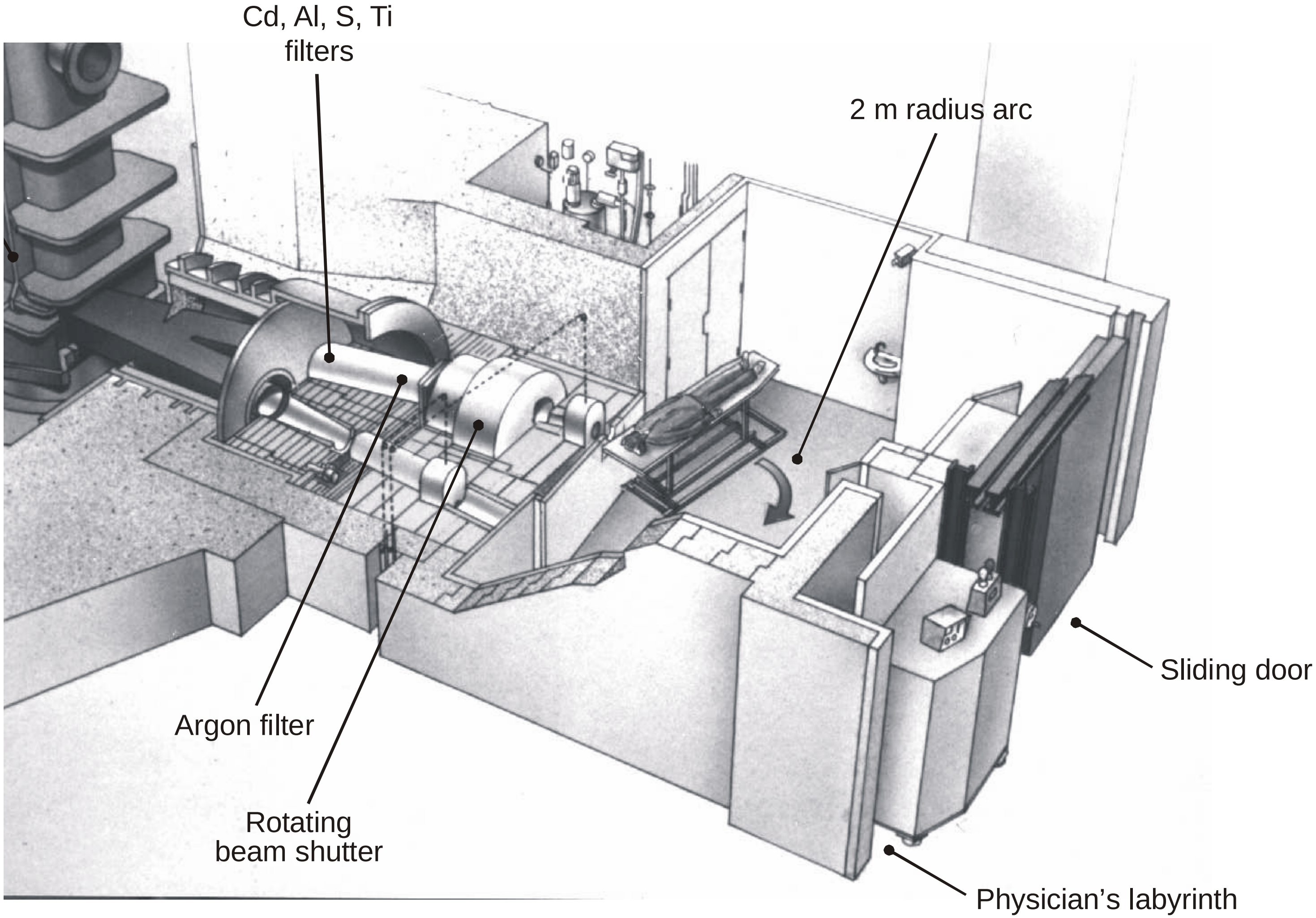


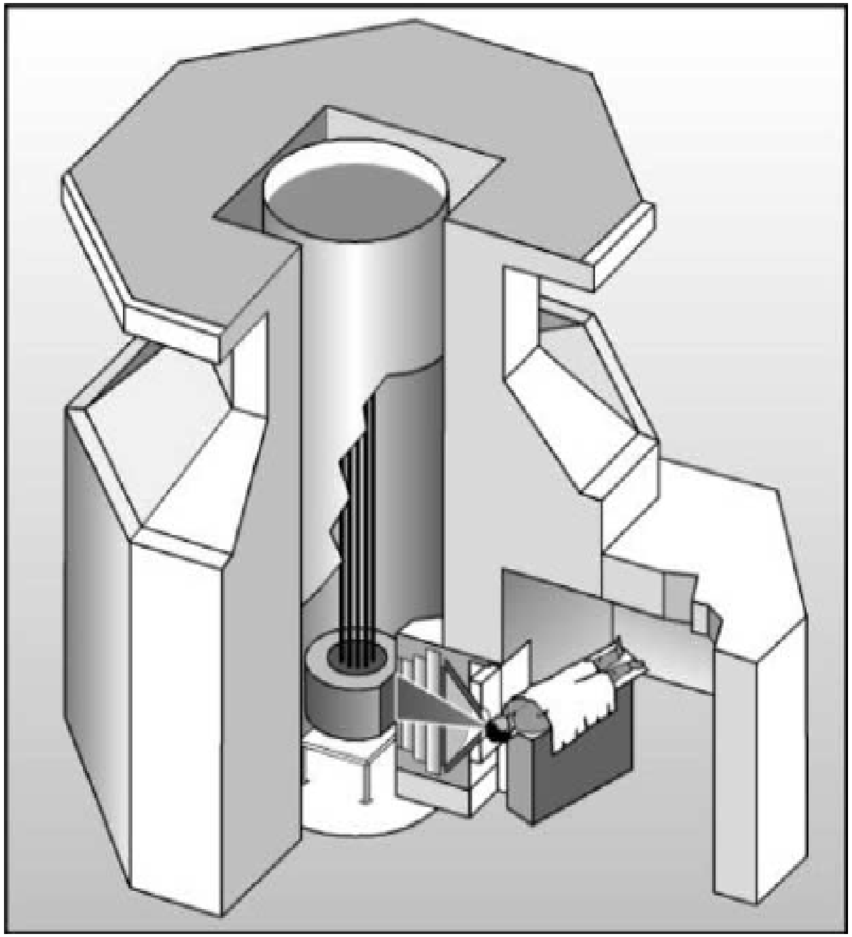
Illustration provided by CNEA-Bariloche. Measurements conducted in collaboration with H. Blaumann, O. Calzetta Larrieu and J. Longino, CNEA Bariloche.

Joint Research Centre, Petten

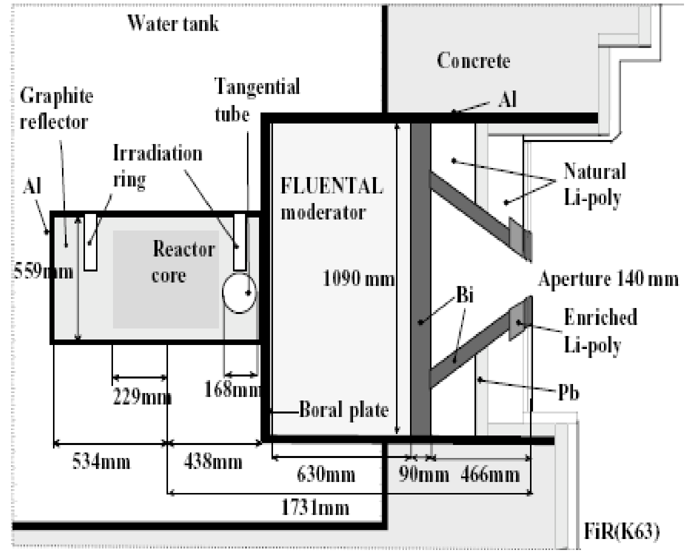


(Illustration provided by the Joint Research Centre, Petten)

FiR 1 reactor Helsinki Finland



use. The measured thermal (<0.5 eV), epithermal (0.5 eV–10 keV), and fast neutron (>10 keV) fluence rates are 8.1 × 10^7, 1.1 × 10^9, and 3.4 × 10^7 neutrons/cm^2/s, respectively, at the exit plane using a 14 cm diameter collimator at 250 kW power [8]. The undesired fast neutron dose per epithermal fluence is 2 Gy/10^{13} cm^{-2} and the corresponding gamma contamination 0.5 Gy/10^{13} cm^{-2} [2]. The in-depth dose



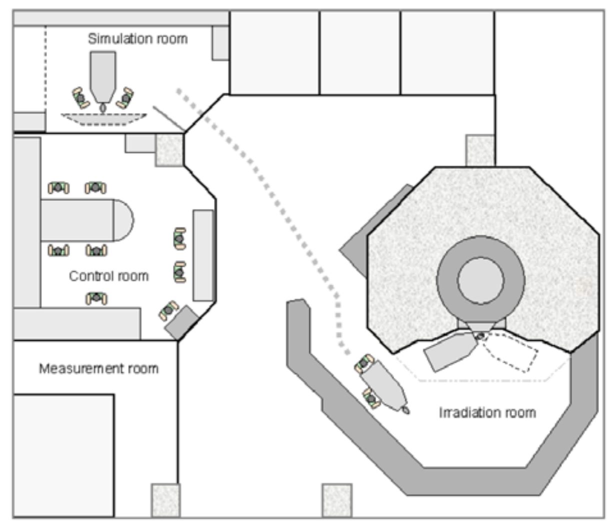


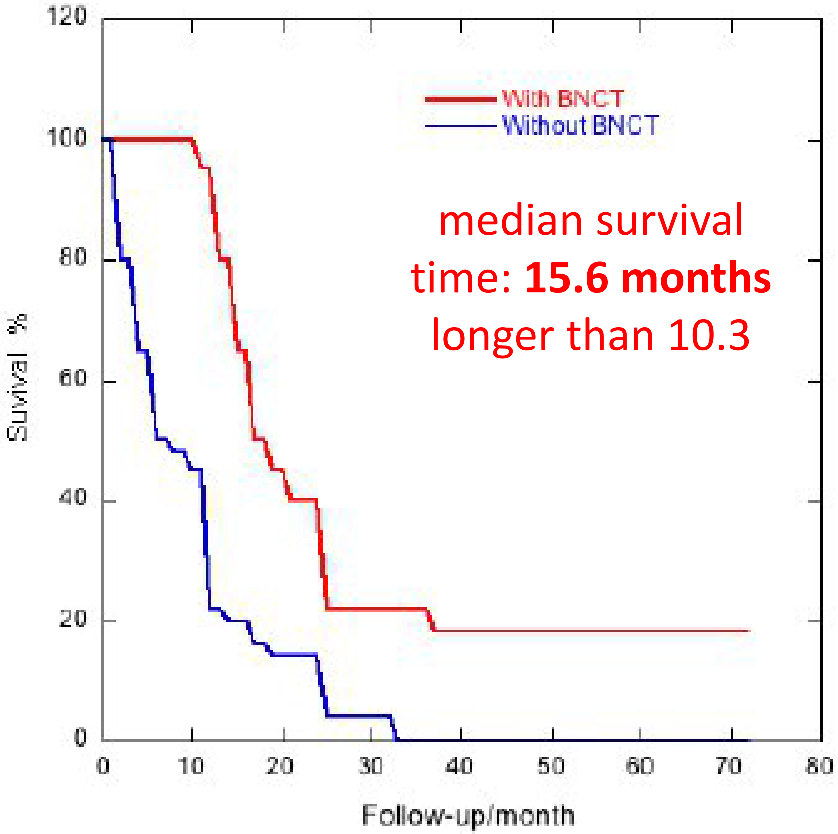
Figure 25. *The floor plan showing the irradiation room and the simulation room of the Finnish BNCT facility.*

BNCT of Glioblastoma Multiforme (GBM)

Modern trials with BPA and BSH and epithermal neutron beams
300 patients

Starting from the 1990s, BNCT trials have been carried out using more selective boron formulations and epithermal collimated neutron beams:

- United States at BNL Medical Research Reactor (BMRR) and at Harvard-MIT using the MITR (79 patients),
- Japan at JRR-4 and at KURR (89 patients),
- Europe at the High Flux Reactor, JRC Petten, The Netherlands (30 patients),
- FiR-1, VTT Technical Research Centre, Espoo, Finland (52 patients),
- LVR-15 Reactor, Nuclear Research Institute Rez, Czech Republic (5 patients),
- R2-0 Reactor, Studsvik Medical, Nyköping, Sweden (43 patients)



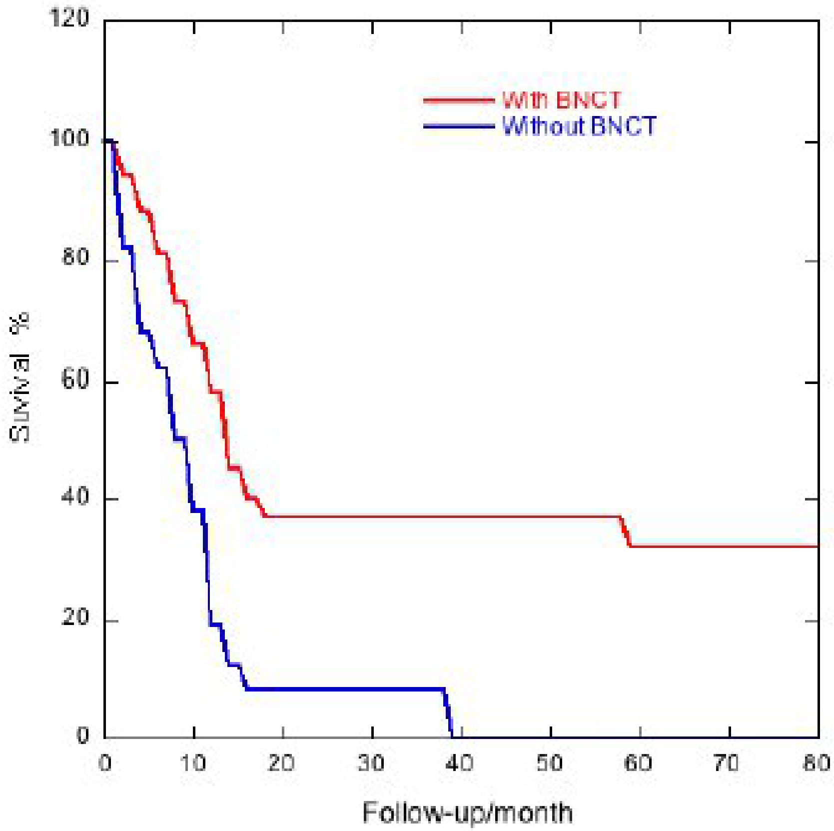
(Kawabata et al. 2009)

BNCT tolerability and **quality of life improvement**

Modern trials with BPA and BSH and epithermal neutron beams
165 patients

From 2001 to 2011 with recurrent head and neck have been treated at KURR, JRR-4, THOR, and FIR-1.

At FIR-1, the most active BNCT center in Europe,
45% achieved a complete clinical response,
31% achieved a partial response,
21% had disease stabilization for a median of 8.5 months (range, 5.1–20.3 months)
3% progressed

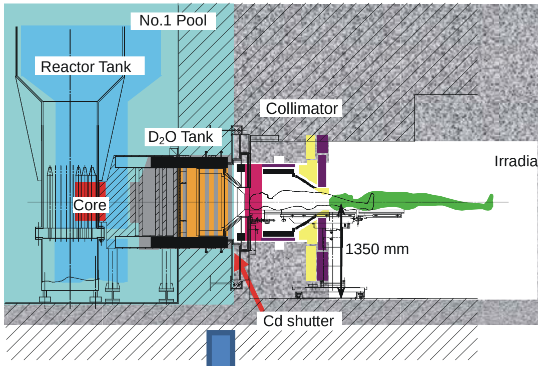


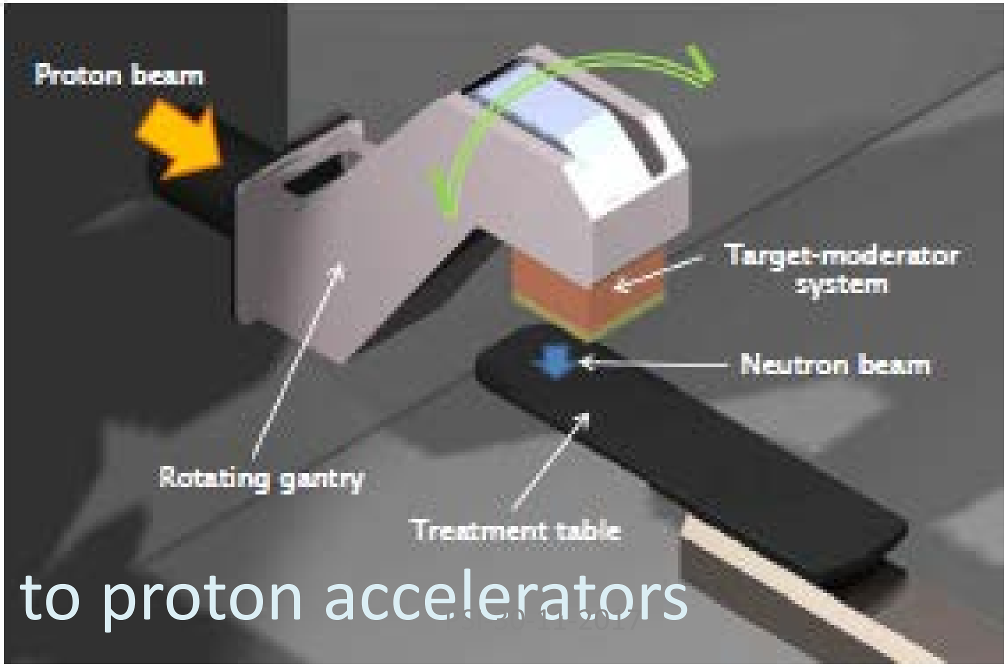
(Kato et al., 2009)

BNCT tolerability and **quality of life improvement**

Neutron sources: from reactors to accelerators

from reactors





to proton accelerators

Neutron sources: accelerators

Table 1. Characteristics of four charged-particle reactions considered for accelerator-based boron neutron capture therapies

Reaction	Bombarding energy (MeV)	Neutron production rate (n/min-mA)	Calculated average neutron energy at 0° (MeV)	Calculated maximum neutron energy (MeV)	Target melting point (°C)	Target thermal conductivity (W/m-K)
$^{7}Li(p,n)$	2.5	5.34×10^{13}	0.55	0.786	181	85
$^{9}Be(p,n)$	4.0	6.0×10^{13}	1.06	2.12	1287	201
$^{9}Be(d,n)$	1.5	$1.3 \times 10^{13*}$	2.01	5.81	1287	201
$^{13}C(d,n)$	1.5	1.09×10^{13}	1.08	6.77	3550	230

*Varies by a factor of three in the literature; this value was determined by comparing simulation and experimental values.

$10^{9}\ cm^{-2}s^{-1}$ ⟹ $(\sim 10^{13}–10^{14}\ s^{-1})$ ⟹ 10-20 mA

power on the target: kW/cm^2

Thermal conductivity
Melting point
Gas permeability

Neutron sources: accelerators

Current status for accelerator-based BNCT in the world

Location		Machine (Status)	Target & reaction	Beam Energy (MeV)	Beam current (mA)
	Budker Institute (Russia)	*Vacuum insulated Tandem (Ready)*	*Solid $^{7}Li(p, n)$*	*2*	*2*
	iPPE-Obninsk (Russia)	*Cascade generator KG- 2.5 (Ready)*	*Solid $^{7}Li(p, n)$*	*2.3*	*3*
	Birmingham Univ. (UK)	*Dynamitron (Ready)*	*Solid $^{7}Li(p, n)$*	*2.8*	*1*
	Soreq (Israel)	*RFQ-DTL (Ready)*	*Liquid $^{7}Li(p, n)$*	*4*	*1*
	Legnaro INFN (Italy)	*RFQ*	*Be(p, n)*	*4-5*	*30*
	CNEA Buenos Aires (Argentina)	*Single ended Tandem Electrostatic Quadrupole (TESQ)*	*Be(d, n)*	*1.4*	*30*
			Solid $^{7}Li(p, n)$	*2.5*	*30*
Japan	*KURRI*	*Cyclotron (Clinical Trial)*	*Be(p, n)*	*30*	*1*
Japan	*University of Tsukuba*	*RFQ-DTL*	*Be(p, n)*	*8*	*10*
Japan	*NCCenter, CICS*	*RFQ*	*Solid $^{7}Li(p, n)$*	*2.5*	*20*
Japan	*Fukushima South Tohoku Hospital*	*Cyclotron*	*Be(p, n)*	*30*	*1*
Japan	*Osaka University*	*Neutron target system only*	*Liquid $^{7}Li(p, n)$*	*~2.5*	*-*
Japan	*Nagoya University*	*Dynamitron*	*Solid $^{7}Li(p, n)$*		
Japan	*Planning and designing : OIST (Okinawa) , Osaka Medical College (Osaka), Edogawa Hospital (Tokyo)*				

By Hiroaki Kumada (Tsukuba Univ.)

Neutron sources: accelerators **electrostatic**

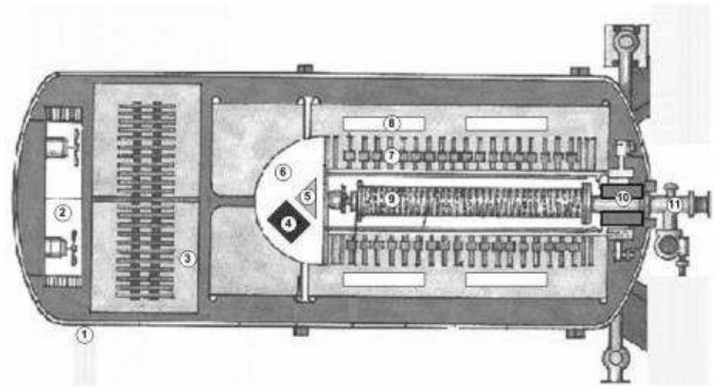
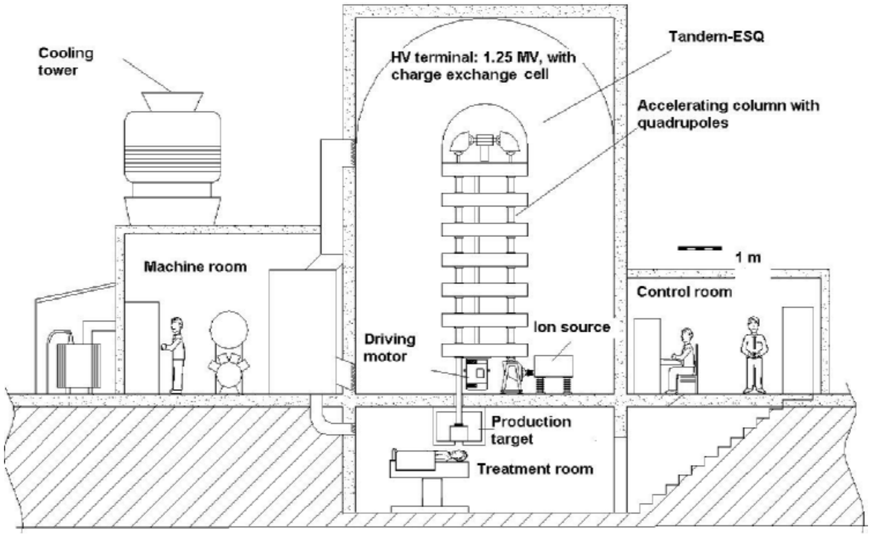


Figure 2: Layout of the dynamitron. The ECR source and selection magnet are pictured as a dark square and grey triangle, respectively.

Overview of the IBA Accelerator-Based BNCT System

E. Forton, F. Stichelbaut, A. Cambriani, W. Kleeven, J. Ahlback, Y. Jongen.
Ion Beam Applications s.a., Chemin du Cyclotron 3, Louvain-la-Neuve, Belgium



A Tandem-electrostatic-quadrupole for accelerator-based BNCT

A.J. Kreiner [a,b,c,*], J.W. Kwan [d], A.A. Burlón [a,b], H. Di Paolo [a,b], E. Henestroza [d], D.M. Minsky [a,b], A.A. Valda [b], M.E. Debray [a,b], H. Somacal [b]

[a] *Departamento de Física, CNEA, Villa Martelli, Prov. Buenos Aires, Argentina*
[b] *Escuela de Ciencia y Tecnología, Universidad de San Martín, San Martín, Argentina*
[c] *CONICET, Buenos Aires, Argentina*
[d] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, USA*

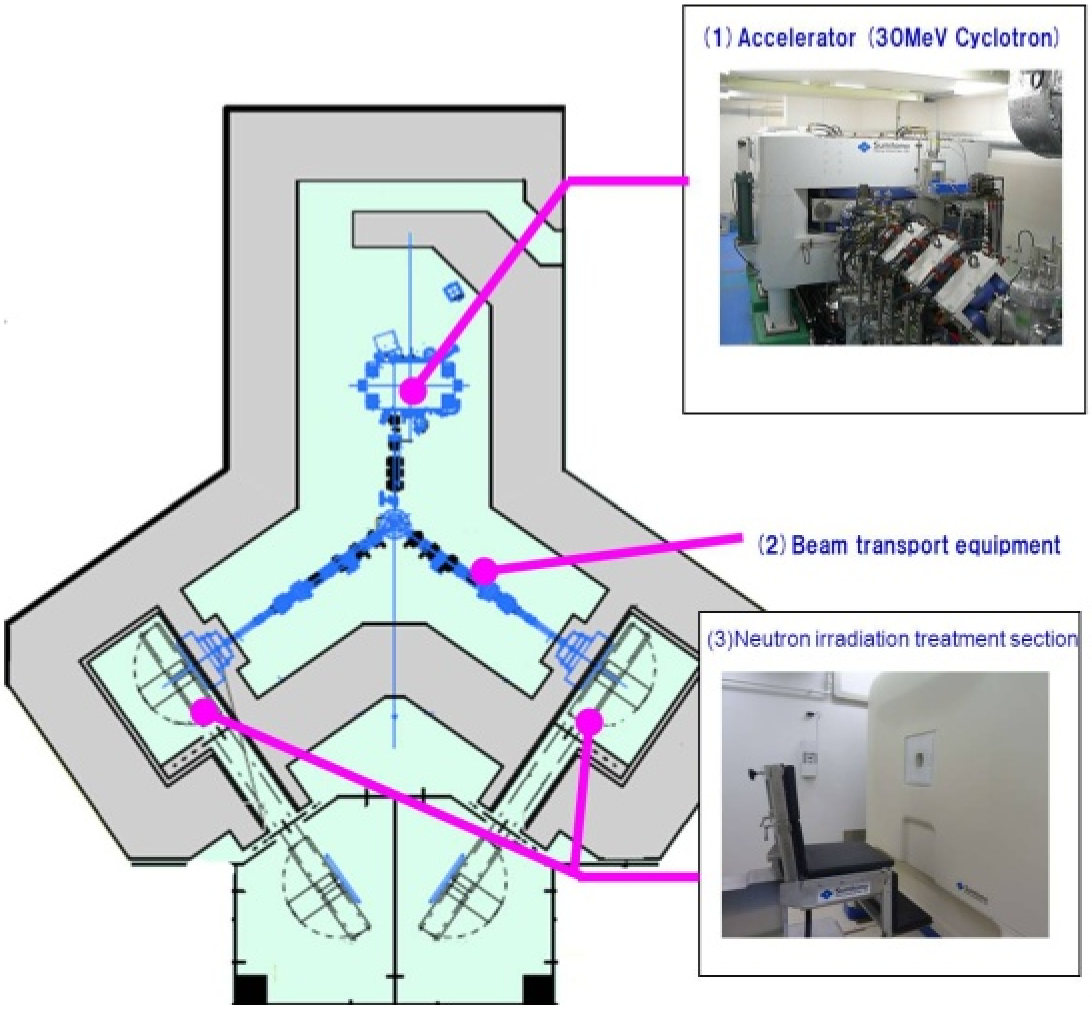
Neutron sources: accelerators **cyclotron KYOTO**

Cyclotron:
Sumitomo Heavy Industry

Neutron Irradiation System

Neutron sources: accelerators **cyclotron FUKUSHIMA**

Cyclotron:
Sumitomo Heavy Industry



Neutron sources: accelerators RFQ TOKYO

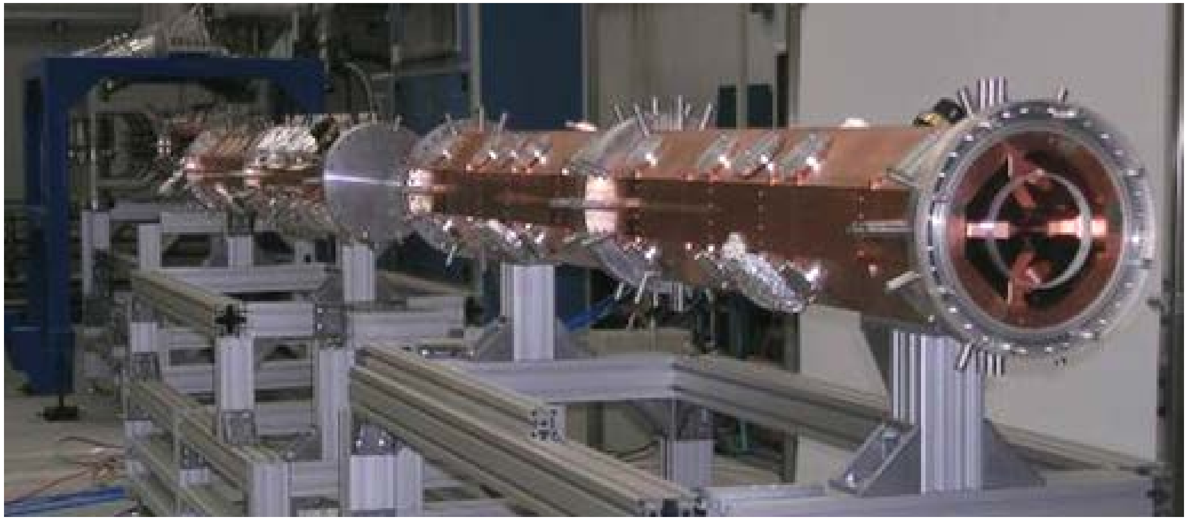
The RFQ tube and the DTL tube and Klystron

- Technologies of front-end Linac of J-PARC
- The proton energy is 8MeV. Peak beam current is 50mA (aver. >5mA, beam power >40kW.)
- 3MeV RFQ(3.2M) + DTL tube (4M).
- Total Linac (7m length, <50 m2)

Ibaraki Neutron Medical Research Center (iNMRC)

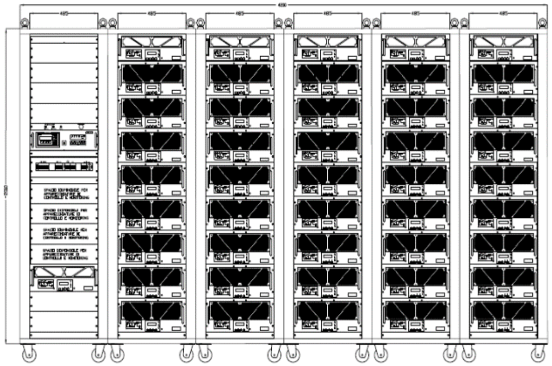
Neutron sources: accelerators **RFQ INFN LNL - PAVIA**

Radio Frequency Quadrupole accelerator of National Institute of Nuclear Physics (INFN)



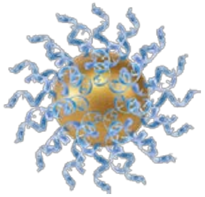
Accelerator type	LINAC
Proton energy	5 MeV
Proton current	30 mA
Beam power	150 kW
Time structure	up to CW
Neutron converter	Be
Neutron source intensity	10^{14} s^{-1}
Total accelerator length	7.2 m

No klystron but 8 independent solid state 125 kW amplifiers



BNCT @ Pavia University and INFN

- Disseminated liver metastases: TAOrMINA project



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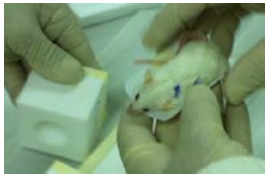
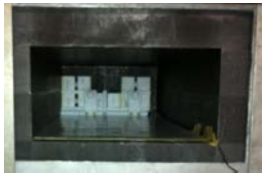
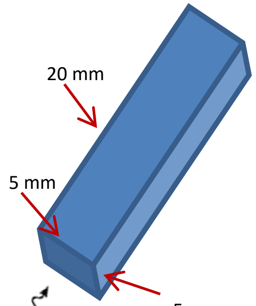
- Tests of toxicity and effectiveness of BNCT by irradiating cell cultures and animal models treated with new boron compounds

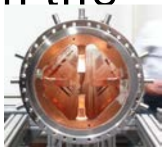




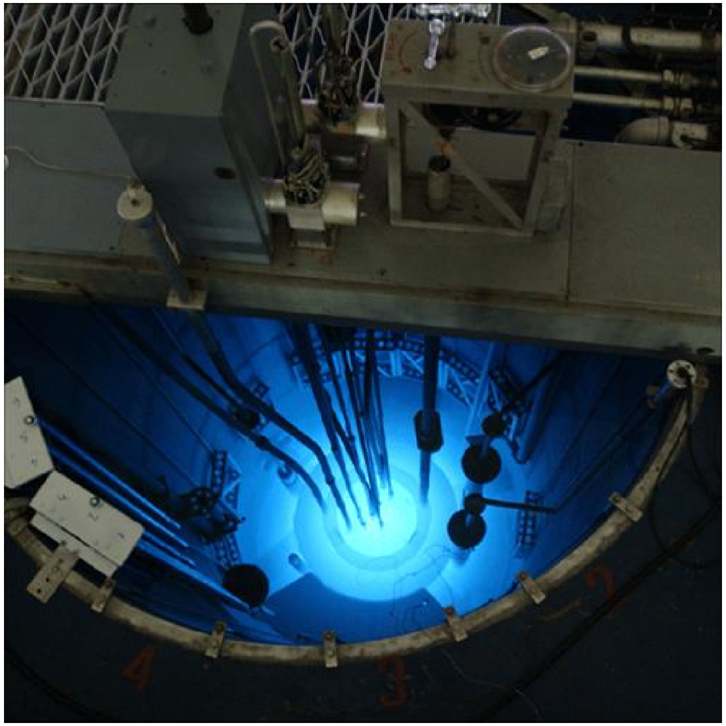
  - Disseminated lung metastases
  - Mesothelioma
  - Limb osteosarcoma

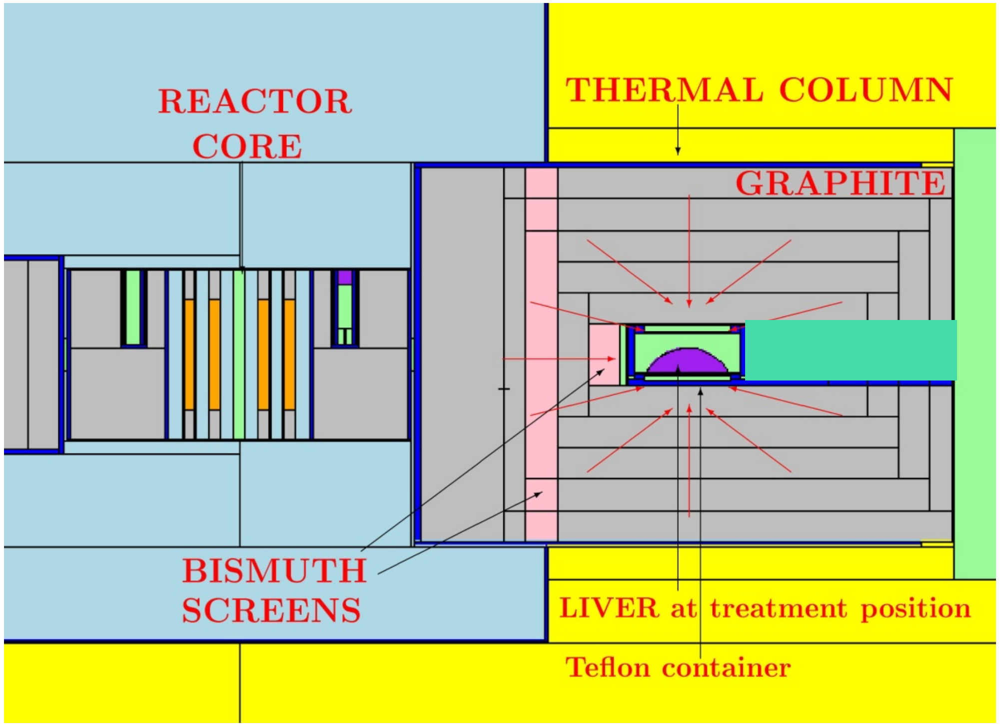


- In vivo boron dose imaging system based on Zinc Cadmium Thelluride detector (SPECT)
- Installation of an accelerator based BNCT system in the Italian Hadron Therapy Center in Pavia



250 kW Triga reactor @ LENA





The treatment is based on the irradiation of the isolated organ in a neutron field where neutrons coming from all directions can irradiate the whole liver

Liver coming out from the patient's body

After 2 hours of BPA infusion the liver was explanted

Liver-out

Refrigerated teflon container

At the reactor thermal column

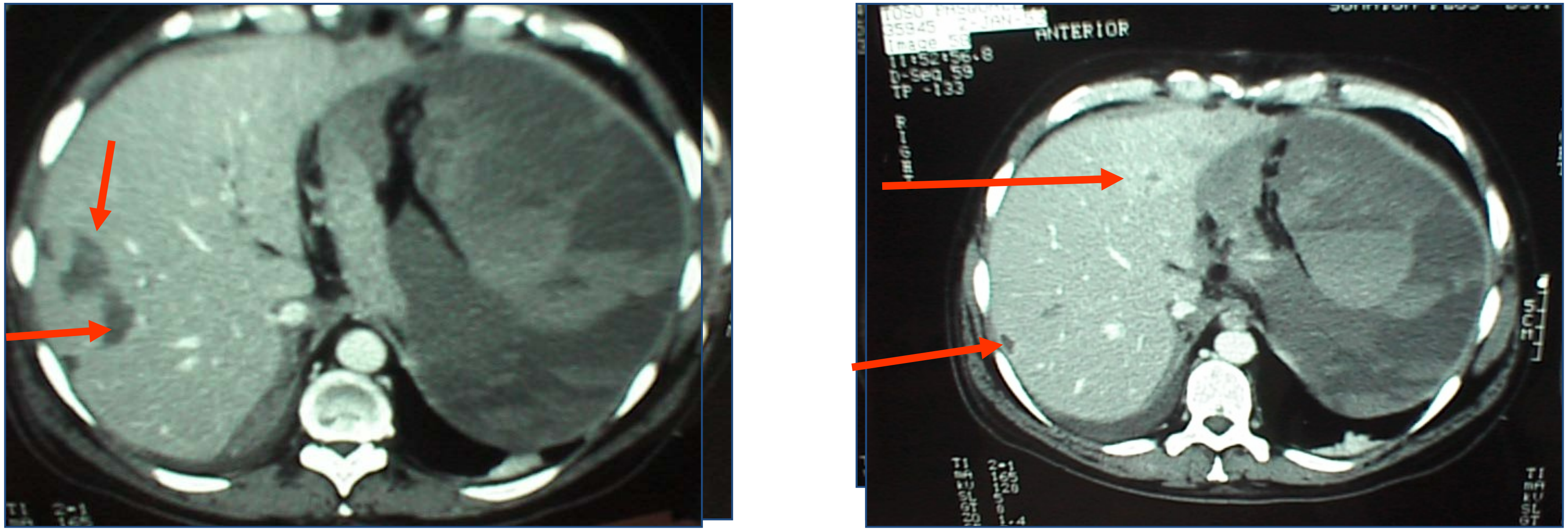
Pushing the liver into the reactor

[Pushing the liver into the reactor](#)

Liver back to the surgery room

CT scan after BNCT

7 days after treatment the CT scanning evidenced the liver in normal condition while the metastases appeared in a necrotic state



Arrows indicate the necrotic zones detected after BNCT

CT scan after BNCT

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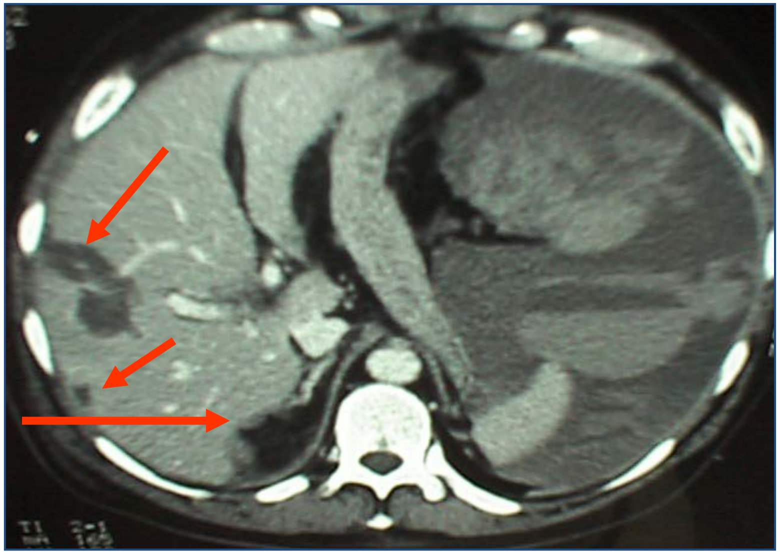

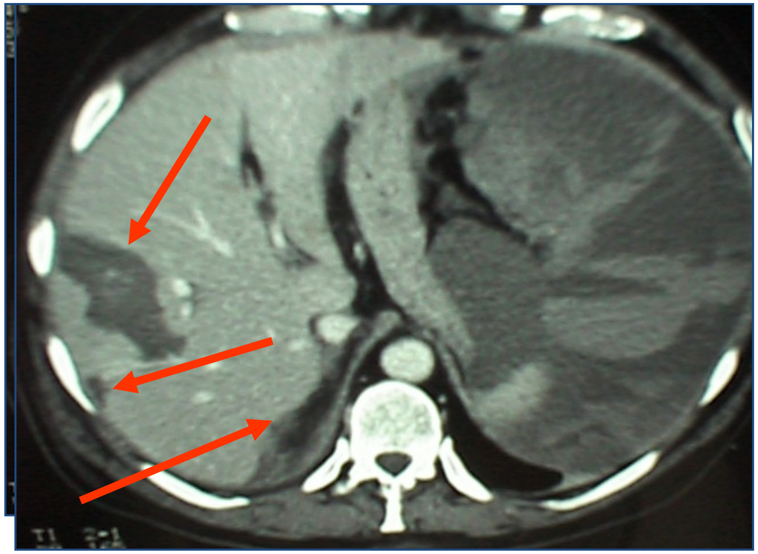

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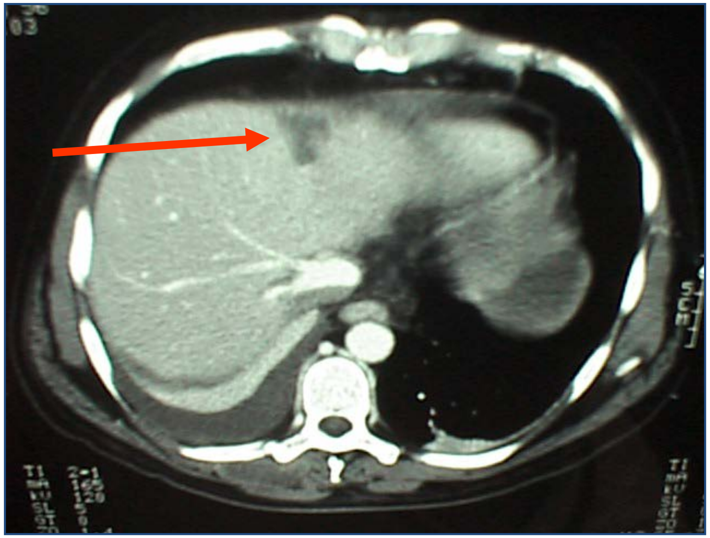


Arrows indicate the necrotic zones detected after BNCT

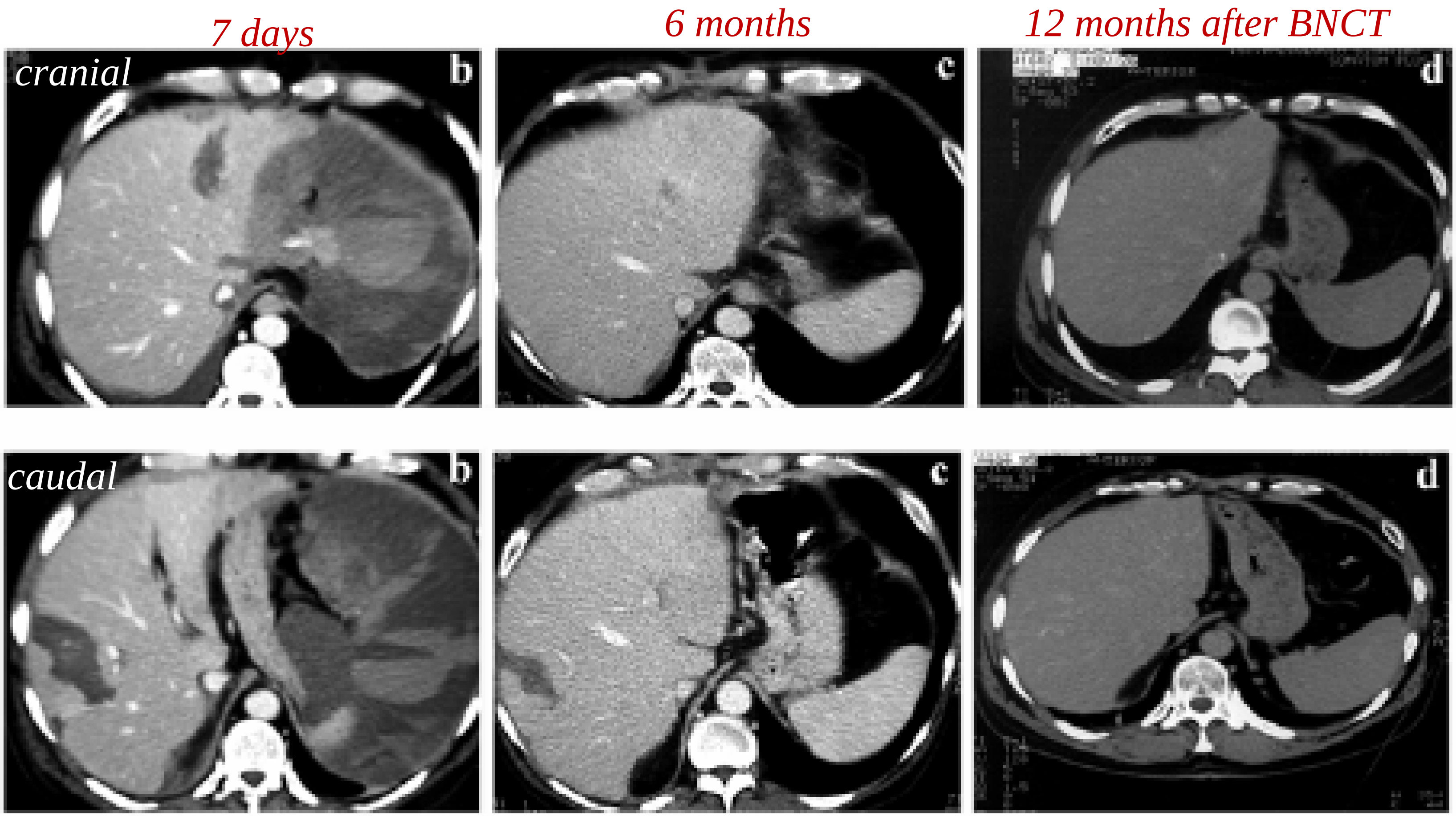
A. Zonta et al. Extra-corporeal liver BNCT Applied Radiation and Isotopes 67 (2009) S67–S75

The outcome of the treatment

In the patient all clinical anomalies and biochemical alterations disappeared within some weeks and the patient was discharged in the 40th p.o.day.

Before leaving the Polyclinic
he recovered all of his functions and his general condition was good.

The outcome of the treatment: 1th patient



Sequence of CT images of liver in the first patient subject to BNCT; evolution at different times of the metastases towards necrosis with final substitution by normal tissues

A. Zonta et al. Journal of Physics: Conference Series **41** (2006) 484–495

BNCT @ Pavia University and INFN

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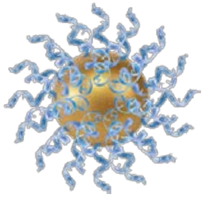
- Research on new boron carriers: boron up-take measurements in vitro and vivo in animal models



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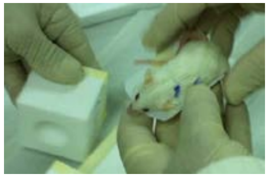

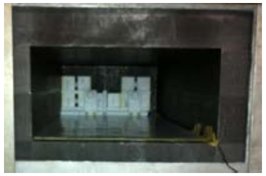

  - Disseminated lung metastases
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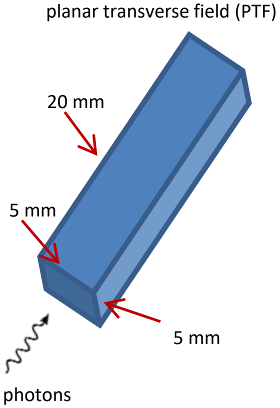

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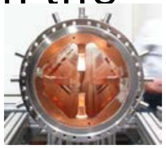
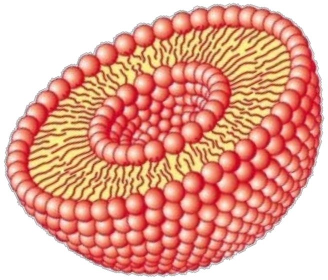
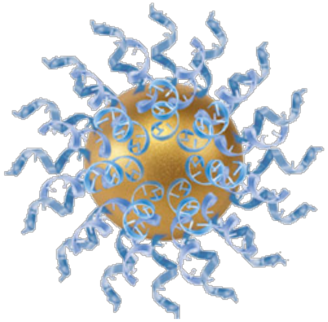


New formulations

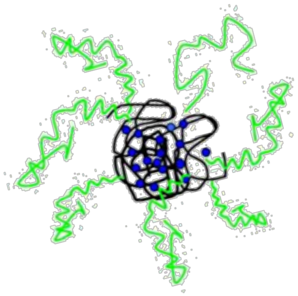
Liposomes loaded with lactosyl-carboranes (LCOB)





Gold nanoparticles
with boron

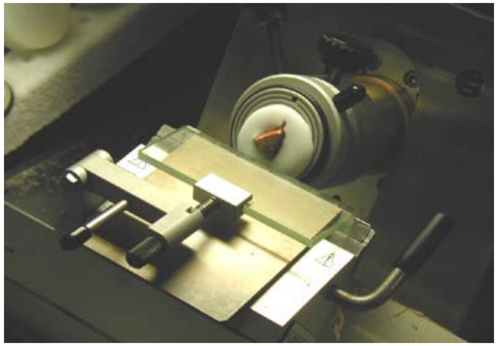
Polimeric micelles with carboranes

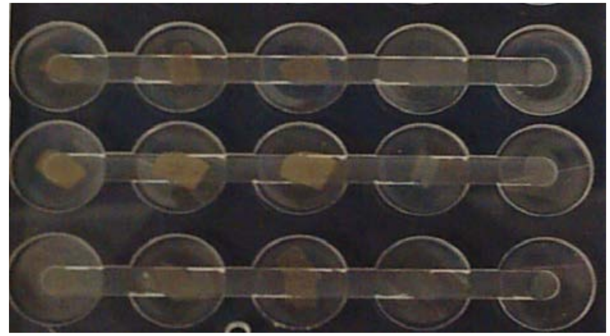


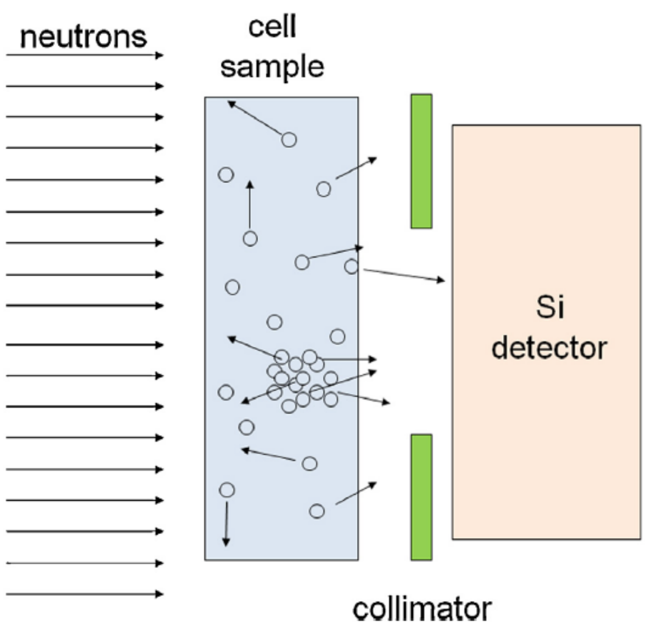
These formulations were tested in vitro (cell cultures of UMR-106); liposomes are being tested in vivo.

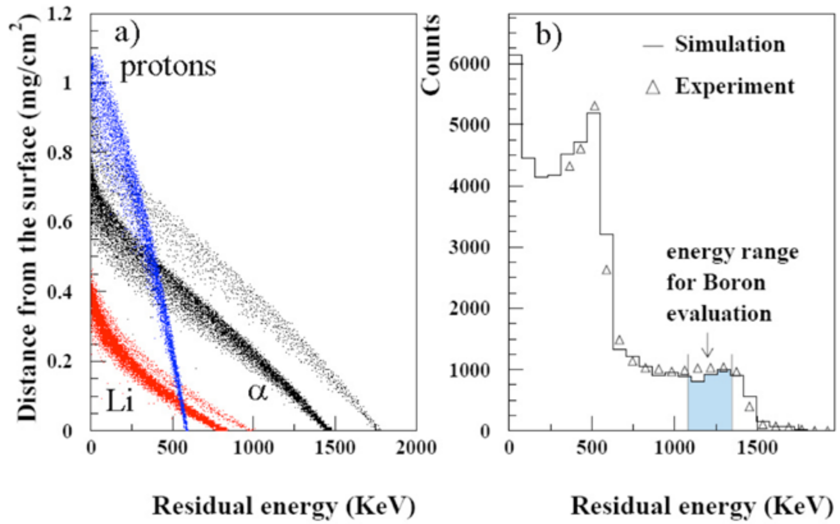
S. Altieri et al., J.Med.Chem. 52 (2009) **D. Pietrangeli et al., Coord.Chem. Rev. (2013)** **L. Ciani et al., Int. J. of Pharm. (2013)**

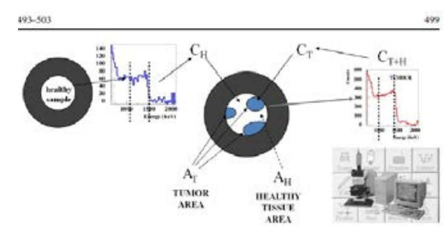
Boron concentration measurement by α spectrometry





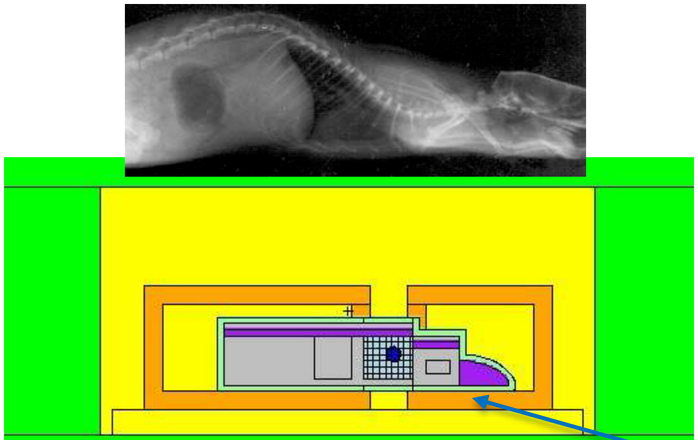




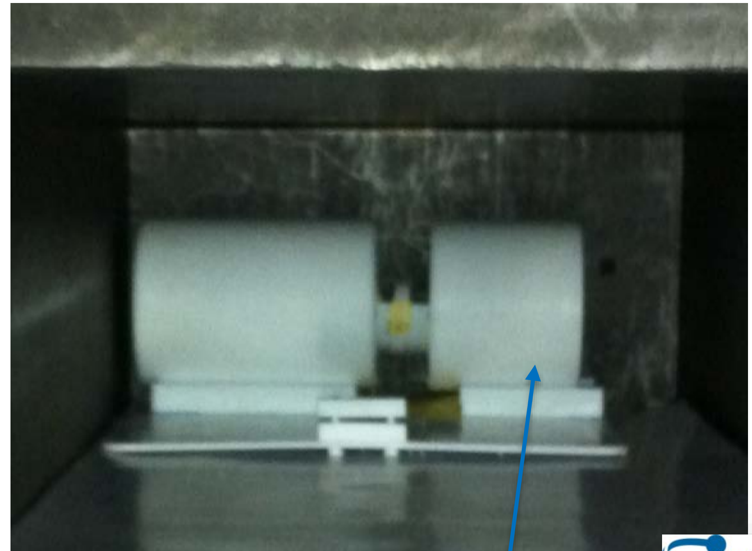


S. Altieri et al. Radiat Environ Biophys (2013) 52:493–503
A Wittig, S. Altieri et al Critical Reviews in Oncology/Hematology 68 (2008) 66–90

Toxicity and effectiveness of BNCT in BDIX rats with BPA

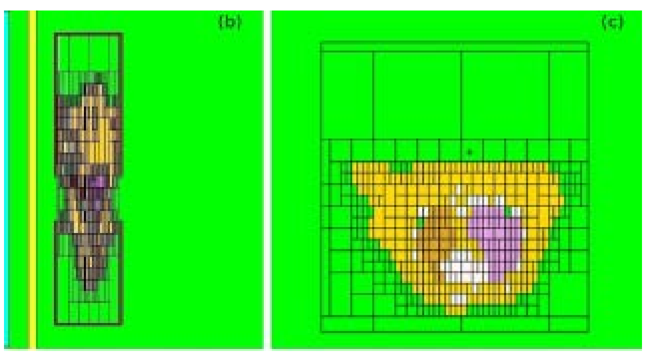


Geometrical MCNP rat model



Li-6 neutron shields

95% $^{6}Li_2CO_3$
$\rho \approx 0.75$ g/cm^3 15 mm thick
≈ 1g/cm^2 of $^{6}LiCO_3$
≈ 150mg/cm^2 of ^{6}Li

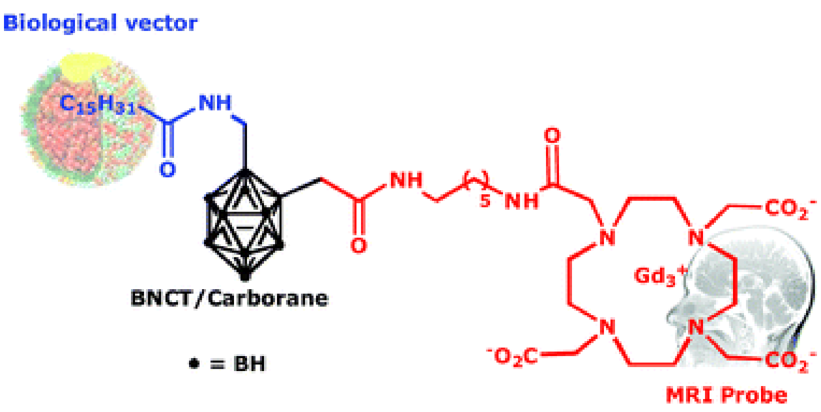


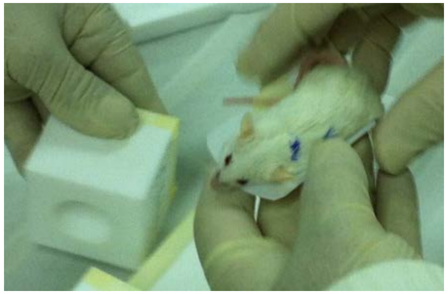
Voxelized rat model

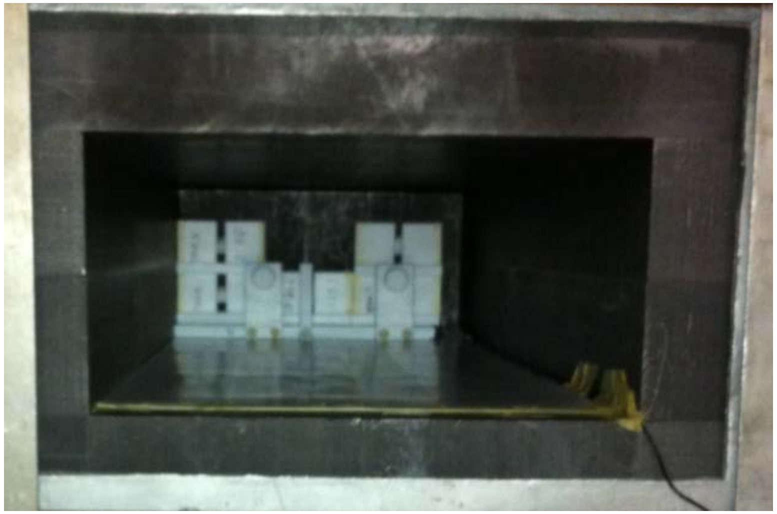
Collaboration with Computational Dosimetry and Treatment Planning group of CNEA (Argentina)

LDL-Boron-Gd adduct: BNCT effectiveness in mice

LDL-B-Gd



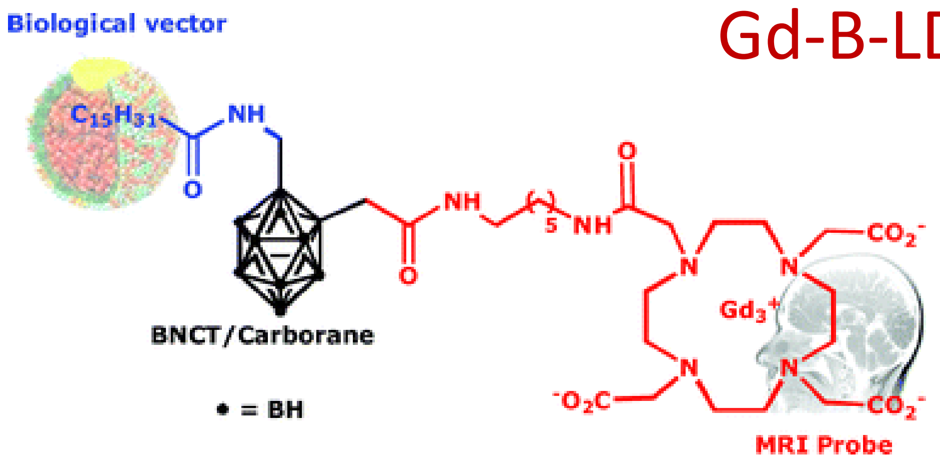




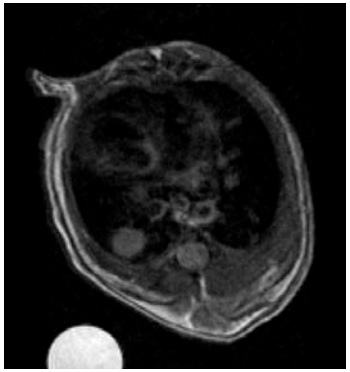
S. Geninatti-Crich et al., Chemistry - a European Journal, 17(30), 8479–8486, 2011

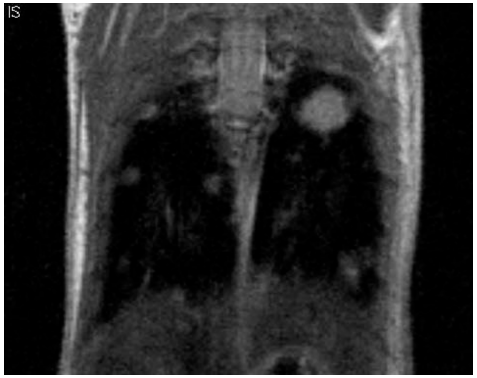
Boron/Gd/LDL adduct: breast cancer lung metastases BALB/C mice

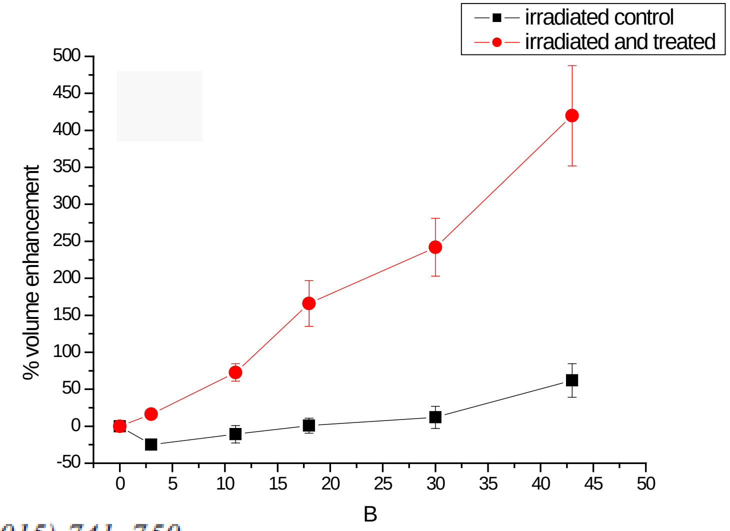
Gd-B-LDL



lung adenocarcinoma in EML4-ALK transgenic mice







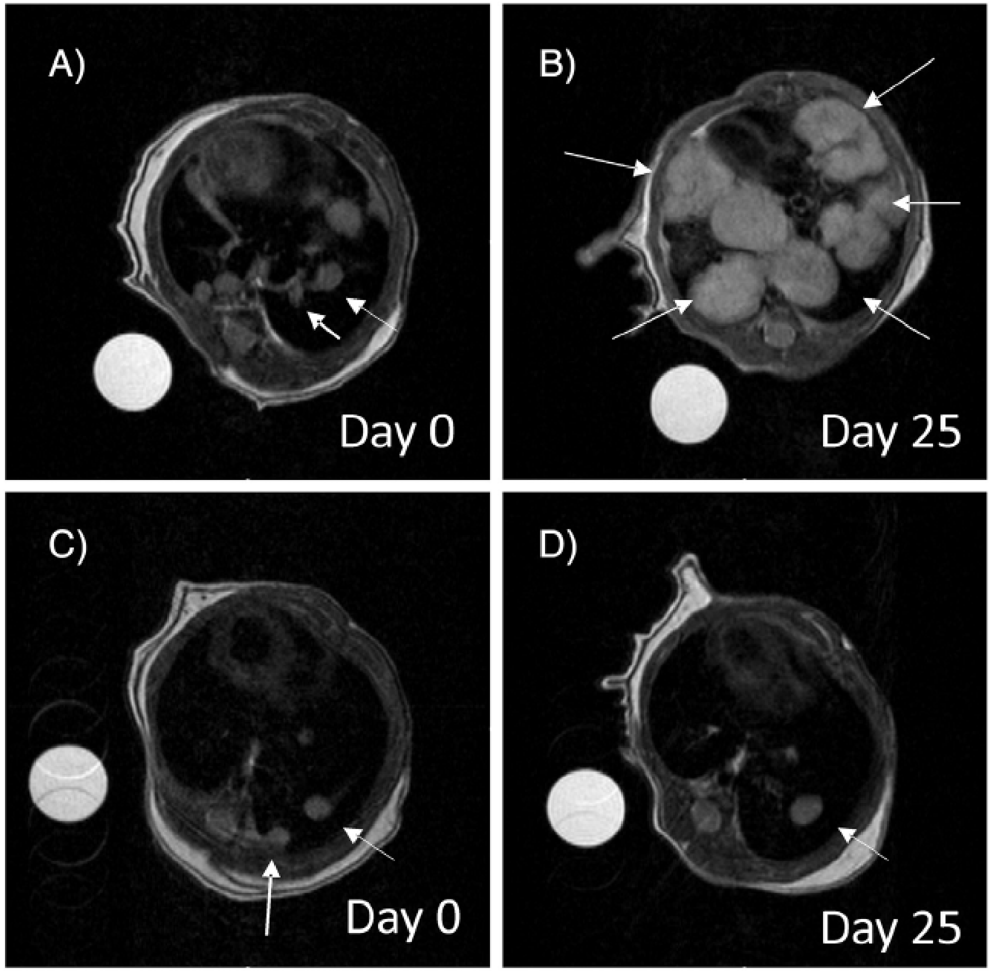
D. Alberti et al / Nanomedicine: Nanotechnology, Biology, and Medicine 11 (2015) 741–750

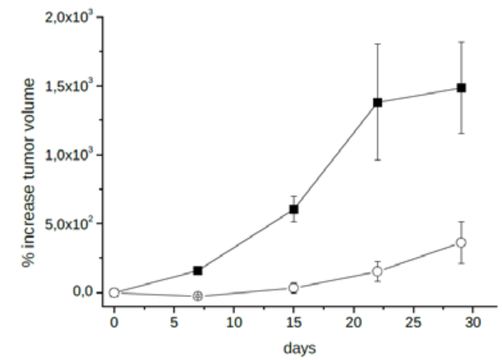
Boron/Gd/LDL adduct: breast cancer lung metastases BALB/C mice

Lung metastases generated by intravenous injection of a Her2+ breast cancer cell line (TUBO).

Irradiated without adduct

Irradiated with adduct administration





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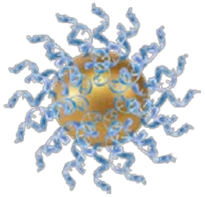

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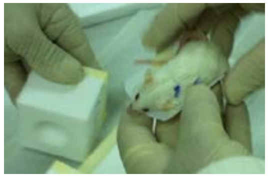

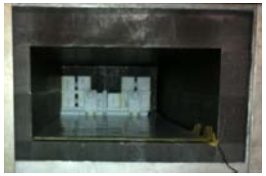

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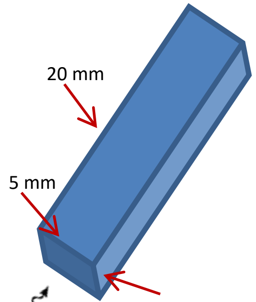

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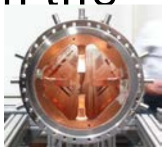


Boron imaging by SPECT

The effectiveness of BNCT treatment depends on the radiation dose deposited locally by the capture reaction on ^{10}B.

This dose is proportional to the ^{10}B concentration and to the thermal neutron flux which are present in the volume at the time of irradiation.

However, the local and real time measurement of these quantities is a big challenge, not yet solved in the BNCT community.

$$D \propto \int n_B \sigma \varphi dV$$

D = dose
n_B = density of B10 nuclei
σ = microscopic cross section of B10 capture reaction
φ = neutron flux
V = volume where the dose is delivered

$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}Li + \alpha + 2.79\ MeV & 6.1\% \\ \left({}^{7}Li\right)^{*} + \alpha + 2.31\ MeV & 93.9\% \end{cases}$$

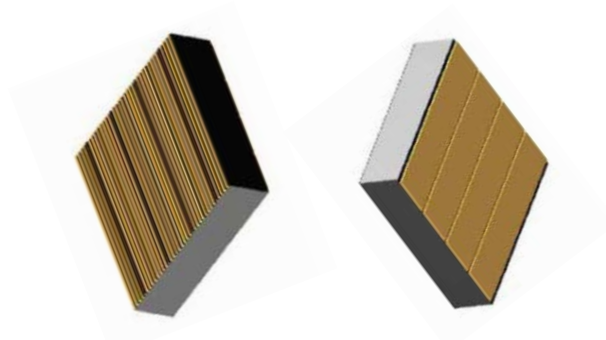
$$\downarrow \rightarrow {}^{7}Li + \gamma\,(0.478 MeV)$$

Boron imaging by SPECT CdZnTe detector

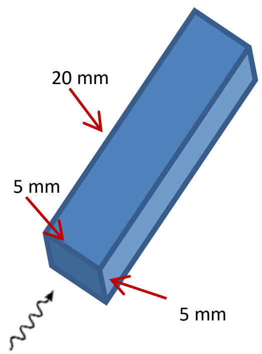
IMEM-CNR
Parma

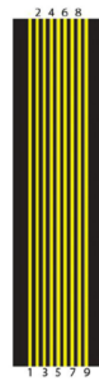
Institute of Materials for Electronics and Magnetism

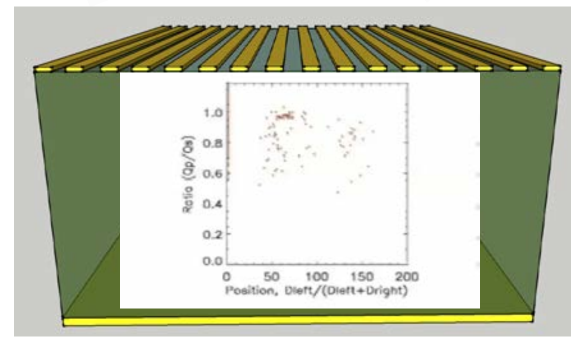
Italian National Research Council

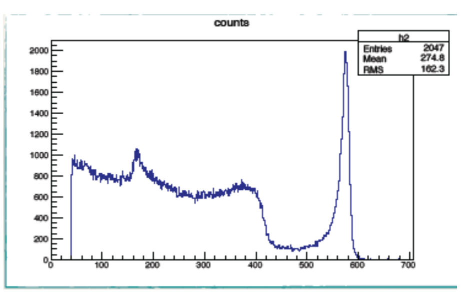


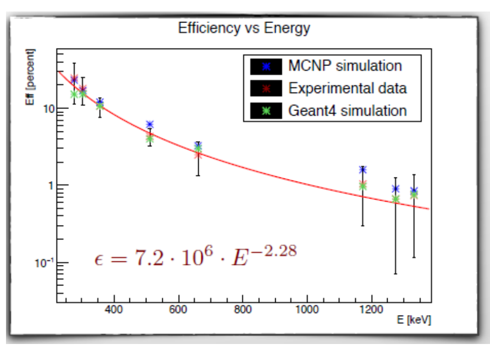
1D detector under test: a drift strip detector 0.5 x 0.5 x 20 mm^3

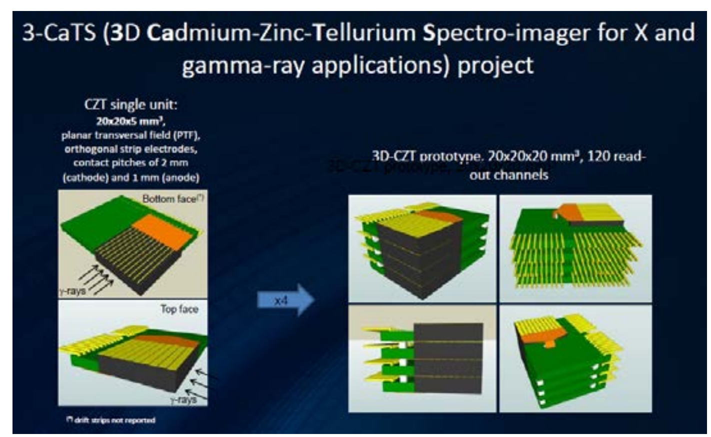








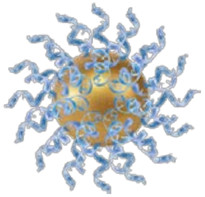




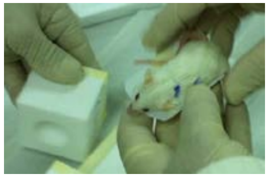
BNCT @ Pavia University and INFN

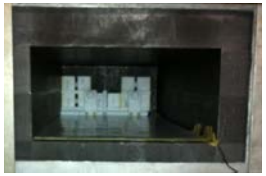
- Disseminated liver metastases: TAOrMINA project

- Research on new boron carriers: boron up-take measurements in vitro and vivo in animal models

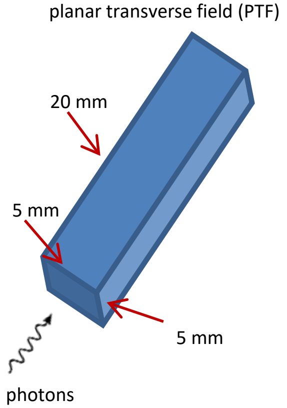


- Tests of toxicity and effectiveness of BNCT by irradiating cell cultures and animal models treated with new boron compounds
  - Disseminated lung metastases
  - Mesothelioma
  - Limb osteosarcoma

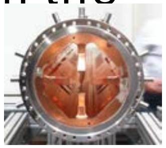




- In vivo boron dose imaging system based on Zinc Cadmium Thelluride detector (SPECT)

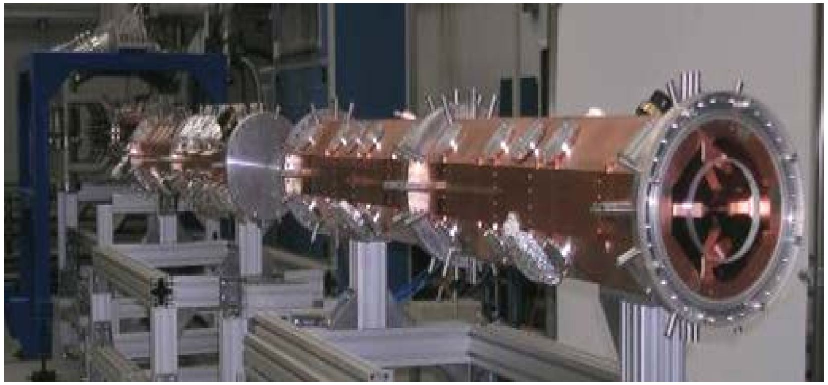


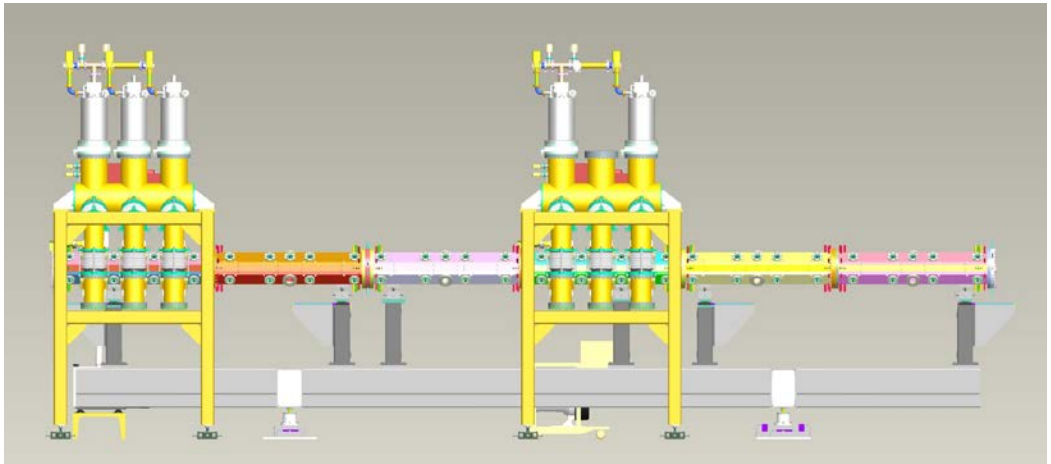
- Installation of an accelerator based BNCT system in the Italian Hadron Therapy Center in Pavia



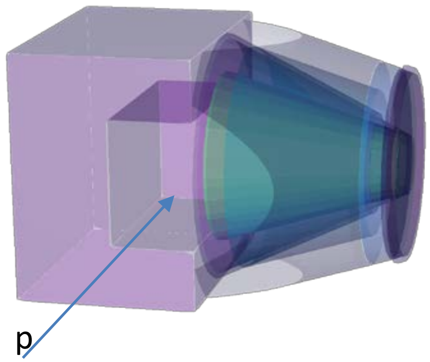
INFN RFQ

- 5 MeV proton RFQ
- 30 mA
- Be target

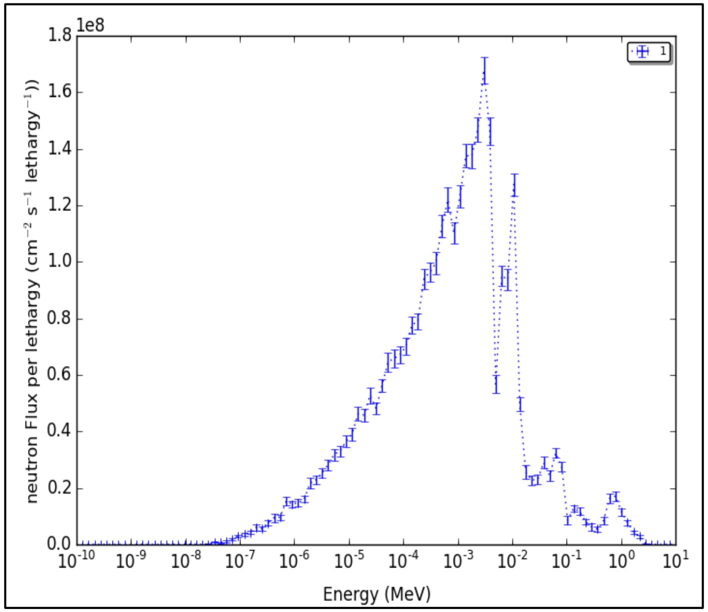


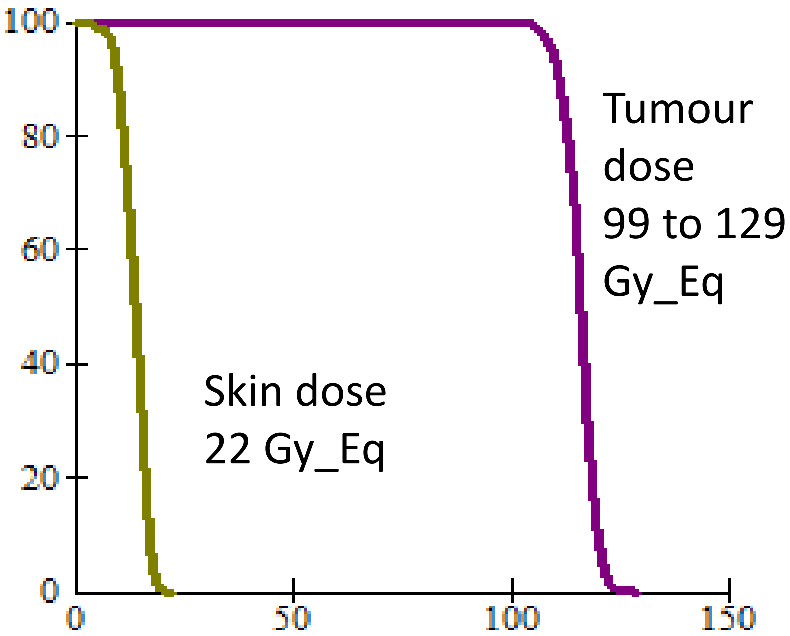


Tailoring the neutron beam around 1 keV

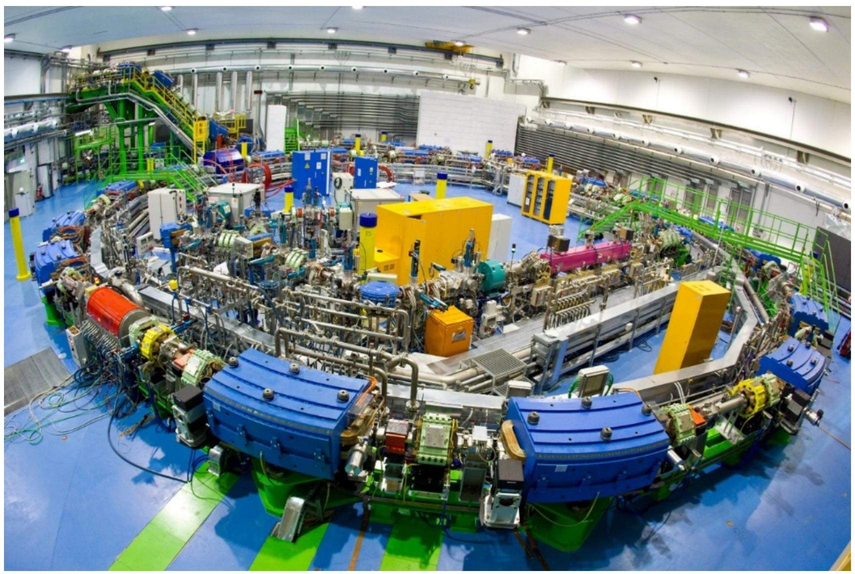


Epithermal n. Flux $2.8 \cdot 10^9$ cm^{-2} s^{-1}

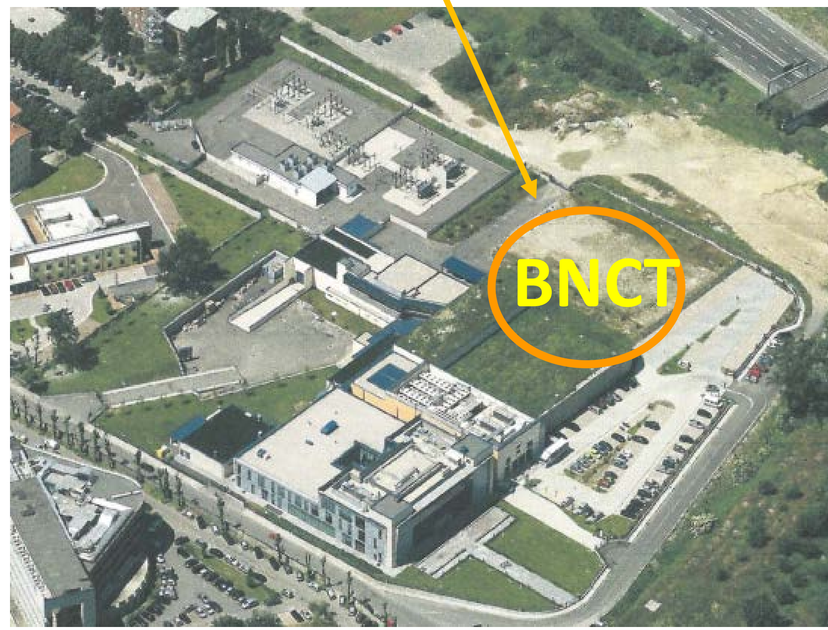




Hadron Therapy Center in Pavia (CNAO)



We are planning to install
An accelerator based BNCT facility
here



fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori

BNCT National and International collaboration

- *University and INFN of PAVIA: Test in vitro and in vivo with new formulations , boron measurements, cell cultures and animal irradiation*
- *University of TORINO: new Boron carrier with Gd –B-LDL for MRI*
- *University of NOVARA: polimeric nanoparticles and liposomes*
- *University of FIRENZE: liposomes and nanoparticles functionalized with B*
- *Universitiy of POTENZA: boronated porphirines*
- *University of PALERMO: dosimetry*
- *LNL-INFN*

International

- NUAA University of Astronautics Nanjing, China
- *CNEA, Argentina*
- *Universities of Nagoja and Okajama, Japan*
- *INL, Idaho, USA: neutron spectrometry in irradiation facilities*
- *HUCH, Helsinki University Central Hospital and FIR 1, Finland*
- *QEH,University Hospital, Birmingham*

Saverio Altieri

Silva Bortolussi
Nicoletta Protti
Ian Postuma
Setareh Fatemi
Francesca Ballarini
Mario Carante
Cinzia Ferrari
Laura Cansolino

Thank you