ABNP2014

Accelerator Based Epithermal Neutron Source by using Thin Layered Solid Lithium Target

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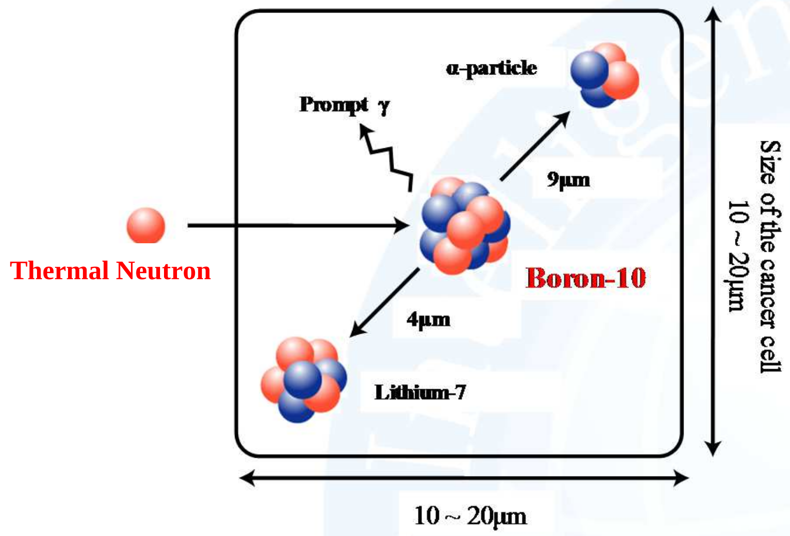
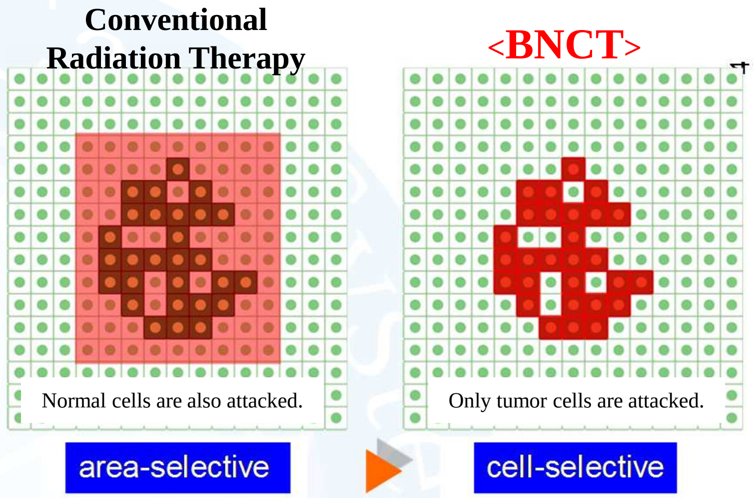
Boron Neutron Capture Therapy :BNCT

Nuclear Reaction of Thermal Neutrons with 10B in Tumor Cells

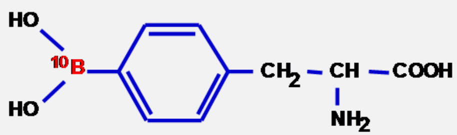




a: ^{10}B-BPA

(*p*-boronophenylalanine)

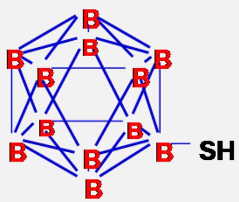
a: ^{10}BPA



b: ^{10}B-BSH

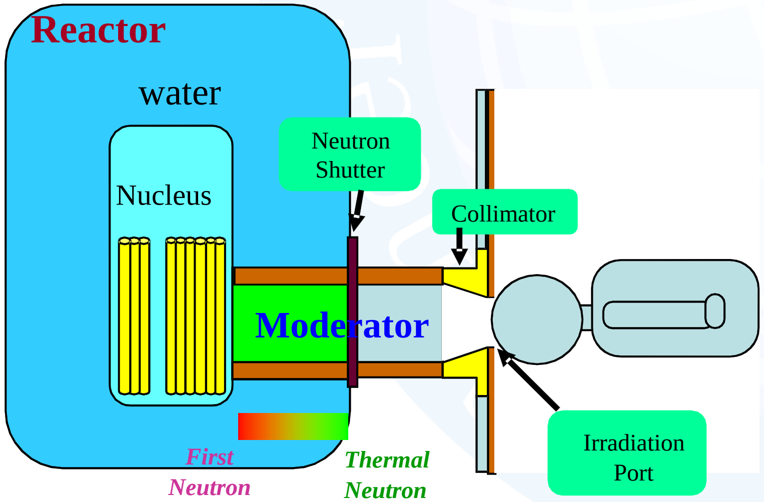
(mercaptoundecahydrododecaborate: $Na_2B_{12}H_{11}SH$)

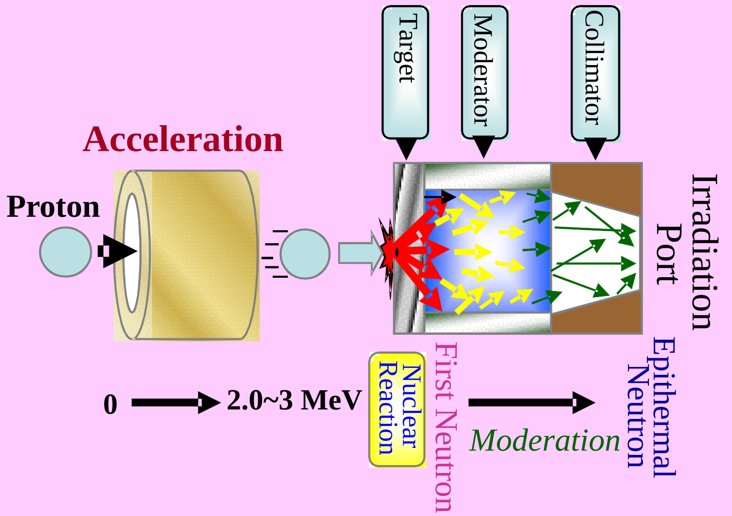
b: ^{10}BSH



Neutron Source for BNCT
Reactor to Accelerator

Now : Reactor	In Near future : Accelerator
• Large Institution • Large Investment • Difficult to Spread • Always nucleus possession	• Small Institution • Small Investment • In hospital • No need the Nucleus • Neutron ⇒ Only PS -ON !





Various types of Accelerator for Neutron Production System

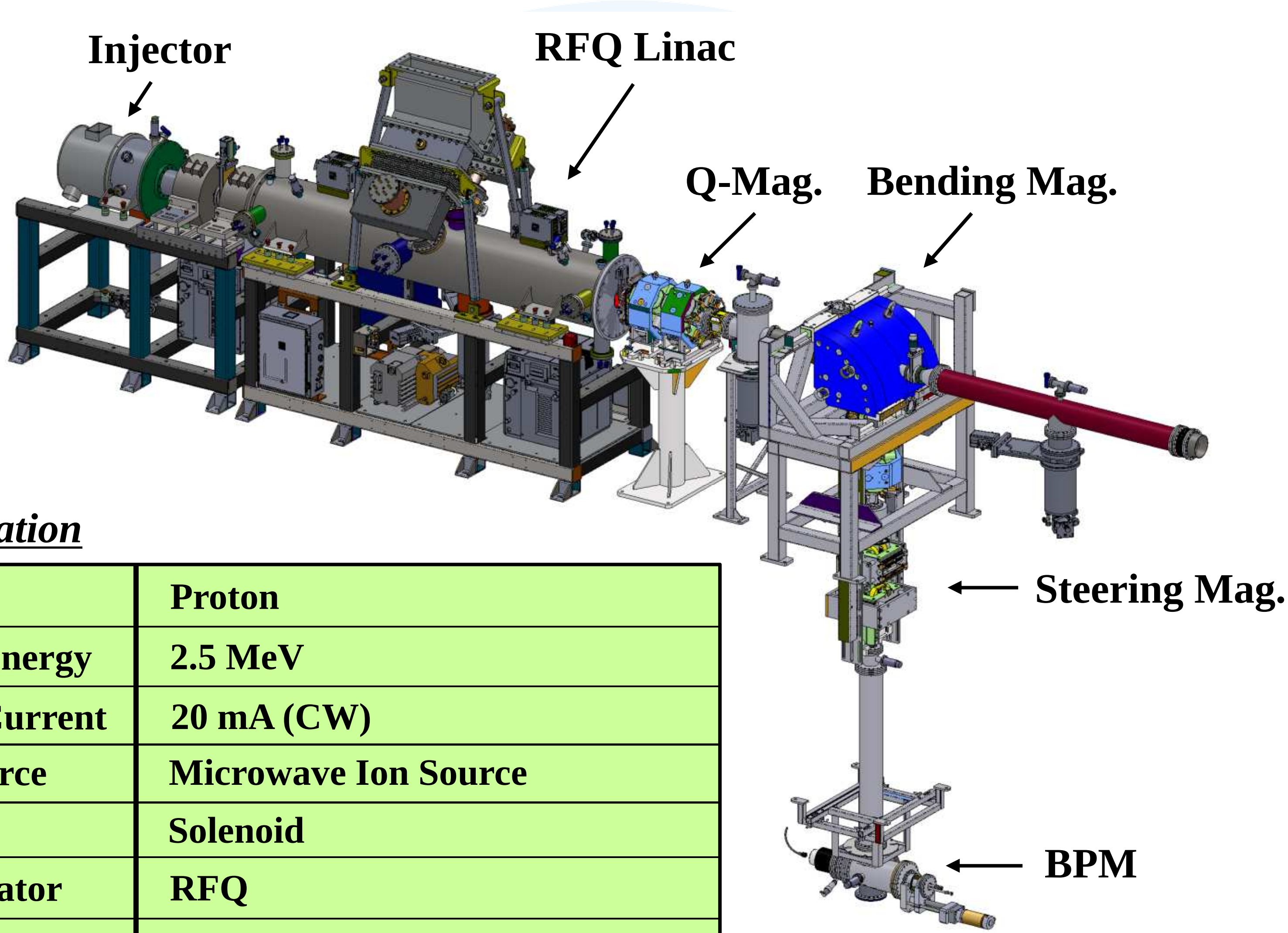
(Currently on development)

Target Materials	Form	Thickness (mm)	Accelerator				
			Particle	Energy (MeV)	Current (mA)	Mode (CW/PM)	Type
Lithium	Solid	0.1	Proton	2.5	20	CW	RFQ
		0.14	Proton	1.9-2.8	15	DC	Electrostatic
	Liquid		Proton	2.5	20	DC	Electrostatic
		0.6	Proton	1.9〜3	20	DC	Electrostatic
Beryllium	Solid	5.5	Proton	30	1〜2	PM	Cyclortron
	Solid	0.5	Proton	8	10	PM	RFQ+DTL

*PM: Pulse Modulation

*CW: Continious Wave

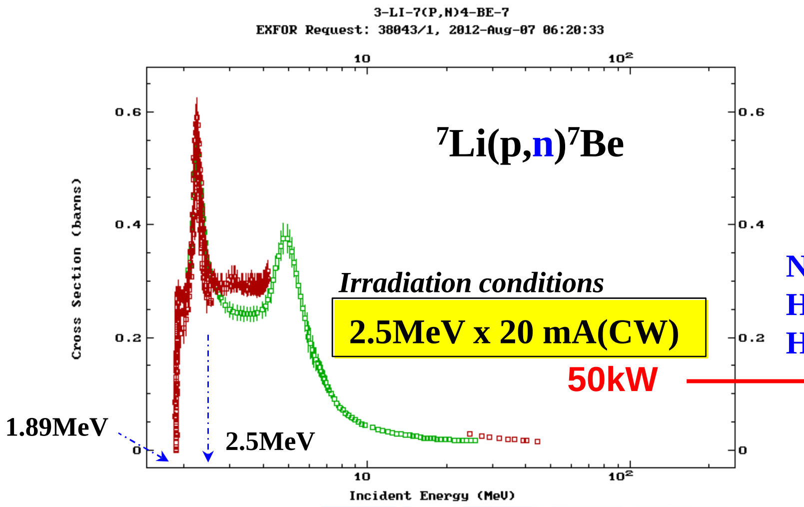
High Current Proton RFQ Linac



Specification

▪Particle	Proton
▪Beam Energy	2.5 MeV
▪Beam Current	20 mA (CW)
▪Ion Source	Microwave Ion Source
▪LEBT	Solenoid
▪Accelerator	RFQ
▪RF	Klystron (330kW CW, 400MHz)

Neutron Production: $^{7}Li(p,n)^{7}Be$



Need for
High Performance
Heat Removal System

LITHIUM

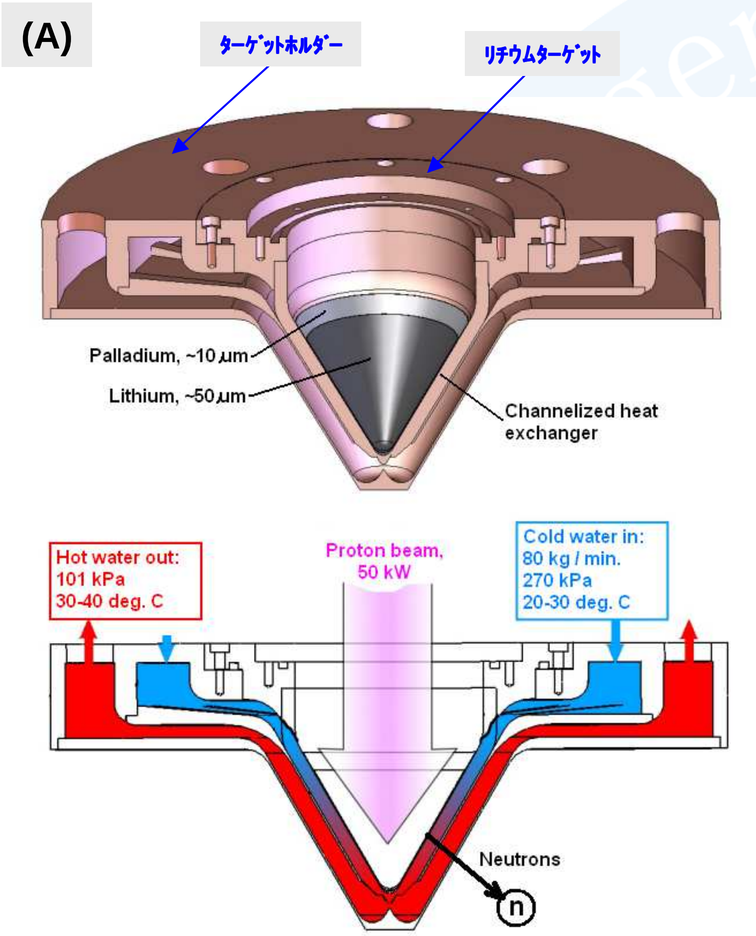
Atomic weight	6.941	g
Isotope		
6Li	7.5	%
7Li	92.5	%
Physical properties		
Density(r.t)	0.534	g/cm3
Melting point	180.54	℃
	453.69	K
	356.97	?
Thermal conductivity	84.8	W/m/K

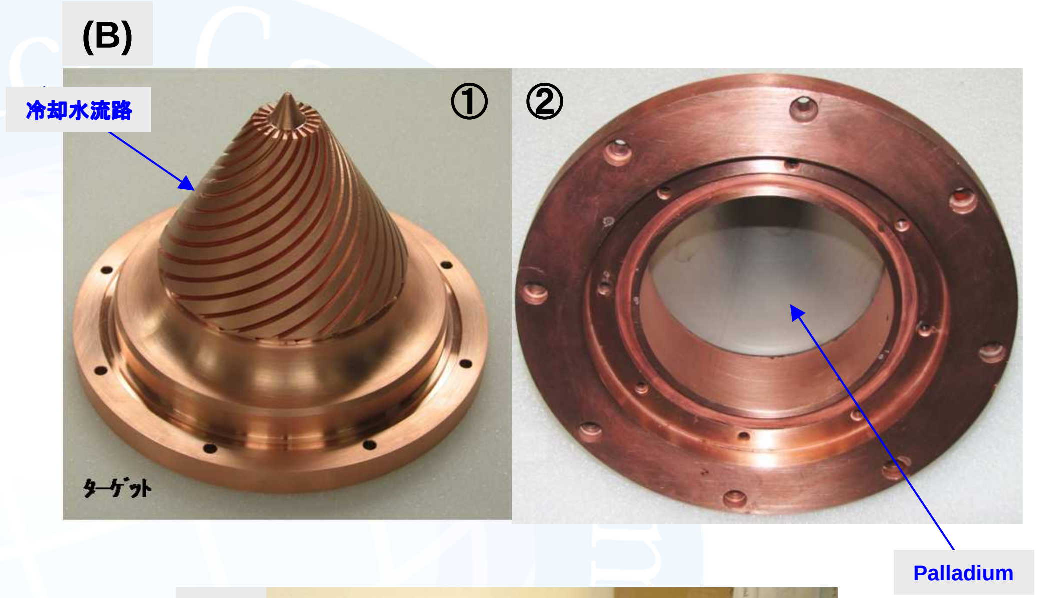
Near-threshold thick target neutron yields for lithium metal

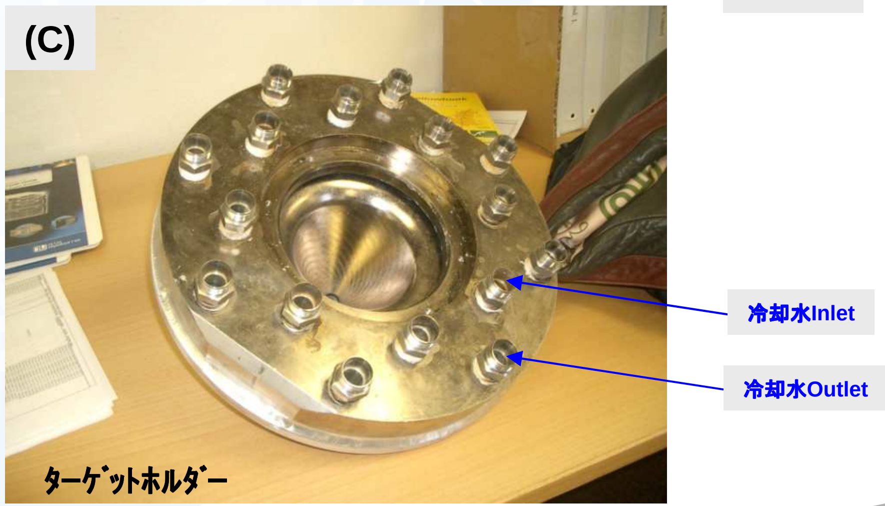
Incident proton energy (MeV)	Total neutron yield (n/mC)	Maximum neutron energy (keV)	Mean neutron energy (keV)	Maximum neutron angle (degrees)	Mean neutron angle (degrees)
1.89	6.34E9	67.1	34.0	30.0	16.5
1.90	1.49E10	87.6	38.3	45.2	23.0
1.91	2.41E10	105.3	42.4	60.3	27.8
1.92	3.35E10	121.4	46.5	180	31.9
1.93	4.30E10	136.6	50.6	180	35.3
1.94	5.25E10	151.1	54.4	180	38.3
1.95	6.21E10	165.1	58.1	180	41.0
1.96	7.16E10	178.8	61.6	180	43.5
1.97	8.12E10	192.1	65.0	180	45.6
1.98	9.08E10	205.1	68.4	180	47.6
1.99	1.00E11	218.0	71.7	180	49.4
2.00	1.10E11	230.6	75.1	180	51.1
2.10	2.13E11	350.4	108.4	180	63.0
2.20	3.62E11	463.4	158.9	180	68.7
2.30	5.78E11	573.1	233.1	180	66.3
2.40	7.48E11	680.6	286.5	180	63.8
2.50	8.83E11	786.7	326.4	180	62.9

Ref) C.L. Lee, X.L. Zhou, Nuclear Instruments and Methods in Physics Research B 152(1999) 1

Thin Layered Solid Lithium Target







Thin Layered Solid Lithium Target

A) Benefit

1) The energy level of neutron generated is low because of low energy level of proton beam.

- The size of accelerator can be small
- Moderator can be simple and compact
- No concern for activation by fast neutron

B) Subjects

1) Heat removal measures

   ＊ Melting point of lithium is low (190^{o}C)

2) Handling of lithium is difficult

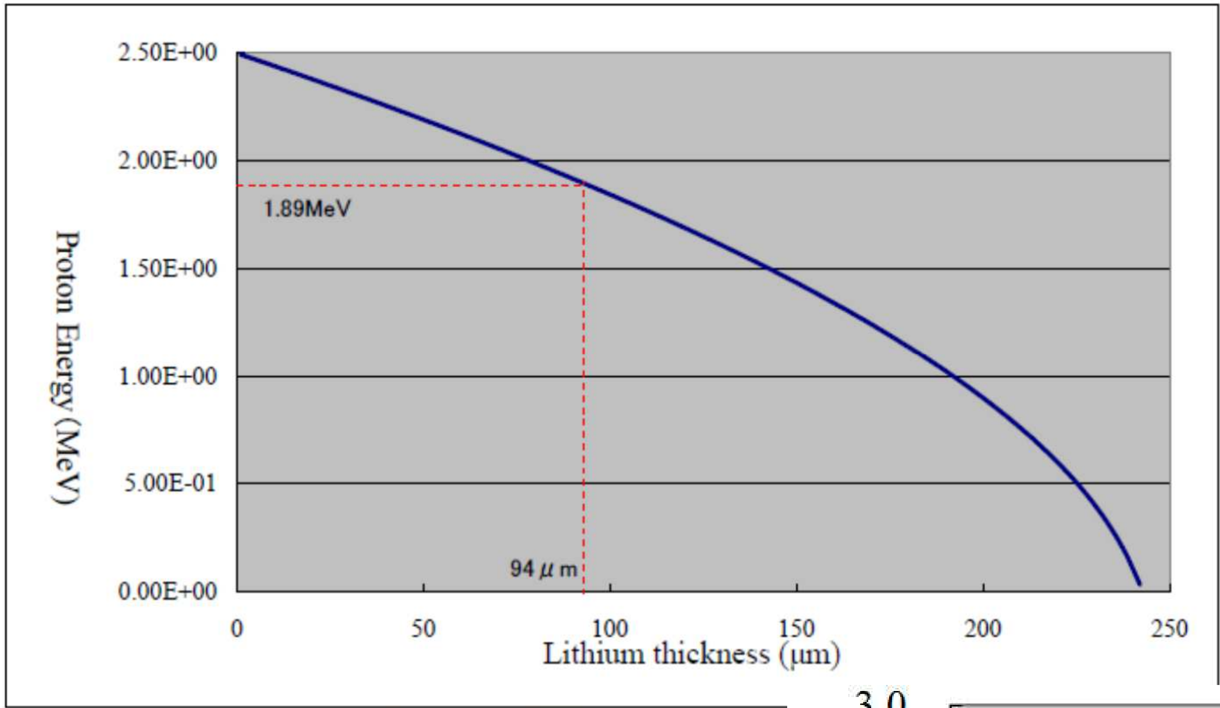
   ＊ Lithium is sensitive to water and air

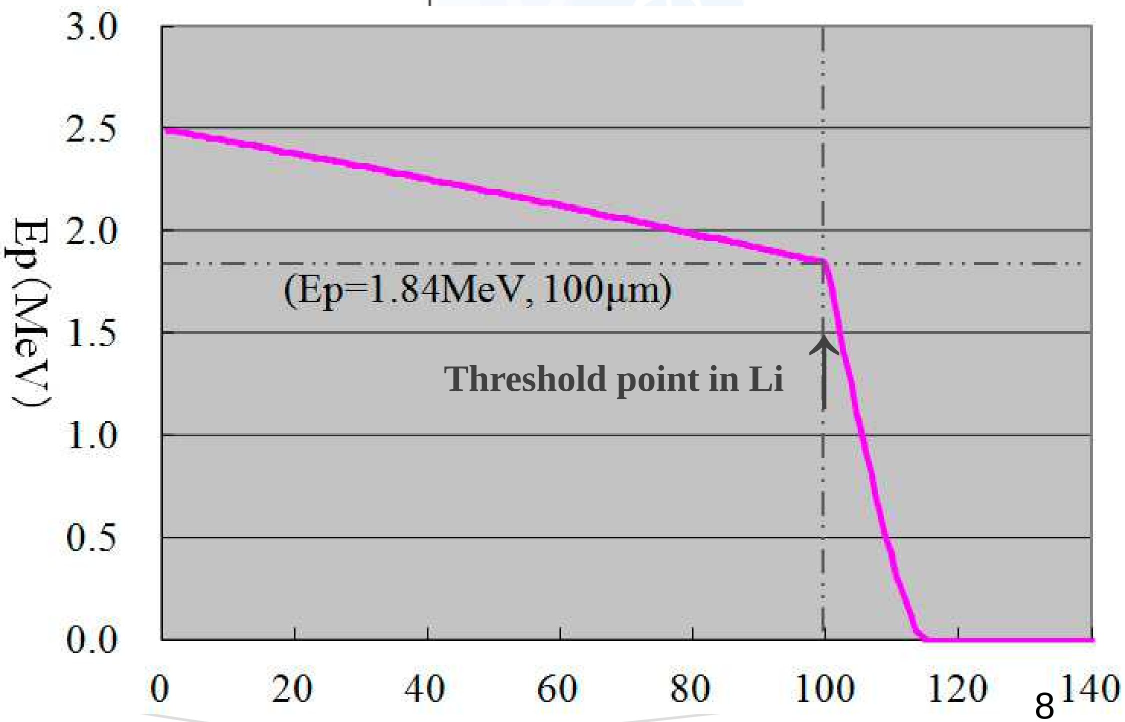
3) Reducing impact of Be-7 (Half life time: 53.3day) by using 7Li (p, n) 7Be

4) Preventing blistering
（※ Other solid target materials also having this problem. ）

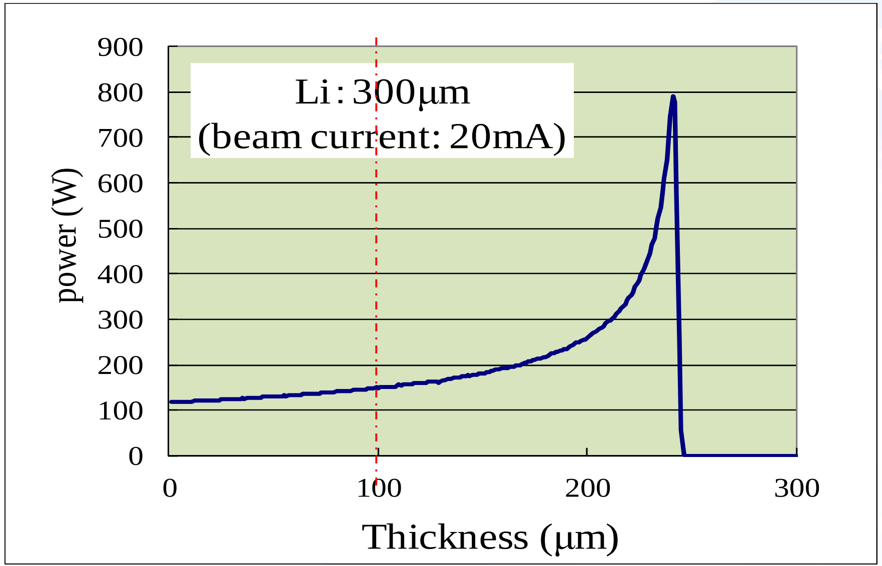
5) Lithium thin layer technology

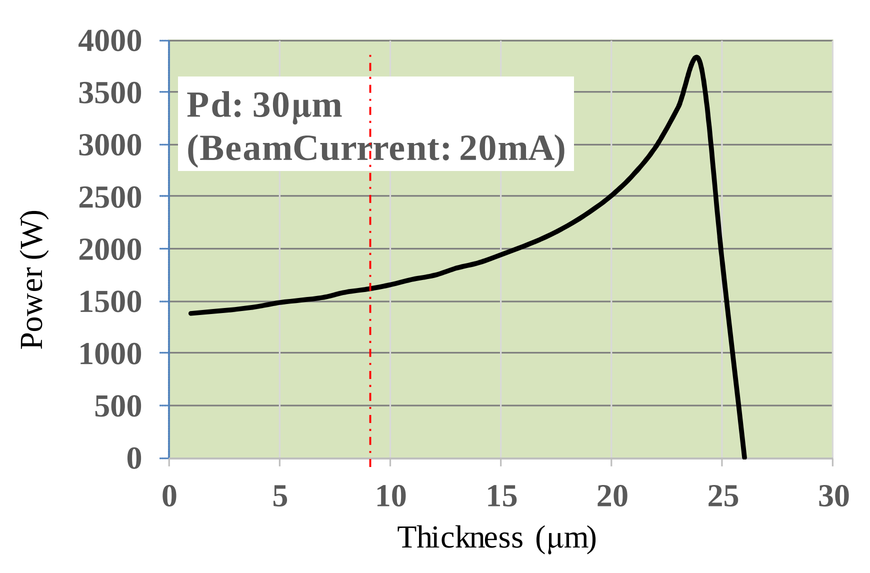
Stopping range of 2.5MeV Proton

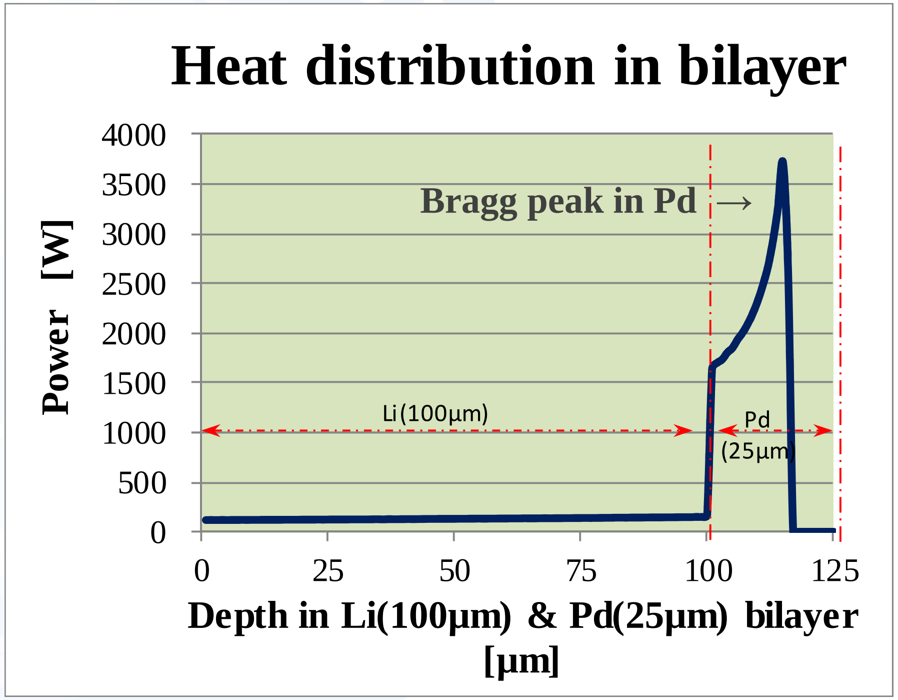




Configuration of the accelerator based Neutron Source

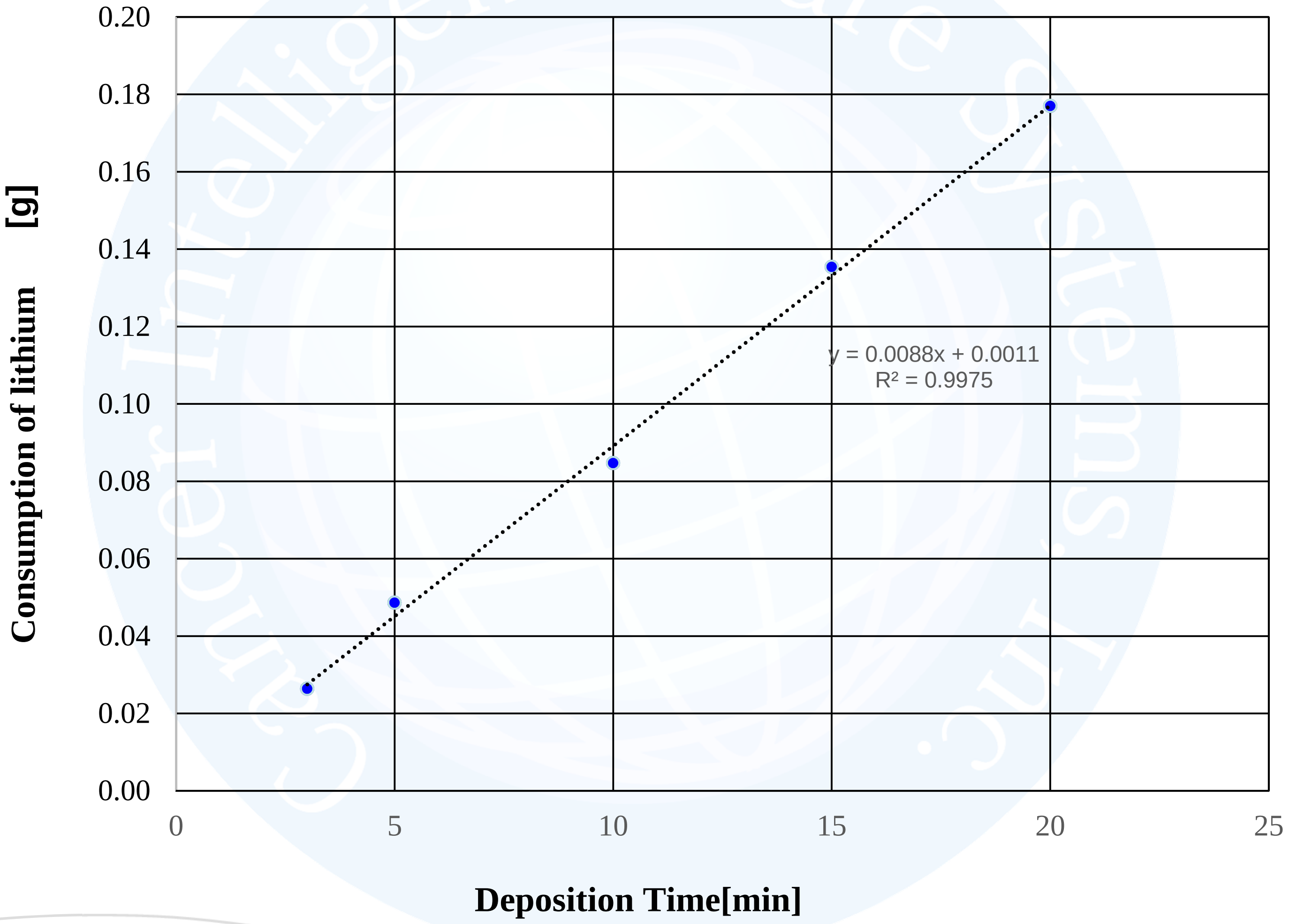




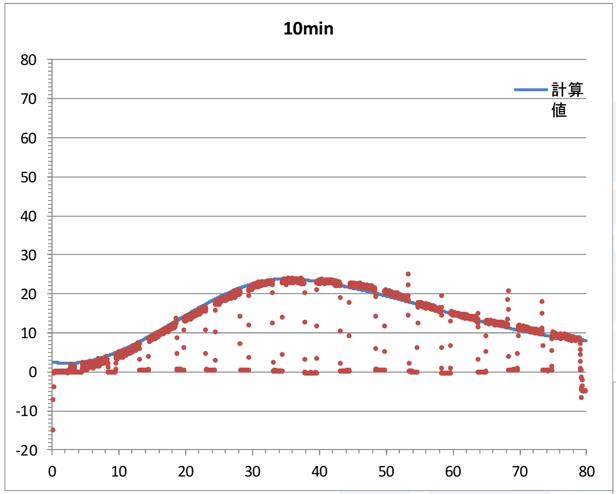


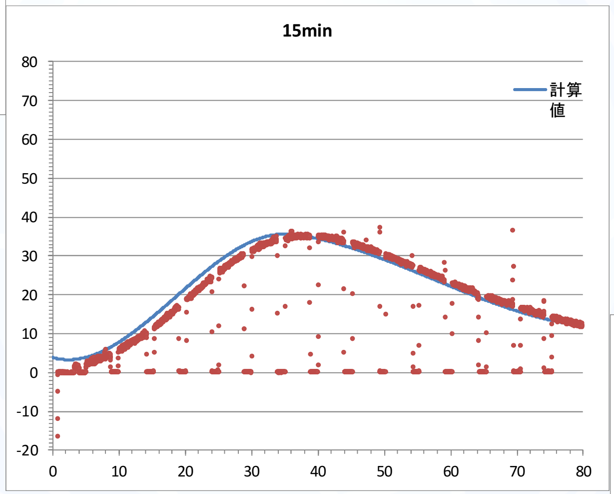
Equipment for decomposition test

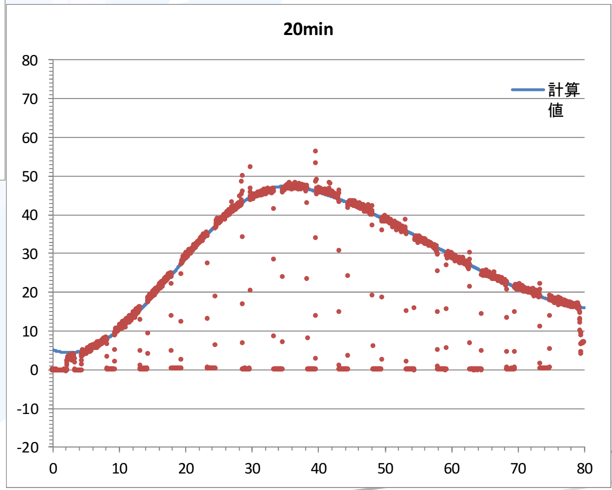
Relationship of Lithium Consumption and Deposition Time



Correlation of Li deposition profile between estimation and measurement







Estimation

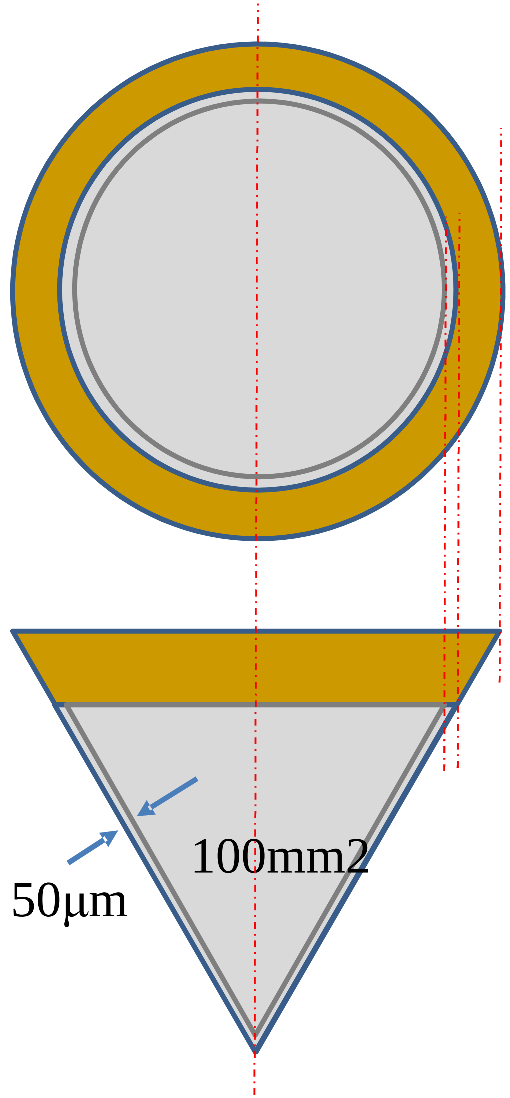
Measurement

Handling of ^{7}Be in compliance with the regulations

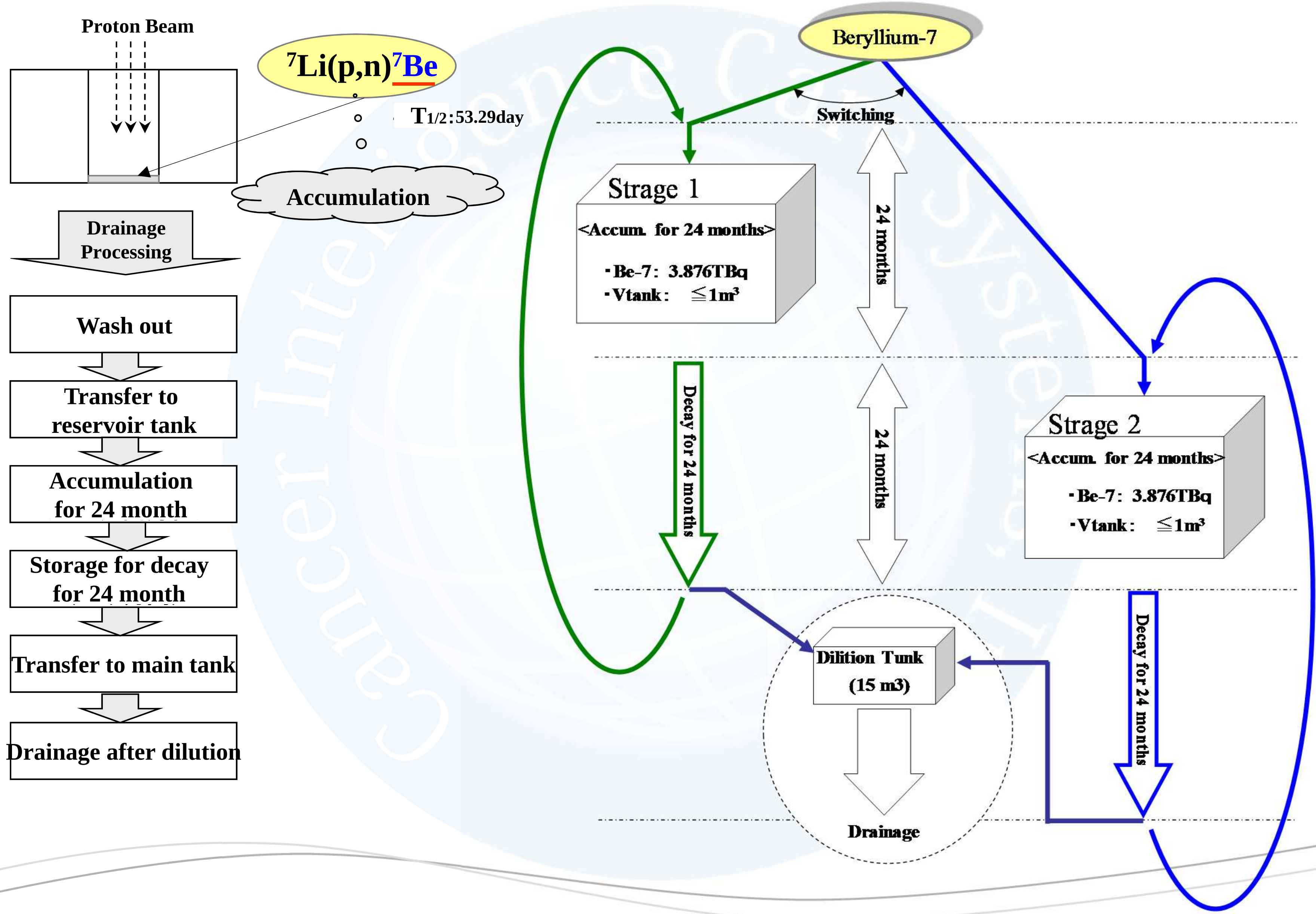
Estimation of the Be-7 saturation yield

Li (Enriched)	6.941 (g/mol)	0.534 (g/cm3)
Li-6	0.12 (%)	
Li-7	99.88 (%)	
Surface area of the target	100.531 (cm2)	
Li thickness	0.005 (cm)	50 ?m
Volume of the Li	0.503 (cm3)	
Weight of the Li	0.268 (g)	
Li6	0.00032 (g)	
Li-7	0.268 (g)	
Number of Li-6 atoms n(Li-6)	2.795E+19	
Number of Li-7 atoms n(Li-7)	2.326E+22 n	
Cross Section ?(Be-7)	0.568 (cm2)	
Proto Flux f	1.243E+15 (n/cm2/s)	
Saturation Yields of Be-7	1.643E+13 Bq	444.0 Ci

Accumulation of Be-7	Radio Activity
Irradiation = 8 hour/day	Yield of Be-7
1 day	7.106E+10 Bq
1 week	3.373E+11 Bq
3 months	2.689E+12 Bq
1 year	3.842E+12 Bq
2 year	3.876E+12 Bq
Decay (2 years)	
2 years	2.915E+08 Bq
Dilution	
15 m3	1.943E+01 Bq
Limit of Be-7	6.000E+01 Bq
Ratio	3.239E-01 *Clear*

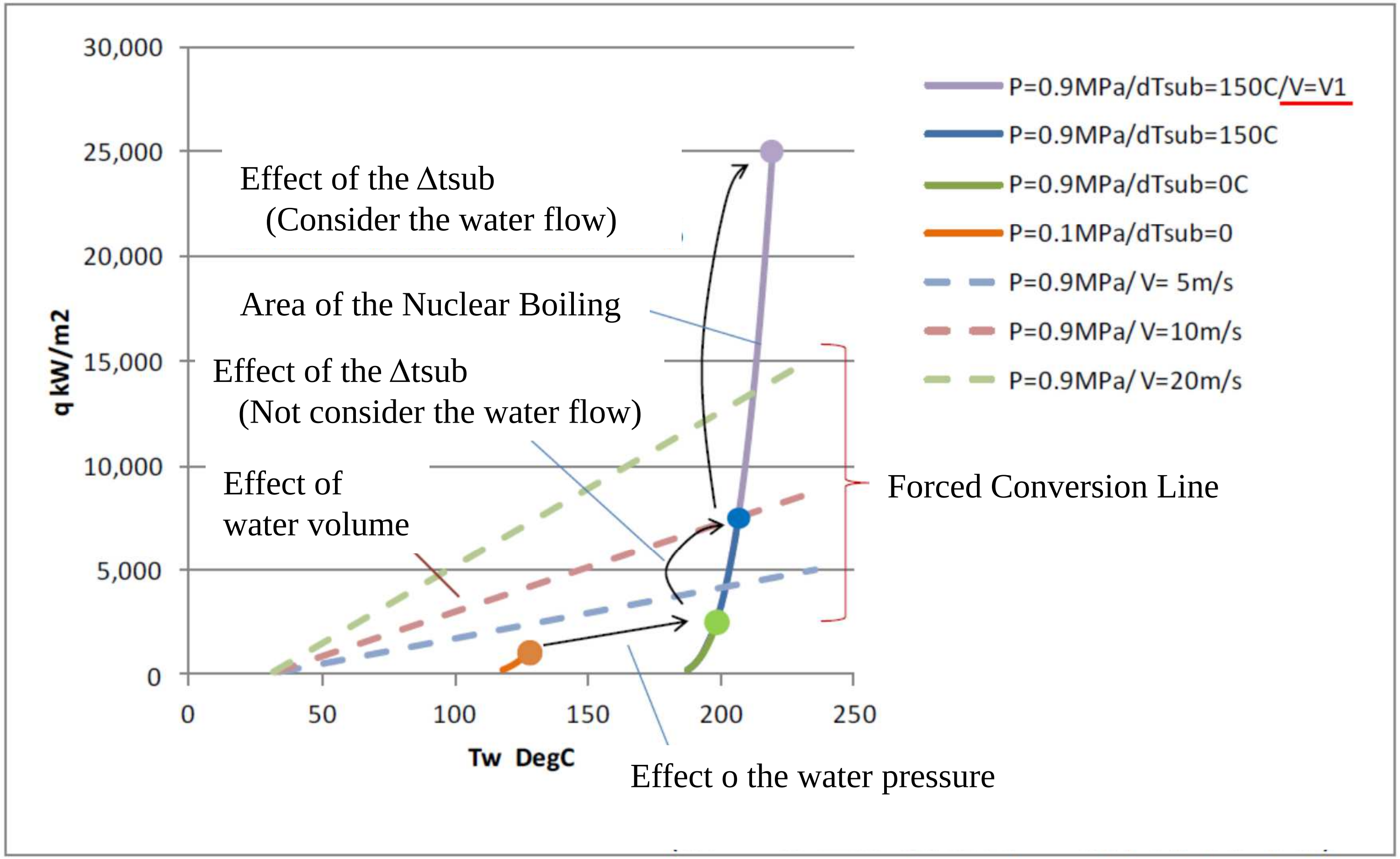


Handling of ^{7}Be in compliance with the regulations



Evaluation of 50kW heat removal

※ Filled Circle showed the CHF point.
(CHF: Critical Heat Flux)

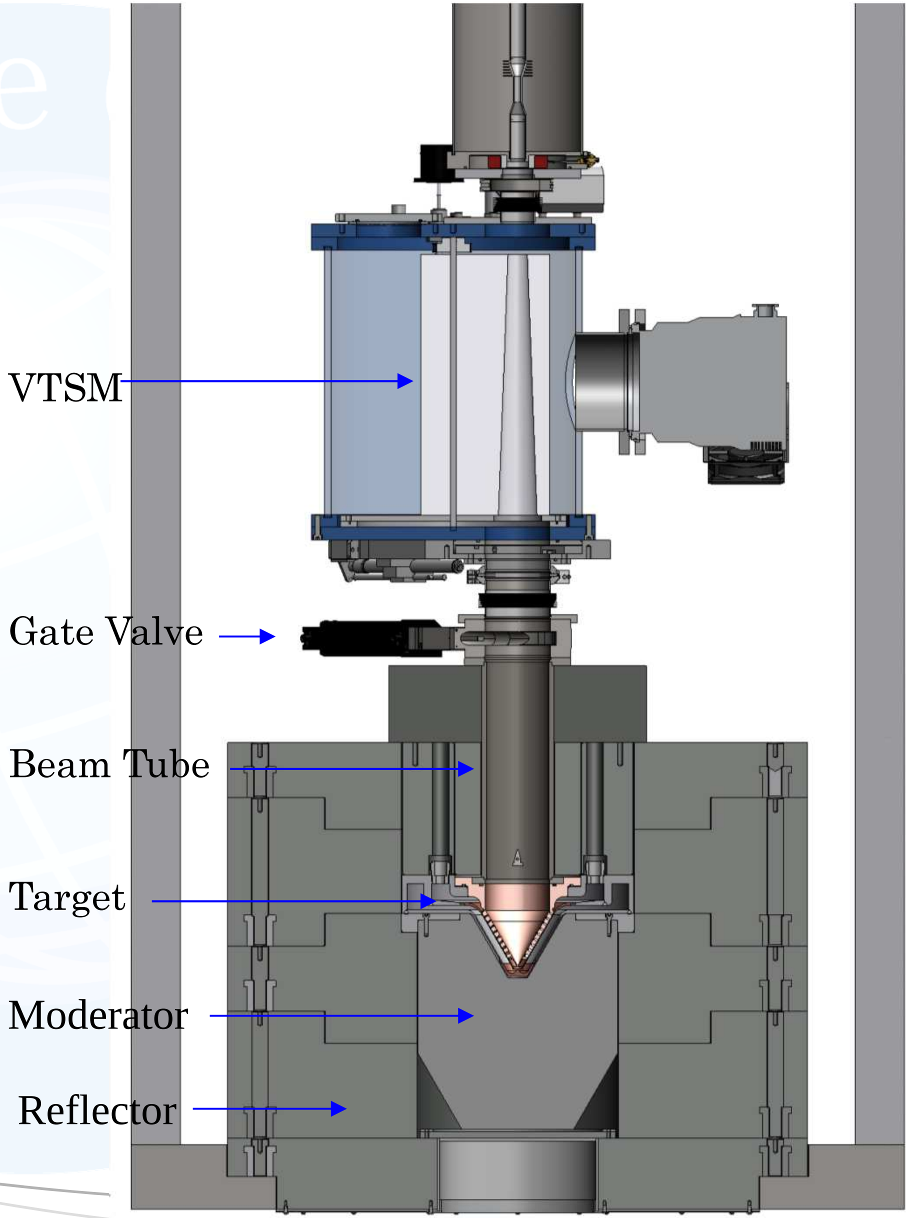


※The data of CHF is quoted from Groeneveld table.

Target Cooling System

Flow rate(L/min)		Pressure (MPa)	
No.	Measu.	**No.**	Measu
FL1	35.4	PS1	1.33
FL2	34.5	PS2	1.3
FL3	36.2	PS3	1.3
FL4	36.2	PS4	1.29
FL5	34.7	PS5	1.36
FL6	34.3	PS6	1.36
FL7	35.9	PS7	1.38
FL8	35.2	PS8	1.35
Total	**282.4**	Average	**1.33**

Lithium Recovery System

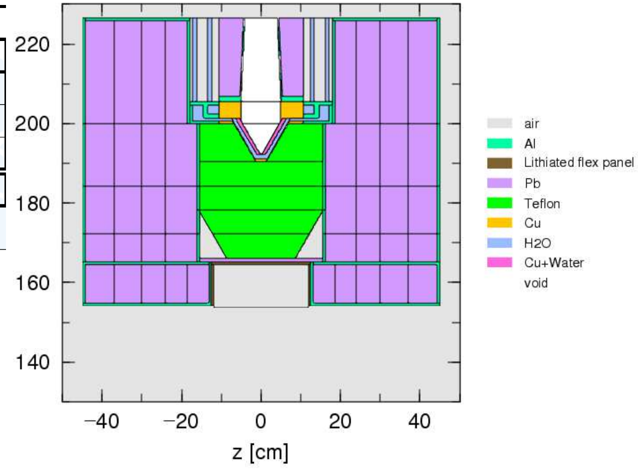


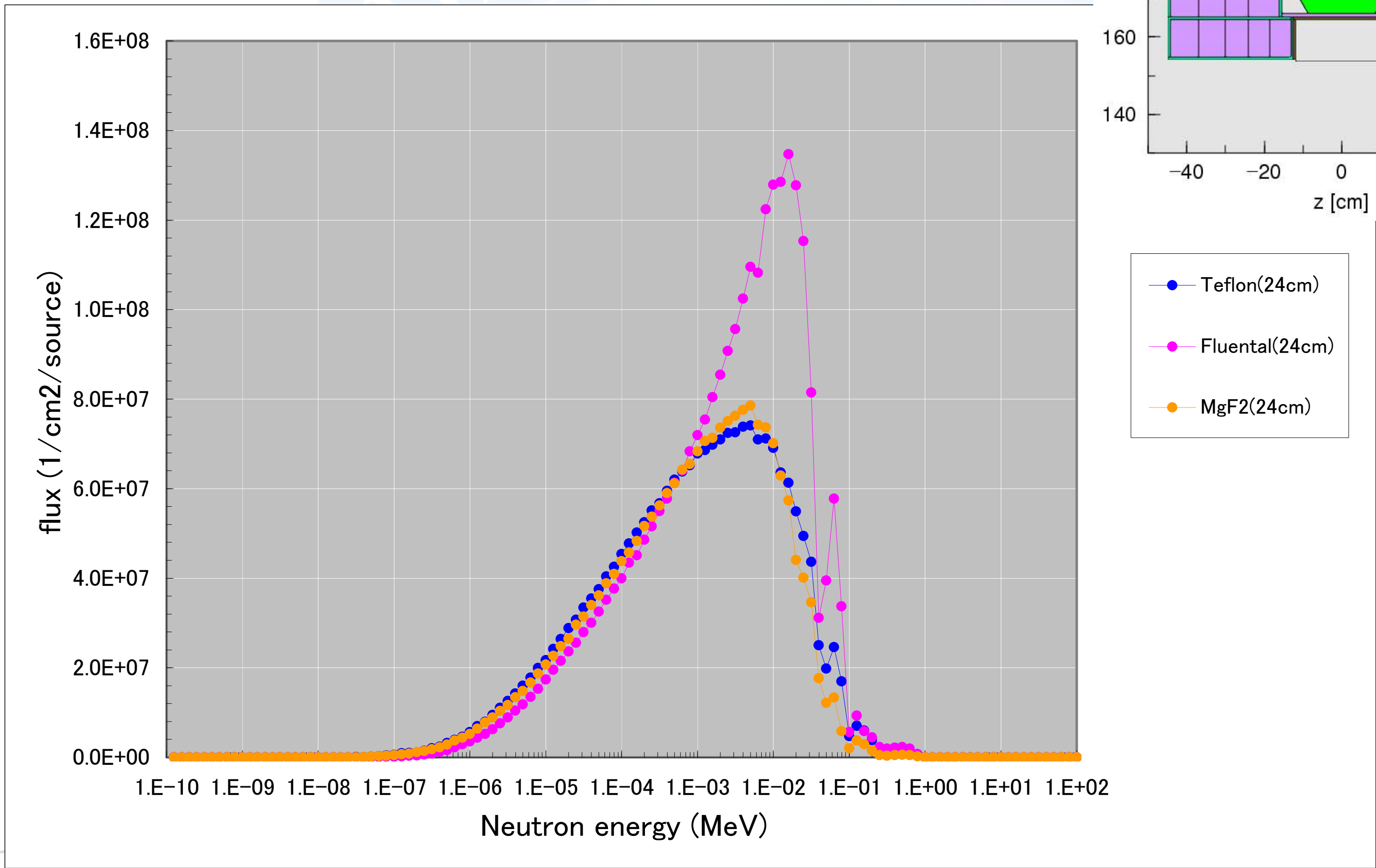
Reflector

Evaluation of Lithium Target System

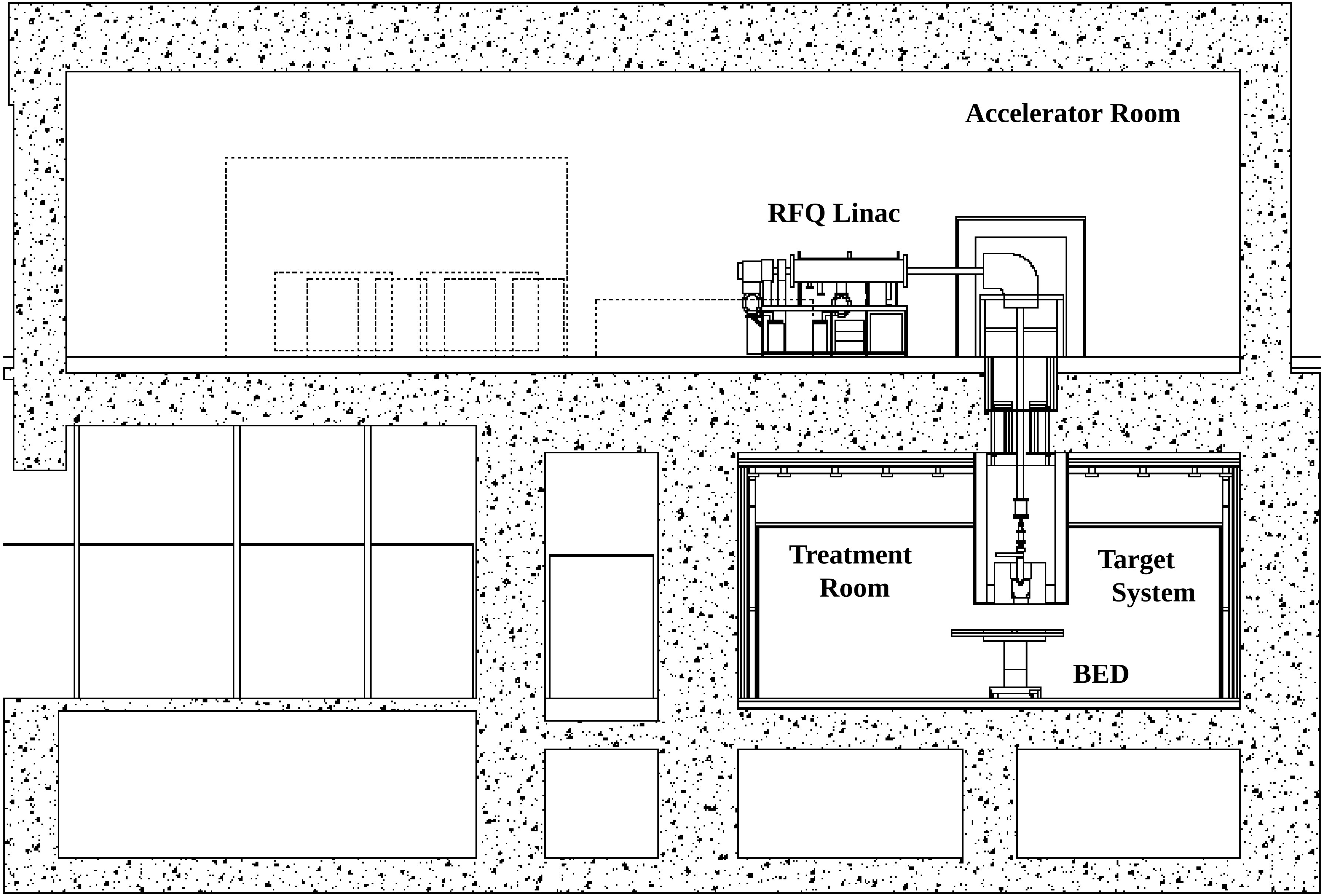
calculated by *PHITS* 2.16

	Teflon(24cm)		MgF2(24cm)		Fluental(24cm)	
	(1/cm2/s)	ratio(%)	(1/cm2/s)	ratio(%)	(1/cm2/s)	ratio(%)
thermal neutron(～0.5eV)	1.36E+07	0.62%	1.24E+07	0.59%	5.58E+06	0.20%
epithermal neutron(0.5eV～10keV)	1.79E+09	81.64%	1.79E+09	85.08%	1.97E+09	71.31%
fast neutron(10keV～)	3.89E+08	17.73%	3.01E+08	14.33%	7.86E+08	28.49%
total	2.19E+09	100%	2.10E+09	100.00%	2.76E+09	100.00%

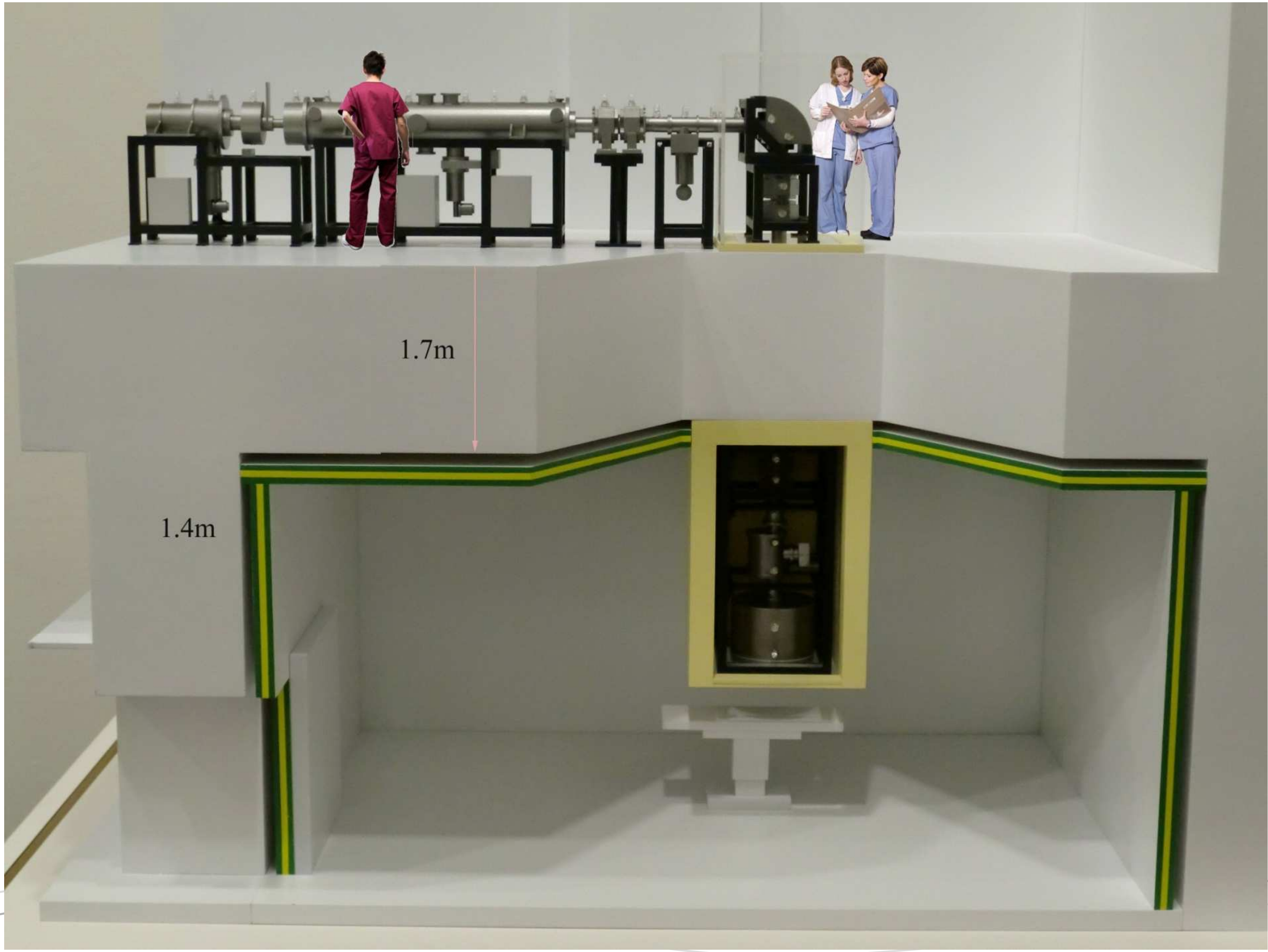




Cross section diagram of the facilities for the Accelerator Based BNCT



3D Model of the BNCT facility



Housing of the Target System & Movable Shield

Close

Open

Accelerator Room

National Cancer Center: New Facility for Accelerator based BNCT

Thank you