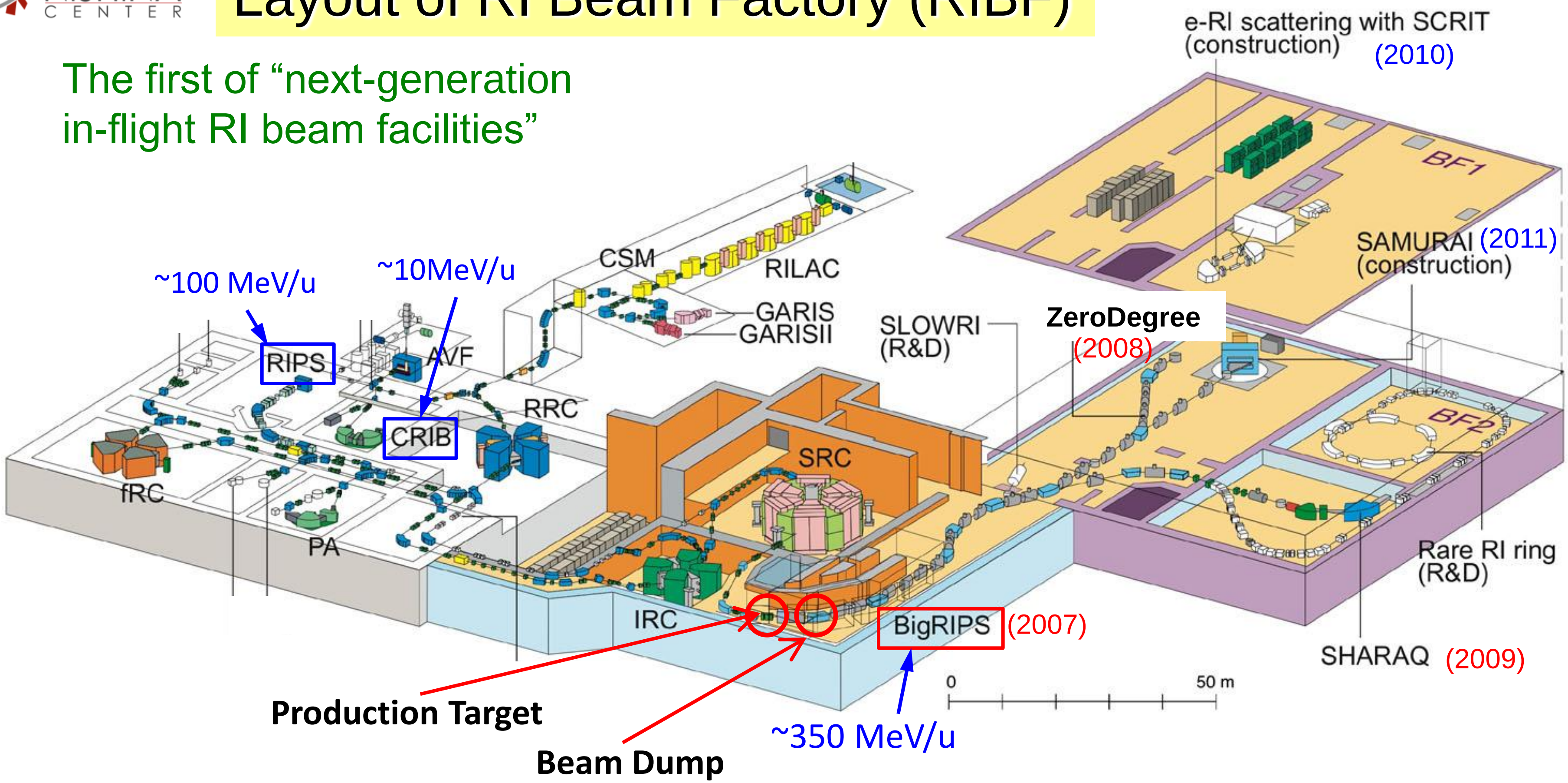
High power target and beam dump system for BigRIPS fragment separator

Koichi Yoshida
BigRIPS Team
RIKEN Nishina Center

Layout of RI Beam Factory (RIBF)

The first of "next-generation in-flight RI beam facilities"



- RIBF accelerator system consists of a linac and four cyclotrons. RRC,fRC,IRC,SRC
- Maximum energy is ~350 MeV/u for heavy ions up to U ions.
- Goal beam intensity is 1 pμA (6 x 10^{12} particles/sec) Max. beam power 83 kW

Available Beam intensity: Beam energy = 345 MeV/n (*250 MeV/n)

$^{14}N^{*}$	400pnA (1.4kW)	^{48}Ca	415pnA (6.9kW)	^{124}Xe	27pnA (1.2kW)
^{18}O	1000pnA (6.2kW)	^{70}Zn	100pnA (2.4kW)	^{238}U	12pnA (1.0kW)

Beam Spot and Power Density

Beam Power(^{238}U 345MeV/n,1pμA=83kW) is dissipated in a target and a beam dump.

▪Target

Beam Spot Size:

ϕ ~1mm (fwhm)

Target Thickness :

Optimum thickness ~ 1/3 of the Range.

Material:

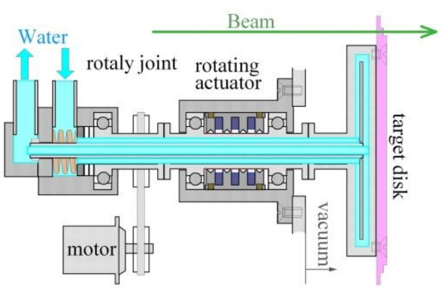
Be, C, W, Pb, etc.

Melt. Point 1284, 3600, 3382, 328 °C

Beam Power in Target (Be 1/3 Range)

Prim.Beam	^{238}U ~	^{48}Ca ~	^{12}C	1pμA
Trg.Thick	4.4 ~	17.2 ~	47.9	[mm] Be
Trg.ΔE	19.7 ~	3.2 ~	0.9	[kW/1pμA]
in ϕ1mm	25.1 ~	4.1 ~	1.1	[GW/m^2]
in volume	5.7 ~	0.2 ~	0.02	[kW/mm^3]

→ Rotating wheel target with water cooling



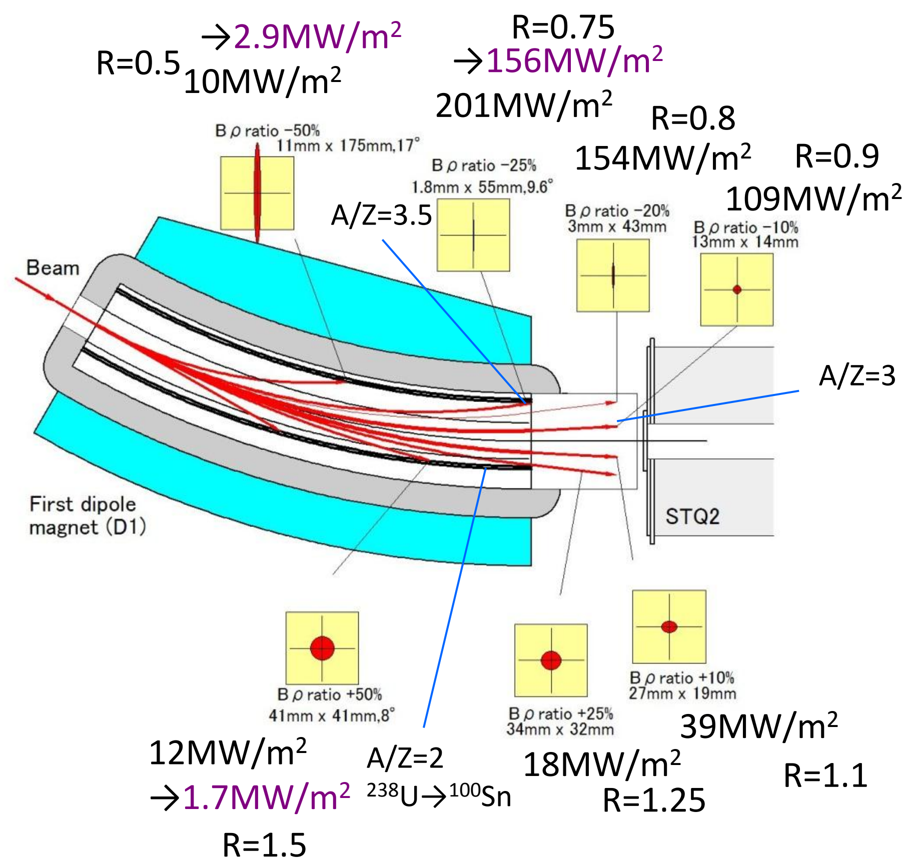
▪Beam Dump

placed inside and exit portion of D1 magnet

Beam Spot Size, Power Density

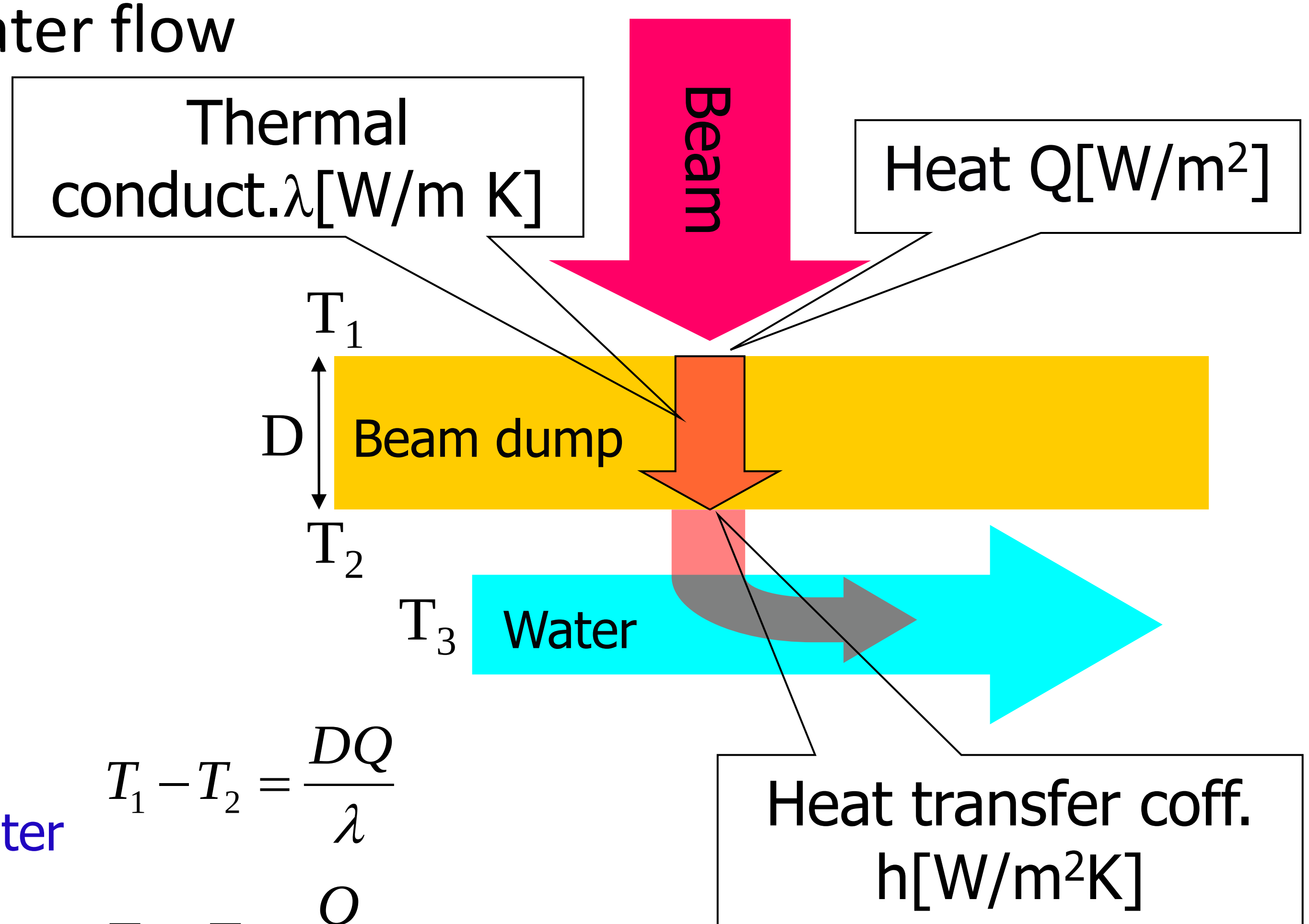
varied as RI beam setting. R= $B\rho_{beam}$ / $B\rho_{separator}$

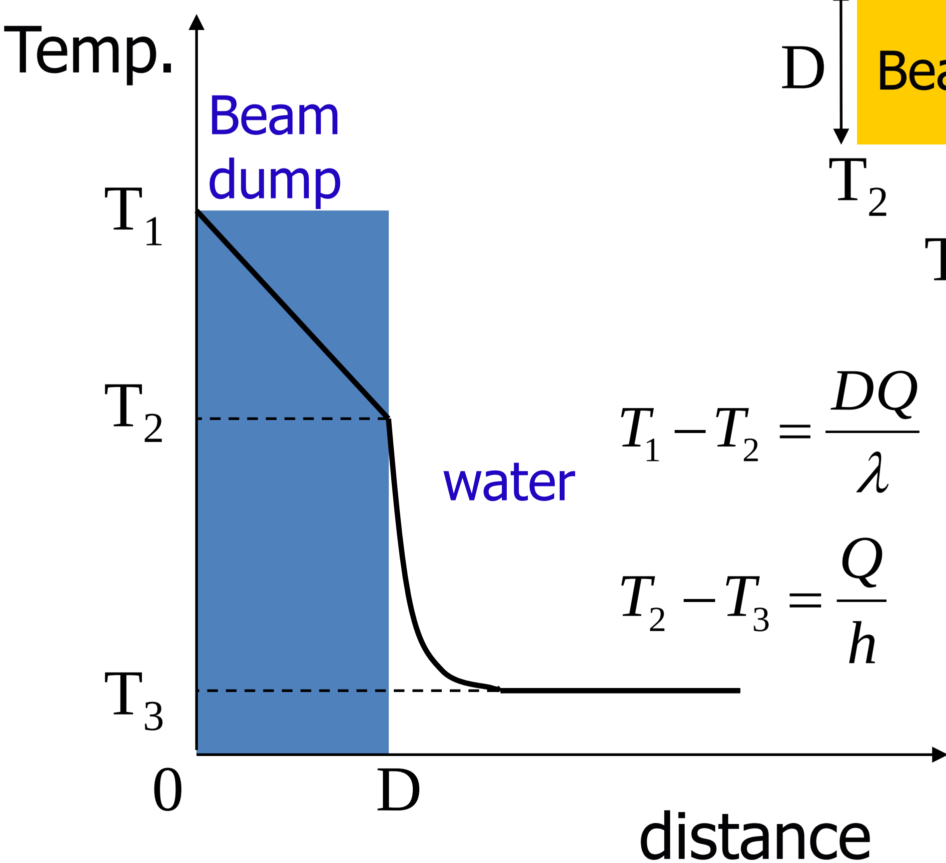
for the case of ^{238}U 345MeV/n with 4.4mm Be target,



→ Stationary system with water cooling

Cooling by Water flow





$$T_1 - T_2 = \frac{DQ}{\lambda}$$

$$T_2 - T_3 = \frac{Q}{h}$$

Heat transfer coefficient: h ↑

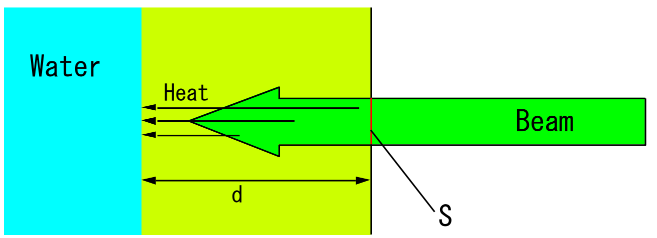
Thermal conductivity: λ ↑

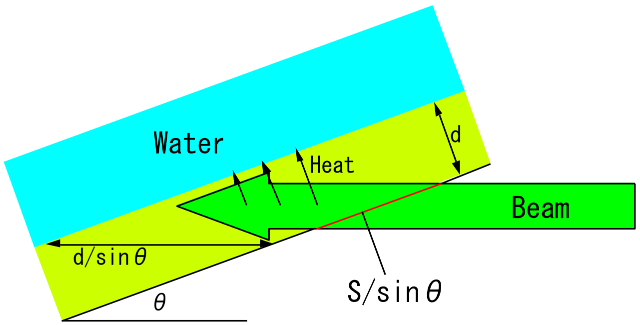
Cu-alloy

Distance: D ↓ tilted wall

Highly efficient method of water cooling

- Tilted Wall

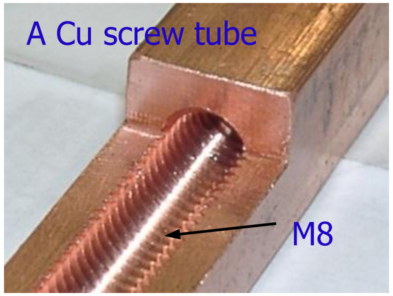


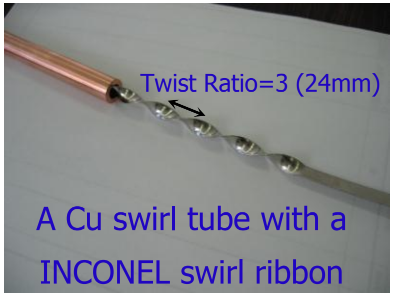


Reduces Power density
Prolongs effective length
by 1/sinθ
sin 10° = 0.17
sin 6° = 0.1

- $h \sim Re^{0.8}\ Pr^{0.8} \sim v^{0.8}$
v: flow velocity →use high velocity

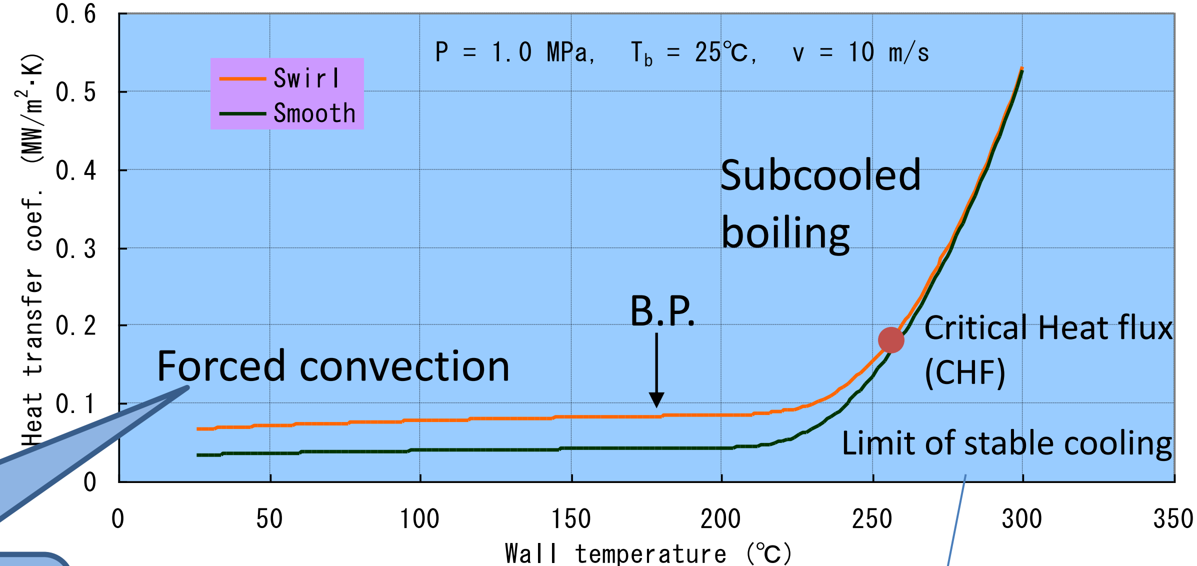
- Cooling tubes with high heat transfer coefficient





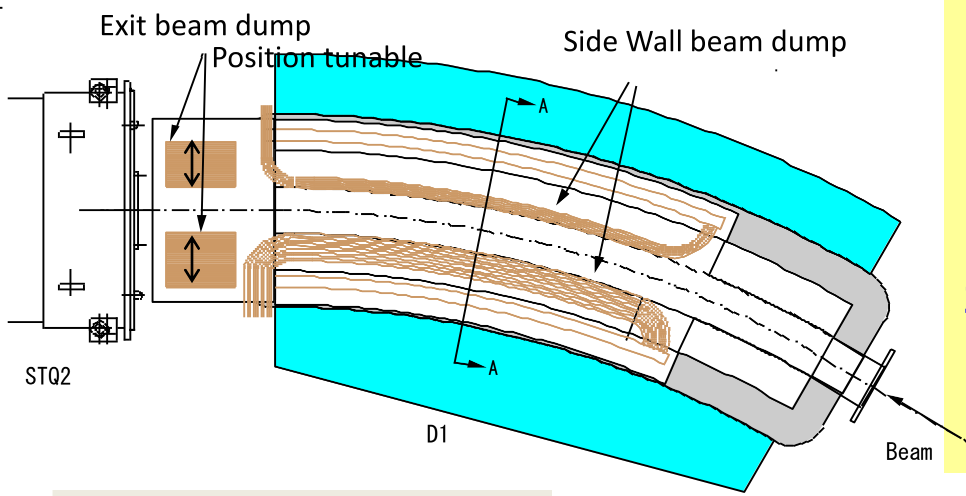
Heat transfer coefficient by JAERI formula

J. Boscary et al. *Fusion Engineering and Design 43 (1998) 147*



Use of highly pressurized water: High boiling point
1 MPa 180°C

High-power water-cooled beam dump for BigRIPS using swirl tubes and screw tubes (maximum beam power ~100 kW)



1) The side-walls of first-dipole gap

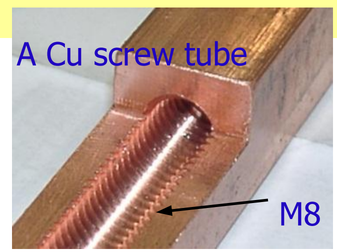
Inside: A screw-tube (Square shape)
OF-Cu 14 x 14 mm^2, φ8mm, ±20°

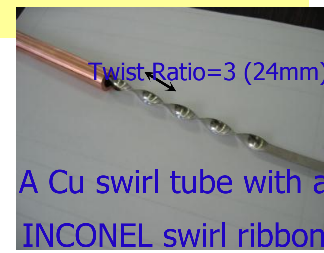
Outside: A swirl-tube (Circular shape)

Cu-Ag alloy φ14 mm x φ8 mm

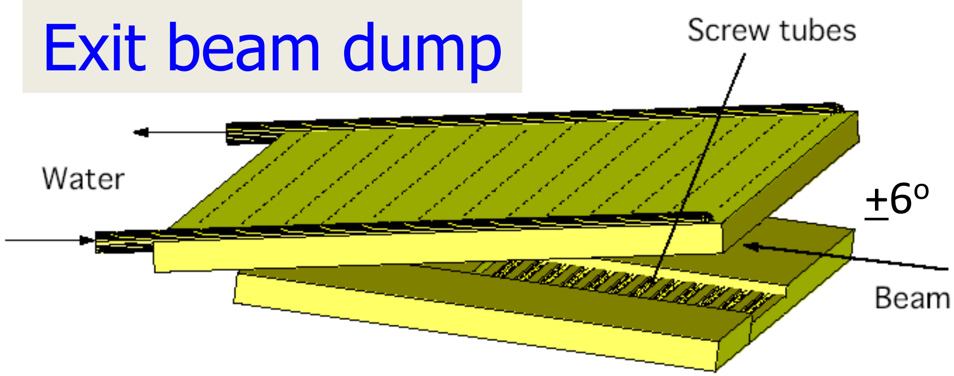
2) The exit of first dipole

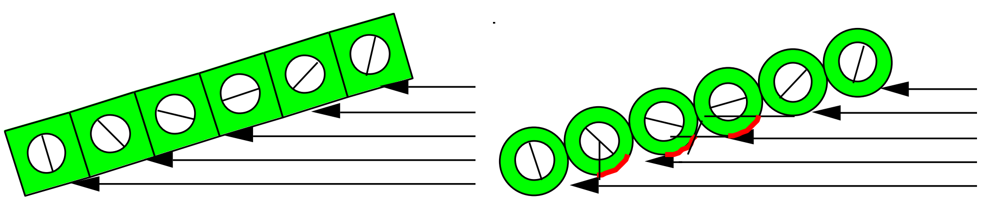
A V-shaped screw-tube beam stopper
Cu-Cr-Zr Alloy M8 screw, 3mm Wall thickness
±6°



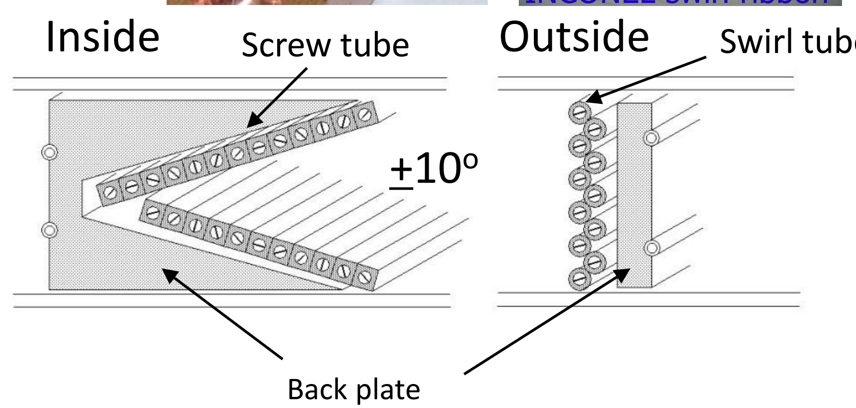


Exit beam dump



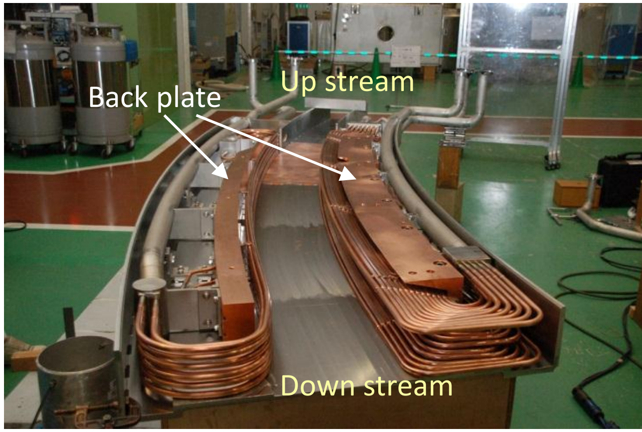


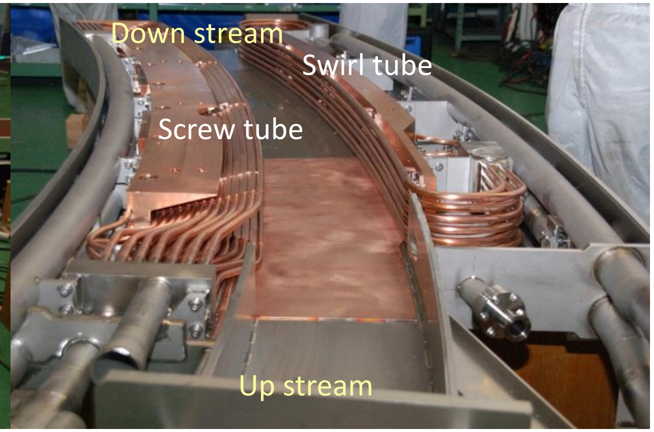
Curved surface suffers high heat flux.

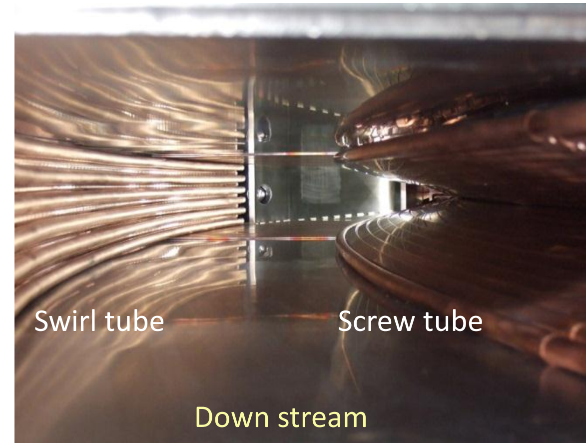


Side-wall beam dump

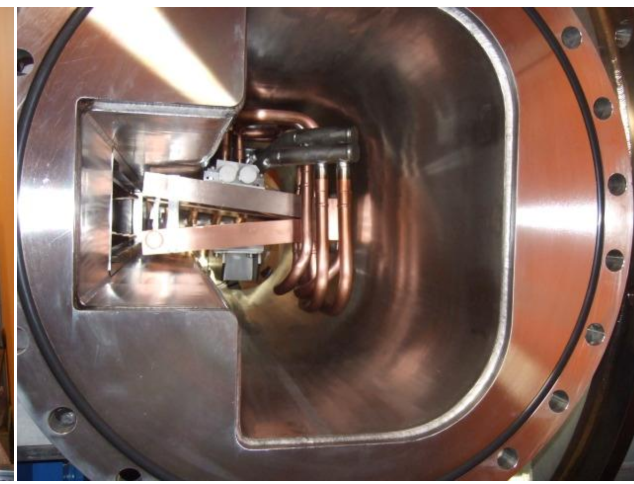
Side-Wall Beam Dump

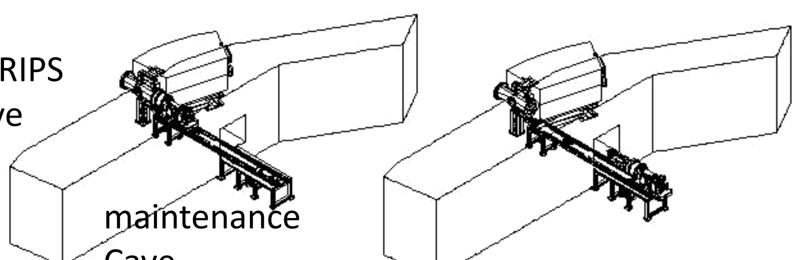






Exit Beam Dump

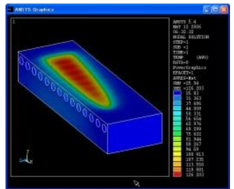




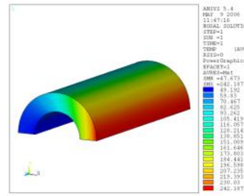
Projected Beam Power Density and ANSYS Simulation

Exit-Dump
Screw tube: M8 screw
3mm Wall thickness,
14mm sep.
material Cu-Cr-Zr alloy
(λ=351W/mK).

T_{max} = 126°C



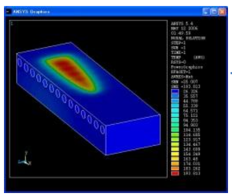
Surface: 242°C
Water side:160°C

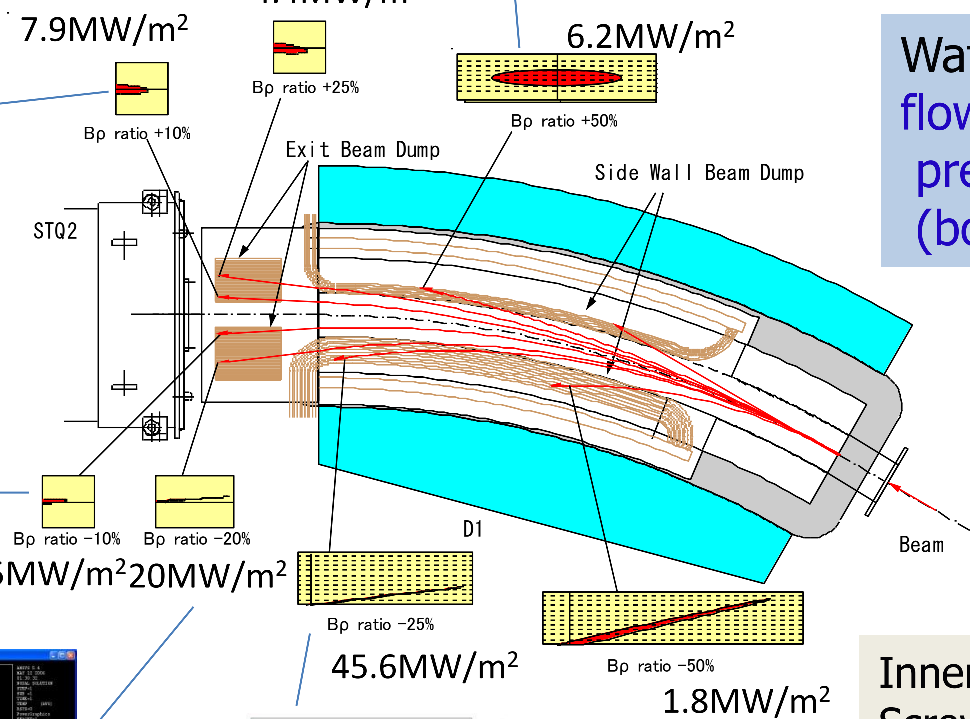


Outer side Dump
Swirl tube: Swirl pitch 3
ϕ(out)= 14 mm, ϕ(in)= 8 mm;
material Cu-Ag alloy
(λ=385W/mK).

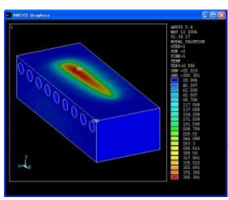
Water conditions:
flow speed=10 m/s;
pressure= 1MPa;
(boiling temp.= 180°C)

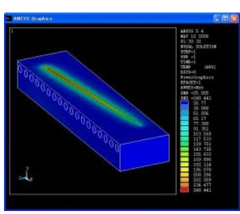
T_{max} = 192°C



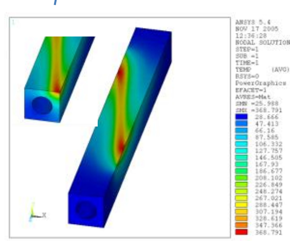


T_{max} = 394°C





T_{max} = 248°C



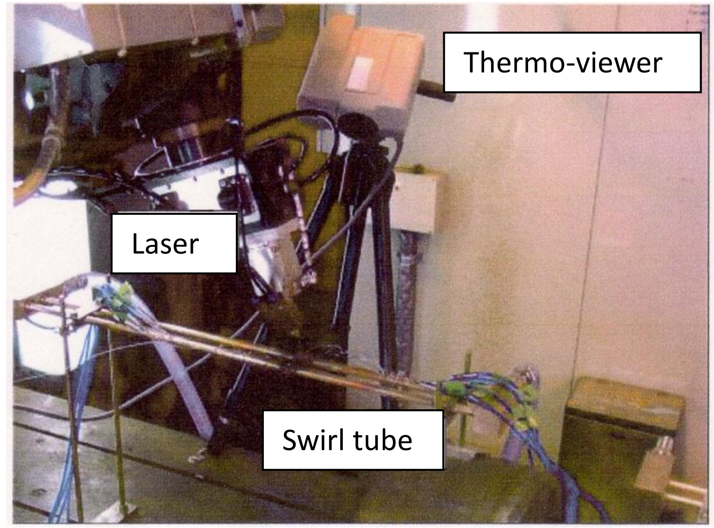
Surface: 369°C
Water side:154°C

Inner side Dump
Screw tube: M8 screw
14x14 mm square
material OF-Cu
(λ=391 W/mK).

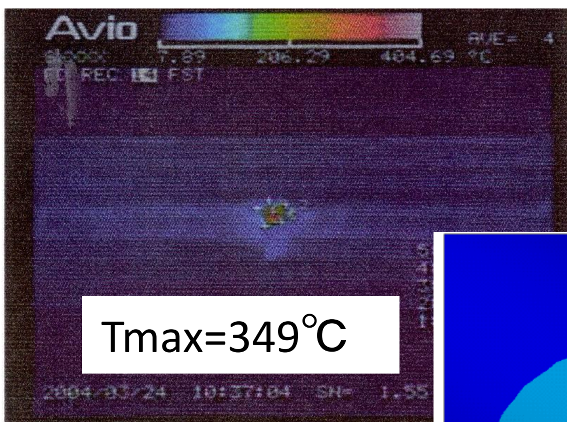
Heating the prototype beam dump by a 1.5 kW CO_2-leaser beam

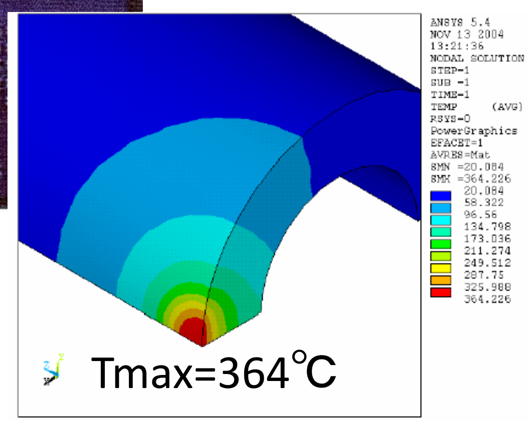
We have examined the cooling capability of a swirl tube with irradiating an expected heat density and spot size, up to 70 MeV/m^2 and 4 mmϕ.

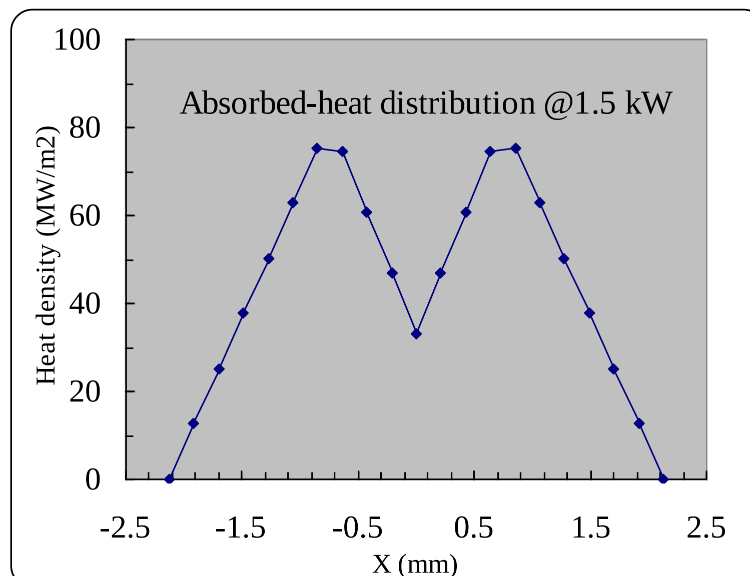
Swirl tube: Cu-Cr alloy
outer 14 mmϕ, inner 8mmϕ
Swirl ribbon: Inconel, pitch 24mm/180^o
Water: 12m/s, 1 MPa



ANSYS calculation reproduces the temperature distribution well.



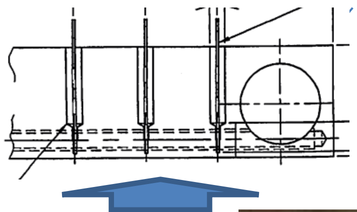




Beam Dump Temperature for ^{238}U 345MeV/n 8.3pnA

Exit-Dump is operated with water of 13°C, 0.7MPa, and 2.6m/s. (Design: 1MPa, 10m/s)

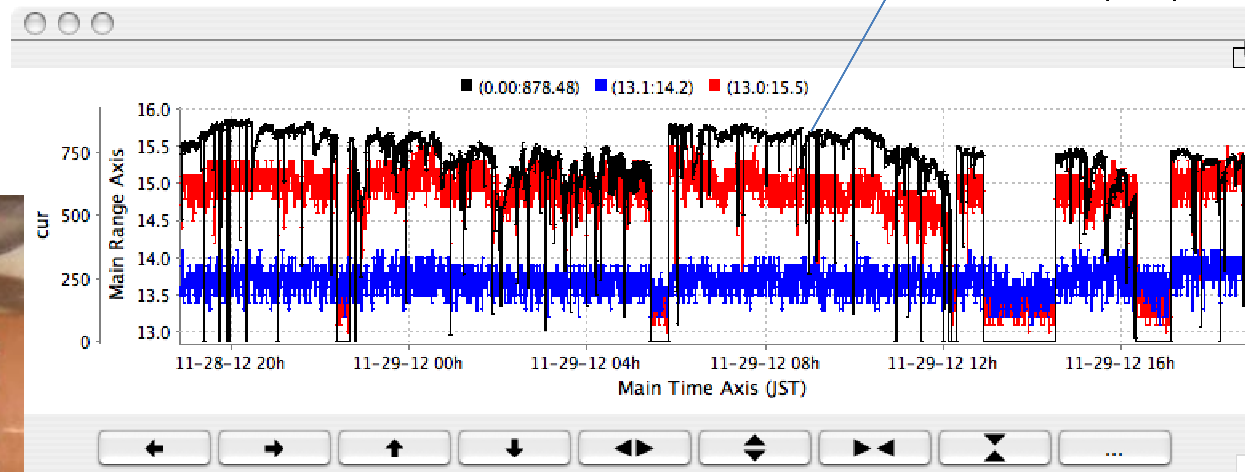
Thermo-couples mounted on the exit beam dump



1mm from the surface

Beam

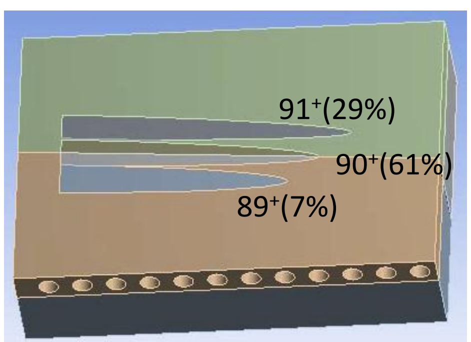
Beam Current (enA)

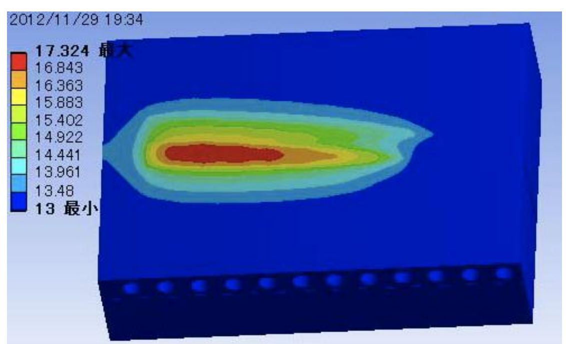


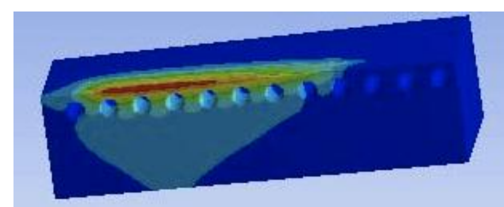
Temperature increase 15.1 – 13.6 =1.5 °C

Estimated beam spot at dump

Heat load : 522W



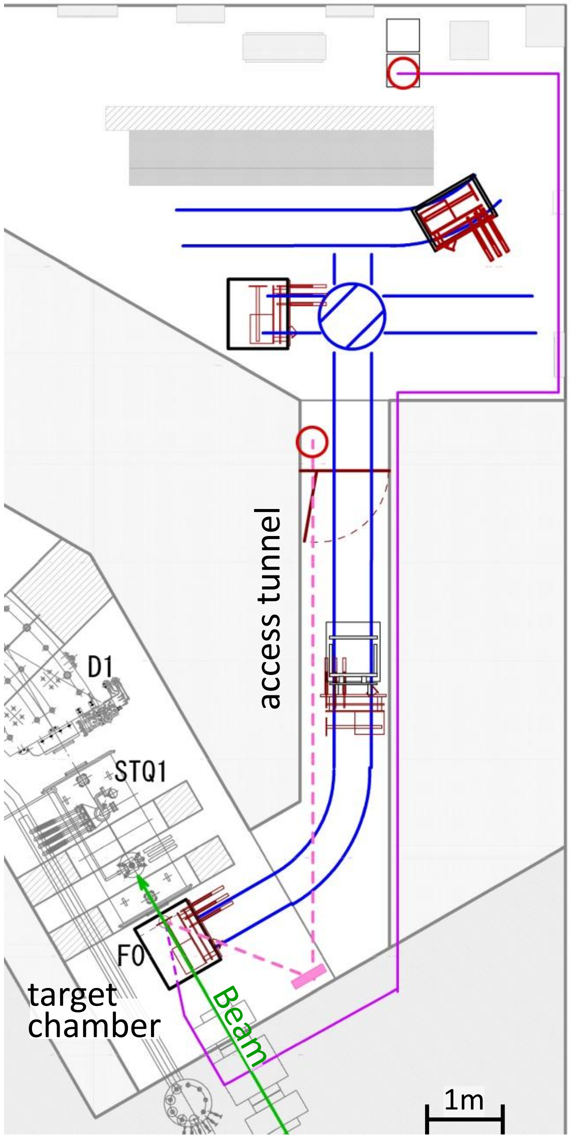


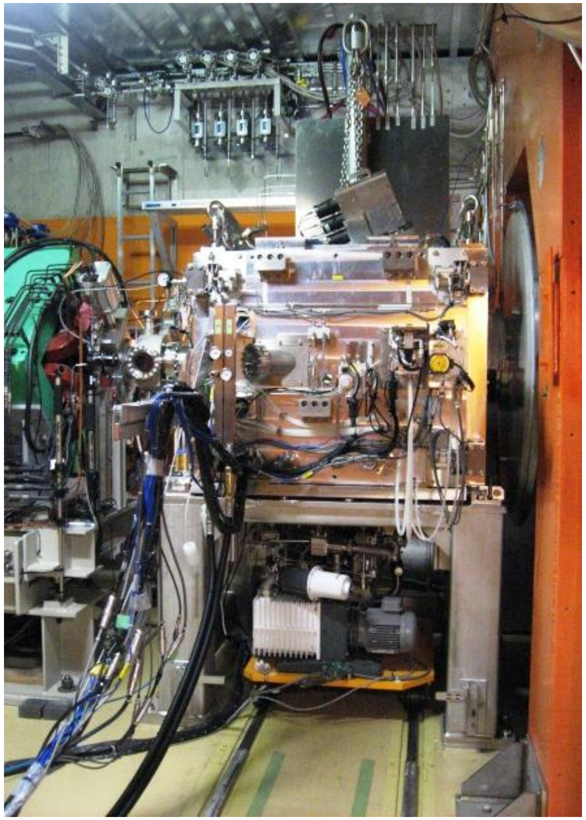


ANSYS simulation: Temperature increase 15.0-13.0 = 2 °C (not bad, although large ambiguity)

BigRIPS Target System

-Two rotating target units and one target ladder (fixed target) are mounted on the side flange.
-The side flange can be carried out by the maintenance cart for maintenances.

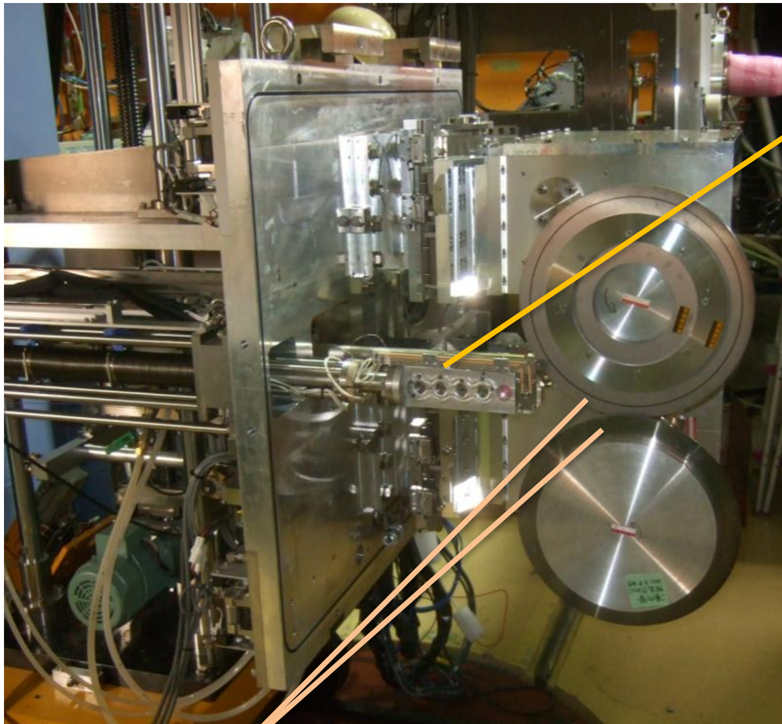




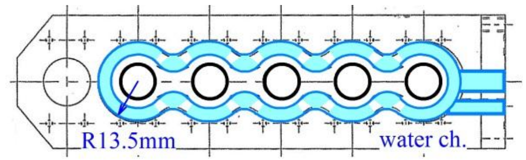
Rotating target

Target ladder (fixed target)

Ladder target and rotating target



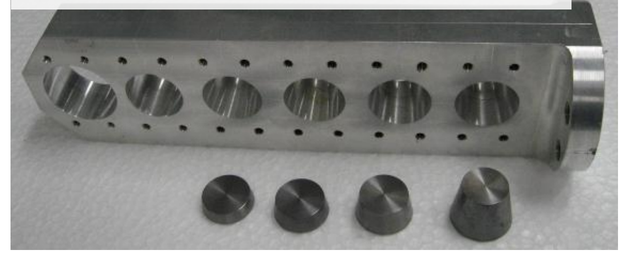
Target ladder (fixed target)



*Diameter : ~ 20 mm
*Thickness : 1 ~ 20, ~ 60 mm

The water way is cut in the ladder.

Ladder target : for Low-power beam



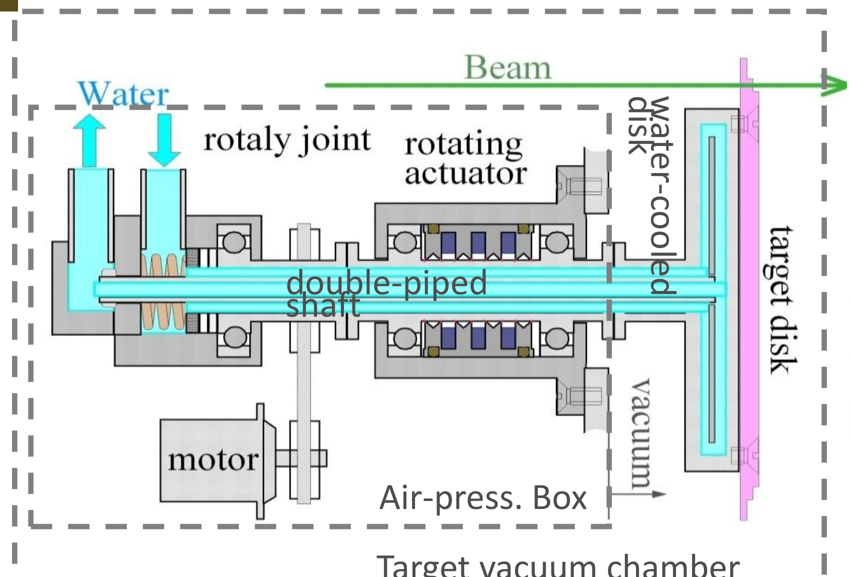
Taper–shape targets are utilized for better thermal contact.

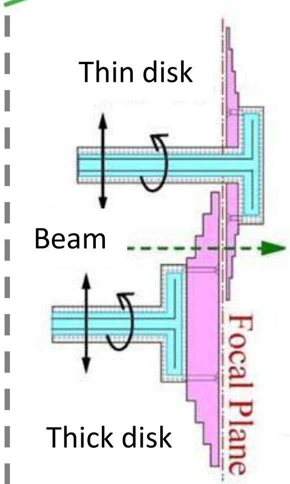
Rotating target

Disk target : for High-power beam

*Size : ϕ30cm
*Material : Be, W
*Step shaped edge
20,15,10 mm thick
for N, Ca, Ar beams
10, 7, 5 mm thick
for Kr, Xe, U beams

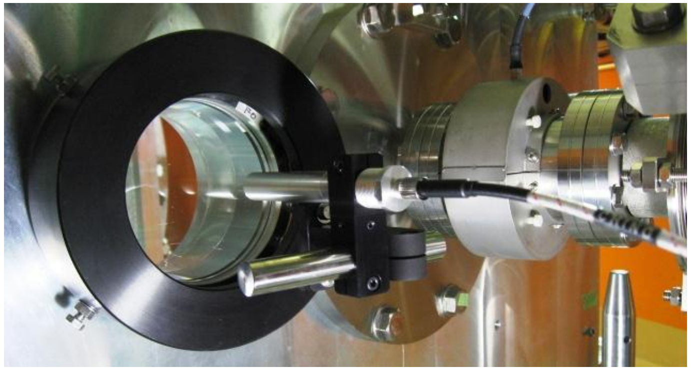
← Be : 20,15,10 mm thick



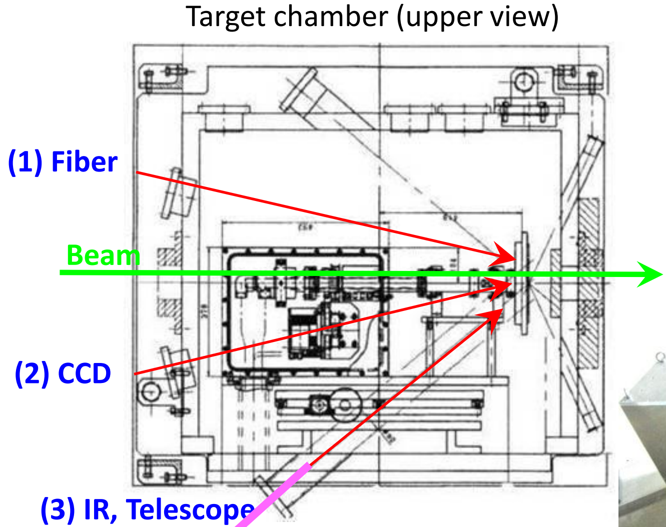


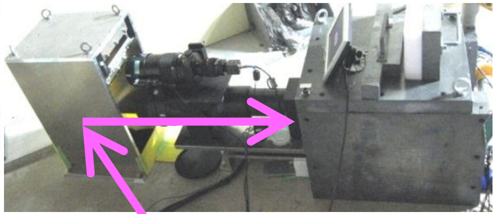
Beam-spot temperature measurements

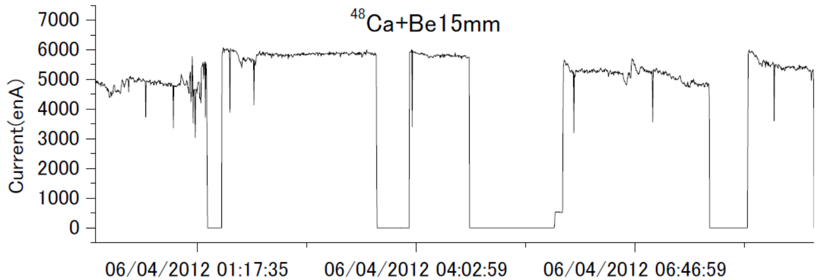
(1) Infrared Fiber Scope

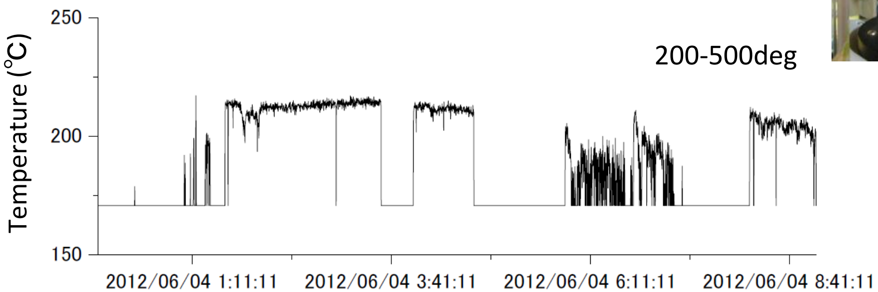


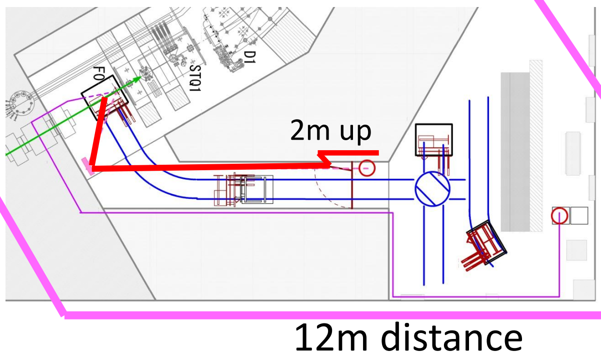
Sapphire view port & Lenz unit mounted on the Target chamber







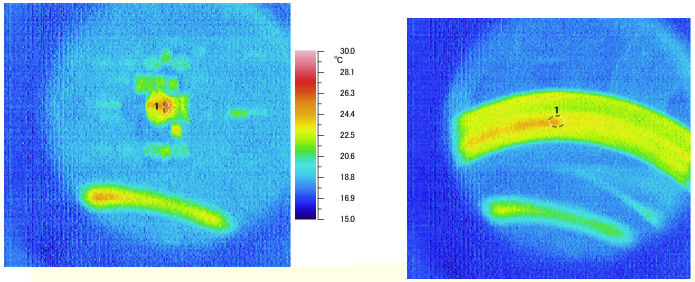




Spot temperature only

Can be used as on-line monitor

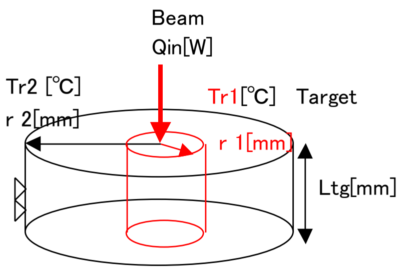
T>200 deg.



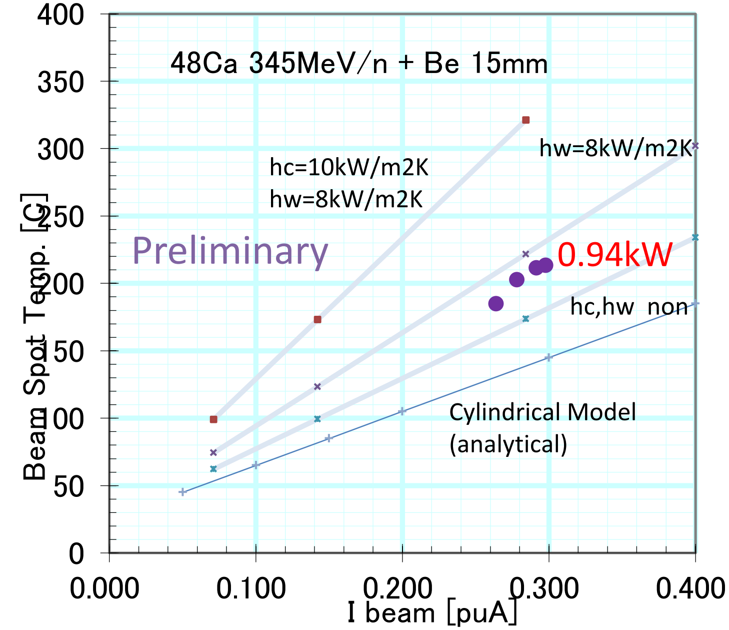
(2) IR thermal image camera

Fixed target (mounted on ladder) ; temperature data & ANSYS Calculation

((Cylindrical model))
analytical model

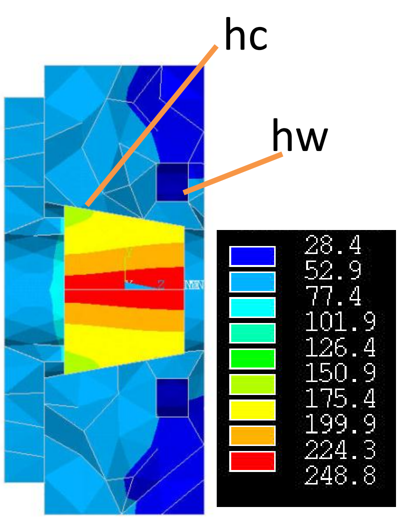


Tr1 : Beam Spot Temp.
= Tr2 + Qin*Ln(r2/r1) /(2πκLtg)
Qin = Ibeam * dE
∝ dE / Ltg

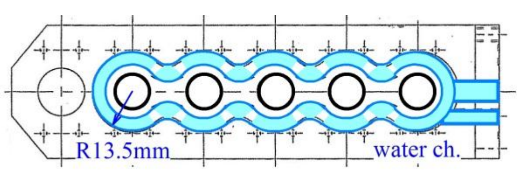


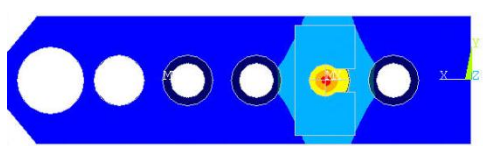
ANSYS calculation
Modeling: whole ladder

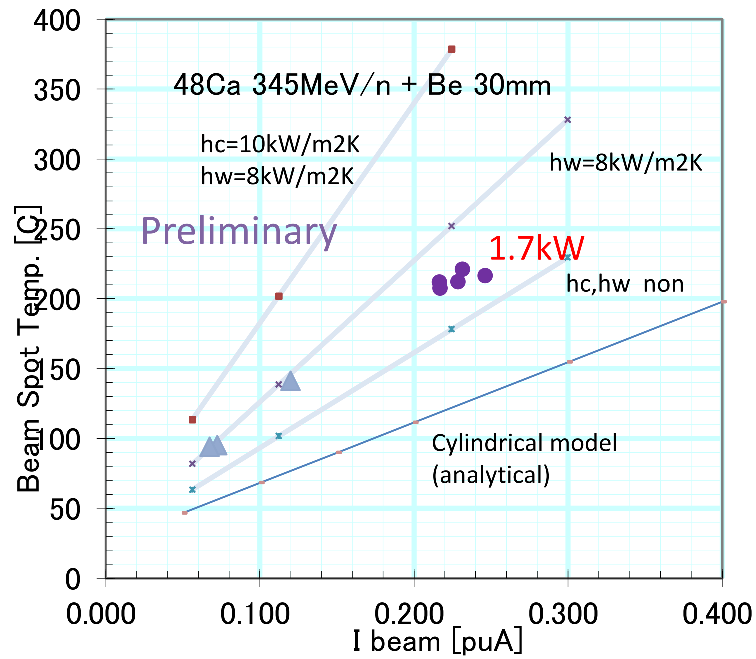
Heat transfer coefficient:
- water-ladder: hw turbulence flow 1.5m/s 8kW/m^{2}K
- Ladder-target:hc typical CPU Heat sink 10kW/m^{2}K



Be 15mm

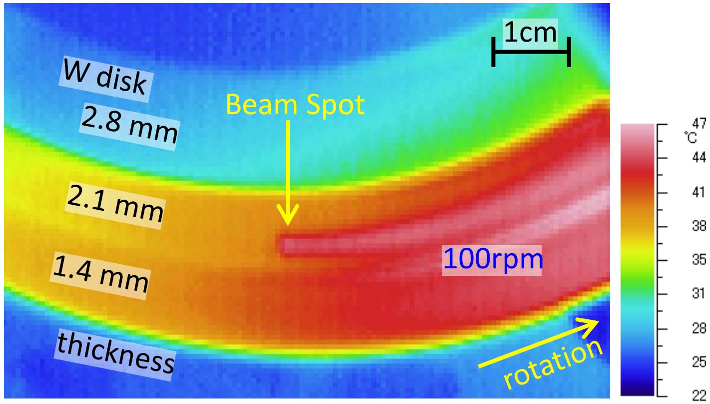


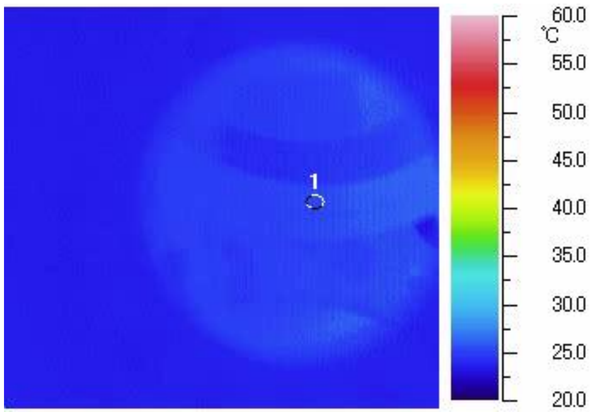


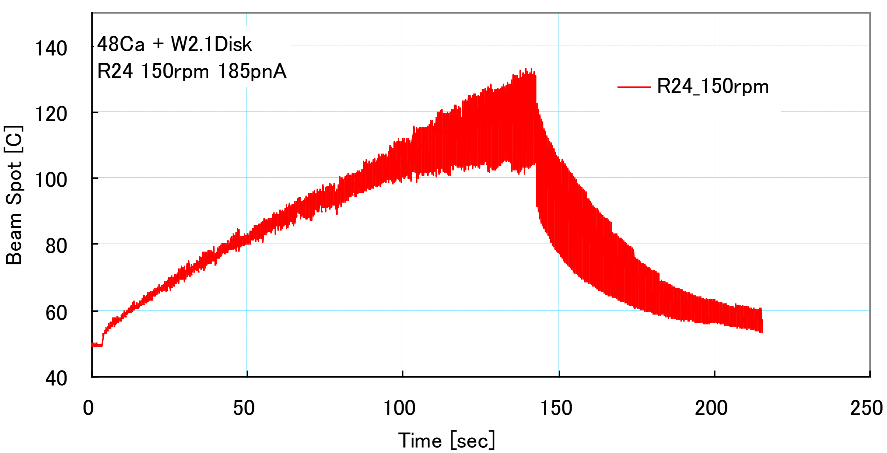


Rotating disk target ; temperature data

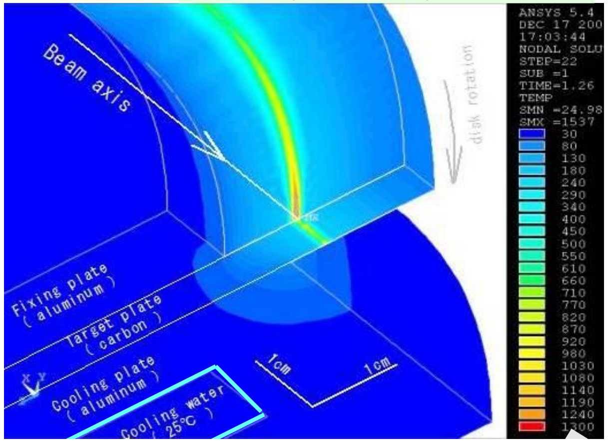
R024) W 2.1mm Disk 150rpm 185pnA (564W)



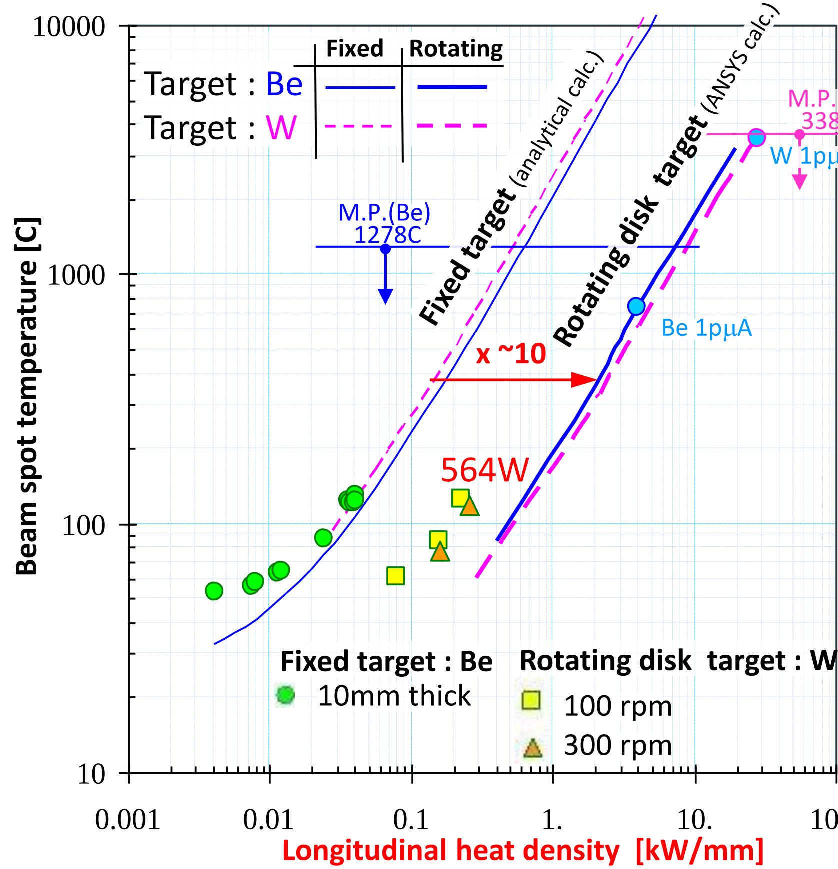




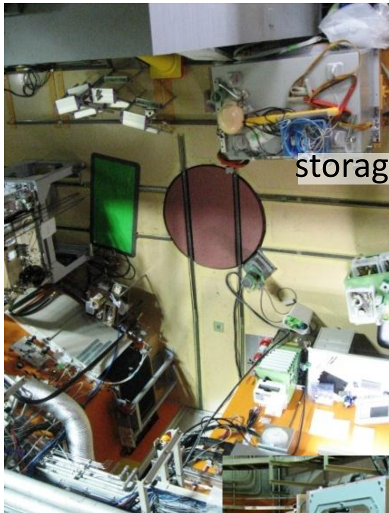
ANSYS (FEM code) simulation

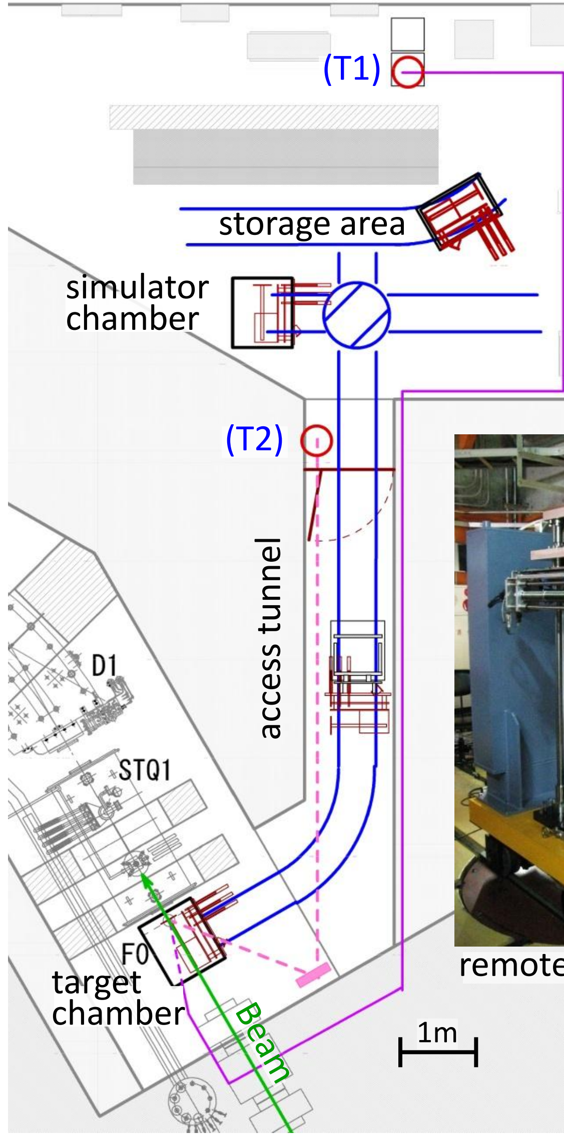


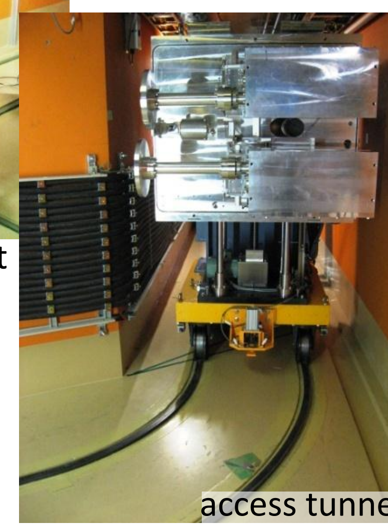
Calculation was made by A. Yoshida.



Target maintenance system



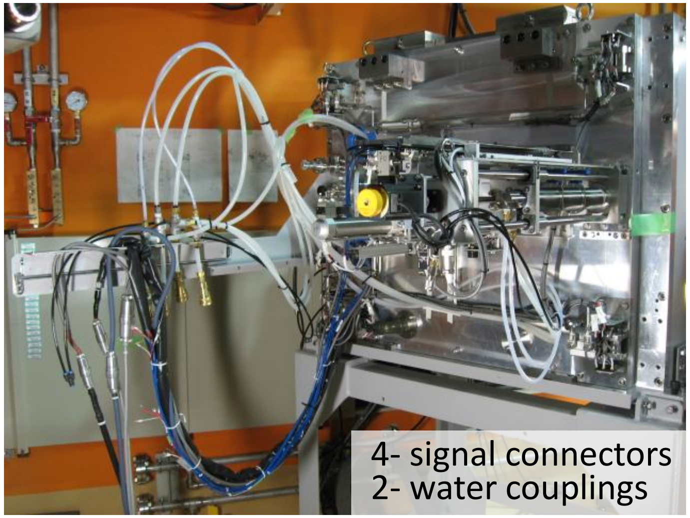




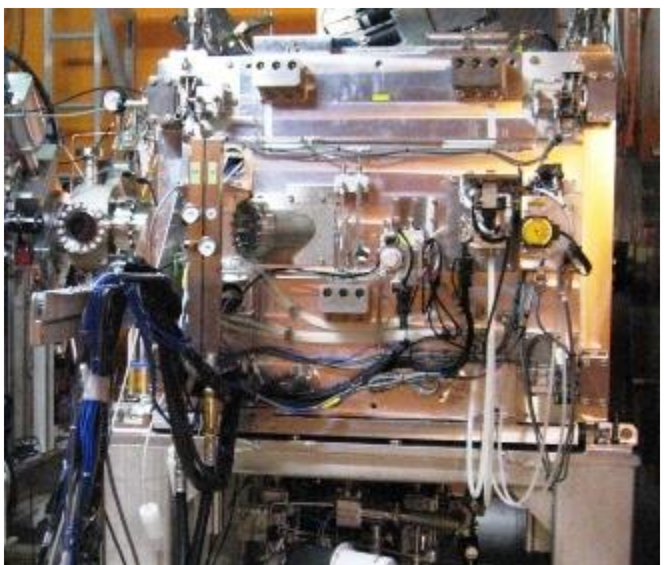
beam spot temperature monitors
(T1) an infrared fiberscope
(T2) infrared thermal camera

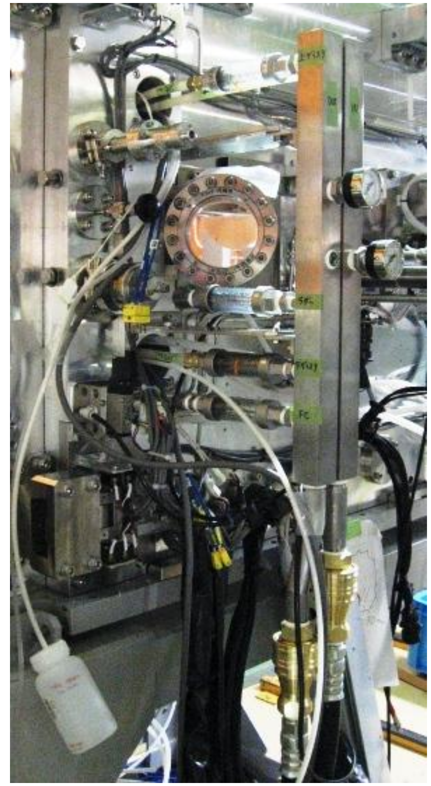
Cable connections at Removable flange unit

2008

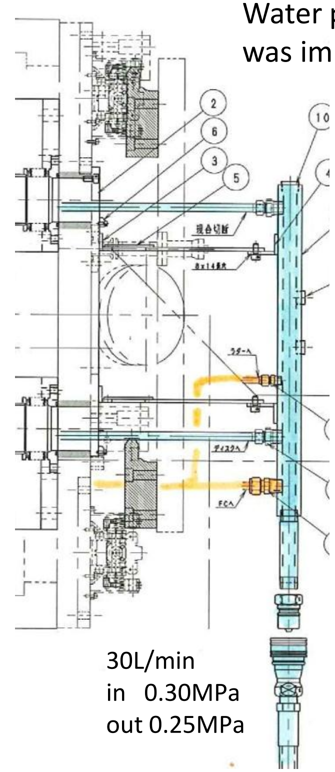


2010





Water pipe connection was improved



30L/min
in 0.30MPa
out 0.25MPa

SP coupler

nitto-kohki.co.jp

Power & signal cables:
Multi-contact connector

Multi-Contact MC
CombiTac STÄUBLI GROUP
multi-contact-usa.com

Summary

- The target system and the beam dump system which cope with ^{238}U 1pμA beam (83kW) have been designed and constructed. Features are described.
- The target and beam dump are operated without severe trouble although available beam intensity is less than1/10 of goal intensity.
- Evaluations of the temperature of target and beam dump at a current beam intensity are important to prove the thermal performance of the target and the beam dump at the high beam intensity.
- Improvement of the maintenance system is progressing .