Compact Sealed lithium target for accelerator-driven BNCT system

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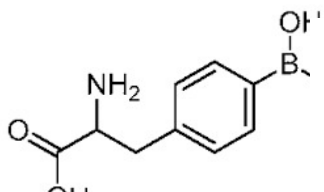
Boron **N**eutron **C**apture **T**herapy (**BNCT**)

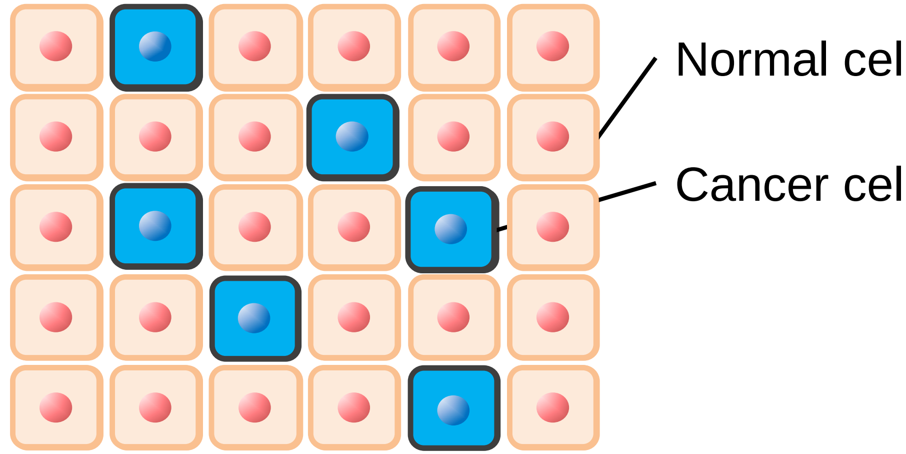
One of the radiotherapies by combining
(1) B-10 drug and (2) neutron irradiation

Step 1
Intravenous injection of a B-10 drug into a patient, which will accumulate in cancer cells.

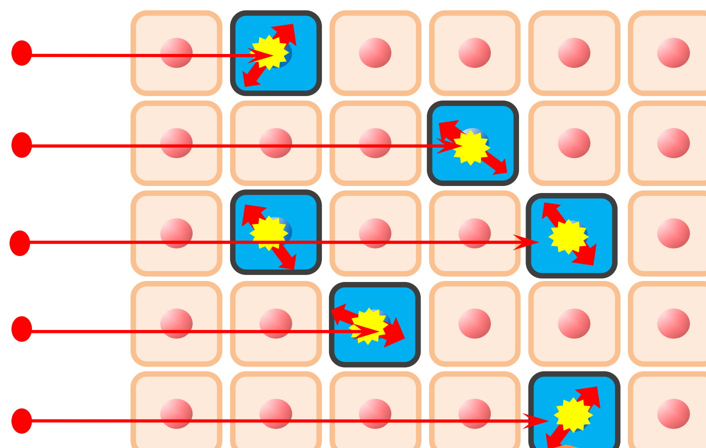


1

BPA
p-dihydroxyboryl-phenylalanine

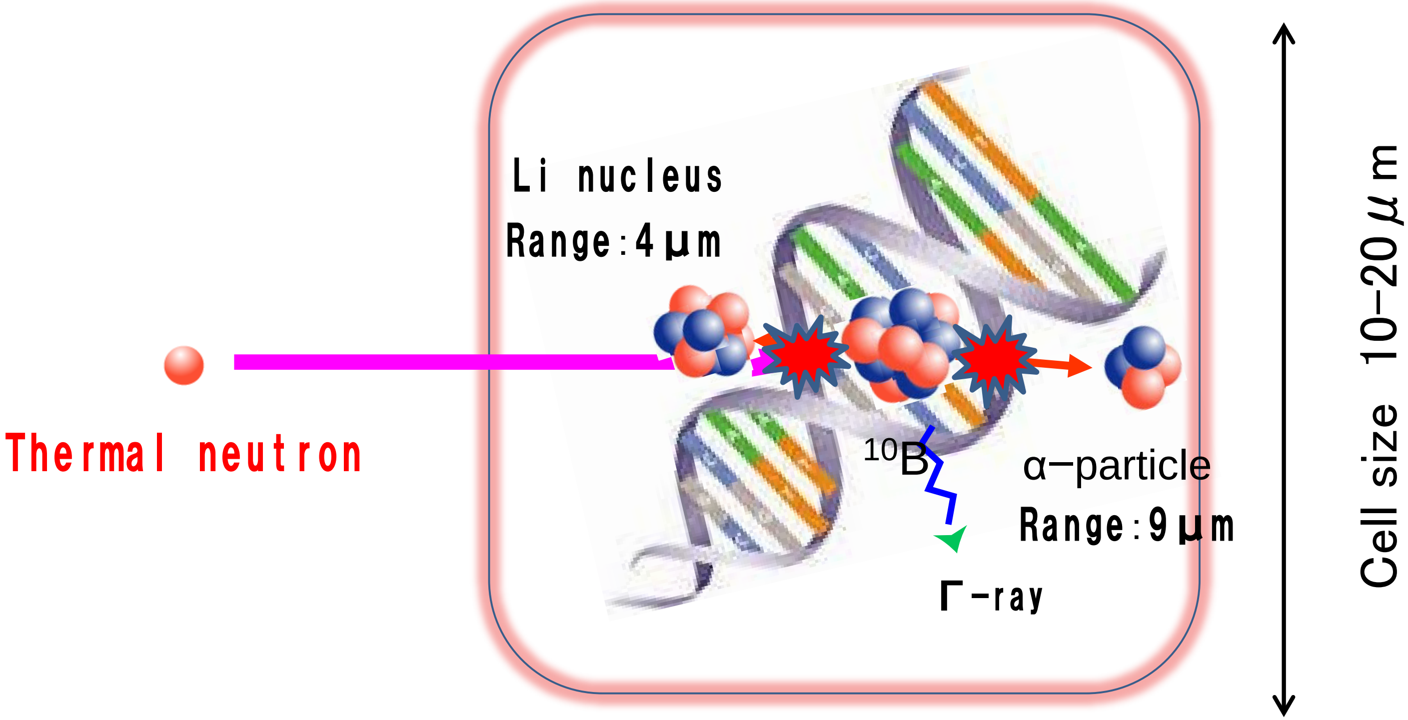


Step 2
Irradiation of thermal neutrons to make a fission of B-10, which will make Li and α particles.



$$^{10}B + n \rightarrow {}^{7}Li\ (1.47MeV) + \alpha\ (0.84MeV)$$

In step 2



Cancer cell contained B-10

The α−particle and Li nucleus cut the double−helical DNA, etc. and kill the cancer cell.

Some cases of BNCT clinical Applications

Before BNCT

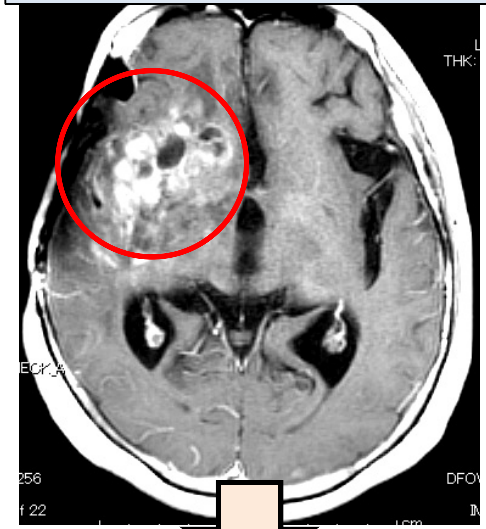
Malignant melanoma

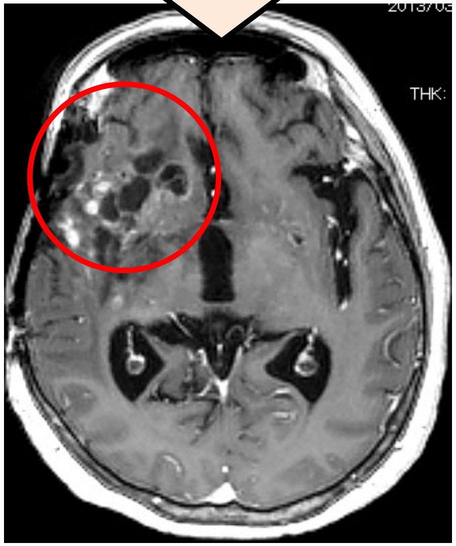
J. Hiratsuka, Radioisotope 64, 115 (2015)

Parotide cancer

K. Kato, Radioisotope 64, 103 (2015)

Malignant Glioma

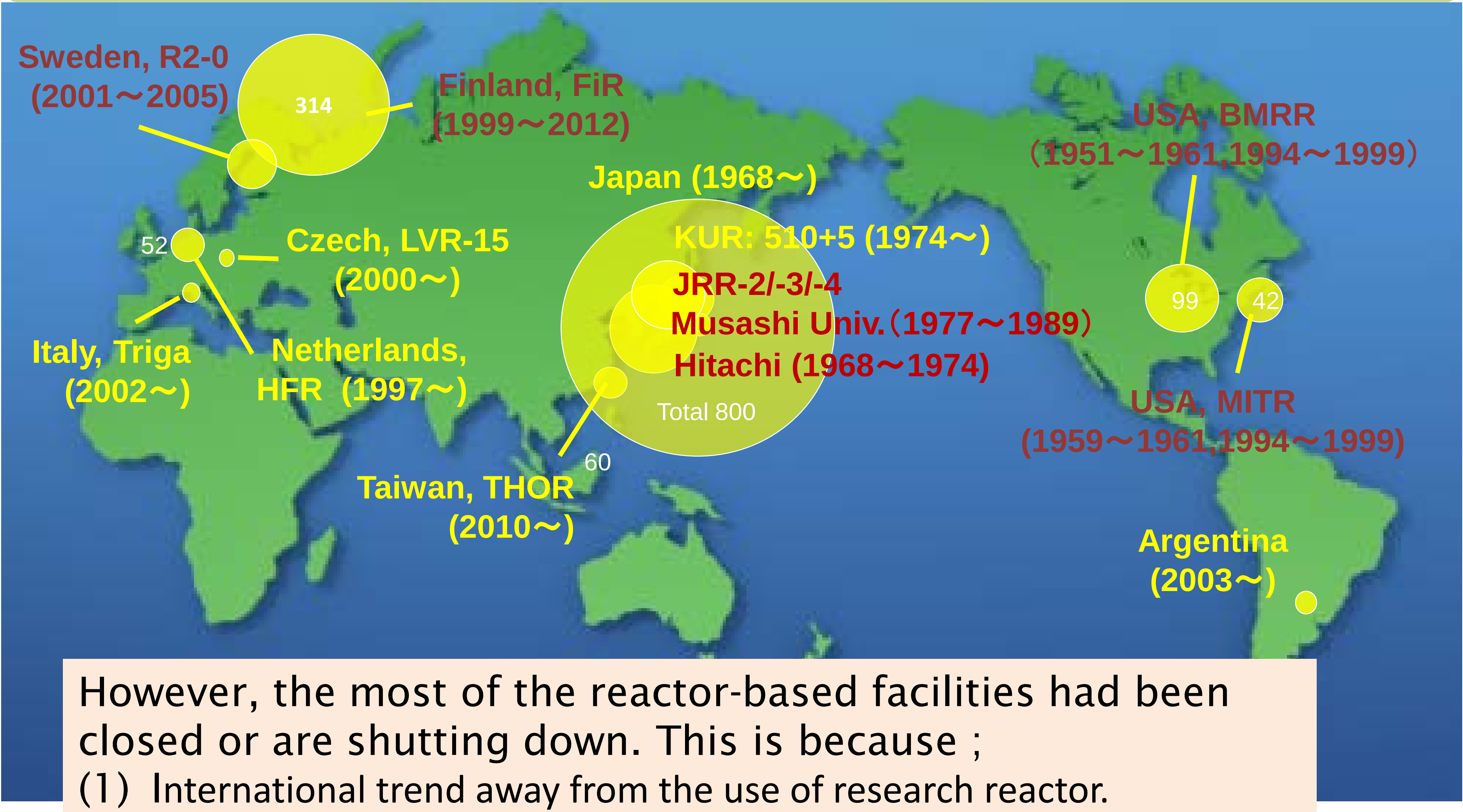




Treated by Prof S. Miyatake
Osaka medical College

After BNCT

Many Reactor-based BNCT treatments had been performed.



However, the most of the reactor-based facilities had been closed or are shutting down. This is because ;

(1) International trend away from the use of research reactor.

(2) Demand of safety BNCT facility for the hospital.

⇒ Now, compact accelerator-driven neutron sources are strongly requested for BNCT!

Accelerator-driven neutron source for BNCT

(Major system configuration)

Accelerator → **Target** → **Moderator*** → **Patient**

Comercial based Cycrotoron, Linac, or DC accelerator

Proton
2 – 30 MeV
40 – 80 kW

Li, Be

Fast neutron

* It is called Beam Shaping Assembly in BNCT.

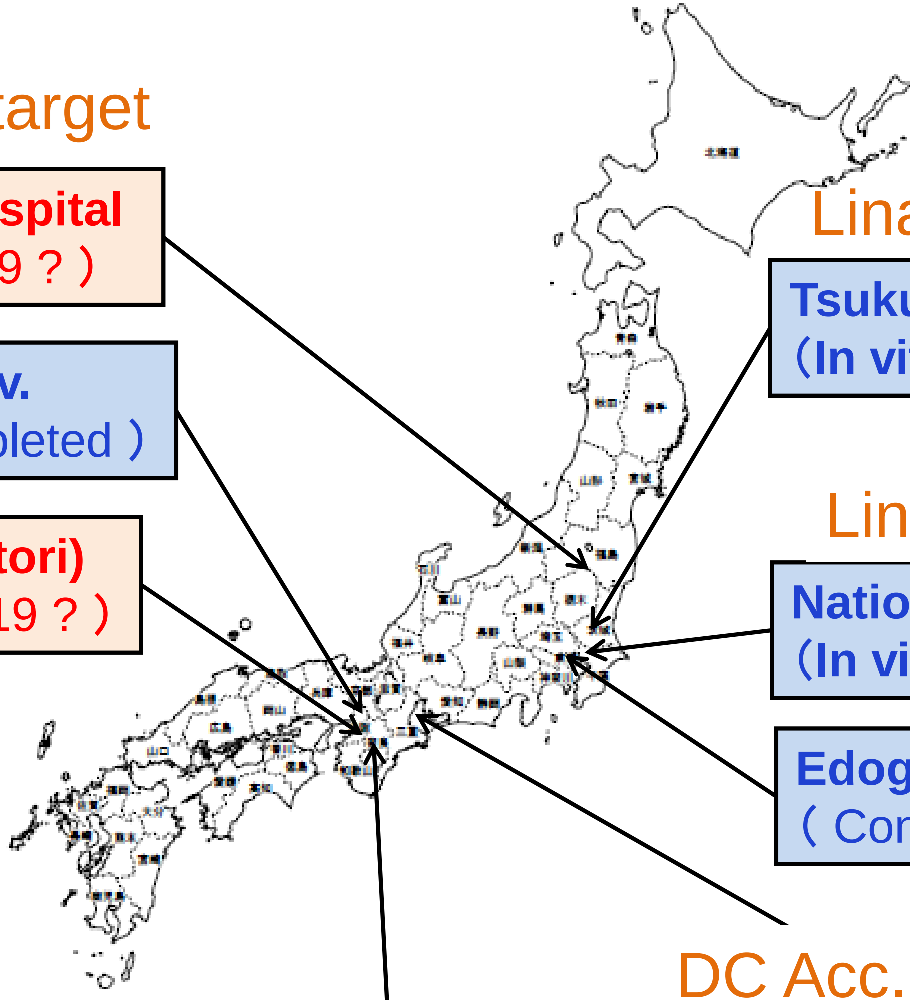
Epi thermal neutron

0.5 eV -10 keV
> 1 x 10^9 n/cm^2 s

Specifications of the BNCT system for clinical application
(1) Sufficient flux and good quality of epi thermal neutron beam (IAEA TECDOC*)
(2) Low radiation exposure to medical and maintenance staffs
(3) Low activation of accelerator and facility
(4) Safe and good reliability as a medical equipment
(5) Easy and quick maintenance
(6) Low construction and running costs

* IAEA-TECDOC-1223 "*Current states of neutron capture therapy*", IAEA (2001).

Two BNCT facilities may complete clinical trial in a year and
Four BNCT facilities are under non-clinical trial phase in Japan.



Cyclotron & Be target

Minami Tohoku Hospital
(Clinical trial ～2019 ?)

Osaka Medical Univ.
(**C**onstruction completed)

Kyoto Univ. (kumatori)
(Clinical trial ～ 2019 ?)

Linac & Be target

Tsukuba Univ.
(In vitro experiment)

Linac & Li target

National Cancer Center
(In vivo experiment)

Edogawa Hospital
(Construction completed)

DC Acc. & Li target

Osaka Univ.
(Planning)

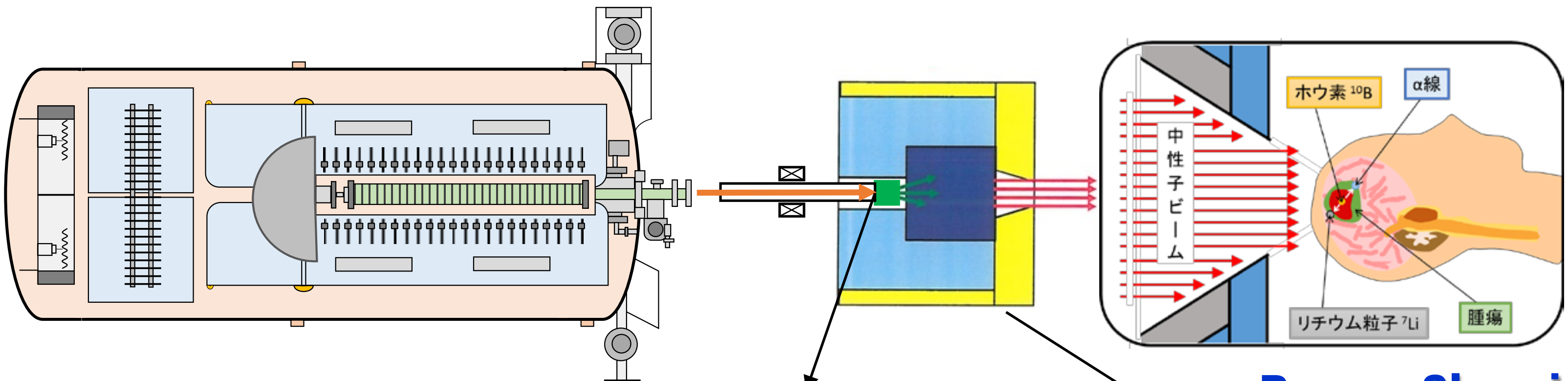
Nagoya Univ.
(Neutron production exp.)

Nagoya Univ. BNCT System

Accelerator

Target
Moderator system

Irradiation area



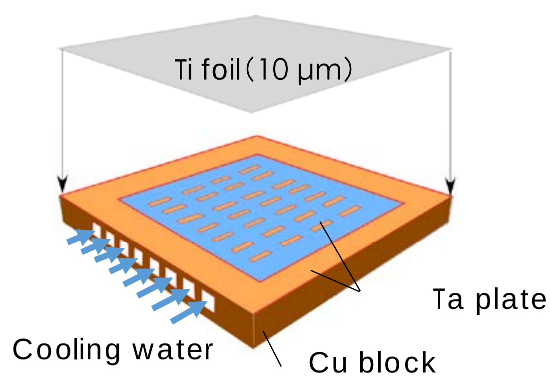
Electrostatic accelerator (Dynamitron)

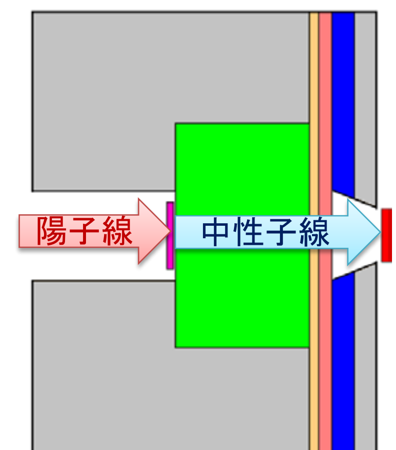
Lithium Target (with cooling system)

Beam Shaping Assembly (BSA)

Proton energy : **1.9~2.8 MeV**
Beam current : **15 mA**

42 kW

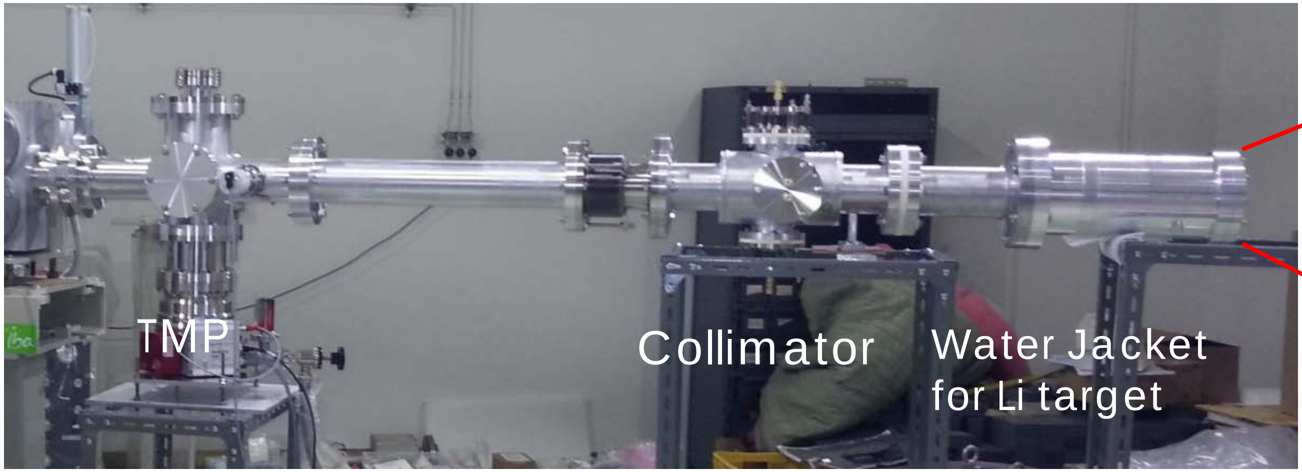




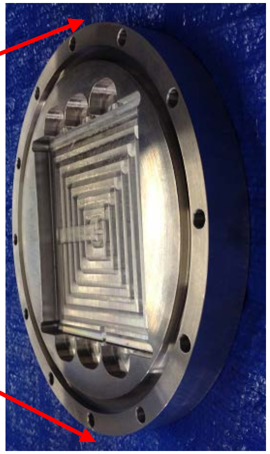
Elecrostaic Accelerator

Dynamitron Accelerator

Beam Line



Target Beam Line



Target

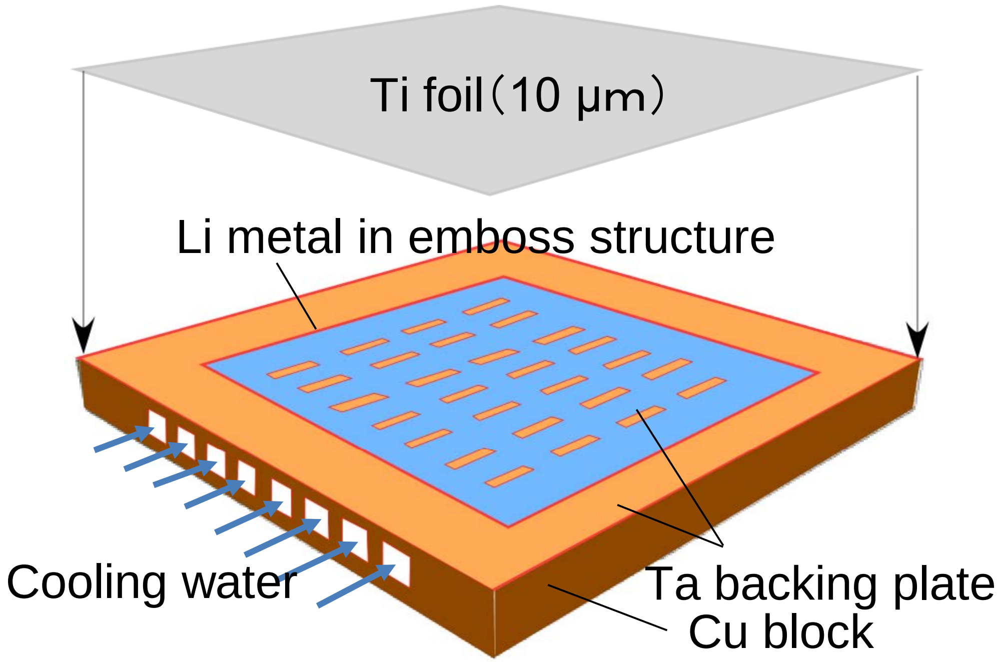
Sealed Lithium Target

Difficulties in chemical properties of Li for target material

1. Low melting point (180℃)
2. Low mechanical properties
3. High chemical reactivity with water & air
4. Activation due to ^{7}Li (p.n) ^{7}Be

Sealed Lithium target

1. Confinement of Li and ^{7}Be
2. Easy handling and quick maintenance



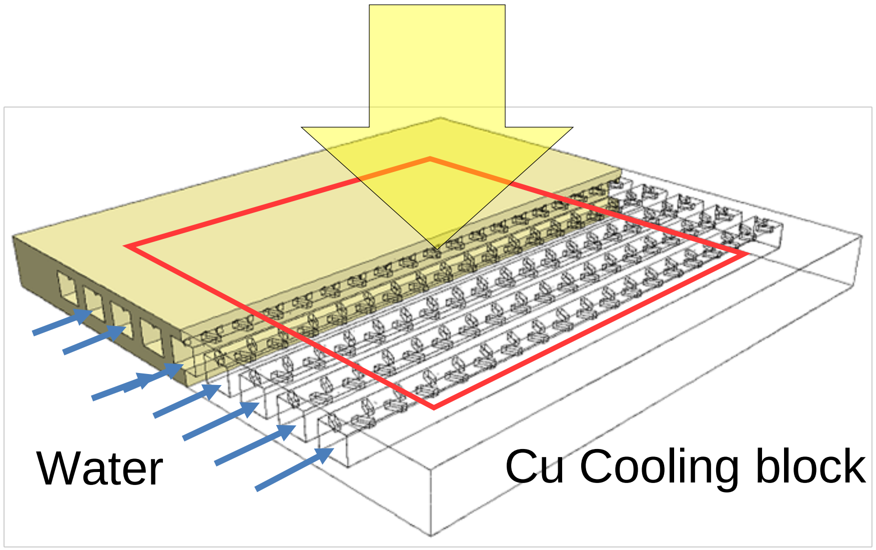
Sealed Li target structure (11cm□)

Technological challenges

1. High efficient heat removable tech,
2. Lithium filling tech. into the emboss structure
3. Remote handling system for target exchange

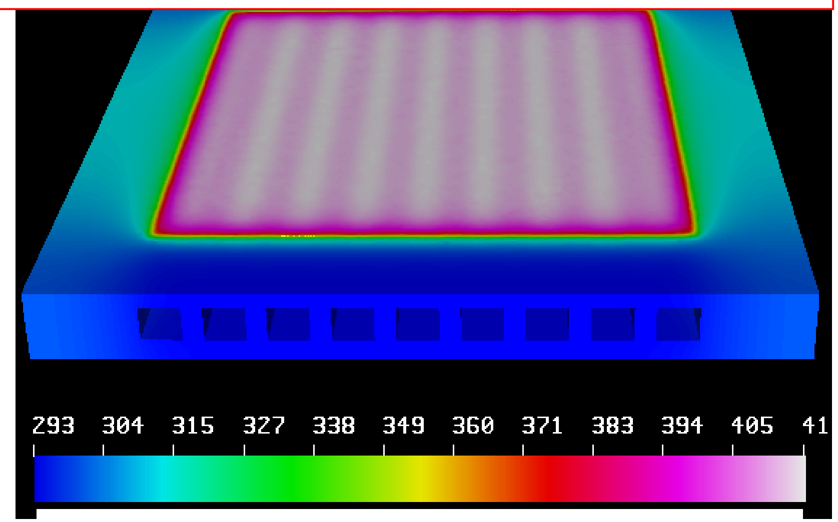
(Challenge 1) High-efficient cooling

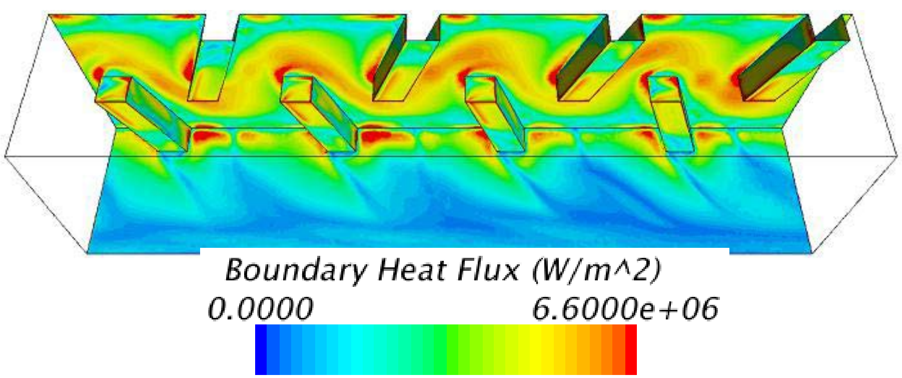
Proton beam
(42kW, 8 x 8 cm²) ⇨ Heat load 6.6 MW/m²



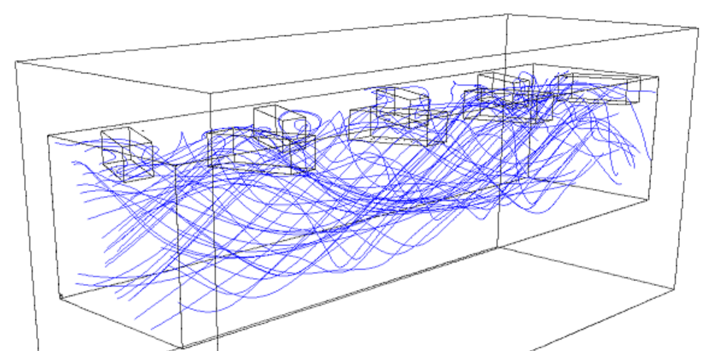
Cooling efficiency was improved by using ribbed water channels

It was confirmed the high-efficient cooling performance (>15 MW/m²) from the target by using an e-beam demonstration experiment. (6th HPTW)



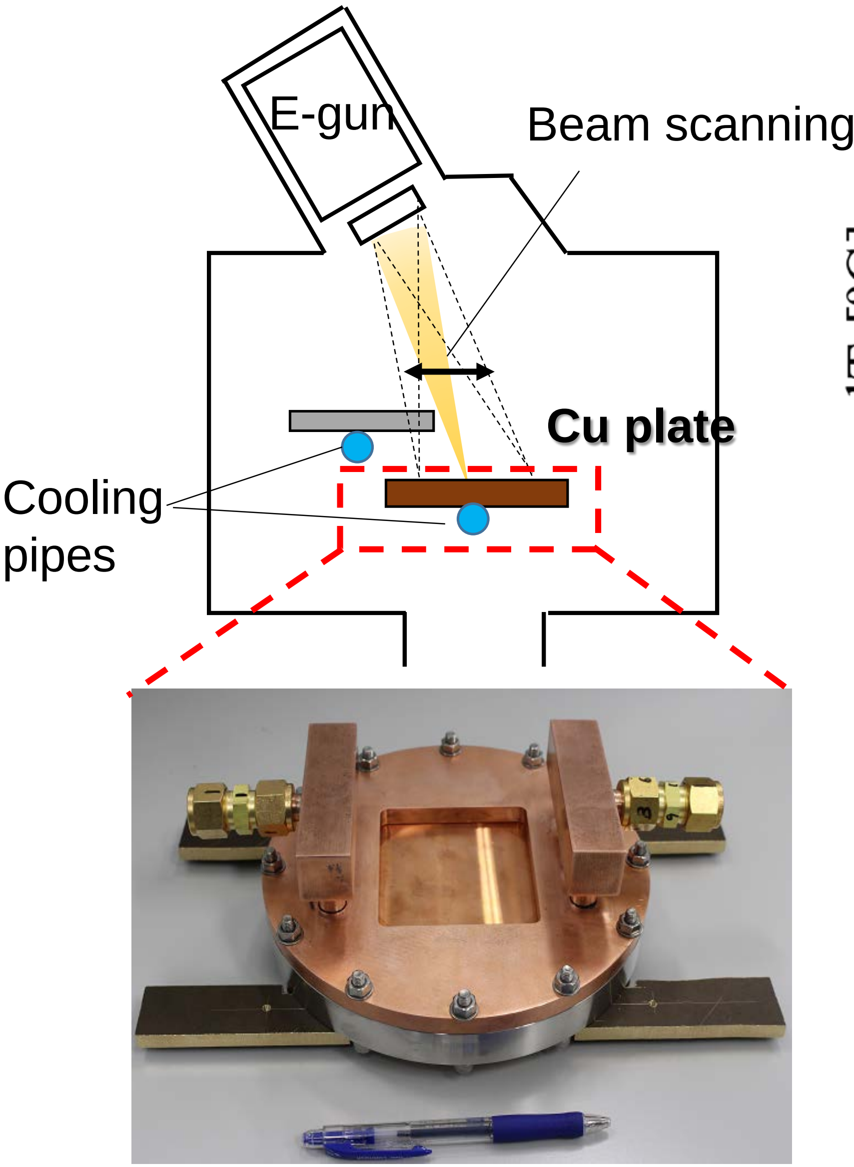


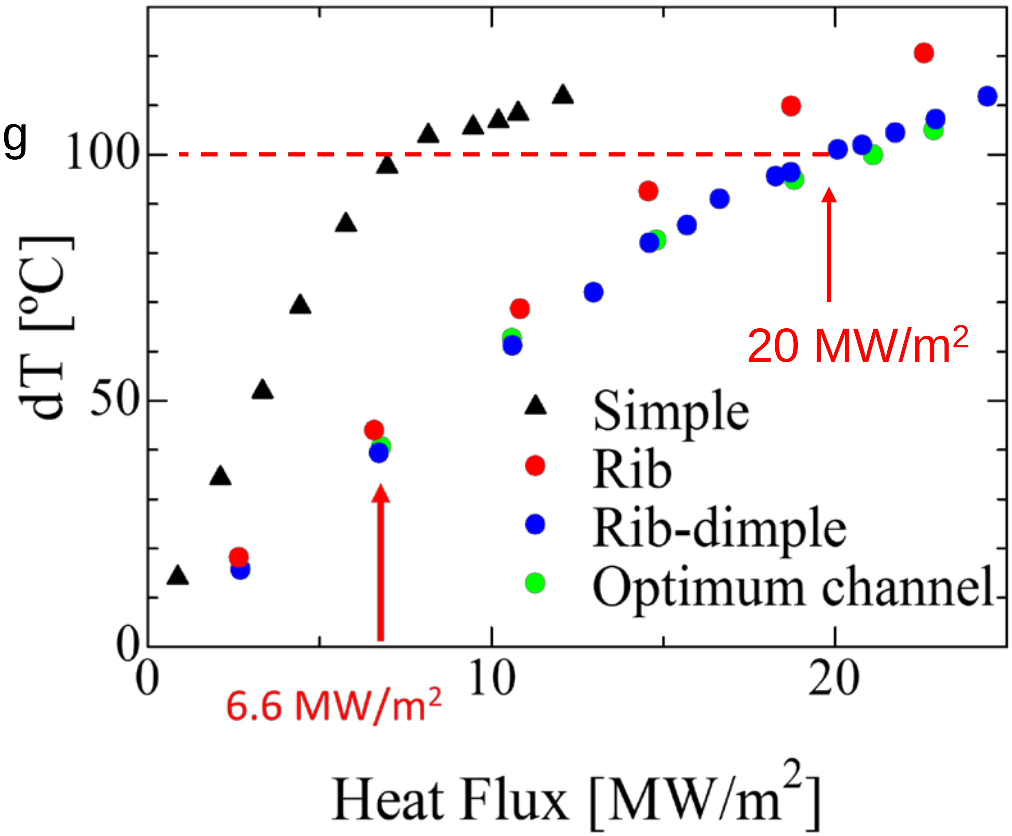
Analysis of heat transfer in a ribbed water channel



Cooling performance test by e-beam

NAGOYA UNIVERSITY



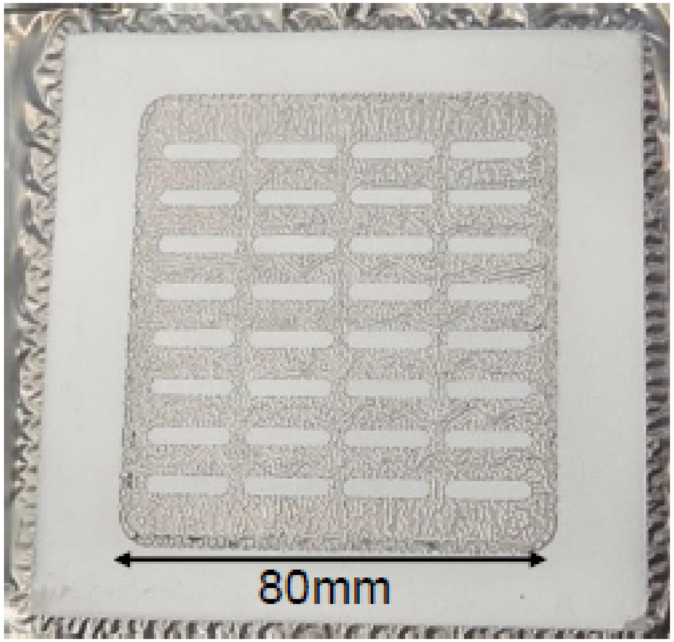


Cooling performance could be improved more than 20 MW/m^2 by optimizing channel structure.

(Challenge 2) Lithium (indium) filling process

Indium thin plate was set in the emboss structure and covered by Ti foil. Then, the Ti foil was jointed on a Ta backing plate by a hot press process.

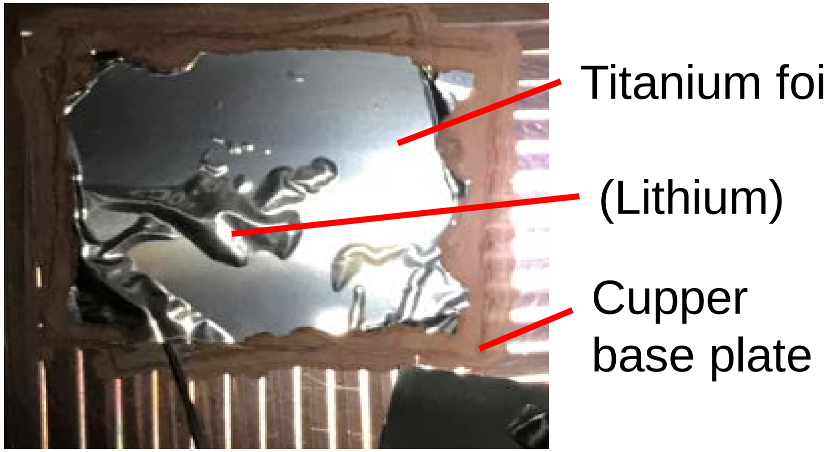
(Report in 6th HPTW)



There are wrinkles on Indium sealed region but there is no crack.

The reason of the foil wrinkle might be poor wettability between the tantalum base plate and indium due to some contamination of the surface, because the diffusion bonding process was not so clean.

On the other hand, when liquid lithium or indium is sandwiched by titanium foil and cupper plate in a vacuum, they have a good wettability.



(Challenge 2) Revised lithium (Indium) filling procedure

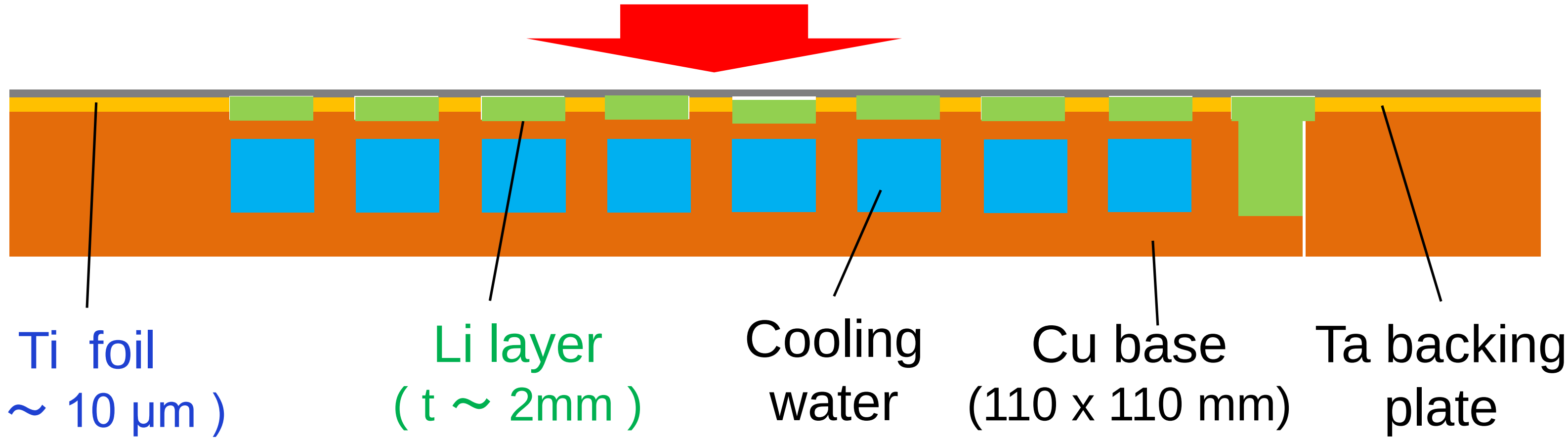
(1) Ta backing plate is connected to a Cu cooling base by HIP process*.
The deep emboss-structure is prepared on the surface of Ta plate.
Ta : High threshold for blistering (H^+ fluence > 1.6×10^{21} H^+/cm^2)
High corrosion resistance and good wettability for liquid Lithium

(2) Thin Ti foil is jointed to the Ta plate by Hot press process.
Ti : High corrosion resistance and good wettability for liquid Lithium

(3) Li is filled to the thin space of the embossed structure.

(4) Proton beam is irradiate to the Li through the Ti foil.
Li and Be-7 can be confined in the target by the Ti foil.

Proton Beam (>2.8MeV, 42kW)



(*HIP : Hot Isostatic Press)

Strengthened metallic foil for the Sealed Li target

(1) For BNCT medical application, Li and Be-7 should be confined in the target by a secure metallic foil during the target life (> 160 hours), which is limited by the damage of Ta backing plate due to the blistering.

(2) To improve the strength of the metallic foil, we developed a titanium alloy foil (10μm) under the collaboration with KOBELCO.

Titanium Alloy-1
Ti – Al (0.5) – Si (0.4)
(mass%)

(3) This has high strength (3 times higher than pure titanium at 400℃), good oxidation resistance and formability like pure Ti.

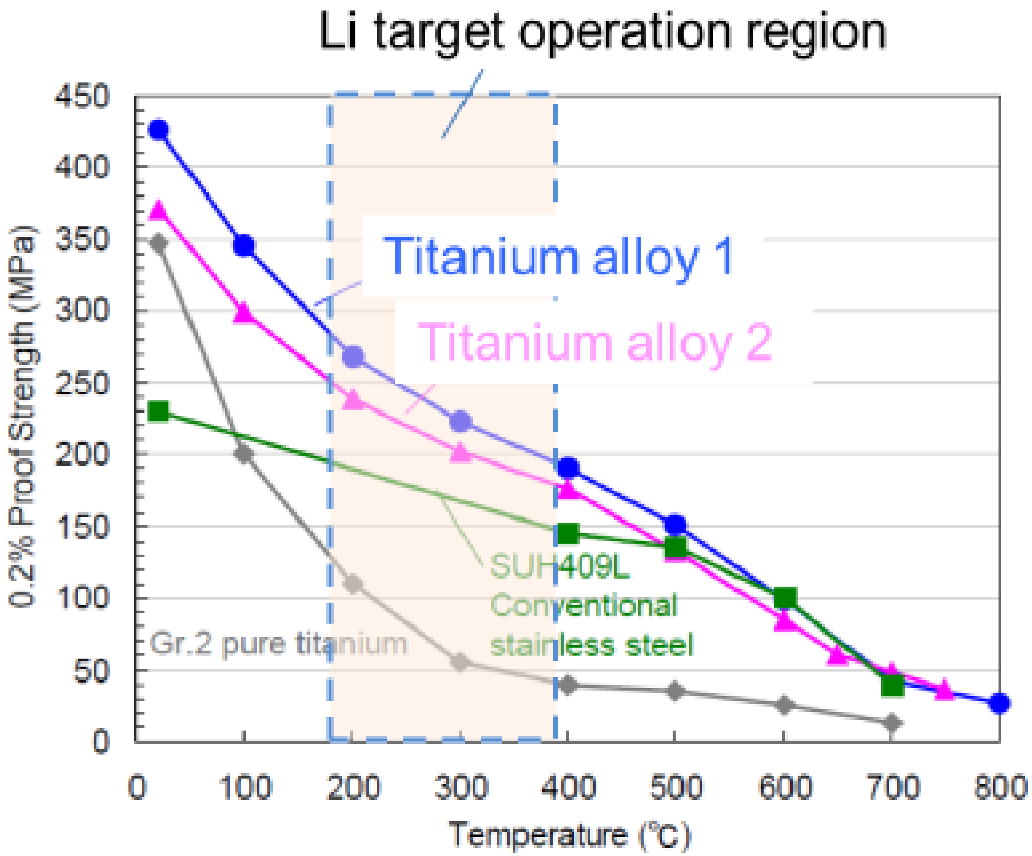
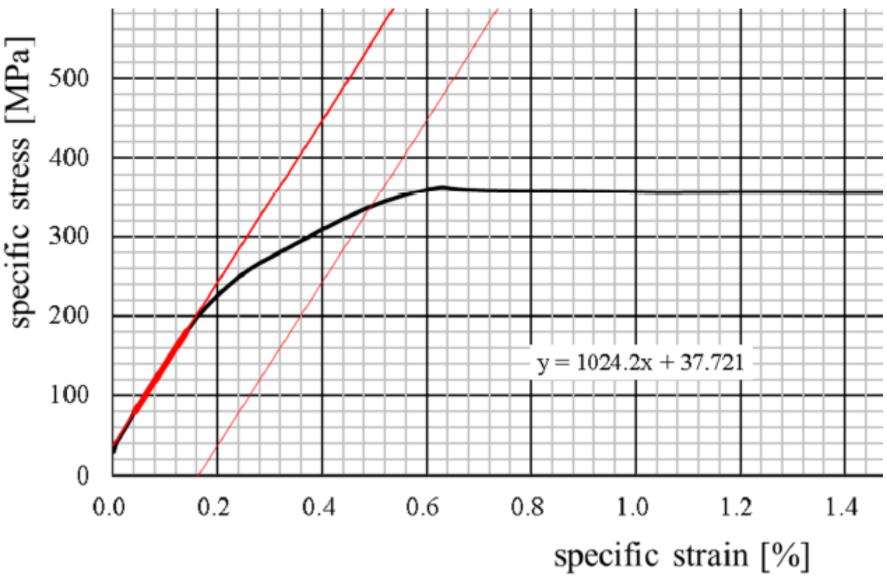
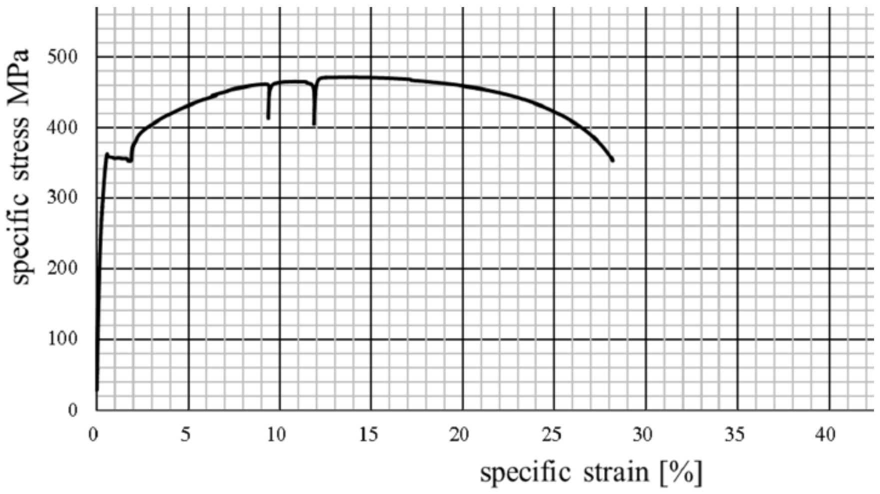


Figure 1 0.2% proof strength at high temperature

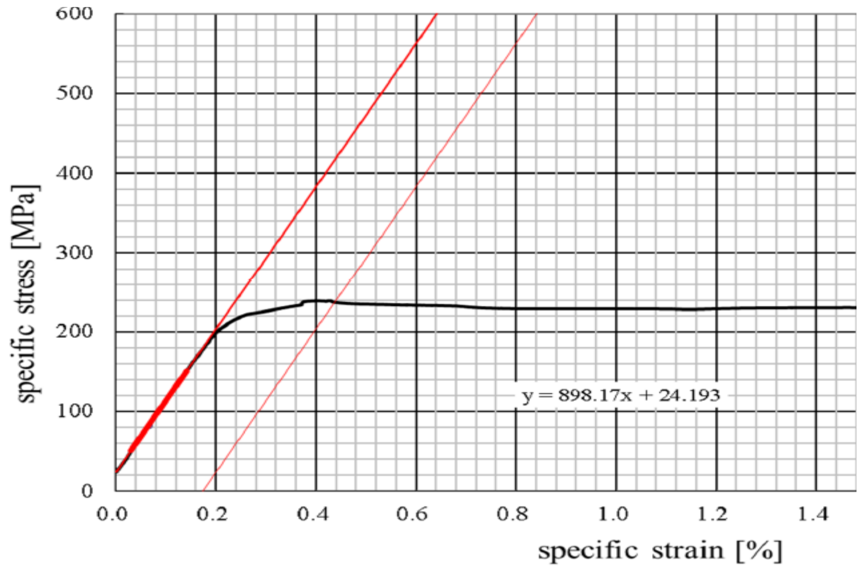
Material : KOBELCO KSTI-0.9SA, Direction : longitudinal

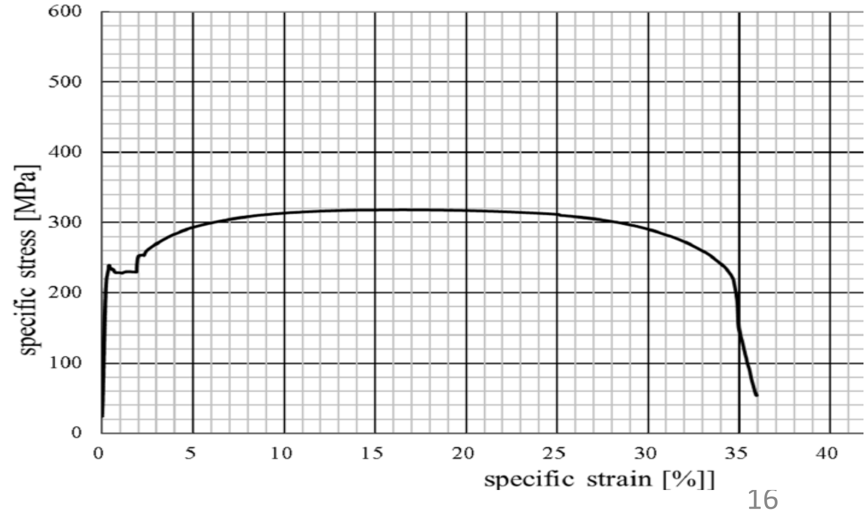
Temperature : 23℃



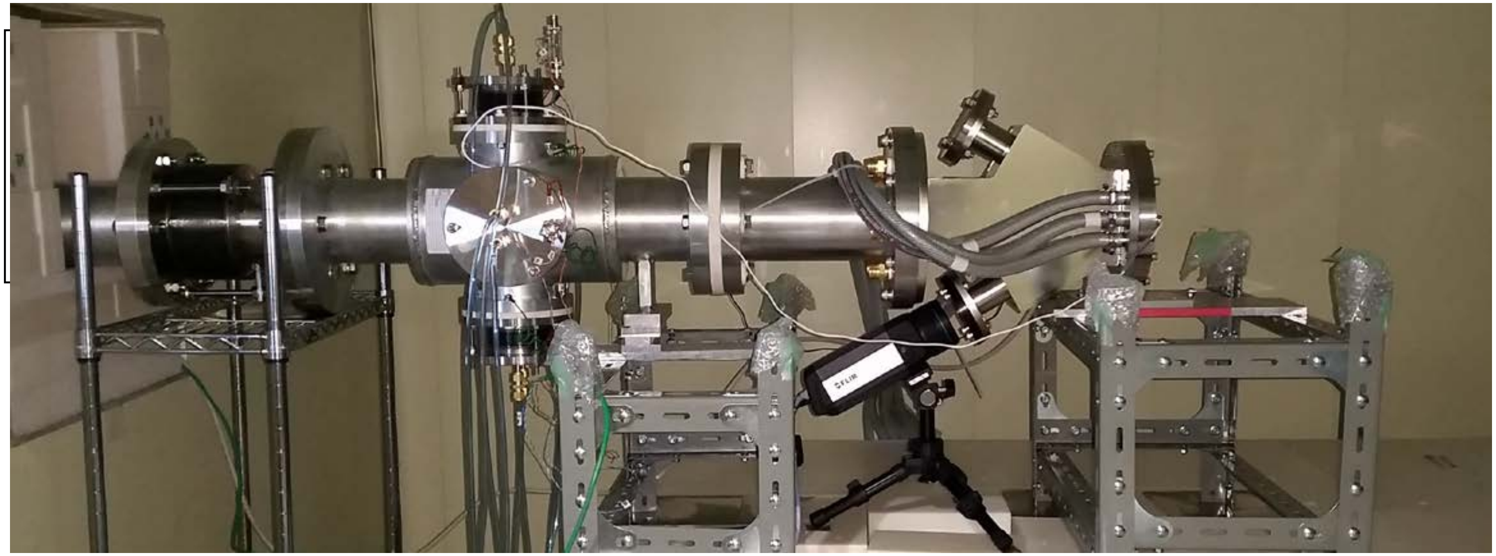


Temperature : 200℃

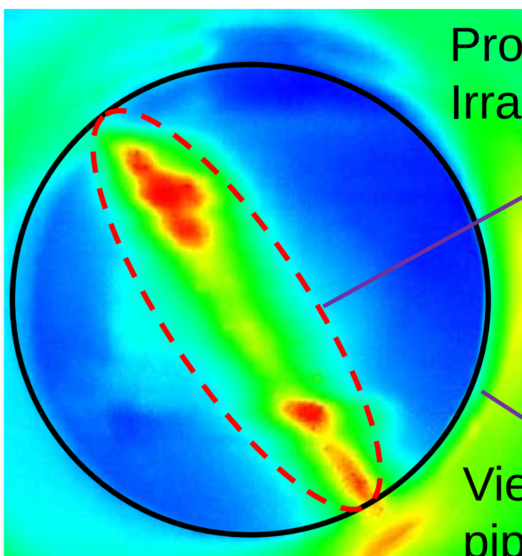




Preliminary beam irradiation test on sealed Indium target



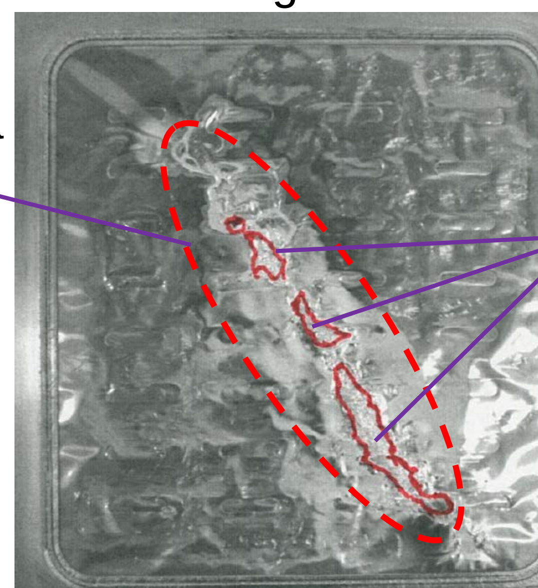
I.R. camera



Proton beam
Irradiation area

Viewing port
pipe edge

Indium target surface



Titanium foil was damaged during beam irradiation ($\sim$5MW/m^2).

(Challenge 3) Remote handling for target exchange

Member of Nagoya BNCT Project

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Trill (13 years)

Thank you for your attention!!