BNCTのための加速器中性子源

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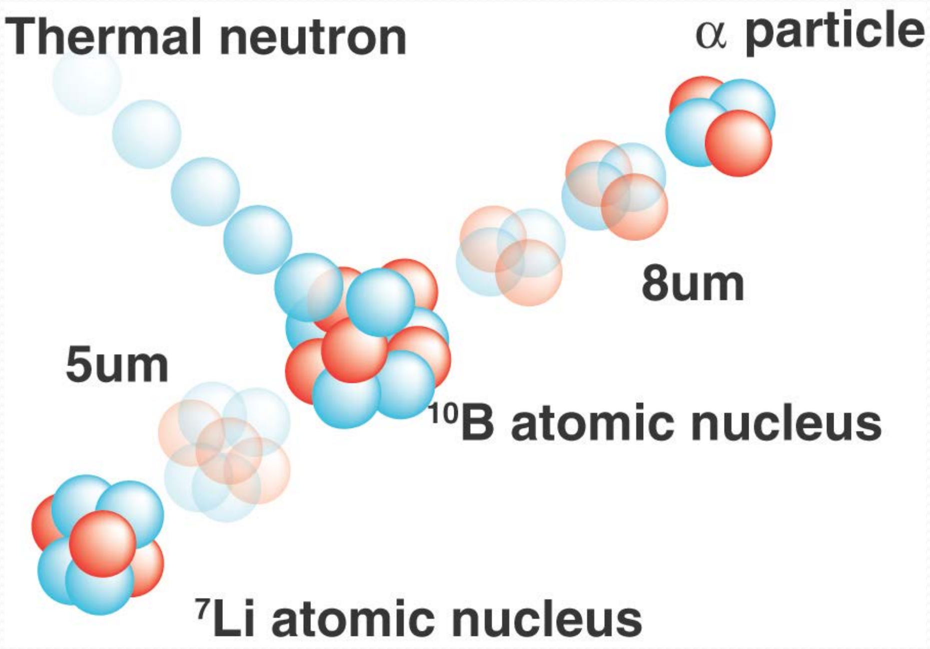
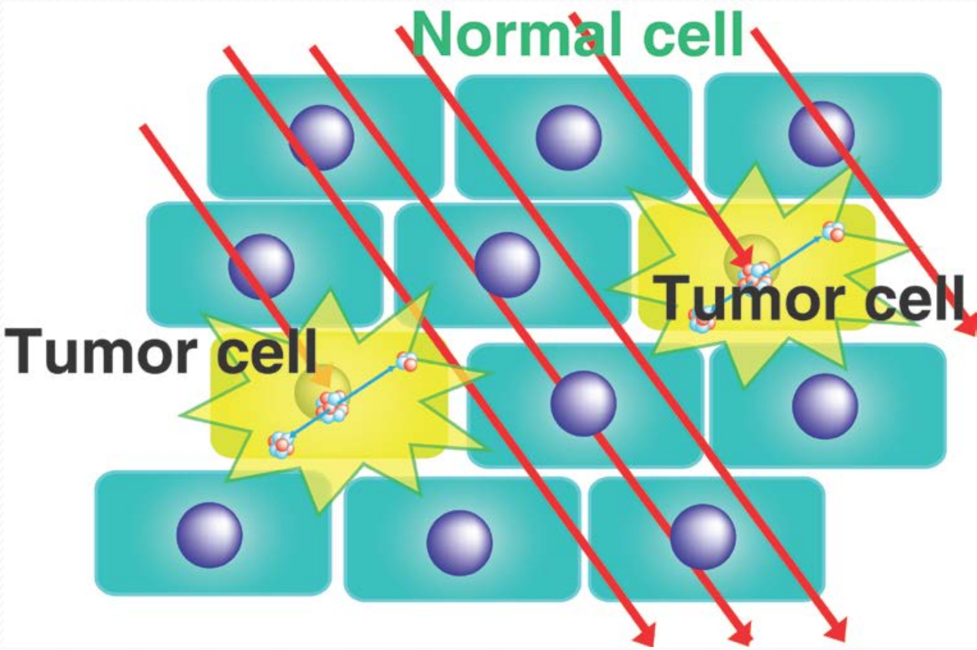
平成25年1月18日　京大炉におけるビーム利用のための次期中性子源検討WS

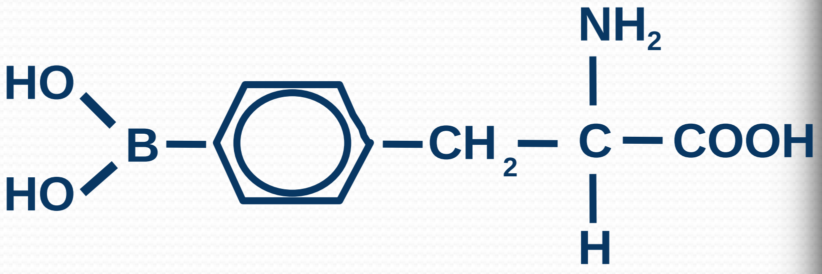
Boron Neutron Caputure Therapy



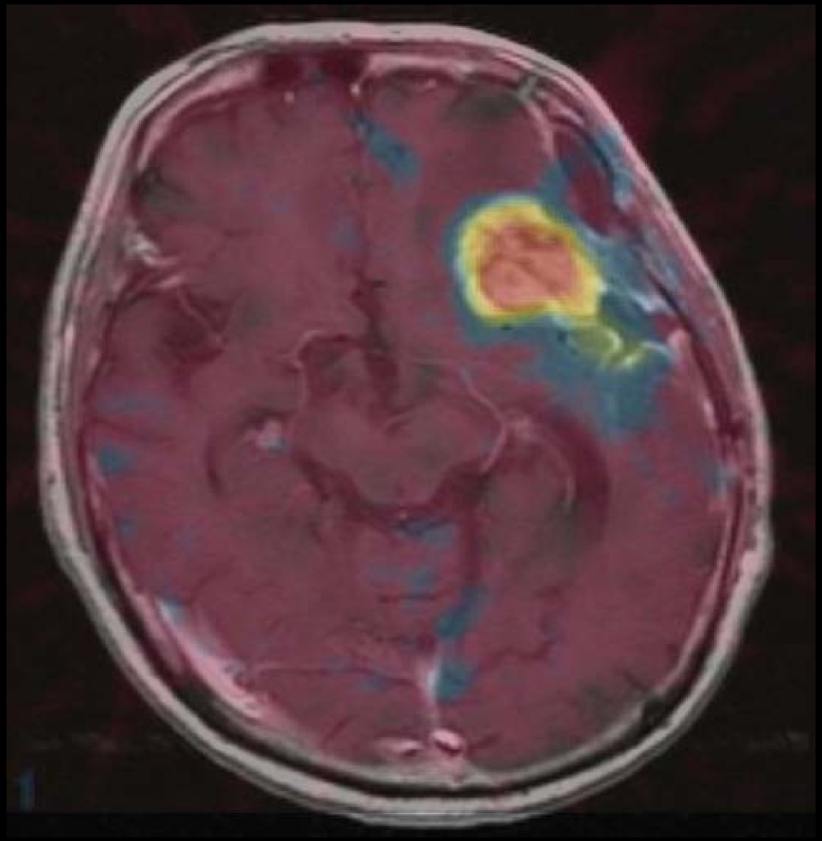


Uptake of boron drug

boronophenyl-alanine(BPA)



sodium borocaptate (BSH)



PET image of BPA labeled by ^{18}F

BNCT facility in the world

R2-0スウェーデン研究炉(2001～2005)52例

FiR-1 フィンランド研究炉(1999～)300例

LVR-15チェコ研究炉(2000～)2例

HFRPペッテン研究炉(1997～)22例

イタリア研究炉(2002～)2例

JRR-2日本原子力研究開発機構33例

JRR-4日本原子力研究開発機構 107例

KUR京都大学原子炉 416例(+53例)

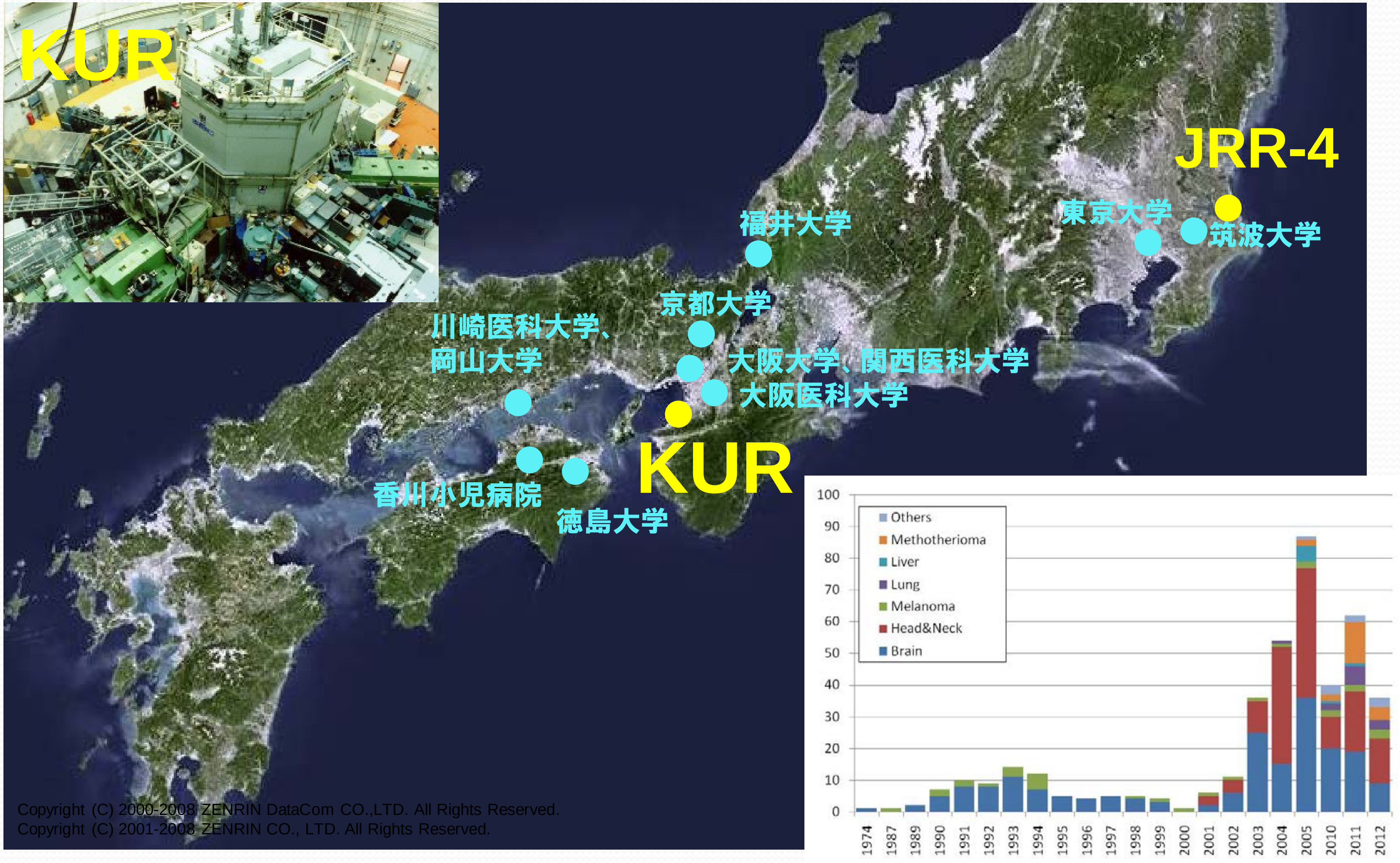
THOR台湾研究炉 20例 (2010～)

BMRR
ブルックヘブン医学研究炉(1951～1961、1994～1999)99例

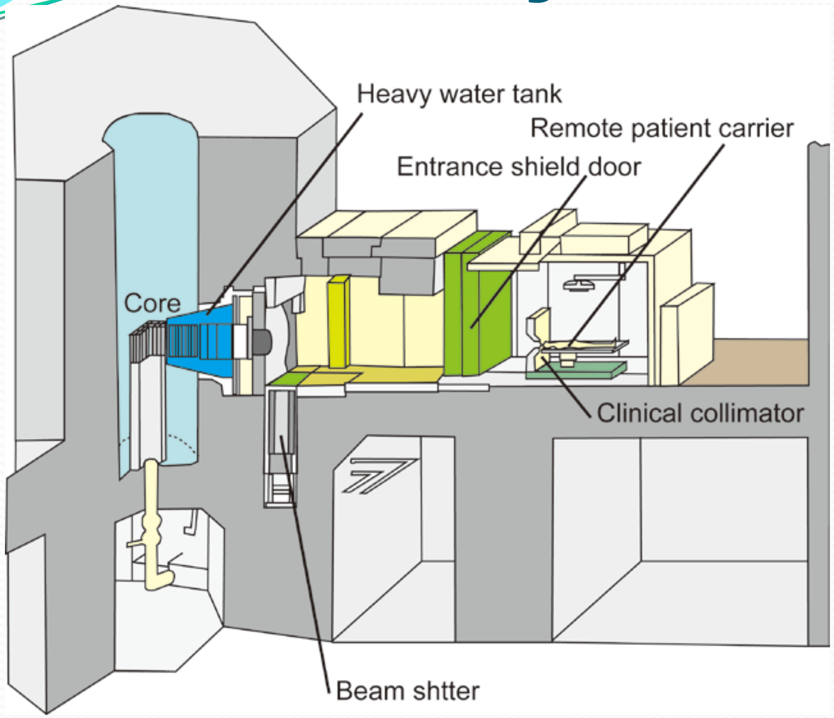
MITR
マサチューセッツ工科大学(1959～1961、1994～1999)42例

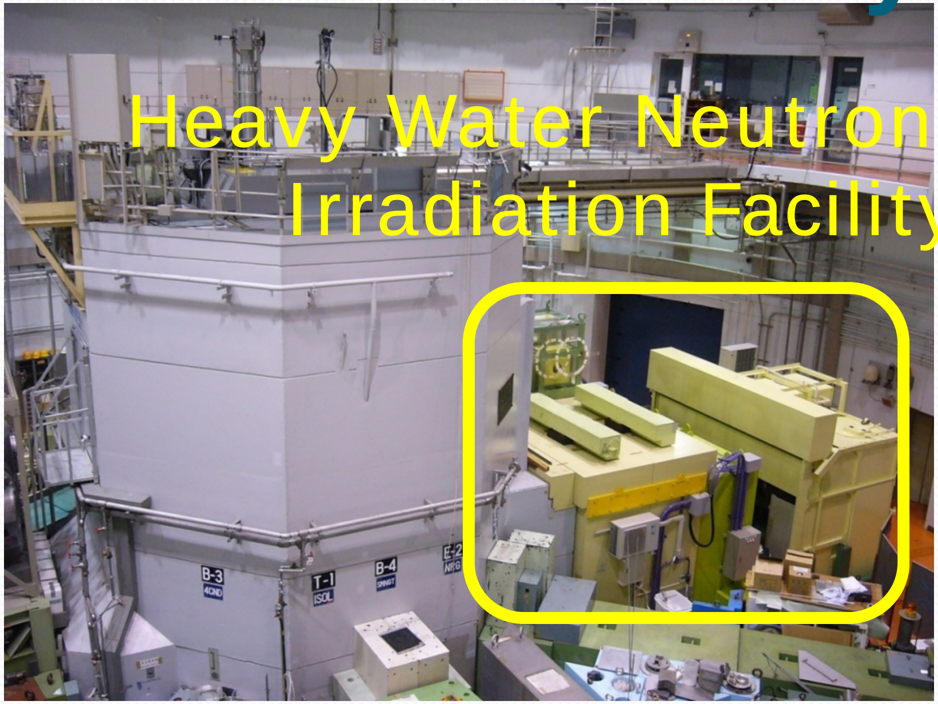
アルゼンチン研究炉(2003～)7例

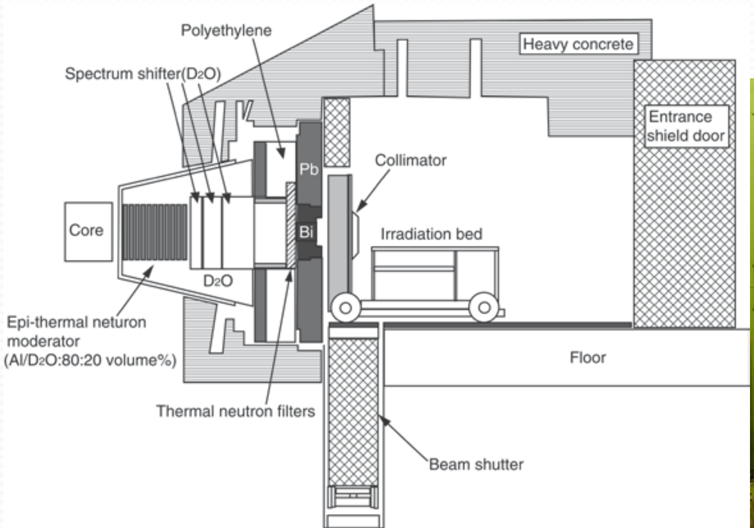
BNCT facility in JAPAN



KUR-Heavy water irradiation facility







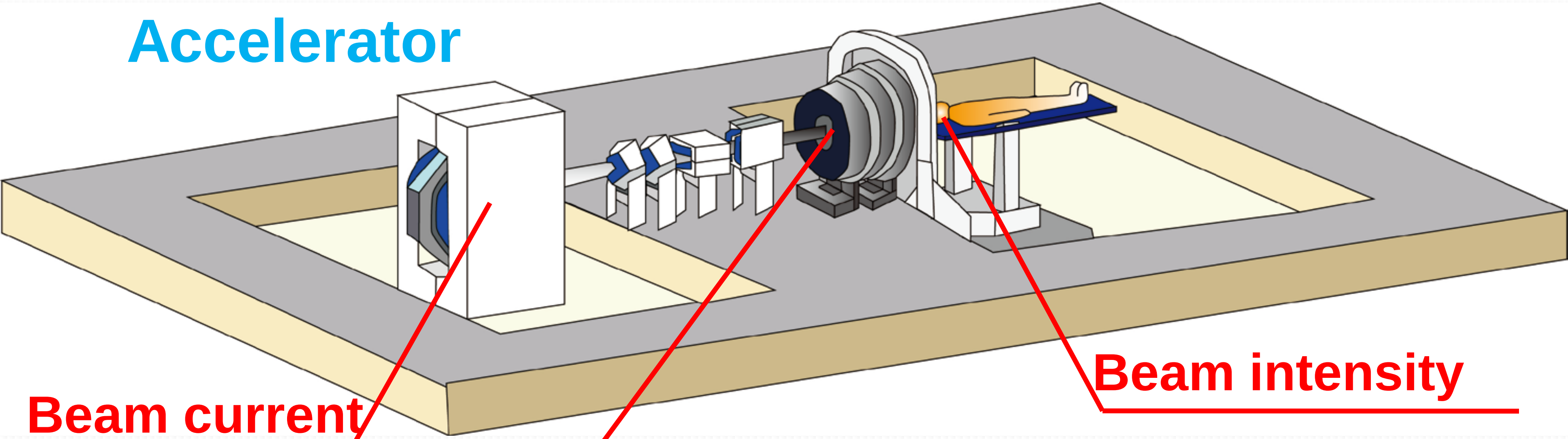
Brain tumor

Head and neck

Accelerator based neutron source

Moderator

Accelerator



Beam current

Beam intensity

Heat reduction on target

Epithermal neutron source> $1\times10^{9}\ \mathrm{cm^{-2}s^{-1}}$

Contamination of fast neutron< $2\times10^{-13}\ \mathrm{Gy\ cm^{-2}}$ ($4\text{-}10\times10^{-13}\ \mathrm{Gy\ cm^{-2}}$)

Contamination of fast neutron< $2\times10^{-13}\ \mathrm{Gy\ cm^{-2}}$

Proton accelerator for BNCT

Proton Energy	Accelerator
Ep<3MeV	electrostatic、RFQ
3MeV<Ep<10MeV	Linac、Cyclotron
10MeV<Ep<100MeV	Cyclotron、FFAG
Ep>100MeV	Synchrotron、Cyclotron、FFAG

Reaction	Proton Energy Ep	Yield （Neutron/Proton）	Melting	Conductivity (W/m/K)	Neutron Energy	Moderator Size
^{7}Li (p,n) ^{7}Be	2.5	1.46×10^{-4}	180	84.7	0.1～0.5	Small
^{9}Be (p, n) ^{9}B	4	1.6×10^{-4}	1278	201	Depend on Ep	Large
Ta (p,xn)	50	7.0×10^{-2}	3017	57.5	Depend on Ep	Large

Trade off

Current ⟺ Heat reduction on target

Size of moderator ⟺ Neutron yield after moderator

Plan of accelerator based neutron source

Country	Institute	Reaction	Energy（MeV)	Current（mA)
UK	Birmingham Univ	^{7}Li(p,n)^{7}Be	2.8	20
USA	MIT	^{7}Li(p,n)^{7}Be	1.95	>5
USA	BNL	^{7}Li(p,n)^{7}Be	2.5	20
USA	Ohaio St. Univ.	^{7}Li(p,n)^{7}Be	2.5	10
Argentina	Depar. of Fisica	^{7}Li(p,n)^{7}Be	2.5	20
Belgium	IBA	^{7}Li(p,n)^{7}Be	2.8	20
Russia	IPPE	^{7}Li(p,n)^{7}Be	2.3	10
Japan	KURRI	^{7}Li(p,n)^{7}Be	1.9	10
Italy	San GiovanniHosp.	^{2}H (d,n)^{3}He	0.12	300
Italy	INFL-LNL	^{7}Be(p,n)	5	30
Japan	HITACHI	^{7}Be(p,xn)	11	2.85
Japan	FFAG-DDS	^{7}Be(p,xn)	11	70
Japan	Tohoku Univ.	Ta(p,xn)	50	0.35
Japan	Kyushu Univ.	Ta(p,xn)	150	0.14
Japan	CICS	^{7}Li(p,n)^{7}Be	2.5	20
Japan	Tsukuba Univ.	^{7}Be(p,n)	8	10

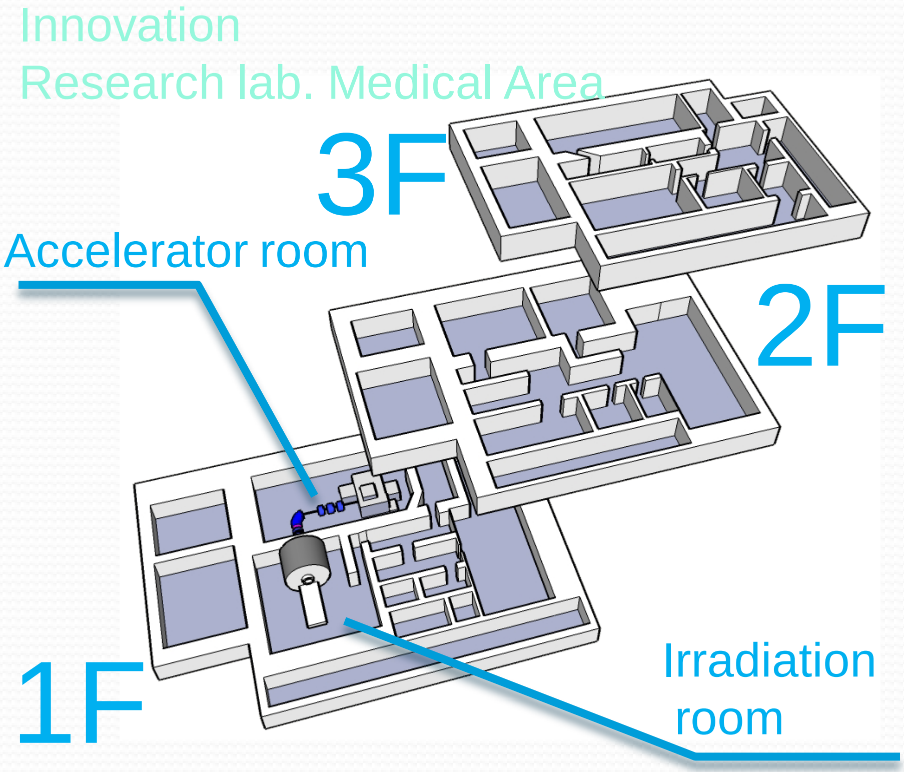
Epithermal neutron source have not yet been realized in the world.

Cyclotron Based Epithermal Neutron Source(C-BENS)

2007 August KURRI and SHI started on the collaboration for developing C-BENS

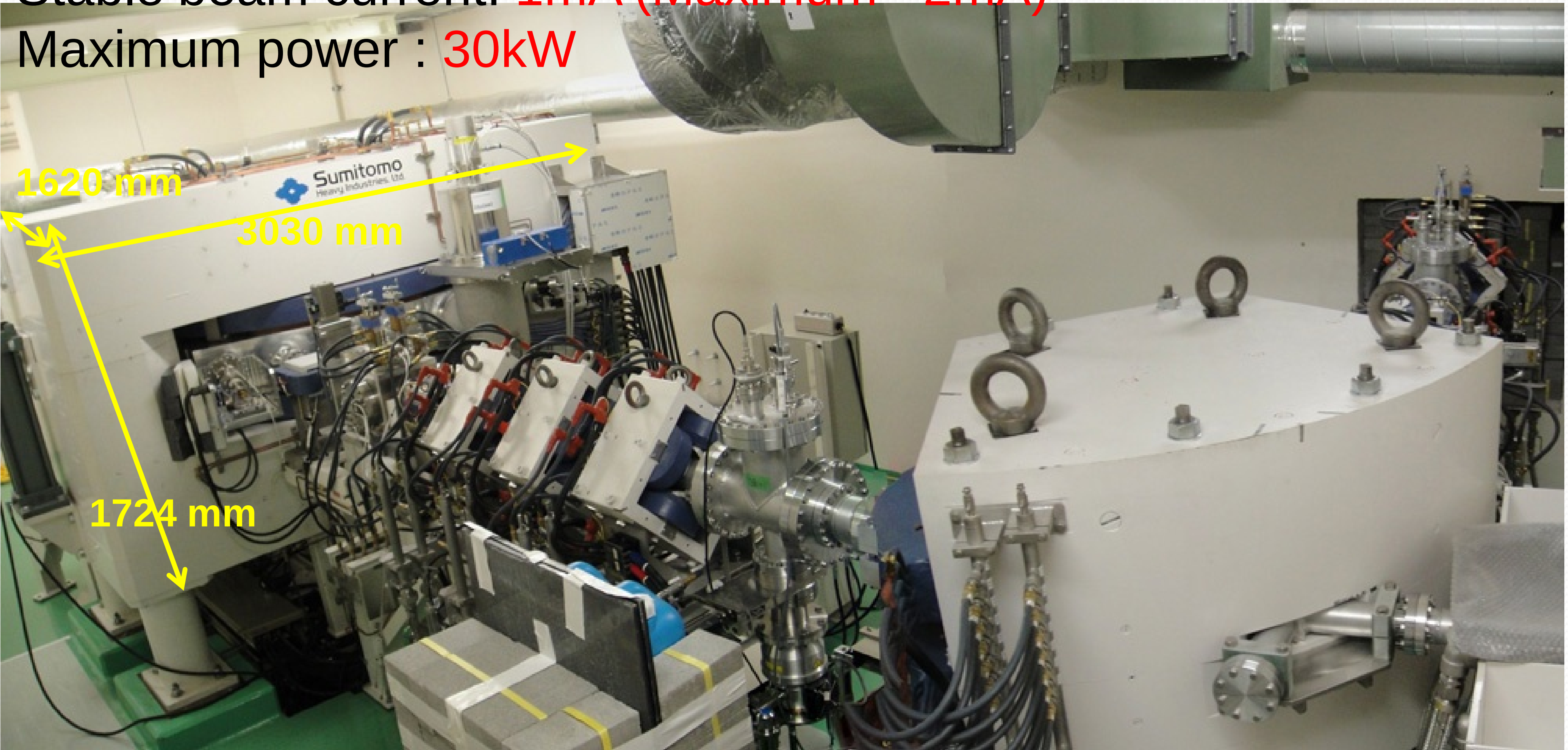
2008 December C-BENS was installed

2009 March The test of neutron production was started.

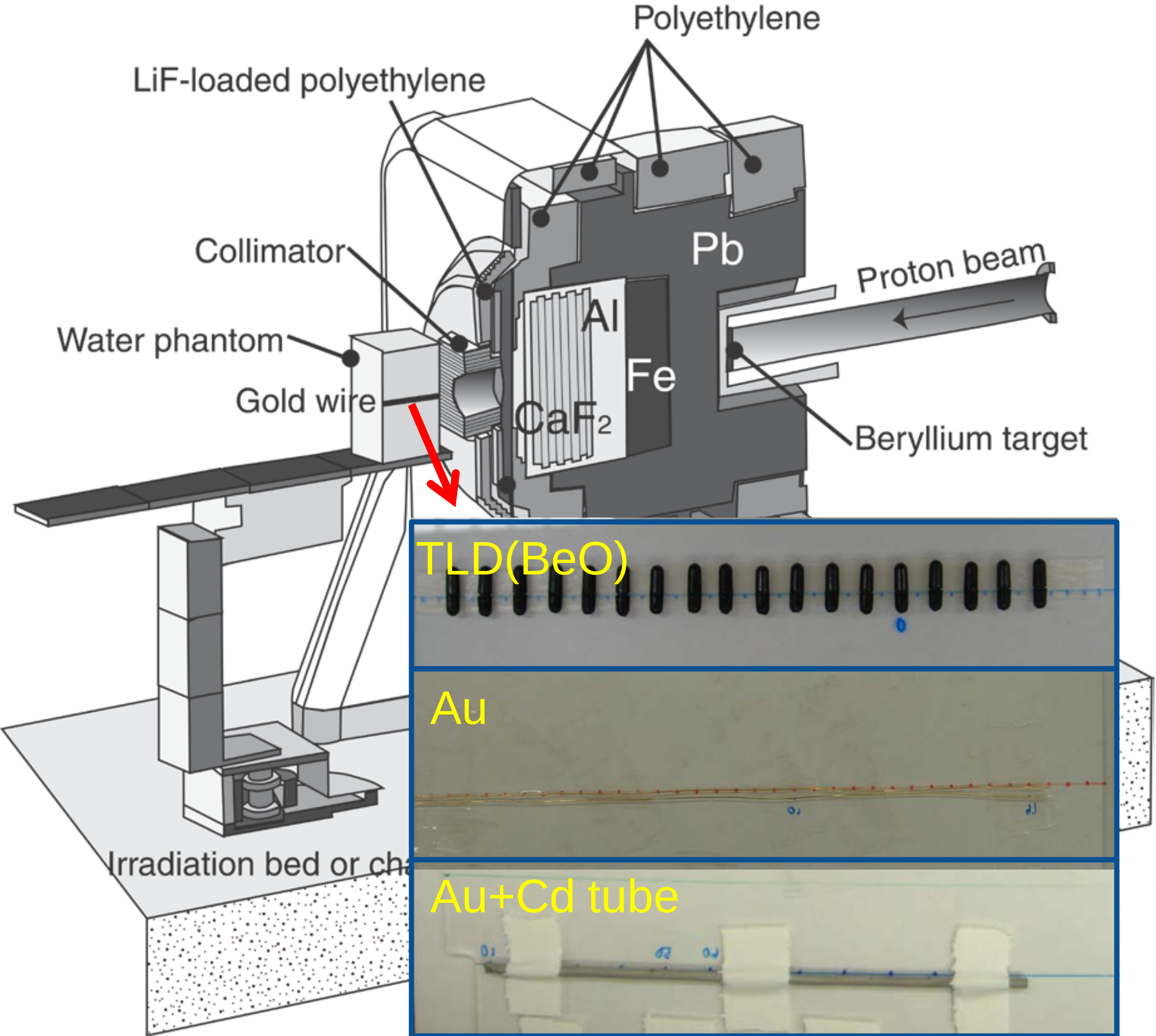


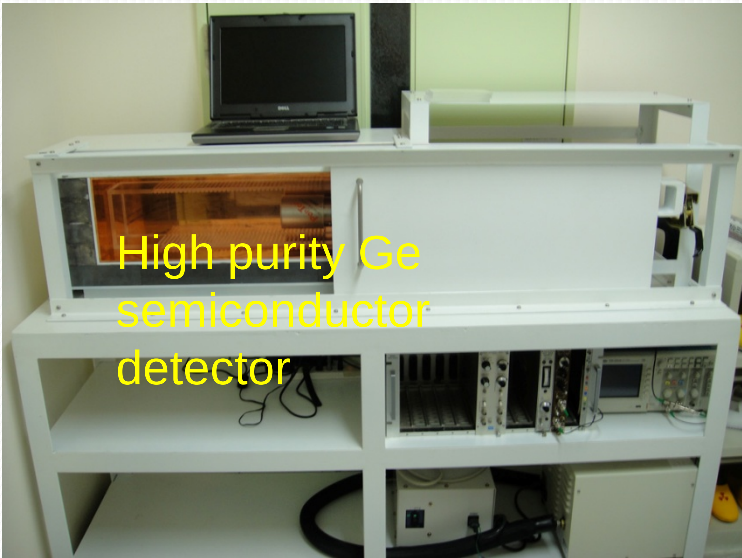
Cyclotron Based epi-thermal Neutron Source(C-BENS)

Sumitomo Heavy Industries:HM30
Accelerated particle : negative hydrogen ion(-H)
Maximum Energy:30MeV
Stable beam current: 1mA (Maximum ~2mA)
Maximum power : 30kW



Experiment of thermal neutron distribution in a water phantom





Reaction rate

Detection efficiency

Gamma emission ratio

Decay factor

Counts of photo peak

$$R = \frac{\lambda C}{\epsilon \gamma \boxed{e^{-\lambda T_c}} \boxed{(1 - e^{-\lambda T_m})} \boxed{\sum_{i=1}^{n} \left(\frac{Q_i}{\Delta t} (1 - e^{-\lambda \Delta t}) e^{-\lambda (n-i) \Delta t} \right)}}$$

Correction of cooling time

Correction of measuring time

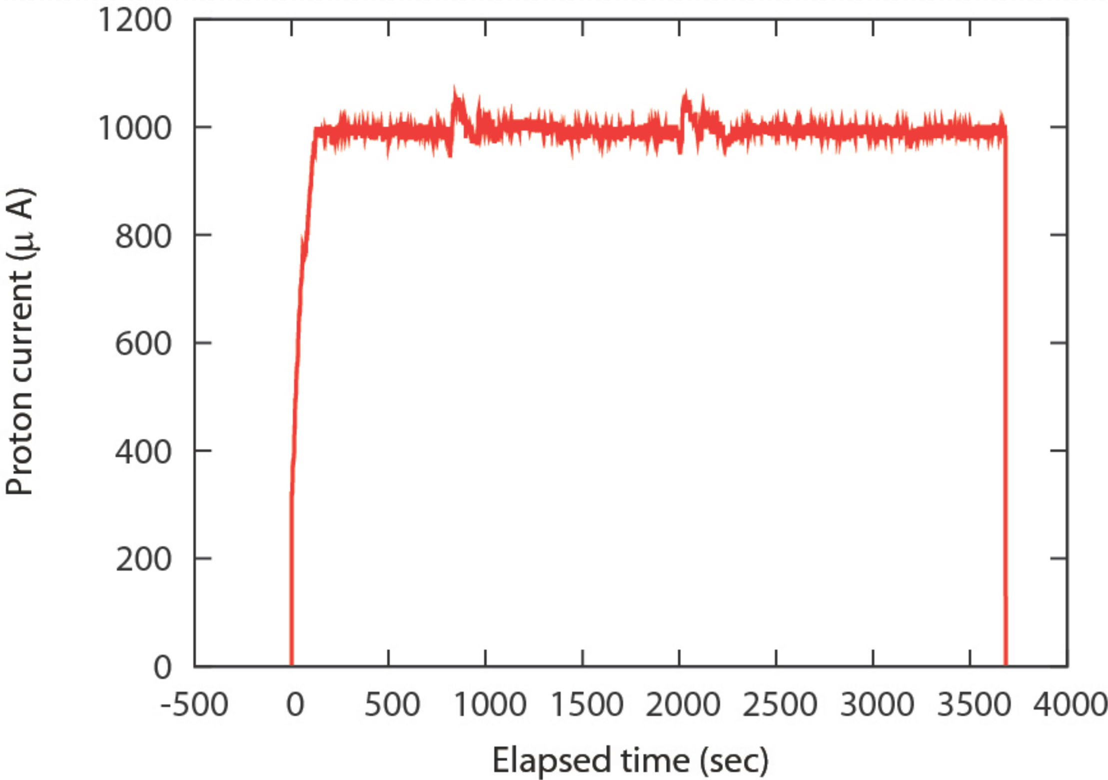
Correction of irradiation time

Cadmium ratio

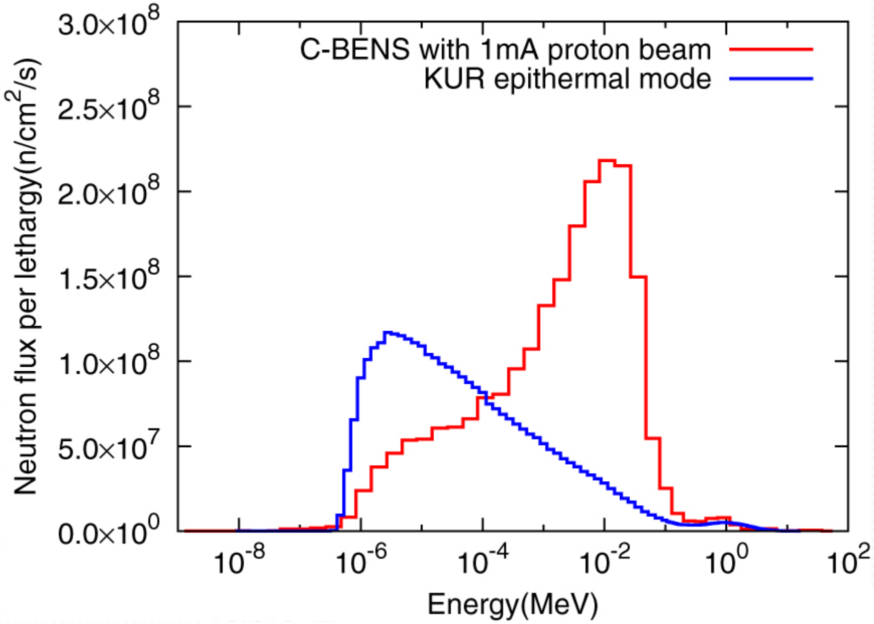
$$CR = \frac{R_{Au}}{R_{Cd}}$$

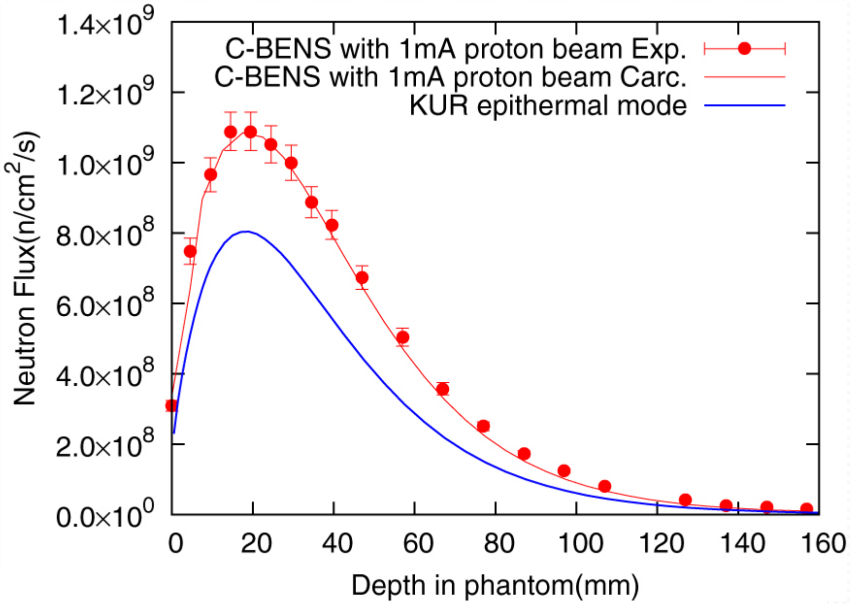
Reaction rate of thermal neutrons

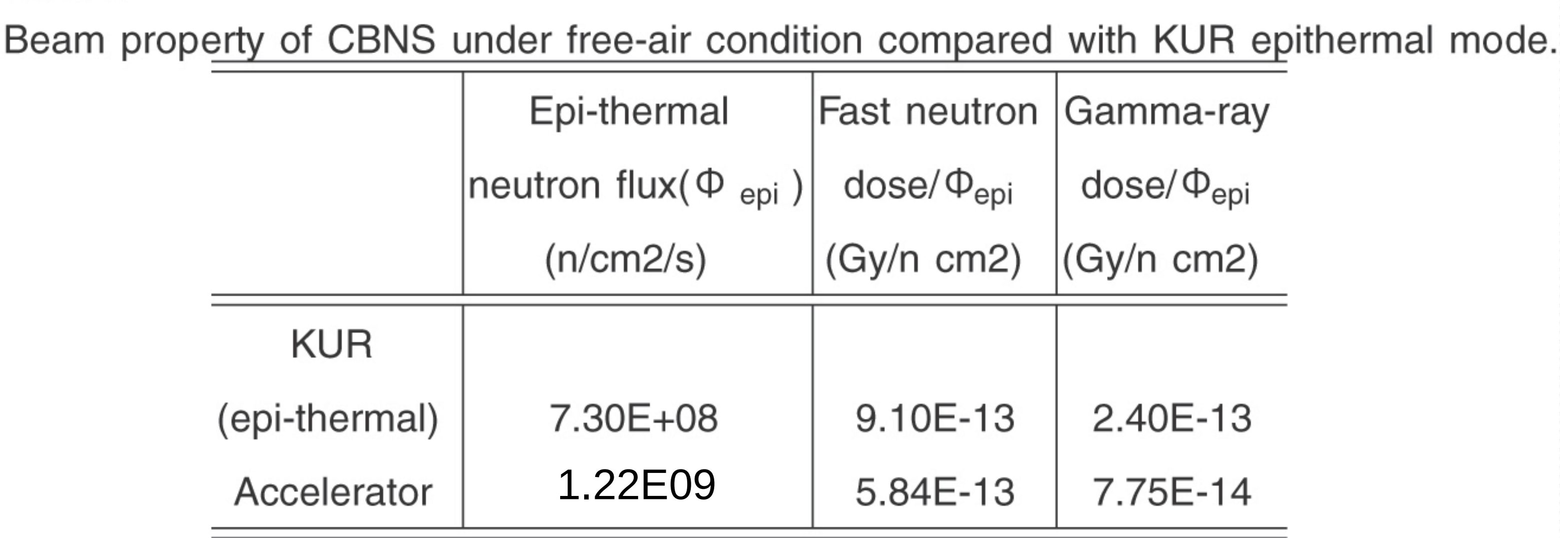
$$R_{thermal} = R_{Au}\left(1 - \frac{1}{CR}\right)$$



Comparison with KUR beam





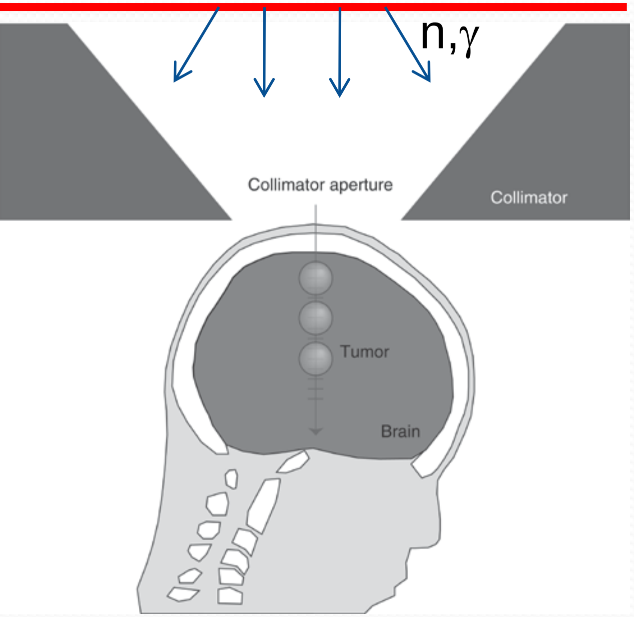


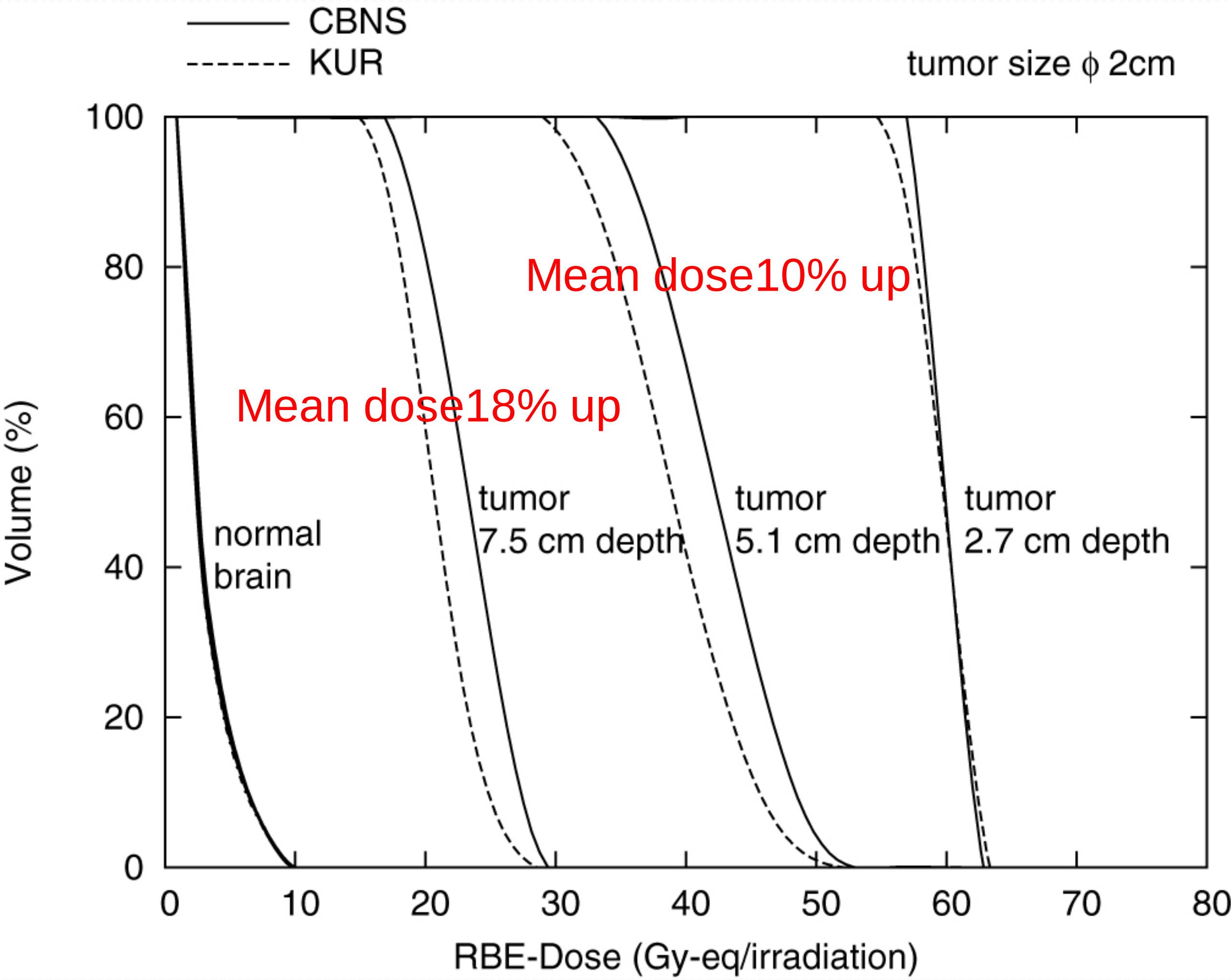
Beam property of CBNS under free-air condition compared with KUR epithermal mode.

	Epi-thermal neutron flux(Φ_{epi}) (n/cm2/s)	Fast neutron dose/Φ_{epi} (Gy/n cm2)	Gamma-ray dose/Φ_{epi} (Gy/n cm2)
KUR (epi-thermal)	7.30E+08	9.10E-13	2.40E-13
Accelerator	1.22E09	5.84E-13	7.75E-14

Dose distribution

Source surface





Mean dose10% up

Mean dose18% up

Summary

- Cyclotron-based neutron source(C-BENS) can be stably operated over one hour with the proton current of 1mA.
- Intensity of C-BENS is about two times higher than that of KUR epithermal beam.
- Clinical trials for recurrent GBM were started in 2012.

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Thank you for your attention