Construction Status of BNCT Facility Using an 8-MeV High Power Proton Linac in Ibaraki, Japan

ABNP14, INFN, April 14-15, 2014

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- T. Hashirano, F. Inoue, K. Sennyu, T. Sugano, M. Yamasaki (Mitsubishi Heavy Industries LTD)

Many Thanks to industry people and Ibaraki local government;

- Ibaraki Prefecture for their total support
- ATOX CO.,LTD, Nihon Koshuha CO.,LTD, Toshiba Electron Tubes and Devices CO.,LTD, TOYAMA CO.,LTD, NEC/TOKIN CO.,LTD and many other industries

Project Organization and Outline of the Facility

iBNCT group:
industry-government-academia research group

KEK
- Accelerator
- Target
- Moderator
- Collimator
- Rad. shielding

Tsukuba University
- Project management
- JRR-4
- Medical system
- Monitoring

Hokkaido University
- Neutron science, moderator

JAERI
- JRR-4
- moderator design
- Radiation safety

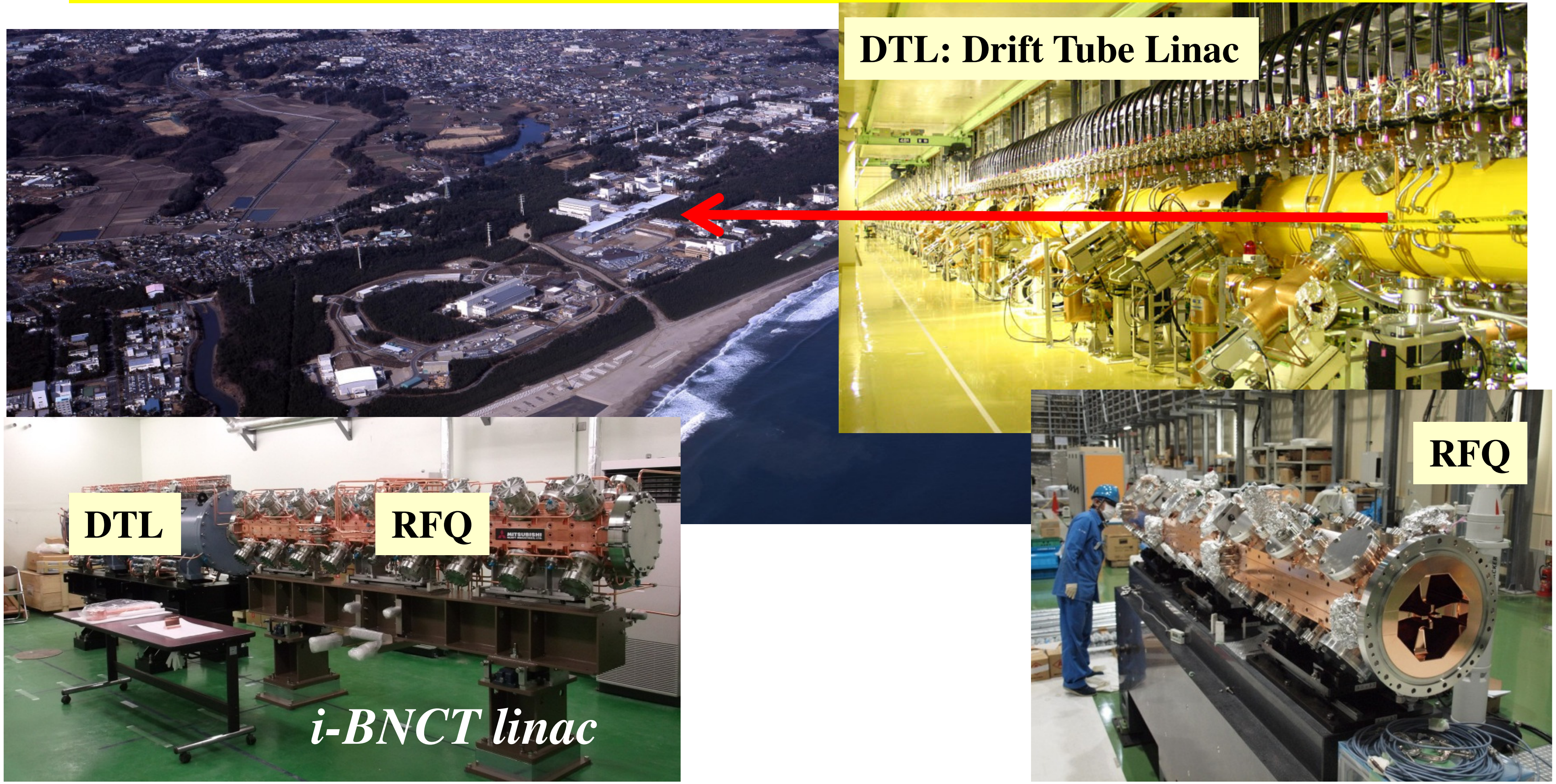
Mitsubishi heavy industries LTD.
- Manufacturing

NAT, ATOX, Taiyo Valve, Toyama, Nihon Koshuha, NEC/Tokin,,,,many companies are involved

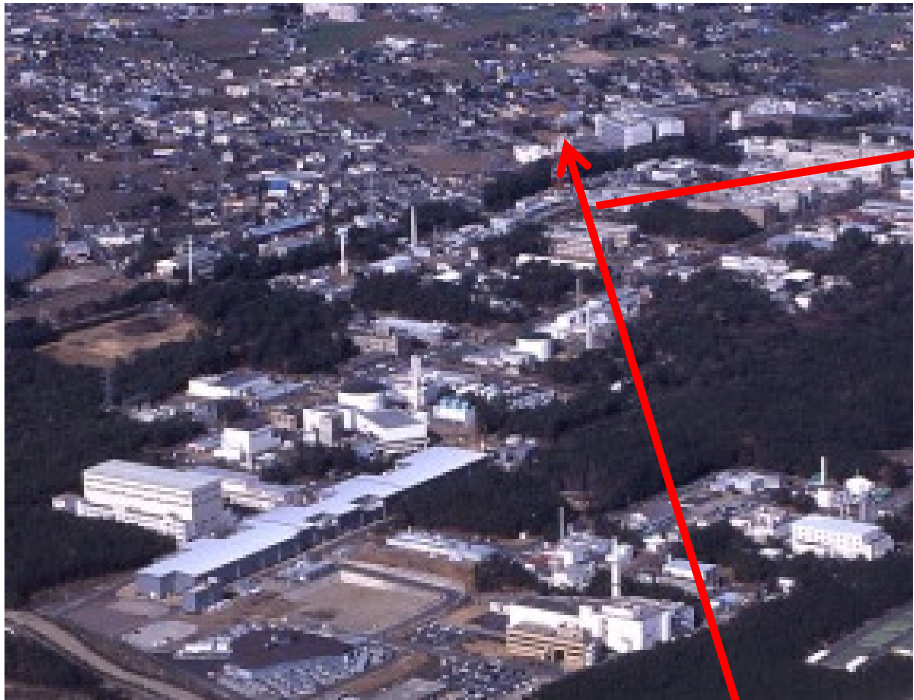
Ibaraki prefecture

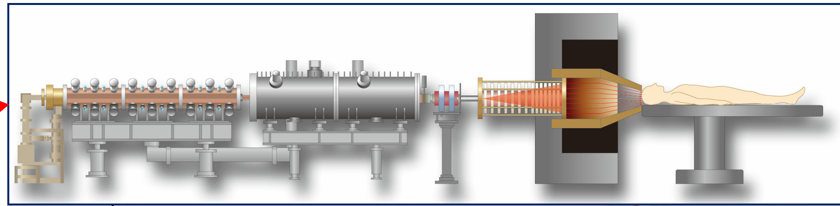
Basic idea of i-BNCT

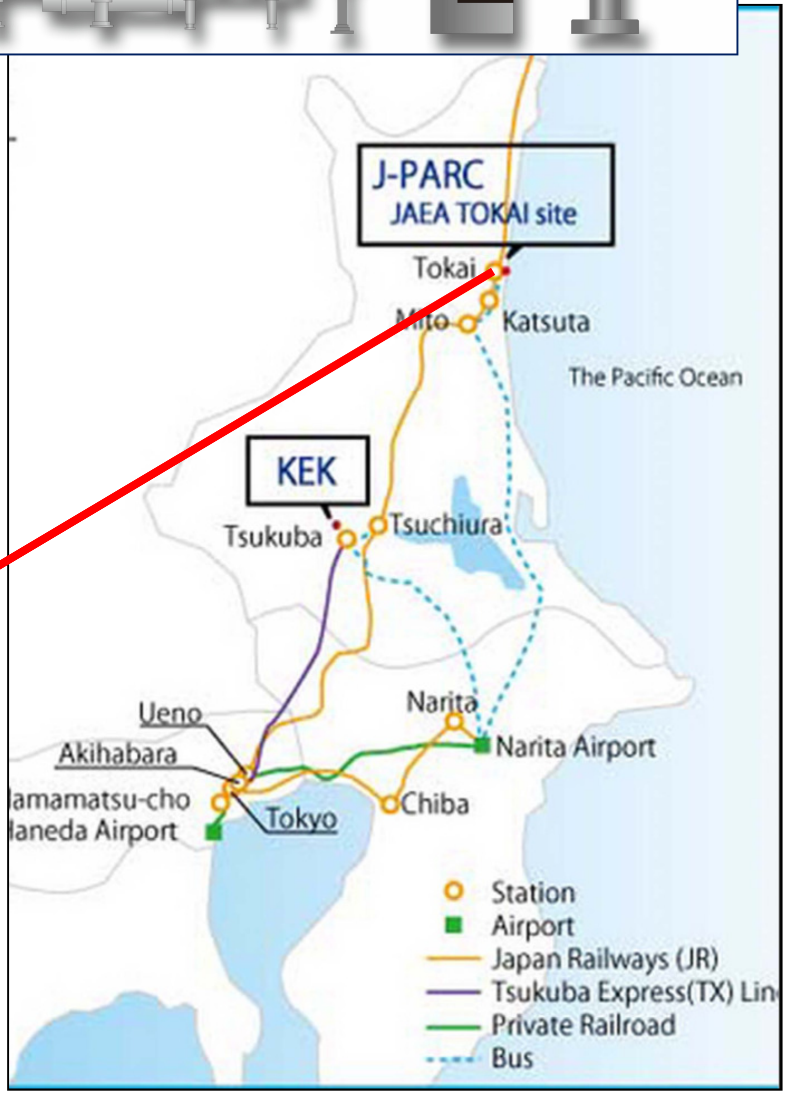
Spin off of J-PARC frontend injector linac technology
RF design is based on J-PARC design

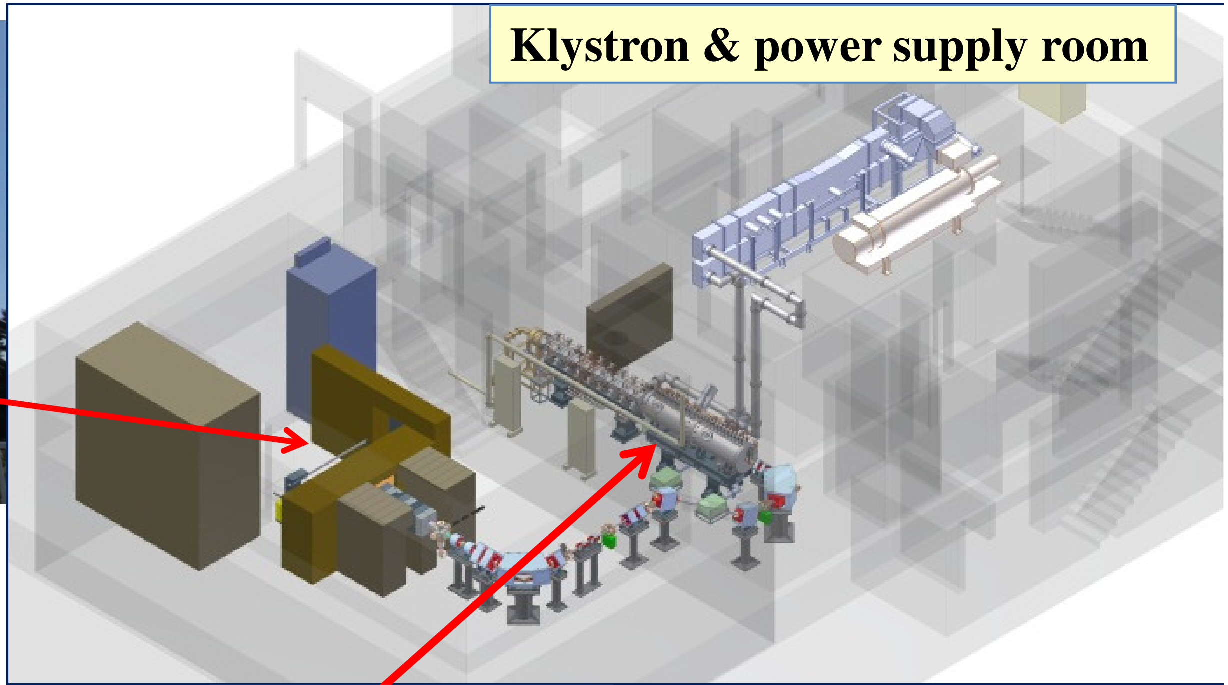


Ibaraki BNCT Construction Site: Ibaraki Neutron Medical Research Center, adjacent J-PARC site (but not J-PARC)



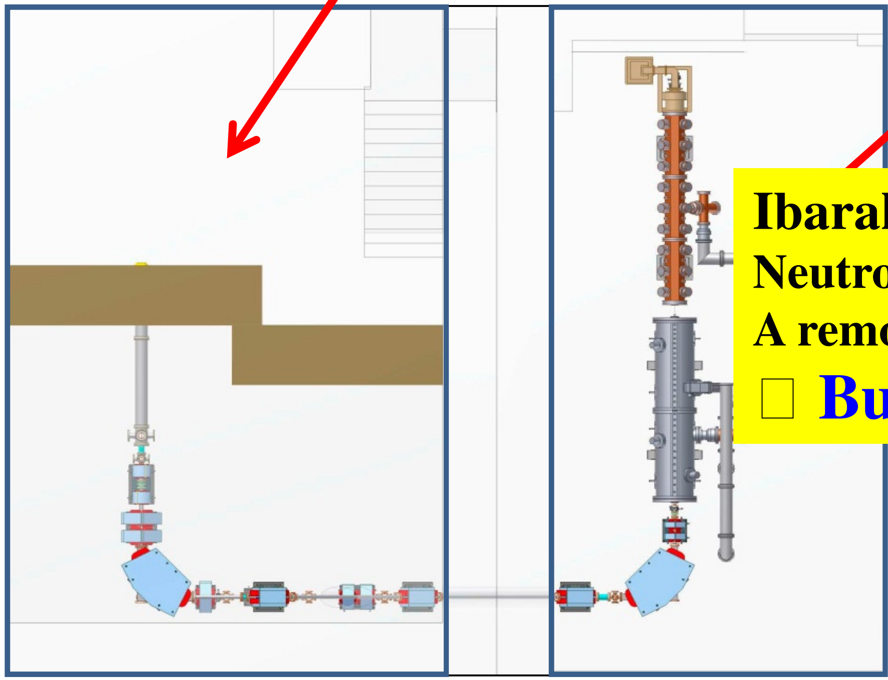




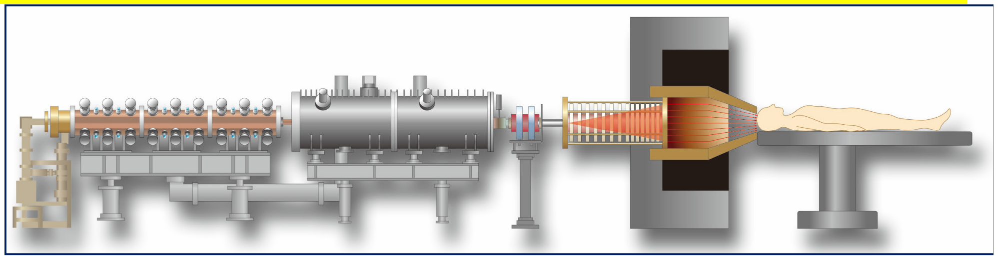


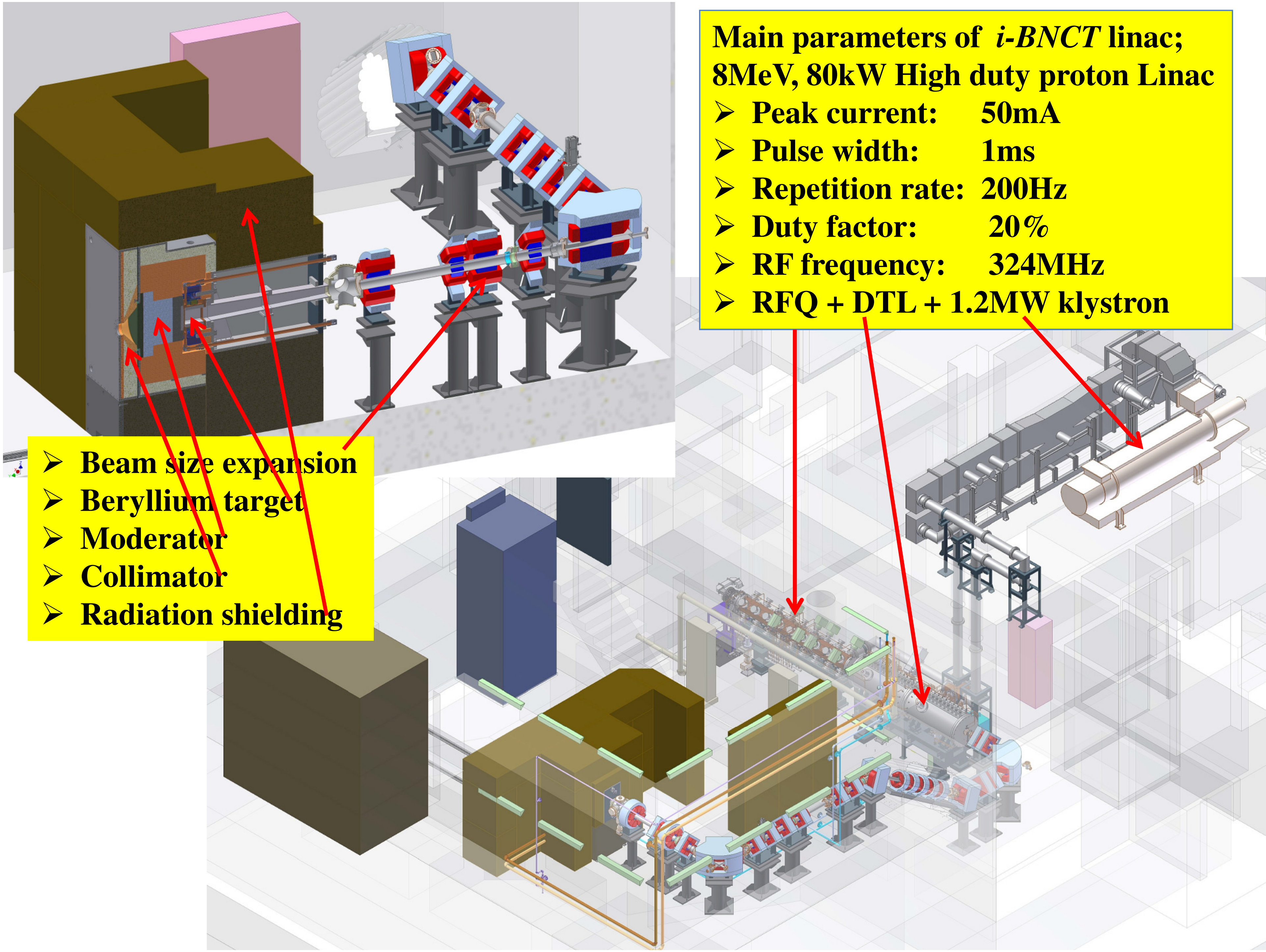
Irradiation room

Accelerator room



Ibaraki prefectural building
Neutron Medical Research Center,
A remodeling building from tele-com. Company, NTT
□ Building is Not optimized for BNCT

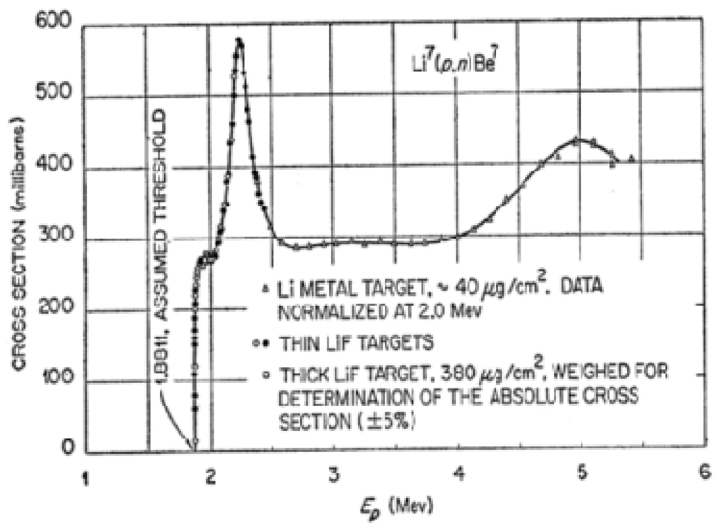


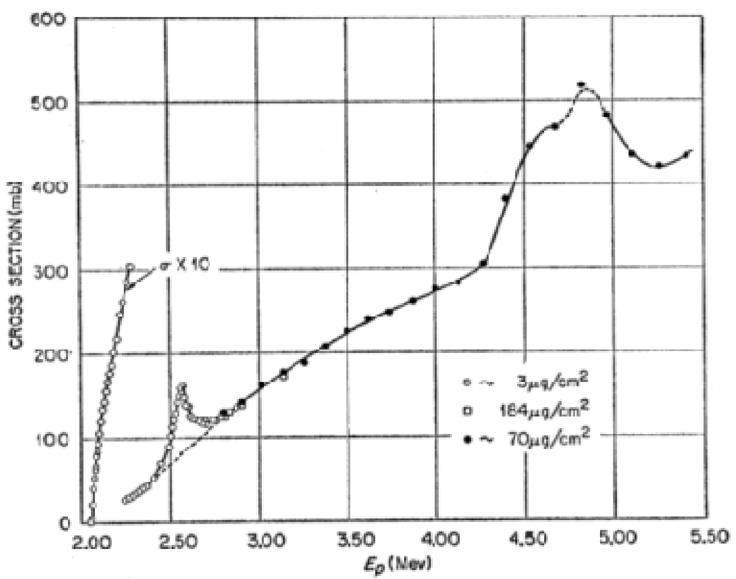

Main parameters of *i-BNCT* linac;
8MeV, 80kW High duty proton Linac
➢ Peak current: 50mA
➢ Pulse width: 1ms
➢ Repetition rate: 200Hz
➢ Duty factor: 20%
➢ RF frequency: 324MHz
➢ RFQ + DTL + 1.2MW klystron
➢ Beam size expansion
➢ Beryllium target
➢ Moderator
➢ Collimator
➢ Radiation shielding

Aiming "hospital friendly BNCT"
:very low residual radioactivity

R. C. Byrd, C. E. Floyd, P. P. Guss, K. Murphy and R. L. Walter, "CROSS-SECTION MEASUREMENT AND LANE MODEL ANALYSIS FOR THE $^{9}Be(p,n)^{9}B$ REACTION", Nuclear Physics A399(1983)94-118

Beryllium or Lithium?





In case of *Li*, the cross section is very attractive,

- ◆ Sharp rise below 2.5MeV
- ◆ Neutron energy spectrum is fine (< 300keV)

But!

target material: priority: hospital friendly

Beryllium: No residual radioactivity for 8 MeV proton

Lithium : $^{7}Li(p,n)^{7}Be$ & $^{6}Li(n,t)^{4}He$

- ^{7}Be has 53 days $T_{1/2}$ and high radioactivity
- Tritium should be avoided for hospital use
- Melting temperature is only 180 ℃
- Chemically very active

our decision: Beryllium target +8-MeV proton

Energy selection

How we decide the beam energy

IAEA GUIDELINE

Epithermal (0.5eV-10keV): 10^9n/(s·cm^2)

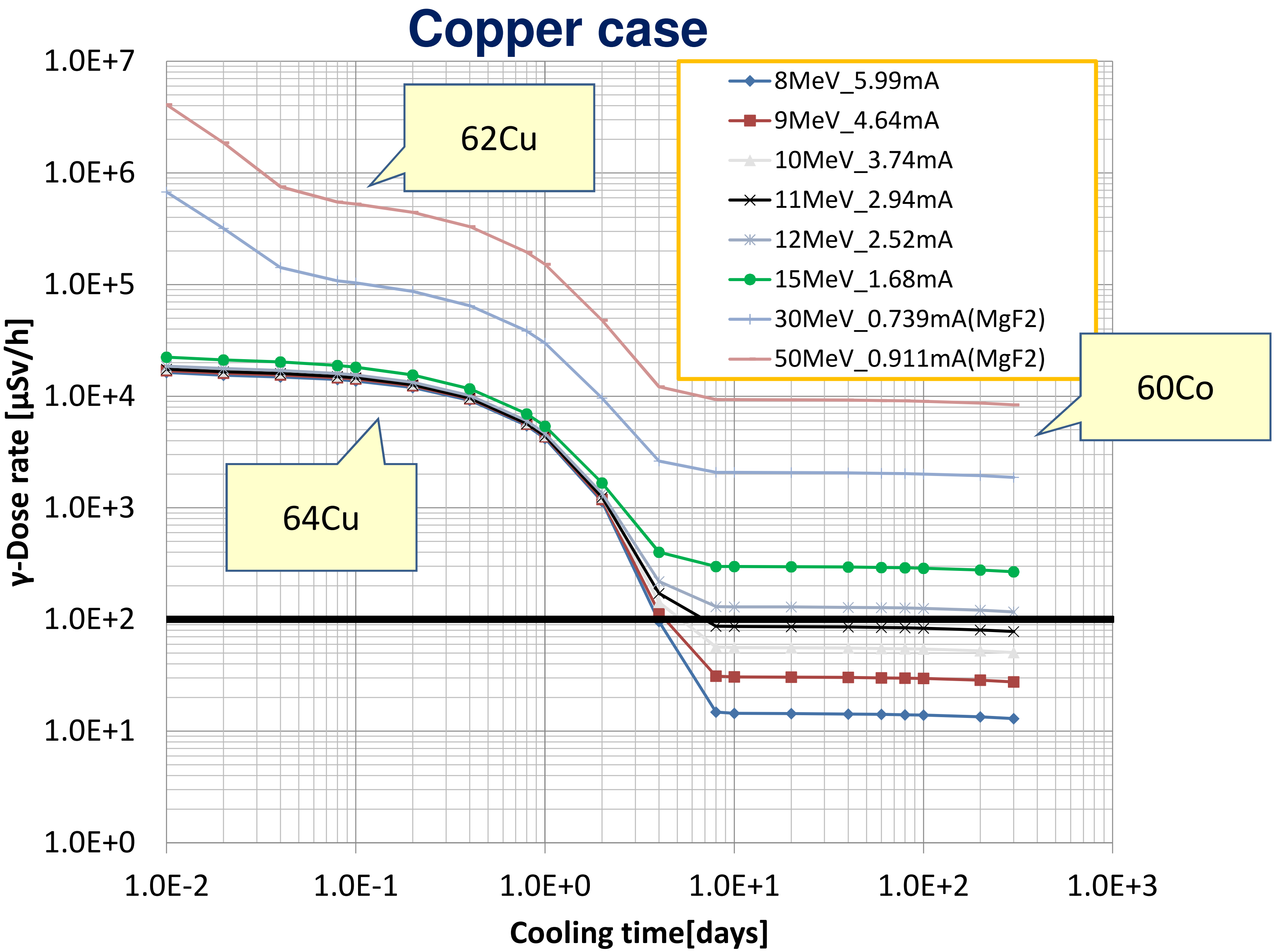
→ to get moderate irradiation time.

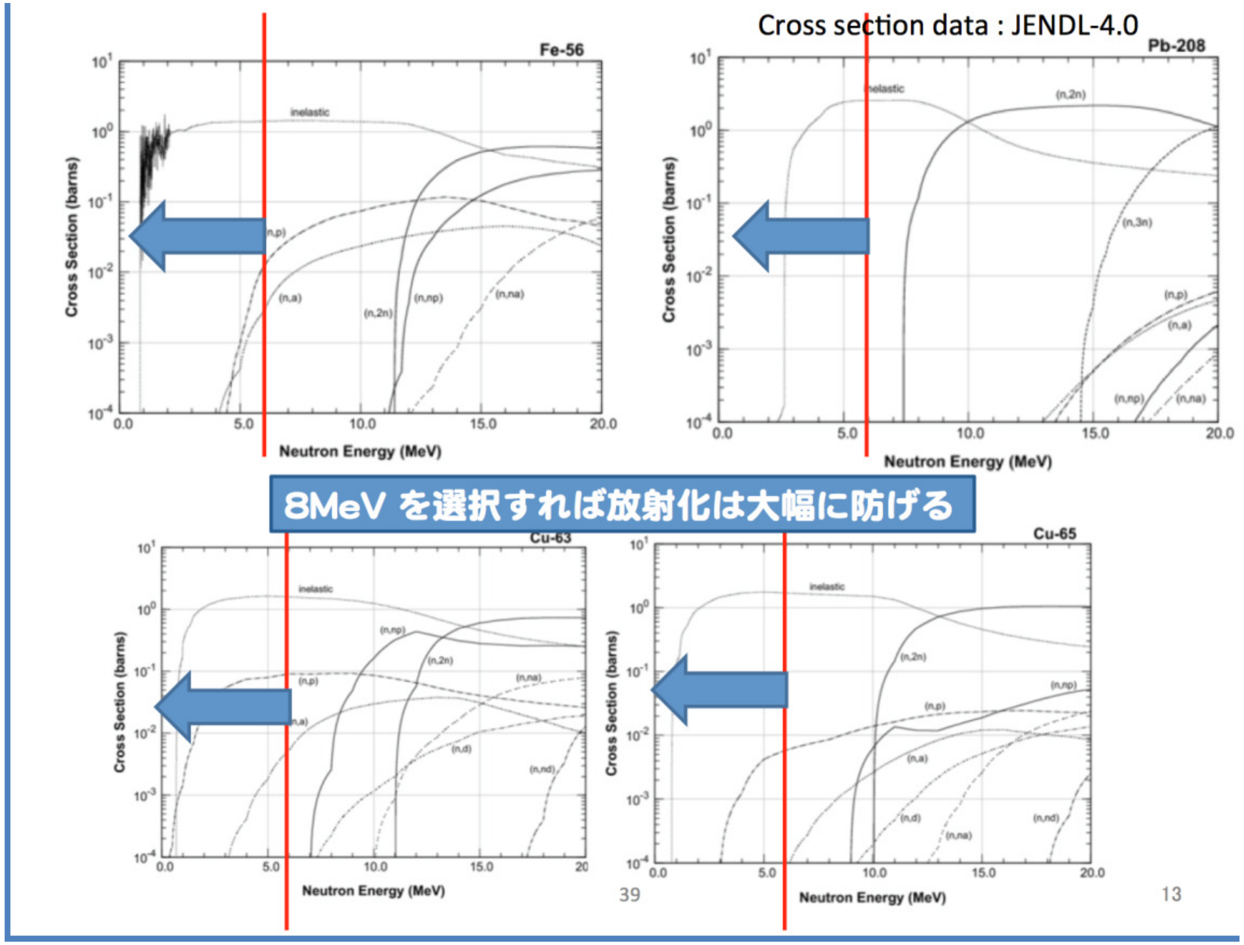
need to reduce following accompanying beam:

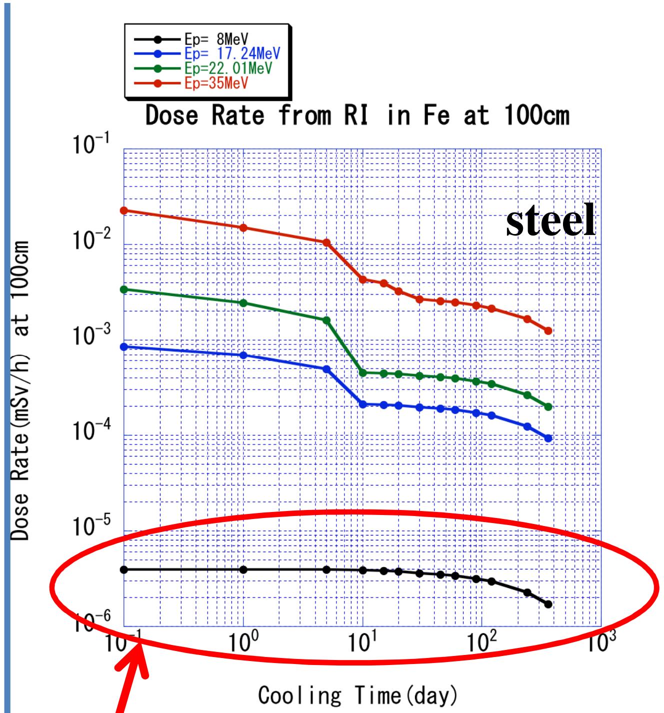
IAEA-TECDOC-1223

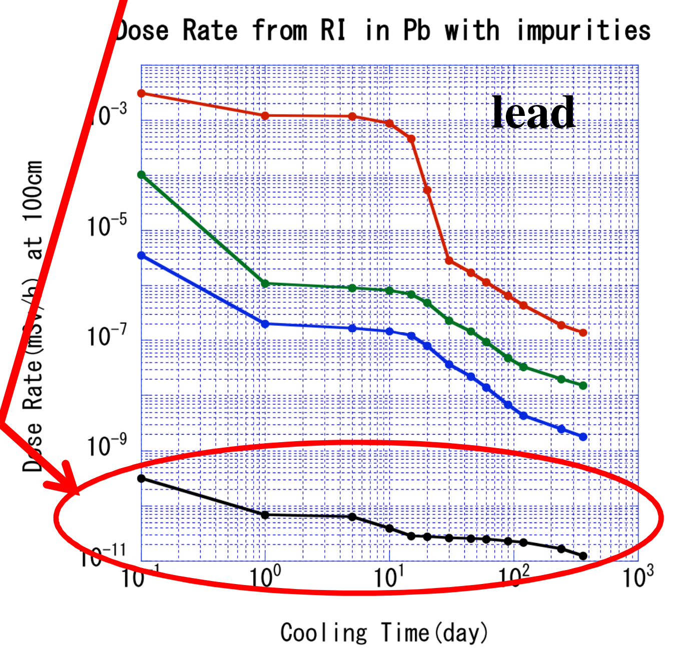
- **Fast neutron >10 keV**
  → 2×10^{-13} Gy cm^2 per epithermal neutron
- **Gamma rey**
  → 2×10^{-13} Gy cm^2 per epithermal neutron
- **Ratio between thermal flux and epithermal flux**
  → 0.05

Residual Radioactivity vs Proton Energy









8MeV proton □ neutron energy < 6MeV

➔We can avoid many nuclear reaction channels

➔Low residual radiation

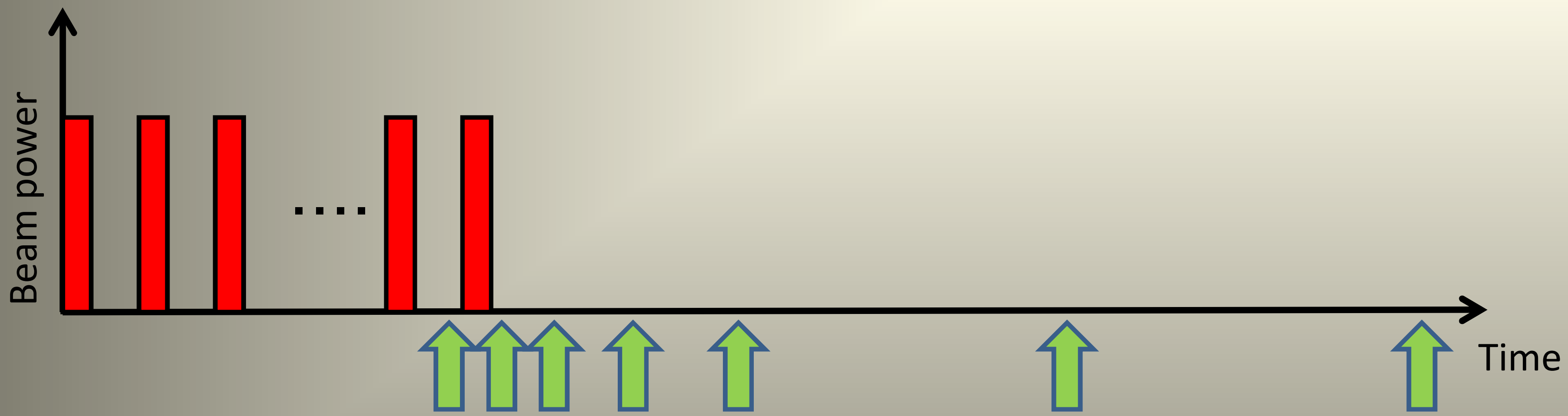
Energy selection

8 MeV was chosen

residual radiation

operation

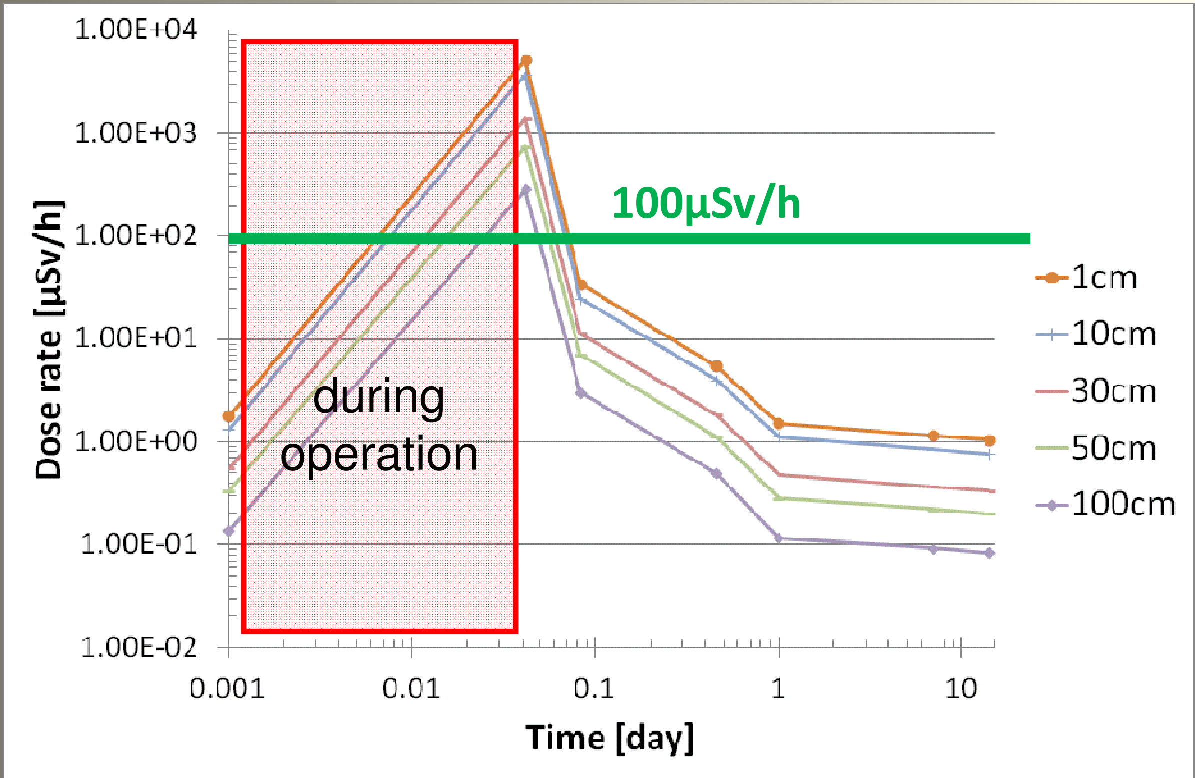
- daily op. : 2hour（30min×2、1hour×1）/ day
- week : 5days（except weekend）/ week
- year : 50weeks（350days）

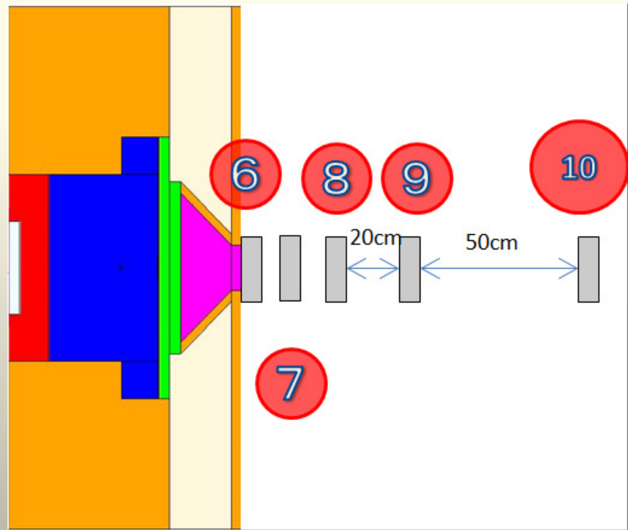


residual radiation

北海道大学
HOKKAIDO UNIVERSITY

Patient side



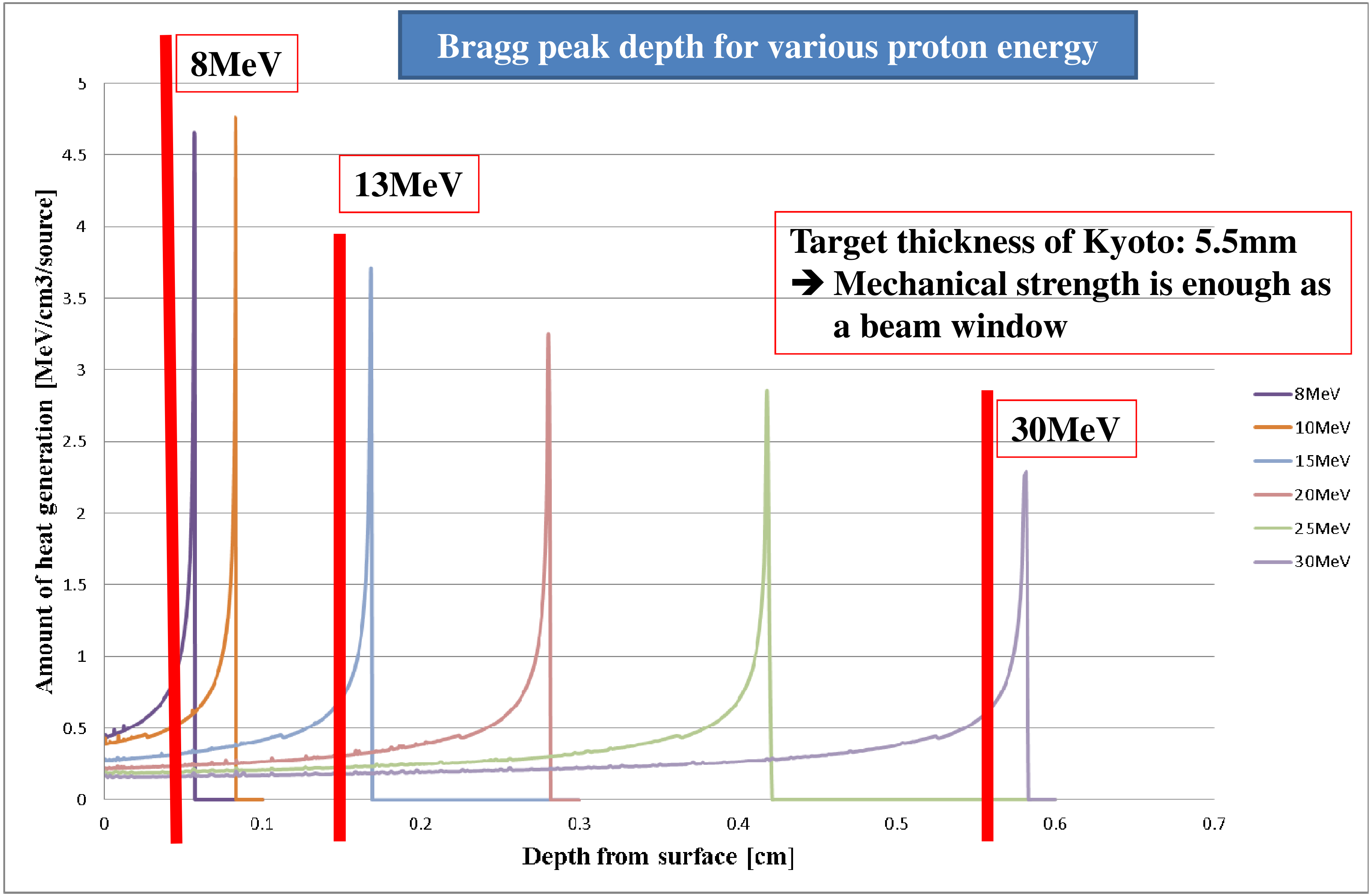


Target development

Crucial items for 8-MeV proton and Beryllium Target

- **blistering**
- **heat removal**

Target thickness of *i-BNCT*: 0.5mm □ not enough mechanical strength as a beam window



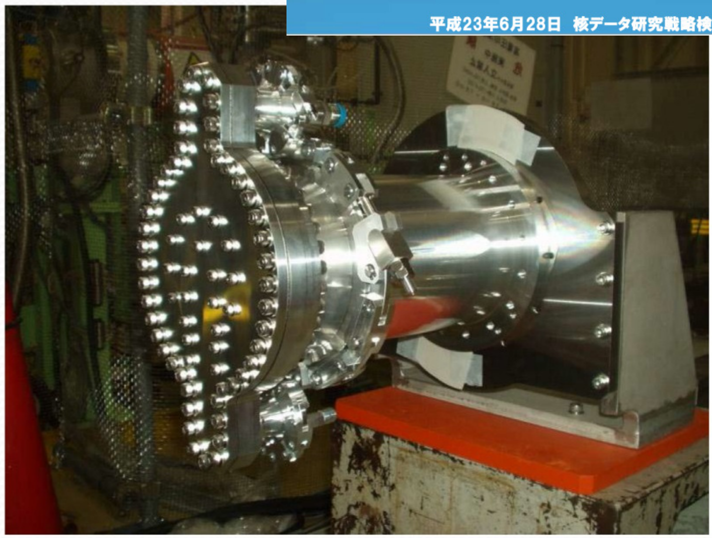

サイクロトロンを用いた
BNCT用熱外中性子源の概要

京都大学原子炉実験所
放射線生命医科学研究本部
医学物理学分野
田中　浩基

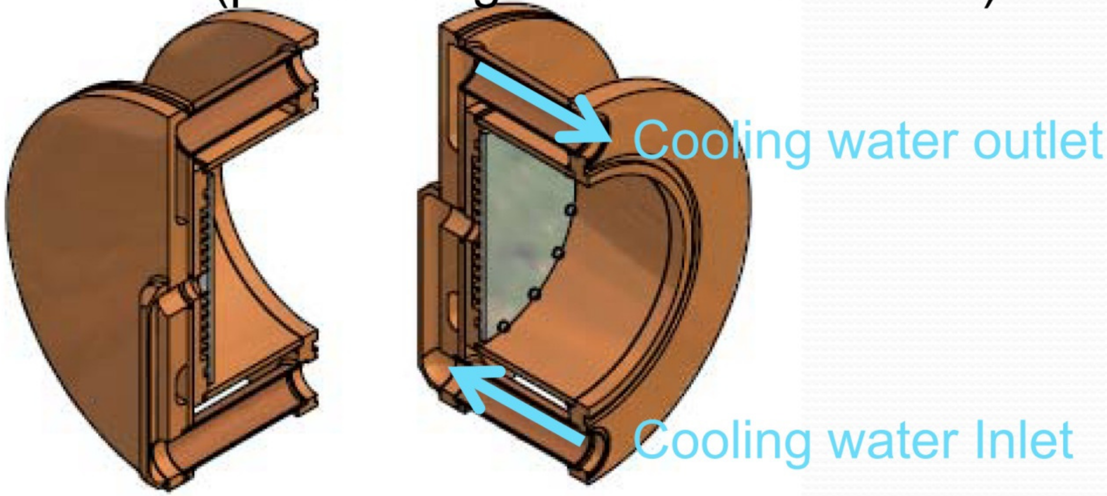
Kyoto system

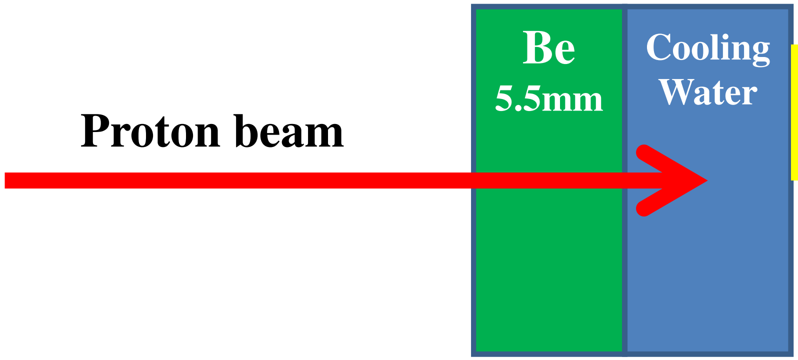
平成23年6月28日　核データ研究戦略検討会@阪大RCNP

Kyoto-Sumitomo



Be target thickness is 5.5 mm
(proton range :5.8 mm at 30MeV)

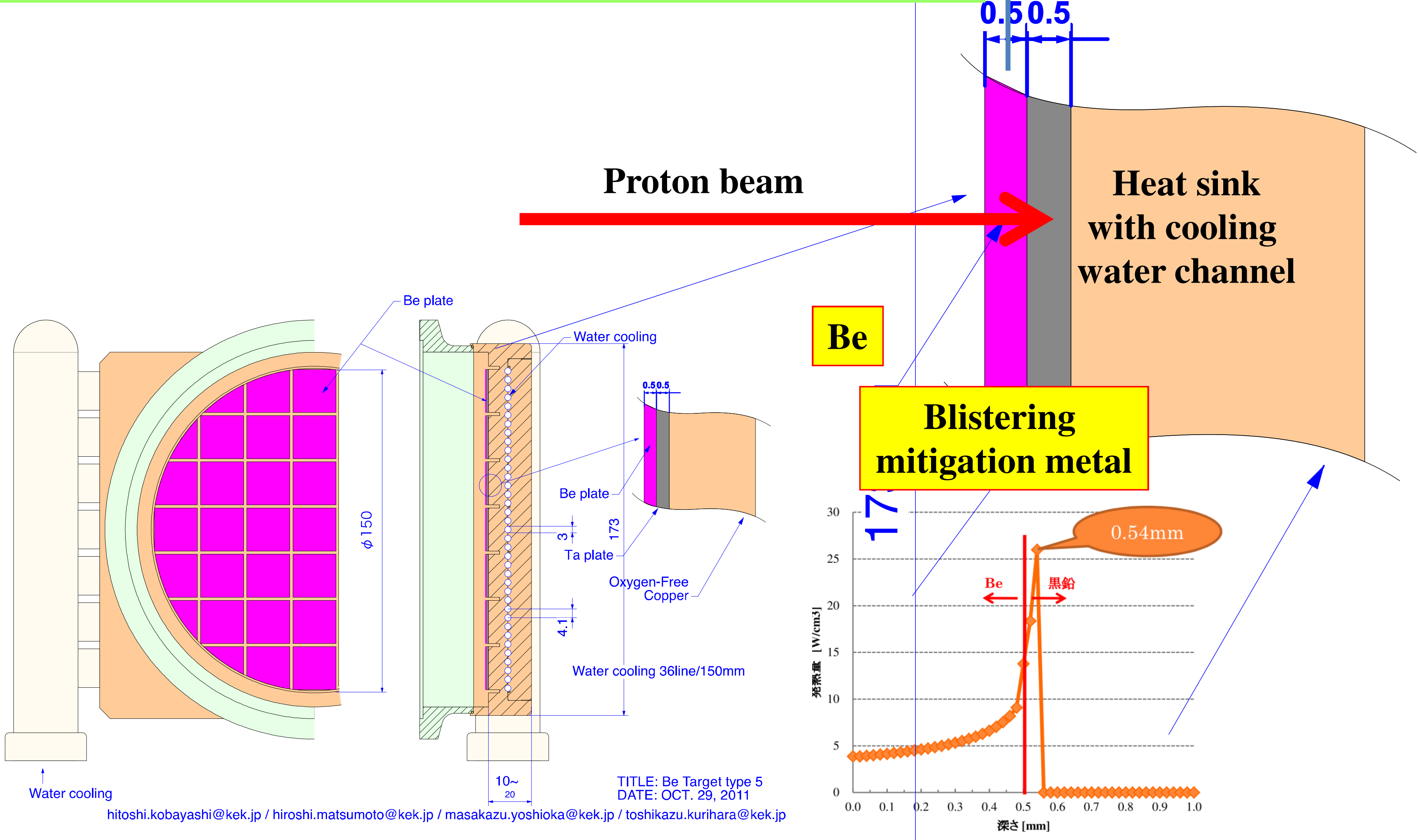




- **Be target strength is enough for a beam window**
- **Beam stops in cooling water, blistering free!!**

Easy fabrication & blistering free

Ibaraki target (separated function)
Target thickness is 0.5mm
□ needs backup plate for beam window

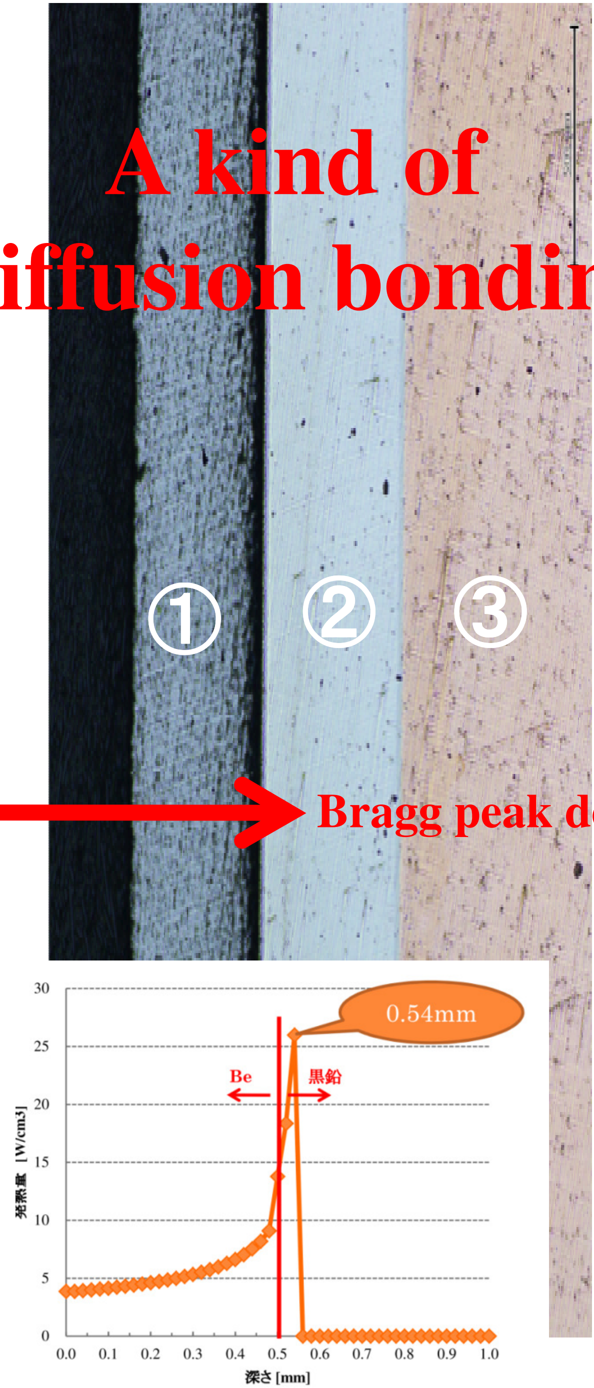


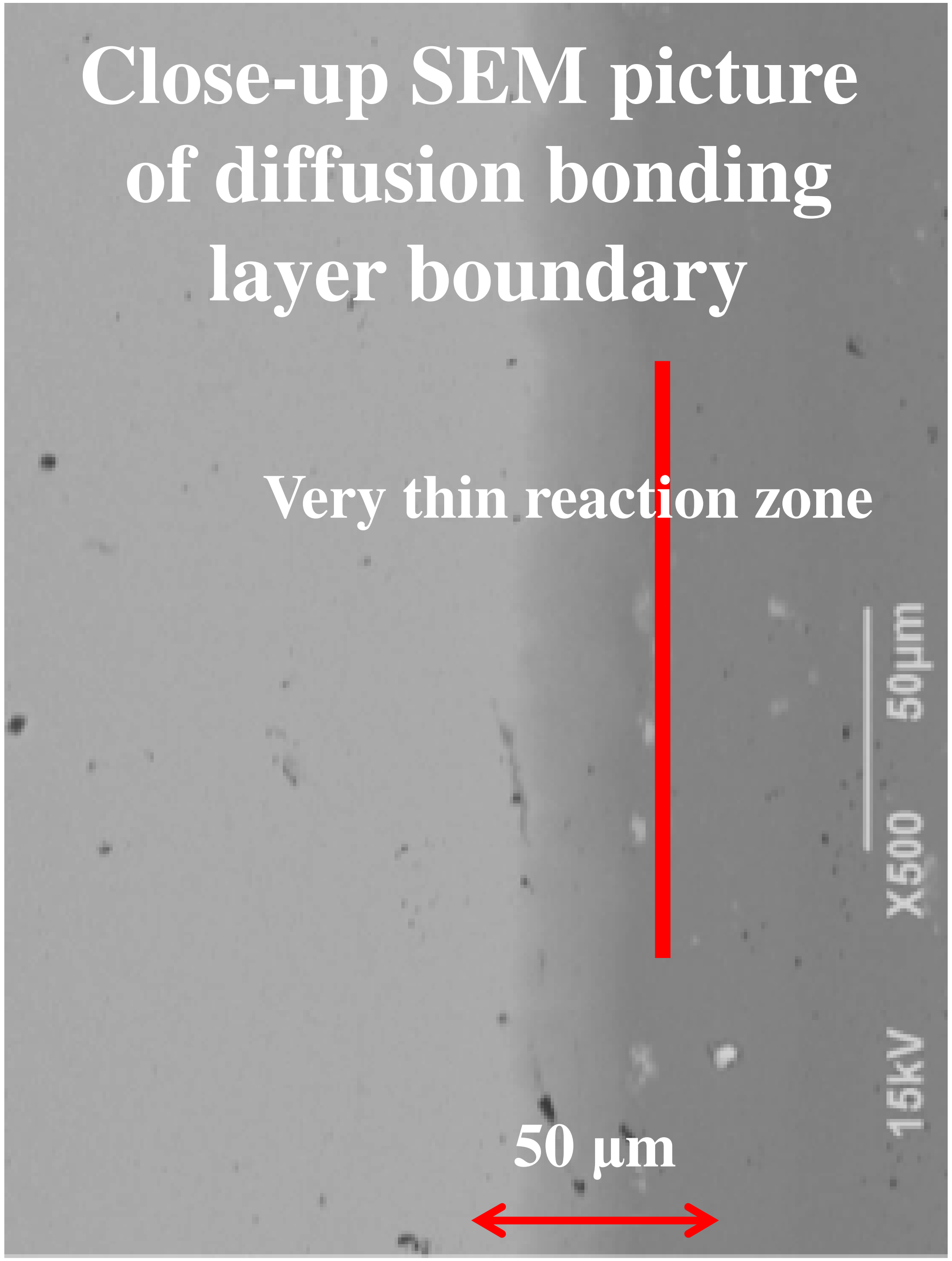
8-MeV Target

Separated function target

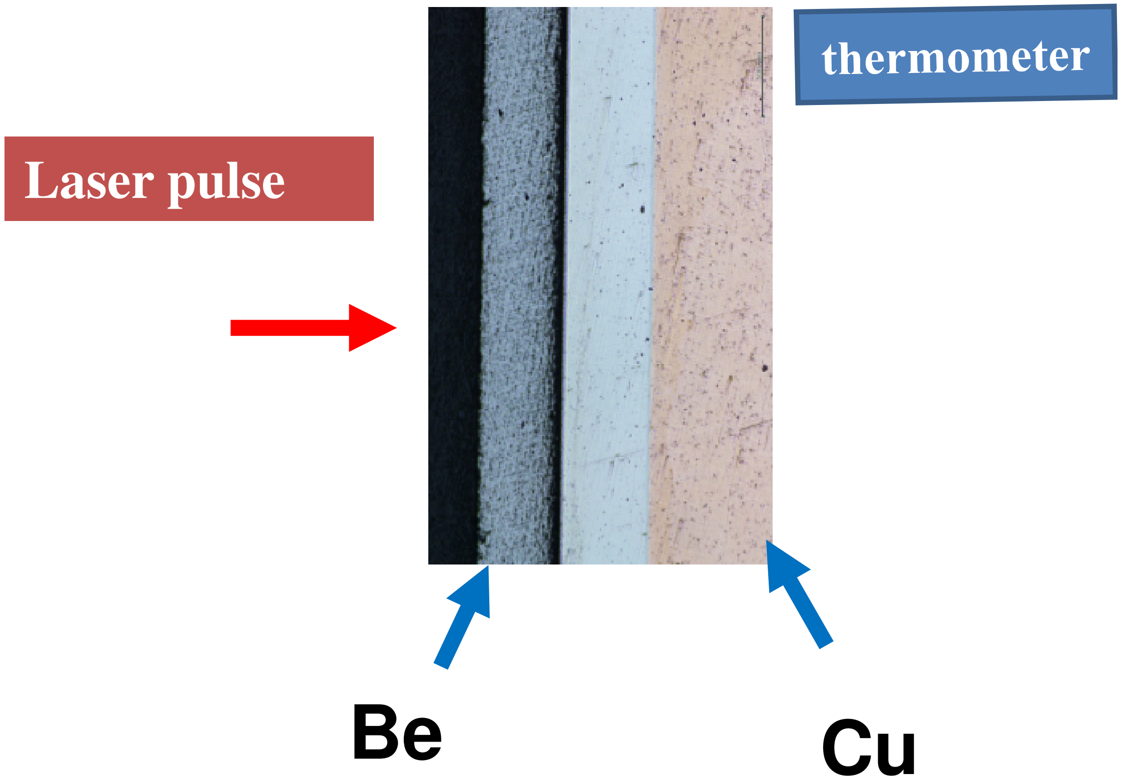
- **top: neutron production**
- **middle: beam stop and blistering mitigation**
- **back: heat sink (water cooling)**

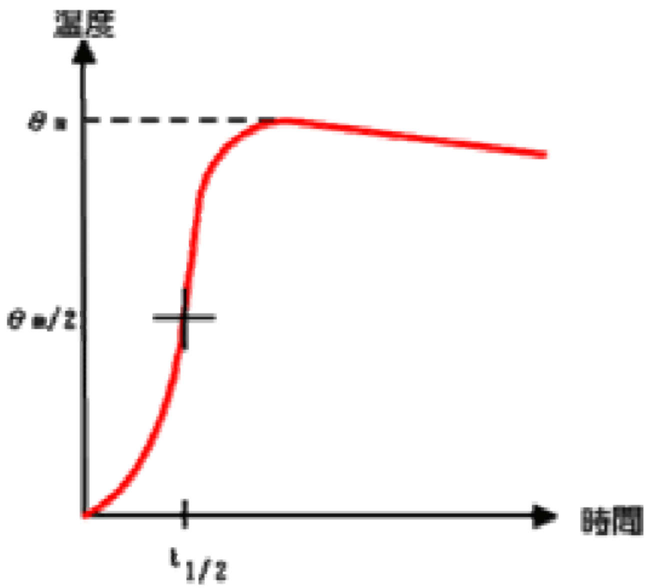
Three layer target


A kind of
diffusion bonding
①
②
③
Bragg peak depth
0.54mm
Be
黒鉛
30
25
20
15
10
5
0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
深さ [mm]


Close-up SEM picture
of diffusion bonding
layer boundary
Very thin reaction zone
15kV X500 50μm
50 μm

Thermal conductivity measurement

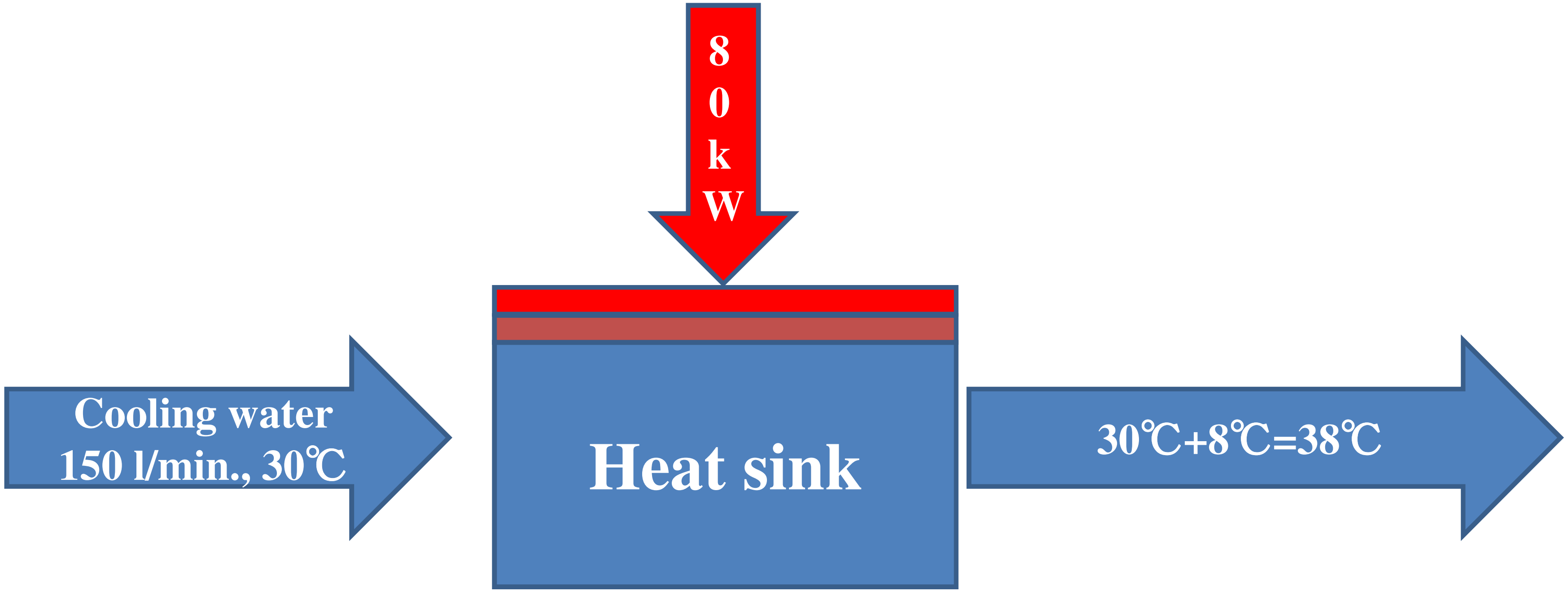




Direct measurement of heat conductivity of three layer metals with laser-flash method
➔200 W/(m/K) □ Good enough for the practical use

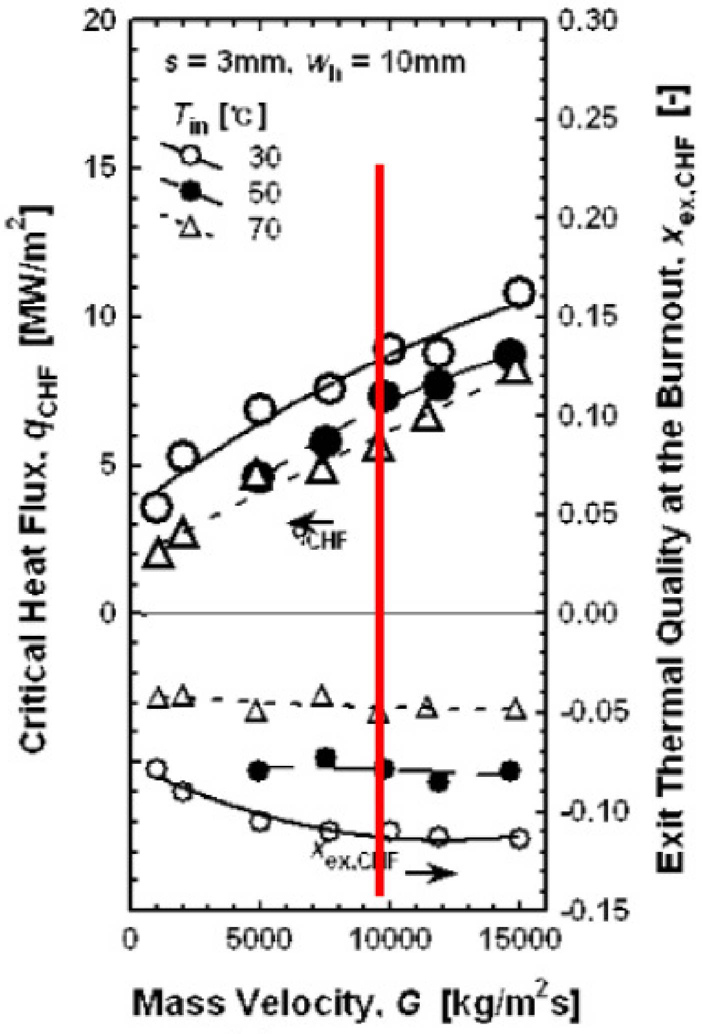
Water cooling of high-density heat load

Surface temperature of the top layer is determined with steady state energy flow from the surface to the heat sink



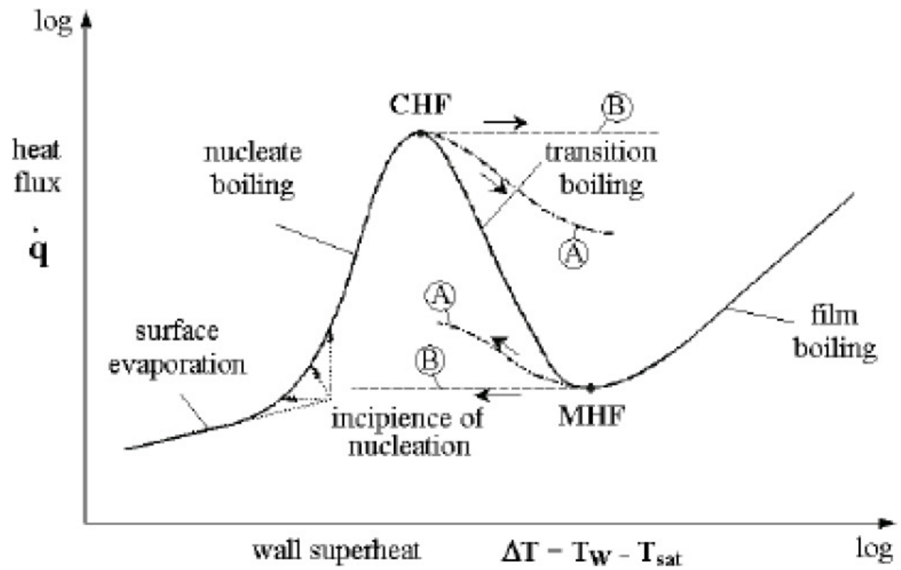
heat load 4.5MW/m^2,
heat transfer in nucleate boiling region.

M. Kureta, H. Akimoto / International Journal of Heat and Mass Transfer 45 (2002) 4107–4115



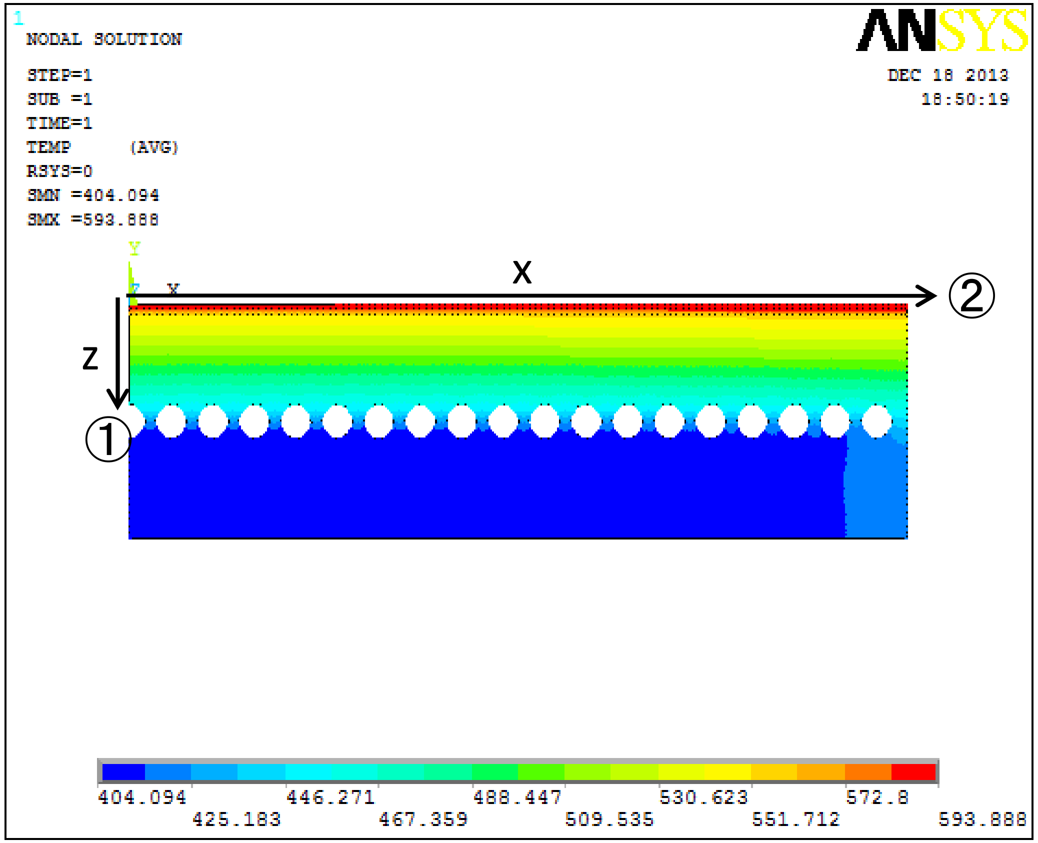
(b) L_h = 100mm

water flow: 10m/s

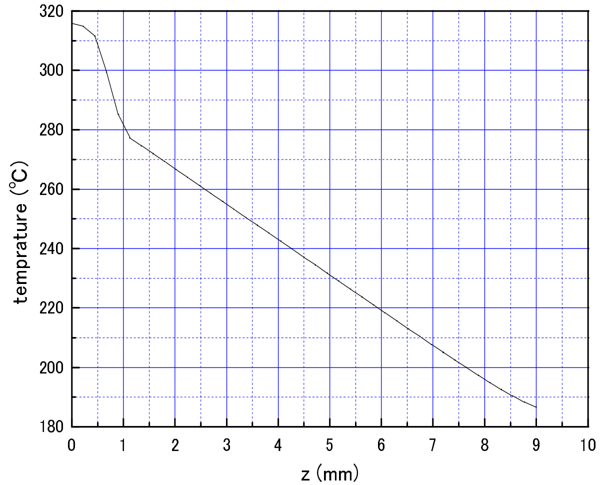


Nukiyama boiling curve in 1930s

Simulation of target temperature

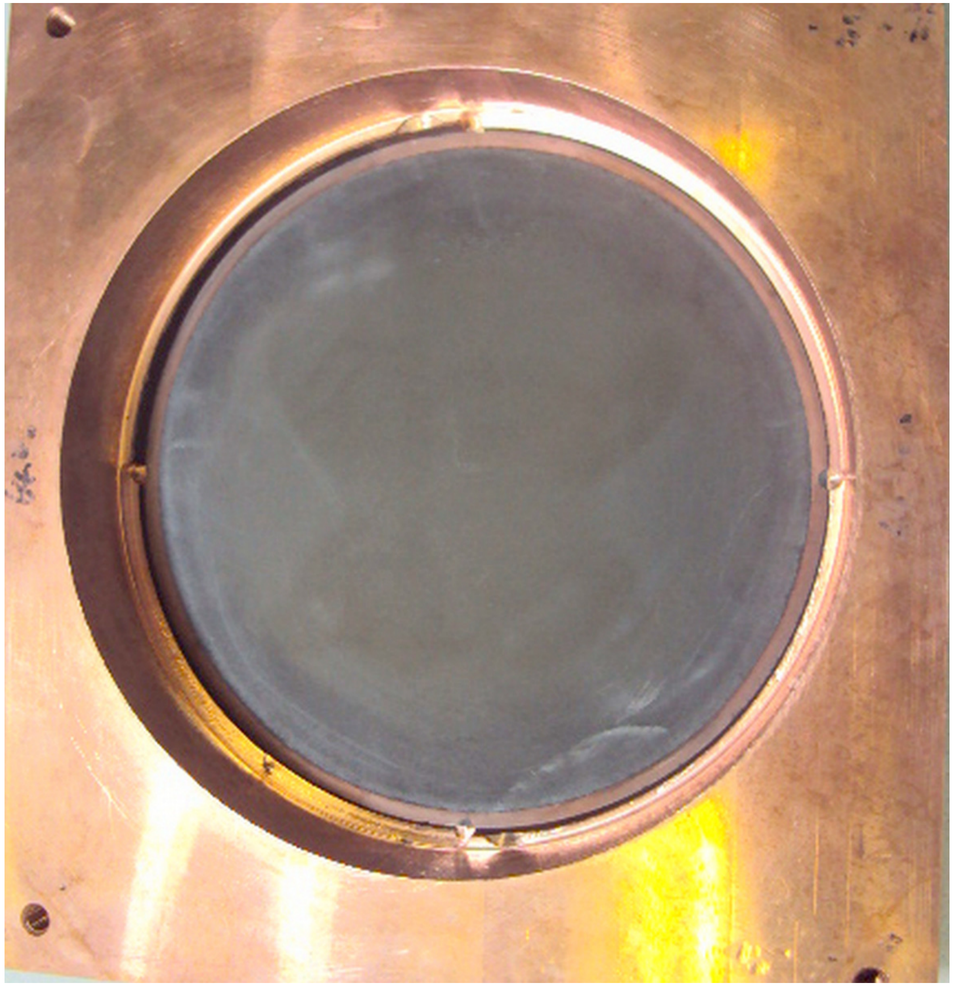


316 ℃

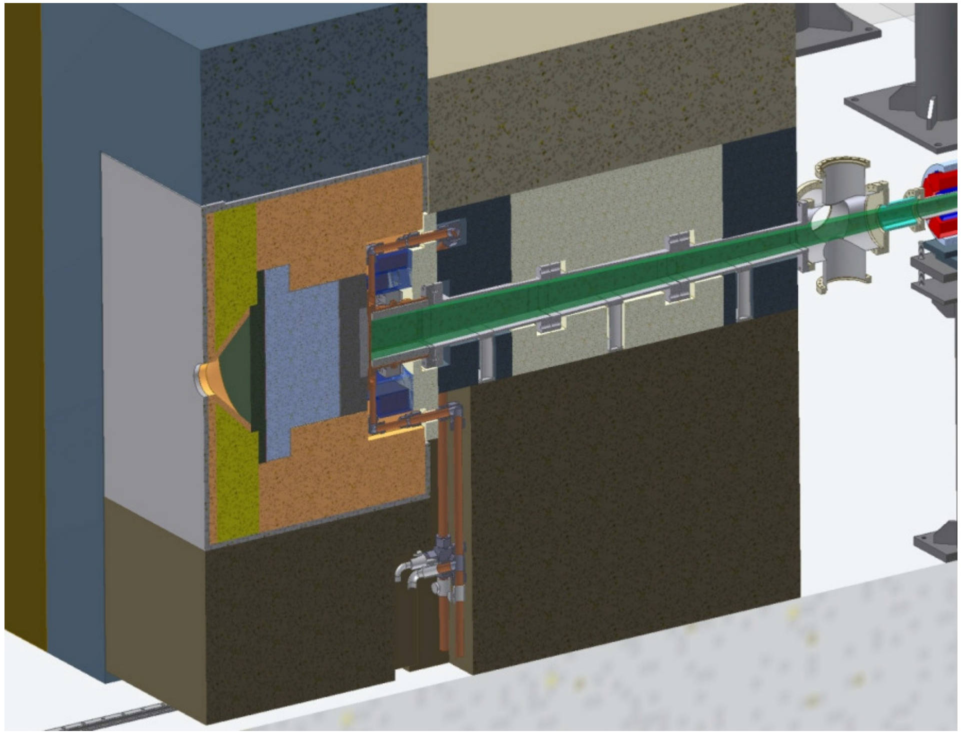


Temperature: surface to cooling pipe

Target manufacturing



Three layer target



Target and moderator

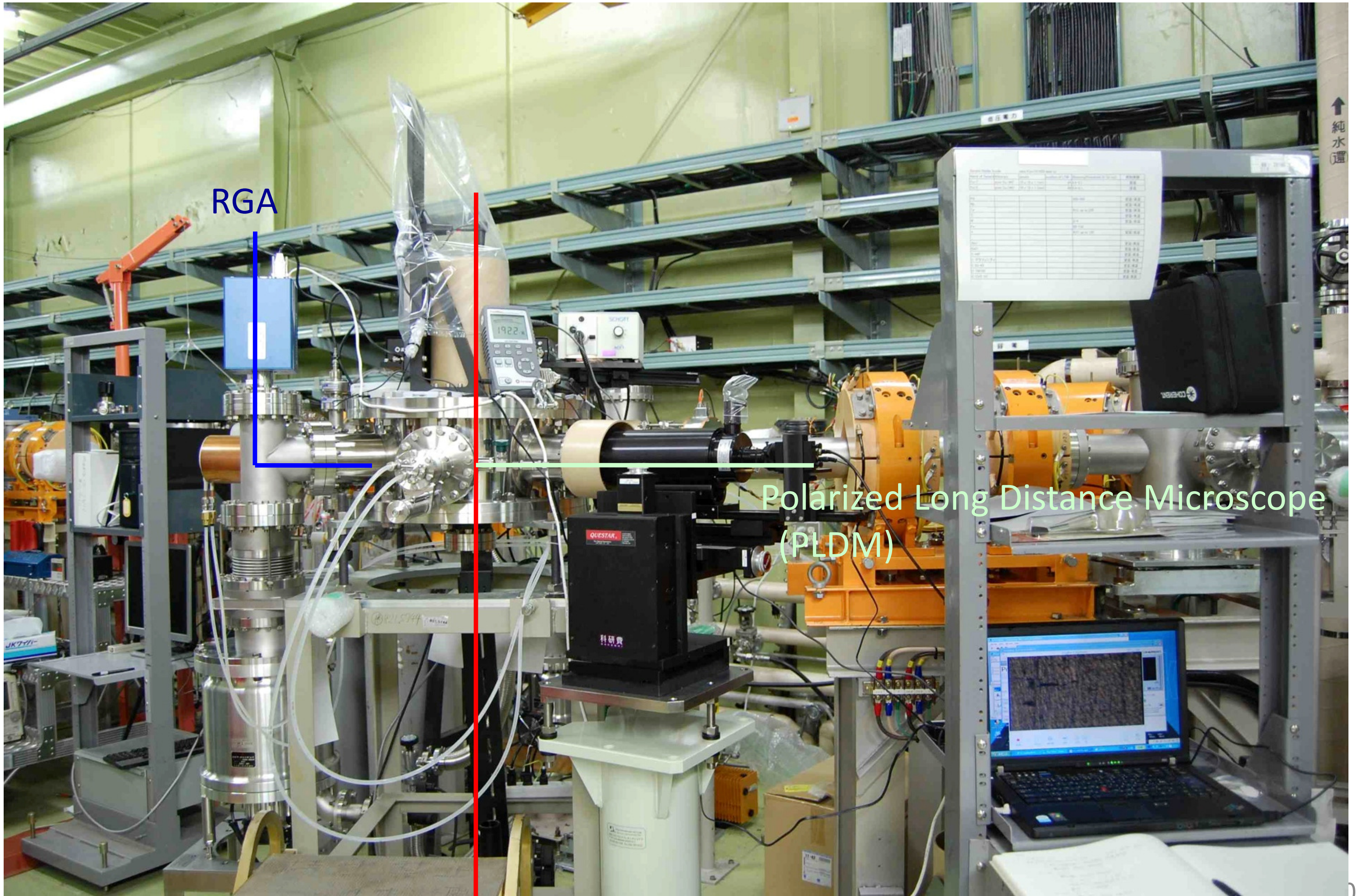
Research of blistering

Blistering is the most crucial issue for low energy target: we have developed observation system of blistering

We have leaned a lot from LENS experiences (13 MeV proton linac)

T. Kurihara

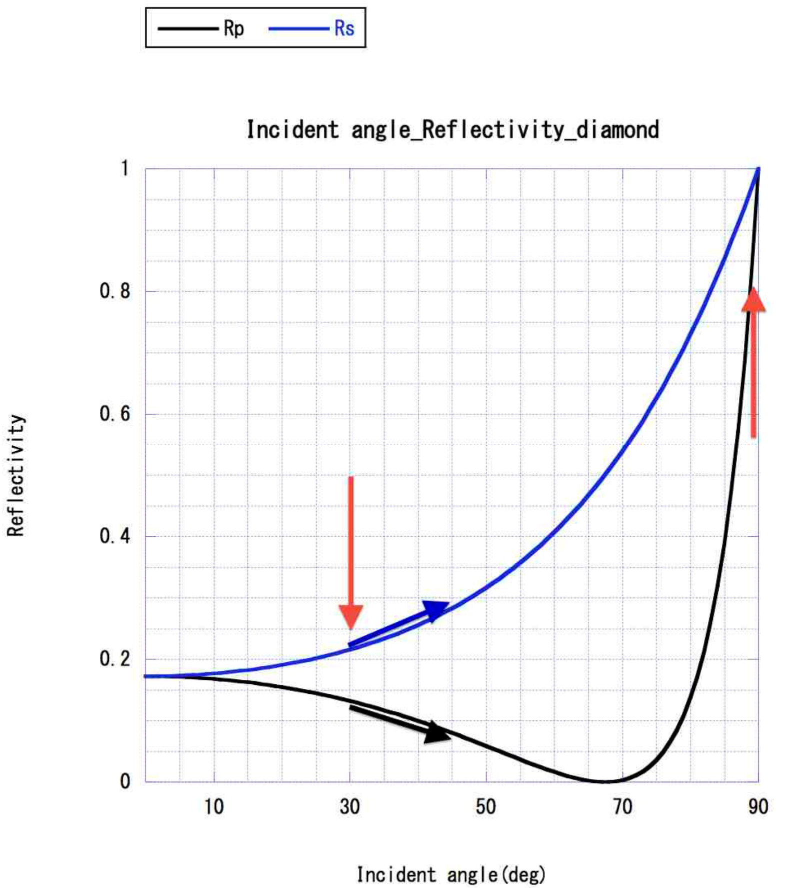
in situ observation of blistering

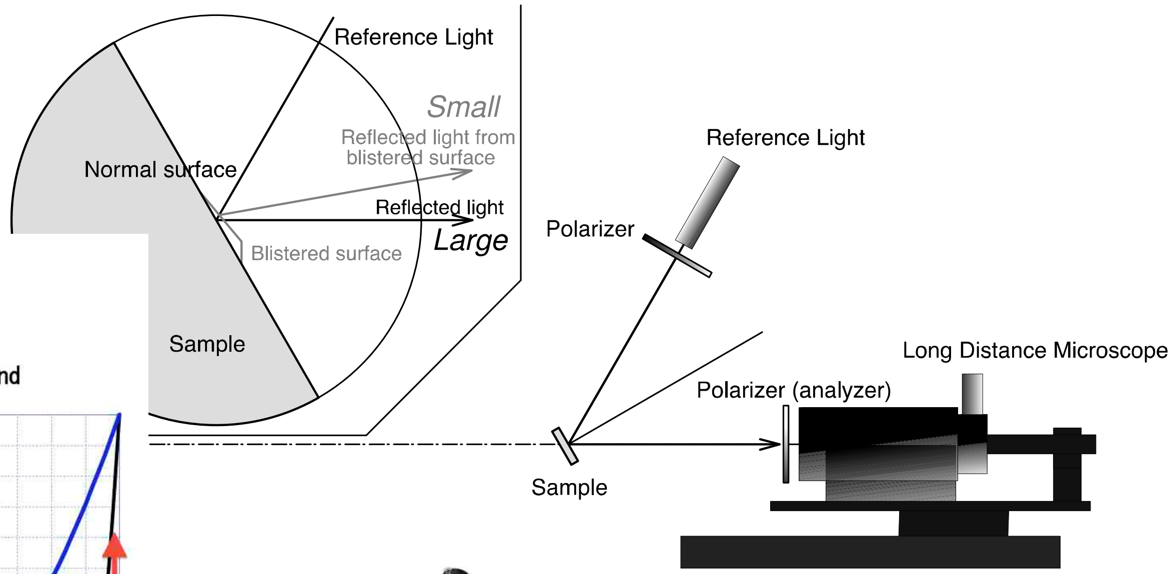


Laser Light Reflectivity Measurement (LRM)

Surface observation with PLDM

– Incident angle dependency of reflectivity of s, p polarized light –





Field of View (2/3" CCD) 2.29, 2.07, 1.41, 1.04, 0.72 (mm at W.D.35.5cm with 0.9X, OPEN, 1.5X, 2.0X, 3.0X)

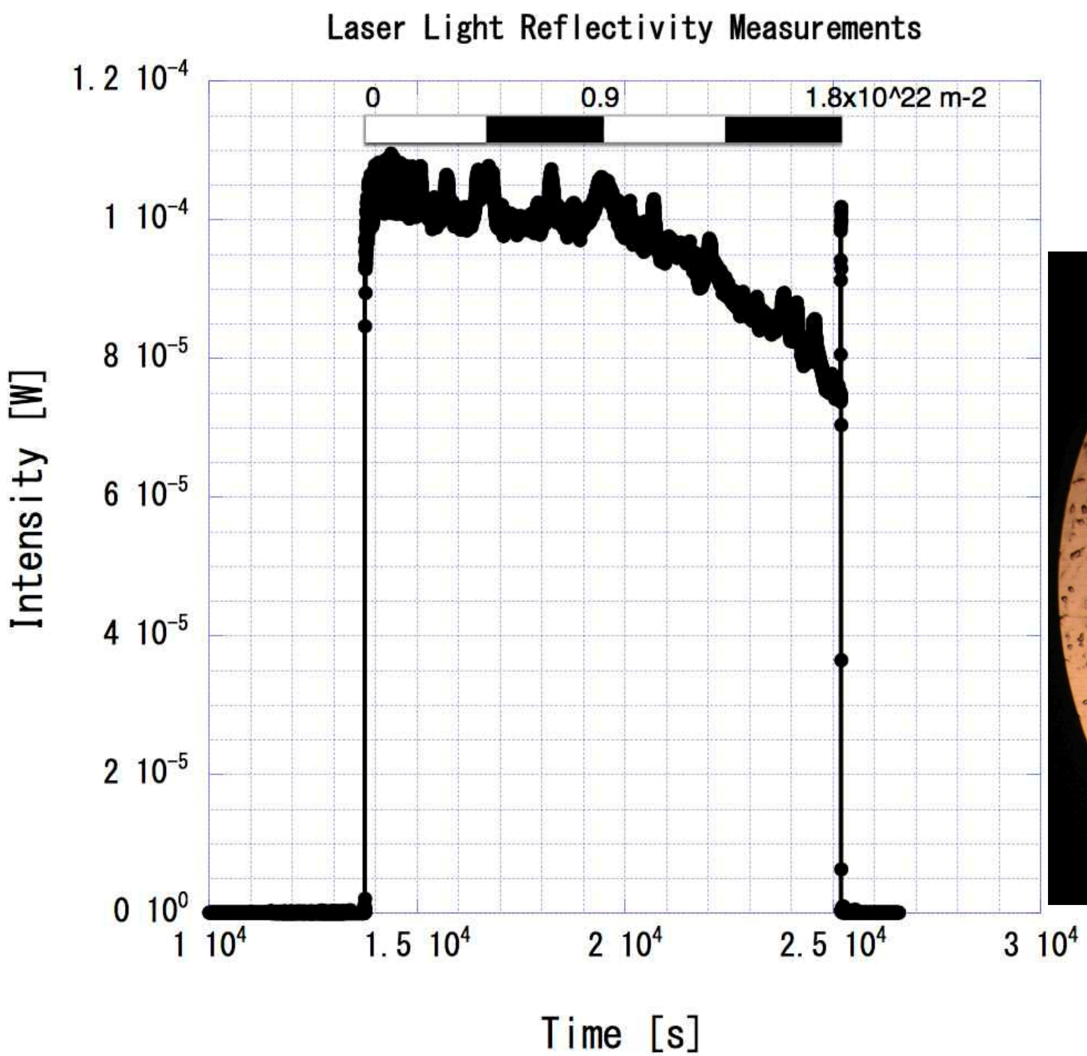
Polarizing Long Distance Microscope (PLDM)

図－1 Nikon 製（OPTIPHOT2－POL） 偏光顕微鏡（透過）

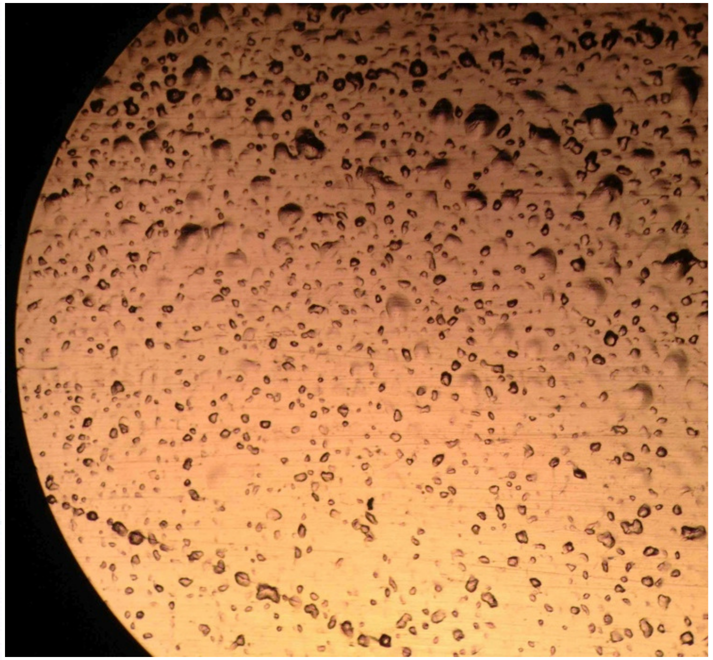
T. Kurihara

blistering observation using reflection

reflected laser intensity



Copper:
Equivalent to
3.5 hour operation



Research will be continued

T. Kurihara

IAEA GUIDELINE

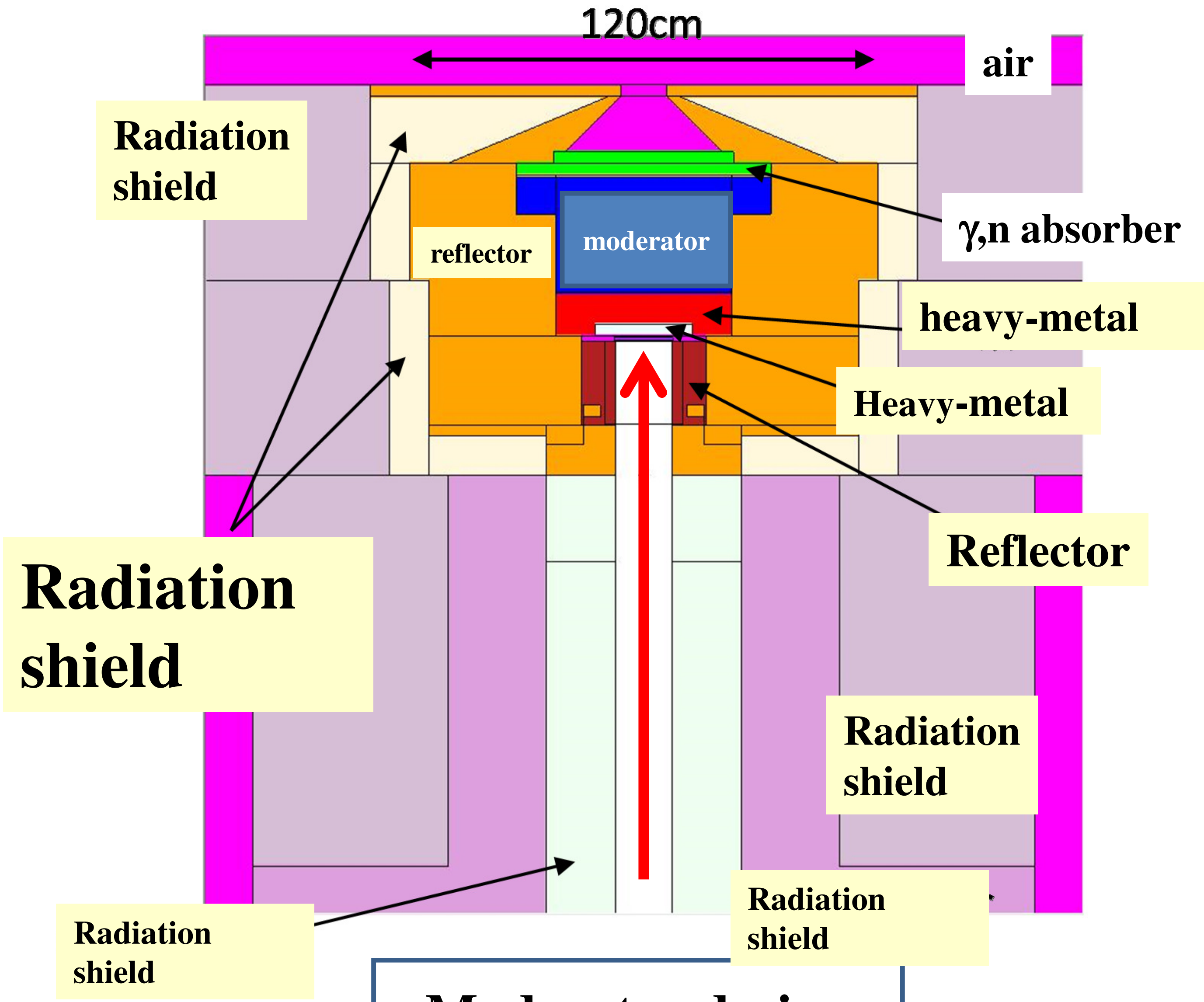
Epithermal (0.5eV-10keV): 10^9n/(s·cm^2)

→ to get moderate irradiation time.

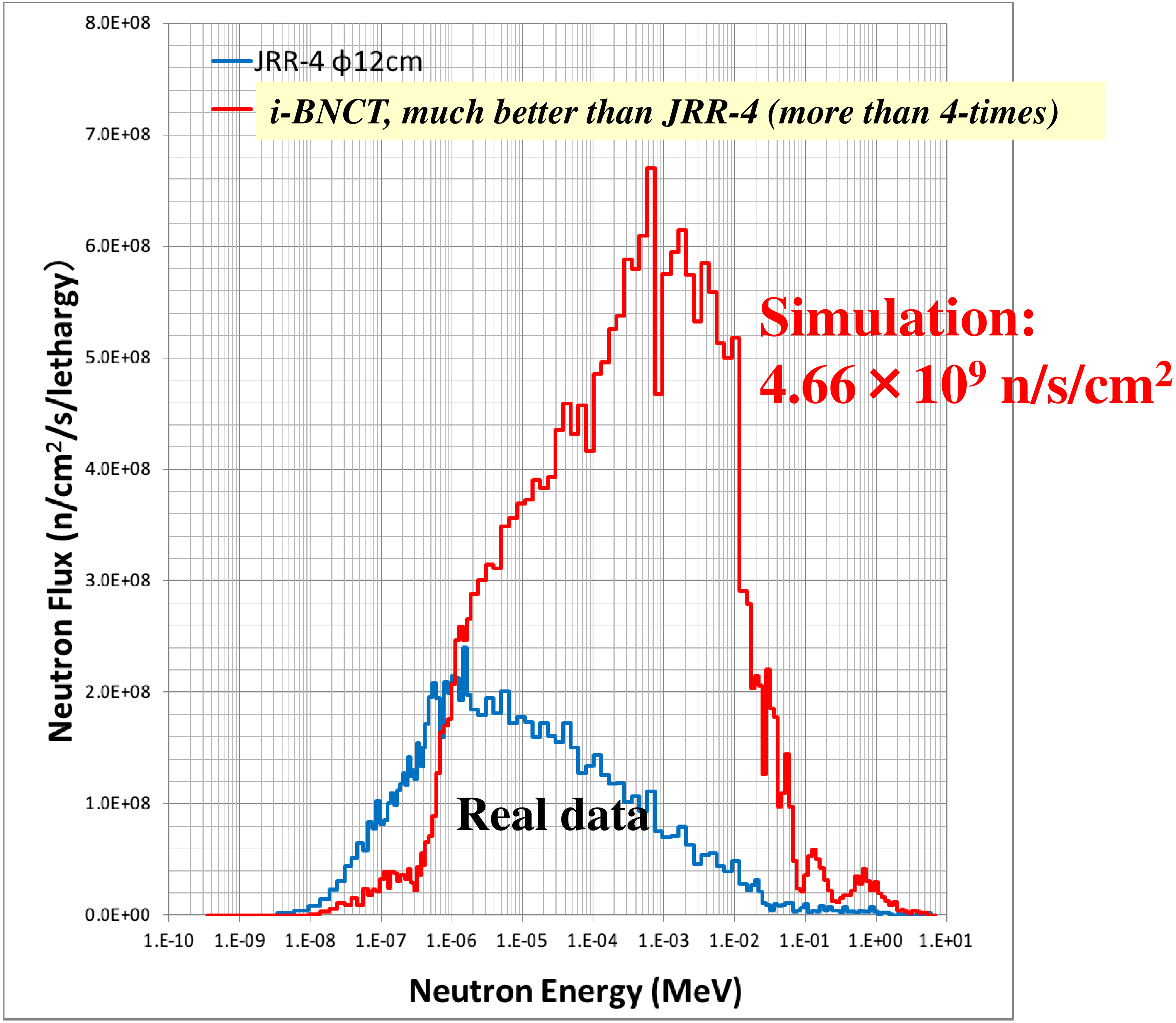
need to reduce following accompanying beam:

IAEA-TECDOC-1223

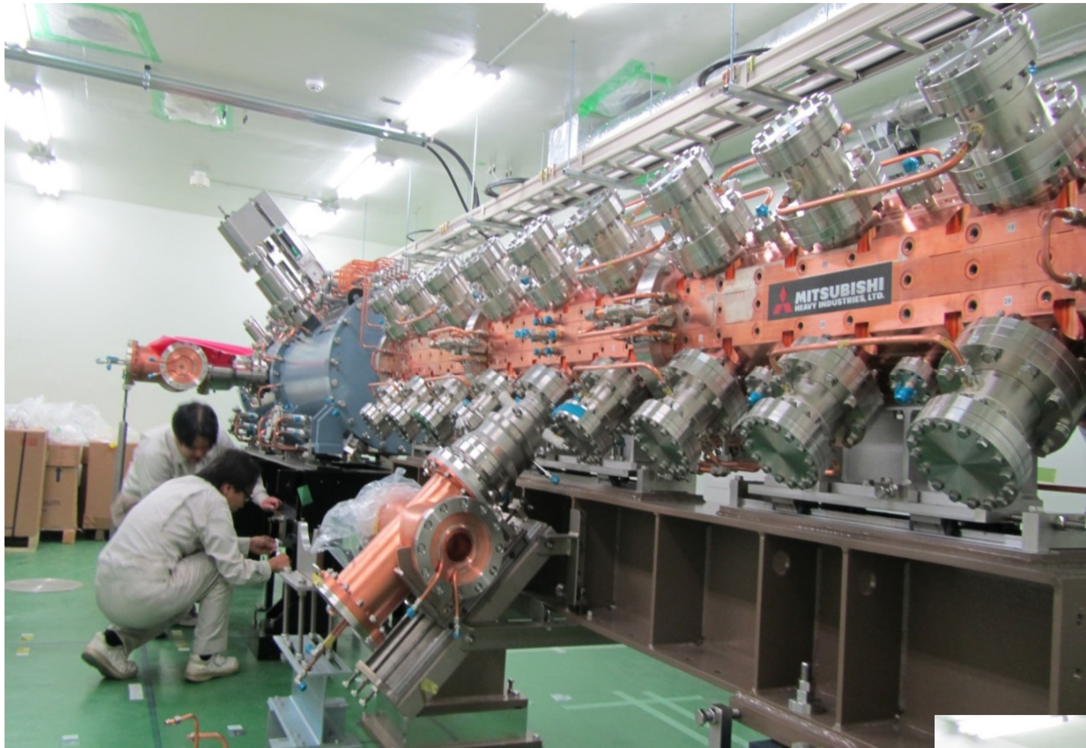
- **Fast neutron >10 keV**
  - → 2×10^{-13} Gy cm^2 per epithermal neutron
- **Gamma rey**
  - → 2×10^{-13} Gy cm^2 per epithermal neutron
- **Ratio between thermal flux and epithermal flux**
  - → 0.05



Moderator design
(Plan view)



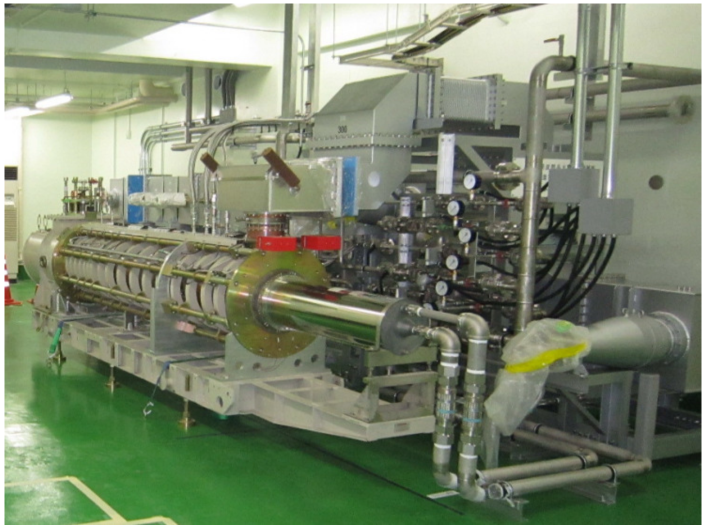
JRR-4 φ12cm
i-BNCT, much better than JRR-4 (more than 4-times)
Simulation:
4.66 × 10^9 n/s/cm^2
Real data
Neutron Flux (n/cm^2/s/lethargy)
Neutron Energy (MeV)
8.0E+08
7.0E+08
6.0E+08
5.0E+08
4.0E+08
3.0E+08
2.0E+08
1.0E+08
0.0E+00
1.E-10
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01



Characteristics of BNCT linac:

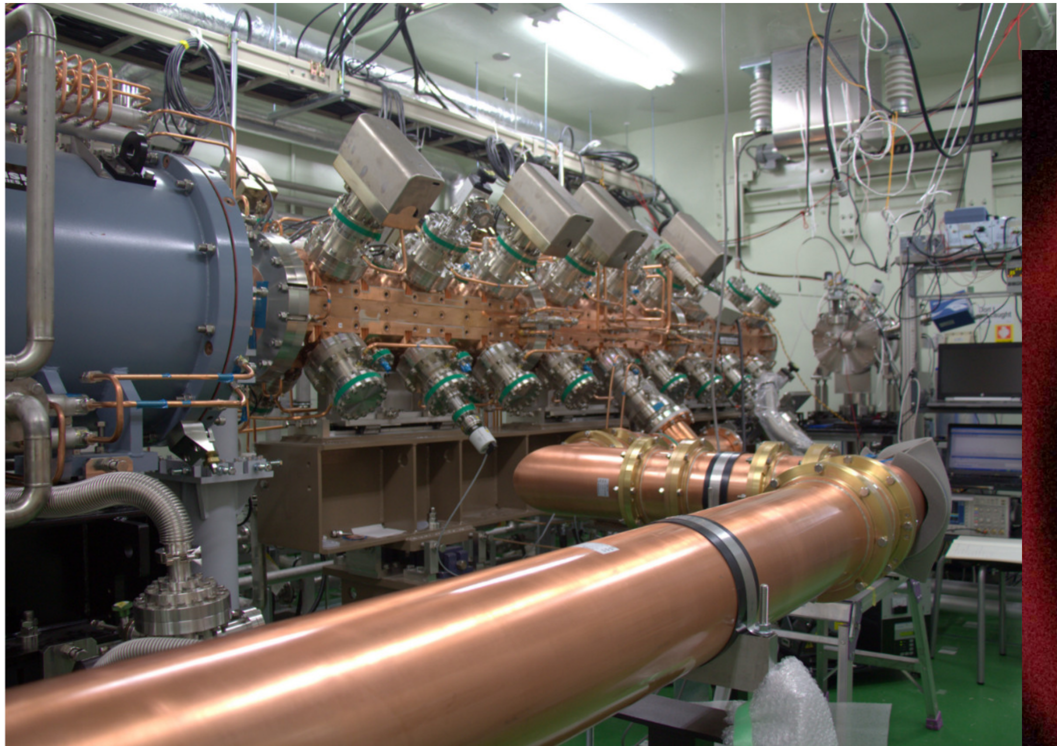
- High duty linac
  - J-PARC: 2.5%
  - BNCT: 20%
- High current linac
  - 50mA peak
  - 10mA average

Construction started 2011



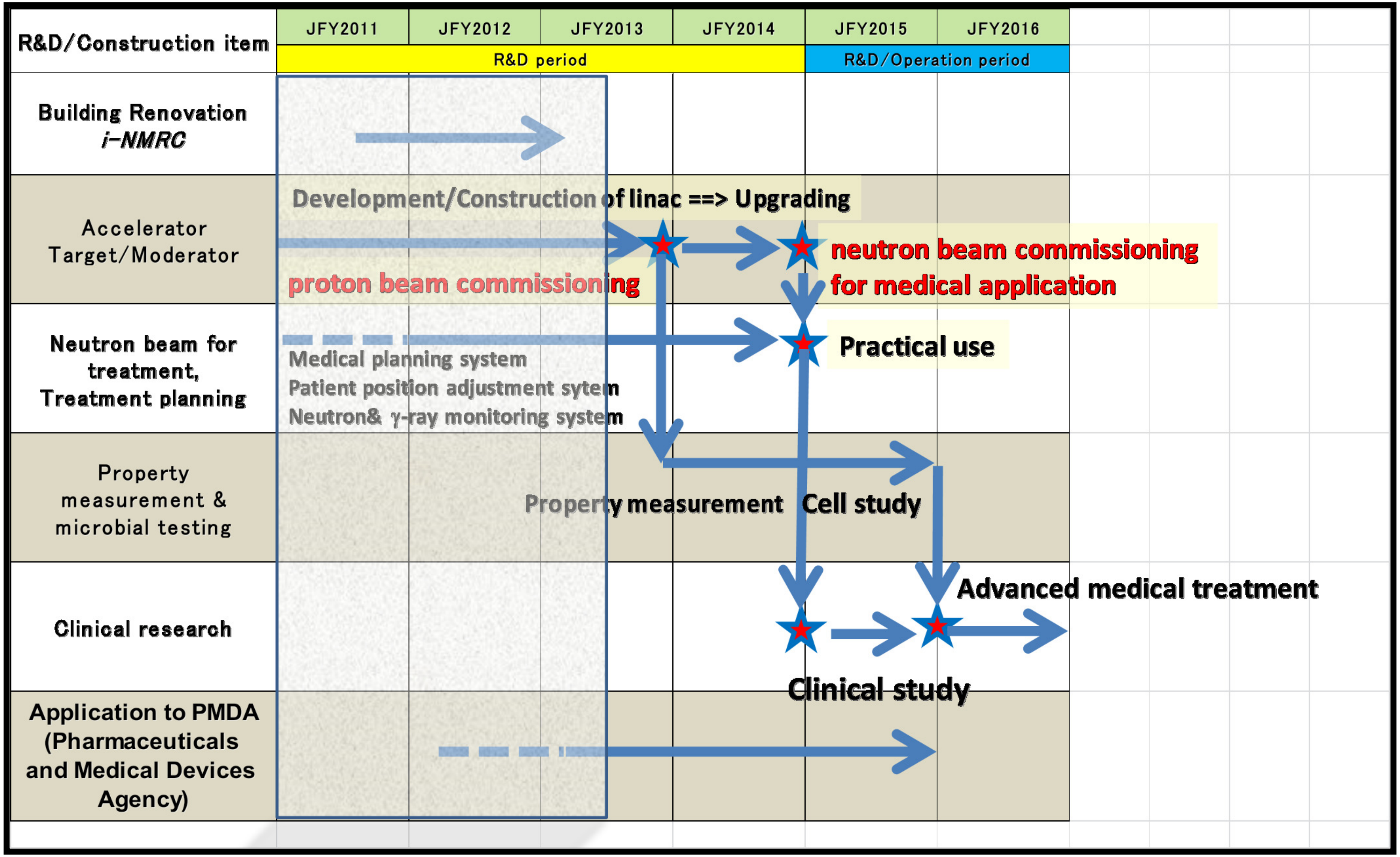
Accelerator status

Installation has just finished



Ion source tuning has started

Timeline of the *i-BNCT* project



summary

- We have just installed acceleartor
- ion source tuning has started
- Expected epi-thermal neutron: 4.66×10^{9} n/(s･cm^2)
- three layers target has been manufactured

  :thermal conductitity 200W/m/K
- further study of blisering will be continued