Operational Experiences of High-Power Production Target and High-Power Beam Dump at BigRIPS separator at RIKEN RI beam factory

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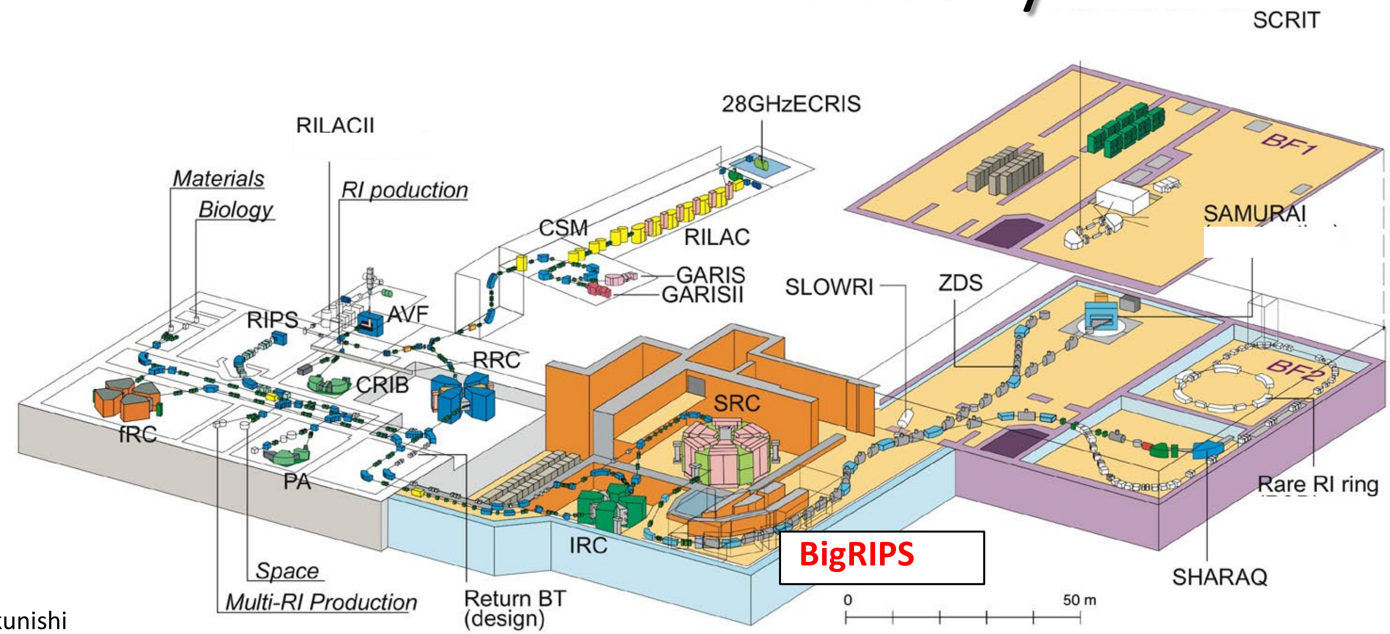
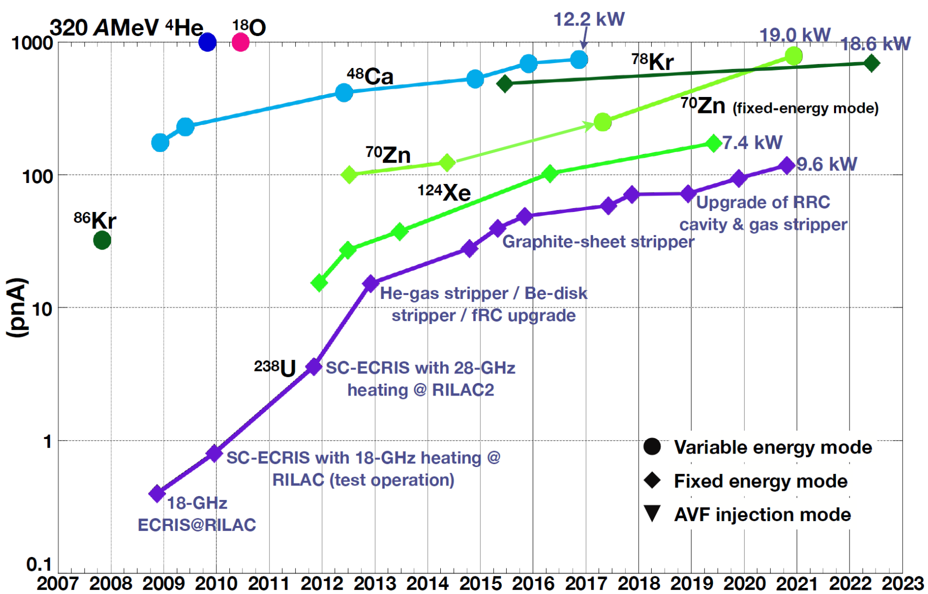
EMIS 2022, Daejeon, South Korea

RIKEN RI-beam factory



Courtesy of N. Fukunishi
As of summer 2022



Beam energies of the beams without explicitly indicated are 345 AMeV.

Operation of RIBF started in 2007

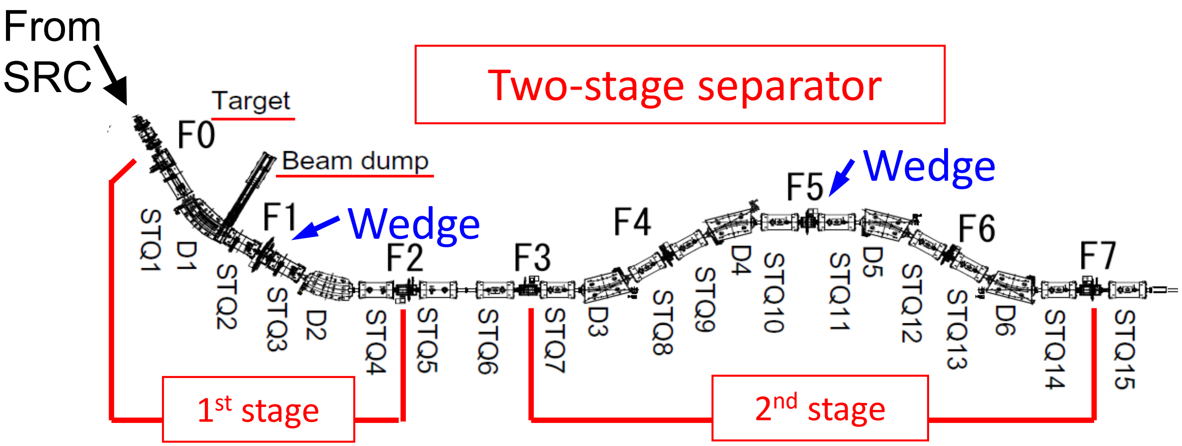
Goal : Intensity is 1puA for all ions up to ^{238}U
Energy is 345MeV/u for heavy ions up to ^{238}U

^{238}U 345MeV/u, 1puA : 82kW

Present : Intensities increase year by year
1/4 Goal beam power is achieved

^{238}U 345MeV/A, 117pnA : 9.6 kW
^{124}Xe 345MeV/A, 173pnA : 7.4kW
^{78}Kr 345MeV/A, 690pnA : 18.6 kW
^{70}Zn 345MeV/A, 790pnA : 19.0kW
^{48}Ca 345MeV/A, 737pnA : 12.2 kW
^{4}He, ^{18}O 1puA…

BigRIPS Fragment Separator



Production & separation

Particle identification & two-stage separation

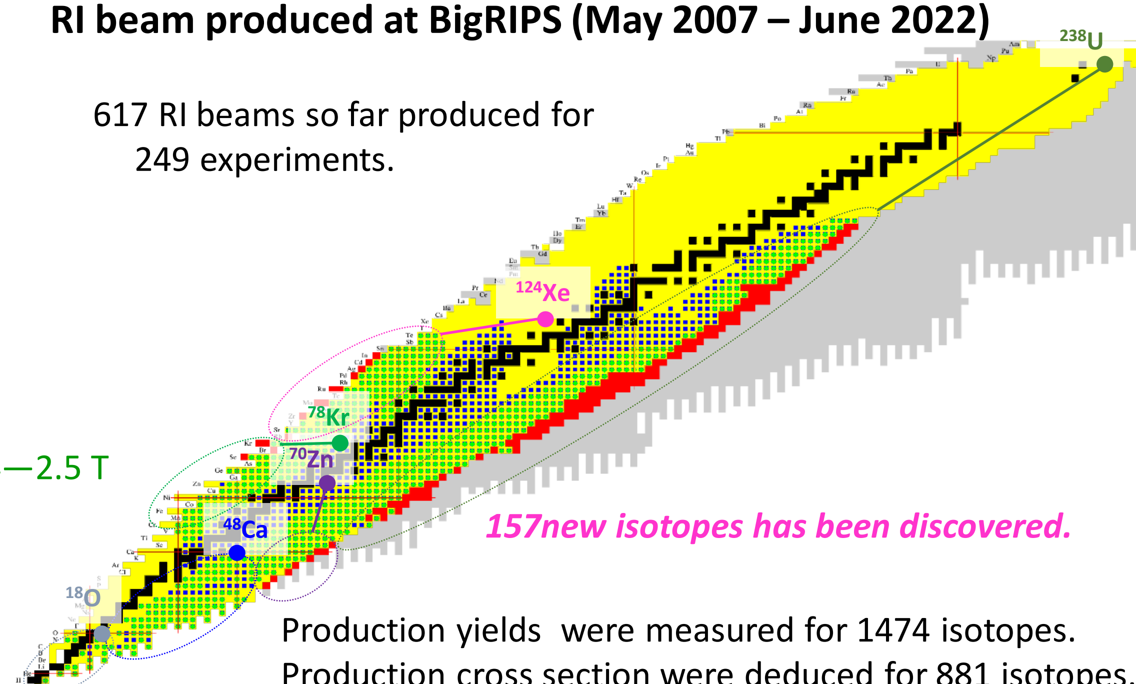
Photo of 2nd stage

Production of RI beams

- Projectile fragmentation
- In-flight fission of ^{238}U beam

RI beam produced at BigRIPS (May 2007 – June 2022)

617 RI beams so far produced for 249 experiments.



Production yields were measured for 1474 isotopes.
Production cross section were deduced for 881 isotopes.

Major features of BigRIPS

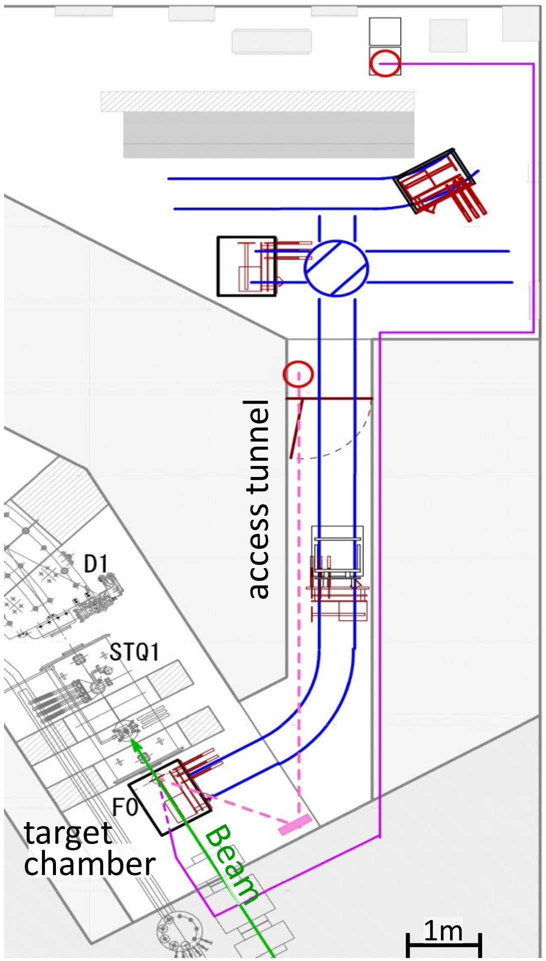
- Large acceptances ±50 mr, ±3%
- Superconducting quadrupoles
- Pole-tip radius = 17 cm, pole tip field = 2.4—2.5 T
- Two-stage separator scheme
- 2nd stage with high resolution
- Max. Rigidity Bρ = 9 Tm

BigRIPS Target System

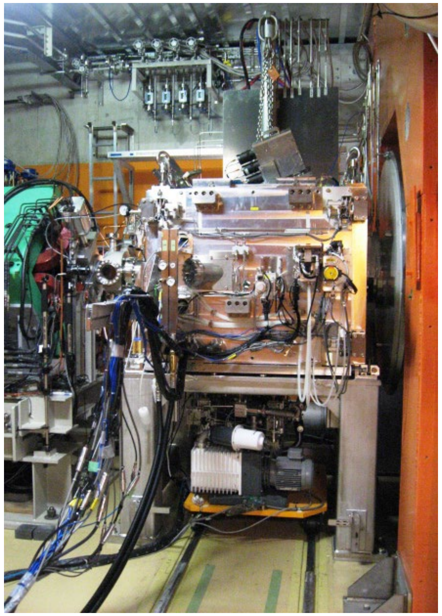
Designed, constructed in 2002 – 2011
by Dr. A.Yoshida and Dr. T .Kubo
NIMA521(2004)65, NIM A590(2008)204
NIM A655(2011)10

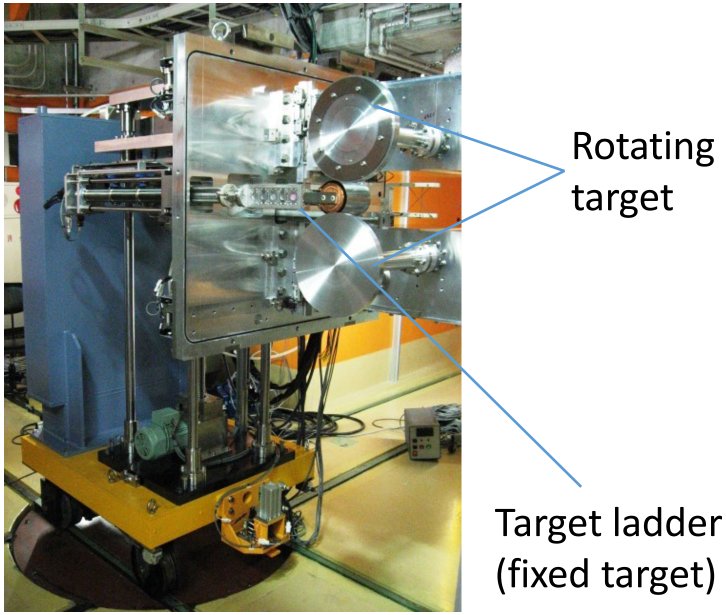
Water-cooled rotating target that use conduction cooling to the cooling water, not radiation cooling.

It is intended to use Be as a production target.
Be has higher RI beam productivity than C, but Be has lower melting point (1287°C) than carbon's 3642°C

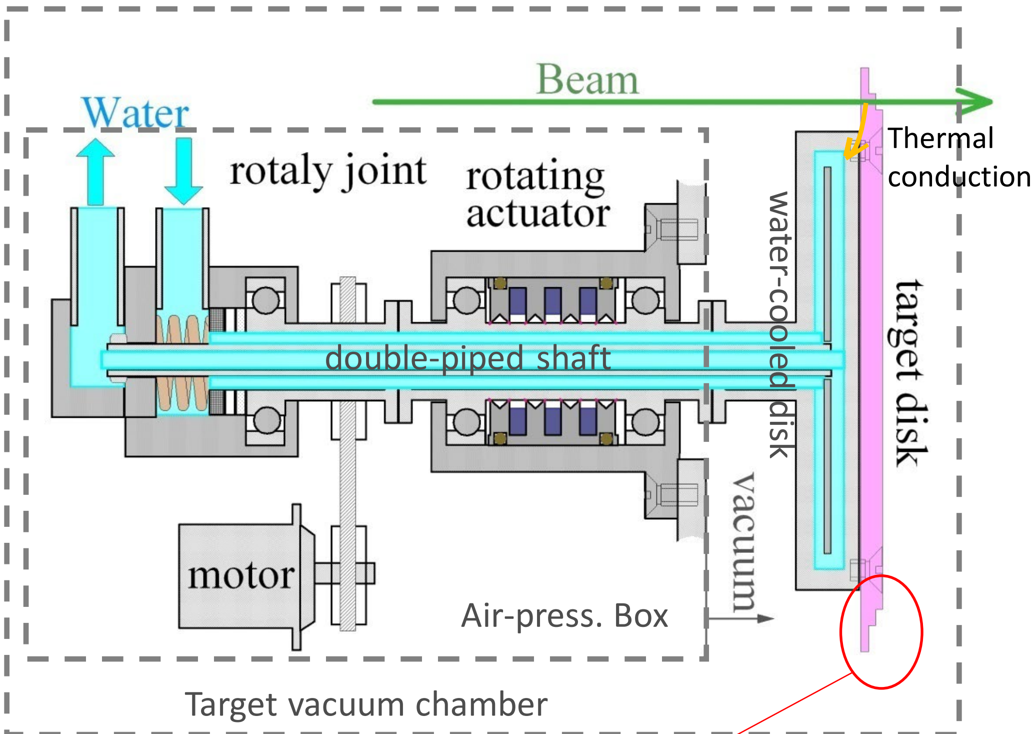


-Two rotating target units and one target ladder (fixed target) are mounted on the side flange.
-The side flange can be carried out by the maintenance cart for maintenances.





Schematic view of water-cooled rotating target

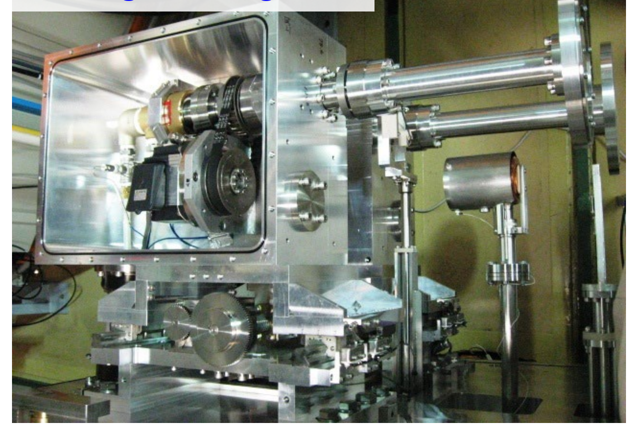


Step structure:
One disk has
three different thicknesses.

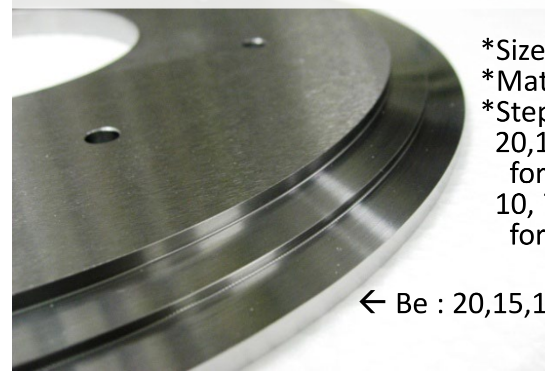
(Components)

- Rotating solid target disk
  to dissipate the heat of the beam spot
- Water-cooled disk
  to remove heat from the target disk
- Rotating actuator & motor
  to rotate the disks in high speed ~ 500rpm
  Rotating actuator: radiation tolerance 1.8 MGy
  A. Yoshida et. al. NIM A590, 204(2008)
- Double-piped shaft & rotary joint
  to introduce cooling water into the water-cooling disk.

Rotating disk target unit



Disk target : for High-power beam

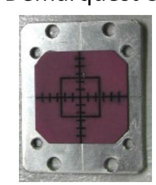


*Size : ϕ30cm
*Material : Be, W
*Step shaped edge
20,15,10 mm thick
for N, Ca, Ar beams
10, 7, 5 mm thick
for Kr, Xe, U beams

← Be : 20,15,10 mm thick

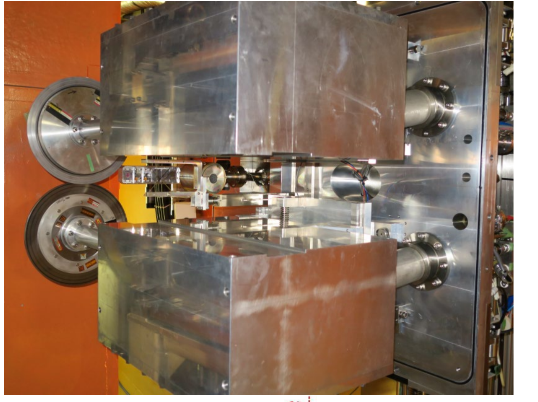
Ladder target : for Low-power beam

Beam viewer
Demarquest Co.



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

Operation of Rotating Target



Since 2015 Fall, rotating targets were mainly used for experiments.

Two set of side flanges were used alternately.

Be with 2-4-5 mm thick for ^{124}Xe, ^{238}U Beam

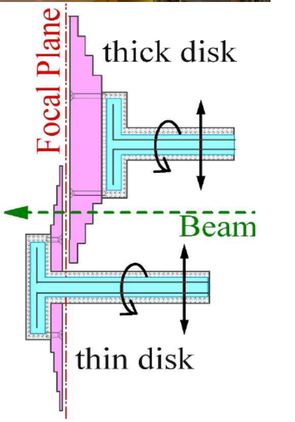
5-7-10 mm thick for ^{70}Zn, ^{78}Kr, ^{124}Xe, ^{238}U Beam

10-15-20 mm thick for ^{48}Ca, ^{70}Zn Beam

From 2018 Fall, Be 1-2-3, 4-6-8 mm thick target mounted on one side flange.

Overlapping use: 1 – 11 mm, 1 mm step for all primary beams

thick target (20, 30mm) for ^{18}O Beam mount on target ladder (fixed target)

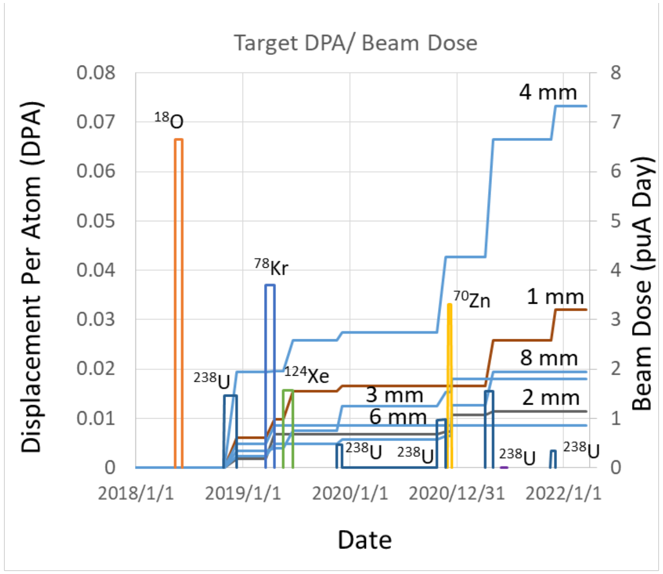


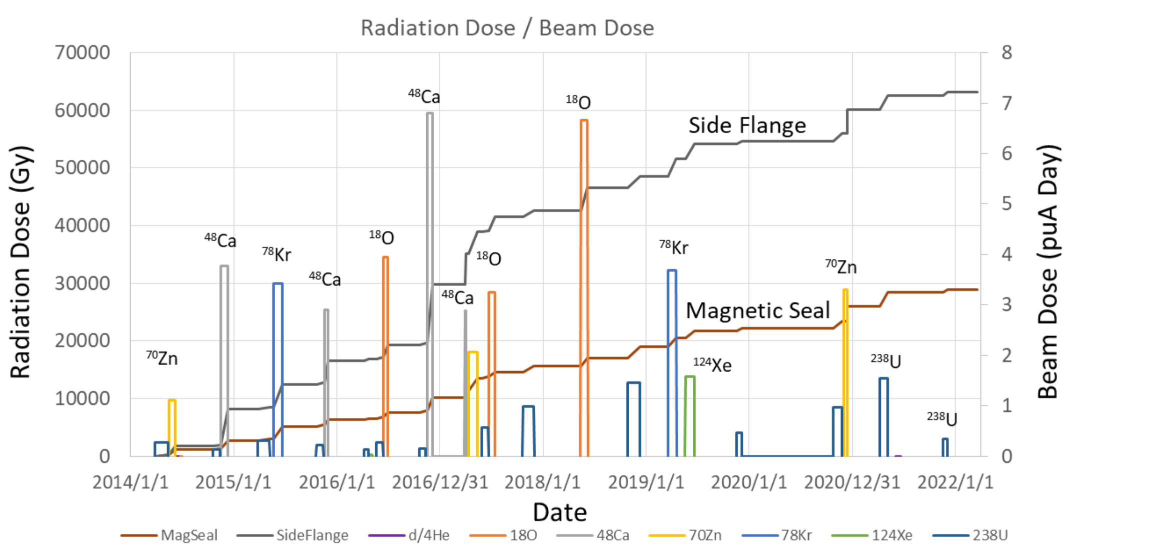
Radiation Damage of target components: PHITS estimation 1pμA ^{238}U irradi.

Target :	4mm thick 1.8×10^{11} Gy, 7.3×10^{-2} DPA	< 10-20 DPA	50-100 days
Rot. Actuator:	29 kGy	< 1.8 M Gy	900 days*
Side Flange(O-ring):	63 kGy	< 1 M Gy (EPDM)	500 days*

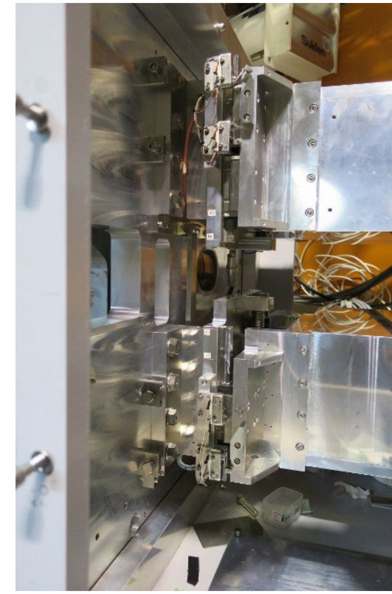
No deterioration was observed.

*with 8mm thick target





Troubles encountered so far



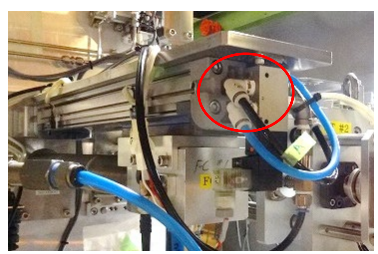
No serious trouble but….

- Positioning Motor of the rotating target unit Jan. 2019
  strange sounds (used since 2010)

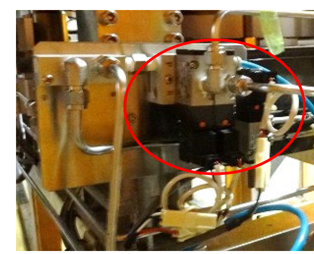
- Rotating actuator Feb. 2016
  worn bearing (used since 2008)

- Solenoid valve of pneumatic actuator
  air leakage from O-ring --- normal rubber (NBR) <100 kGy

Vacuum Gate Valve
Aug. 2022



Faraday CUP
Mar. 2019,
Feb. 2021



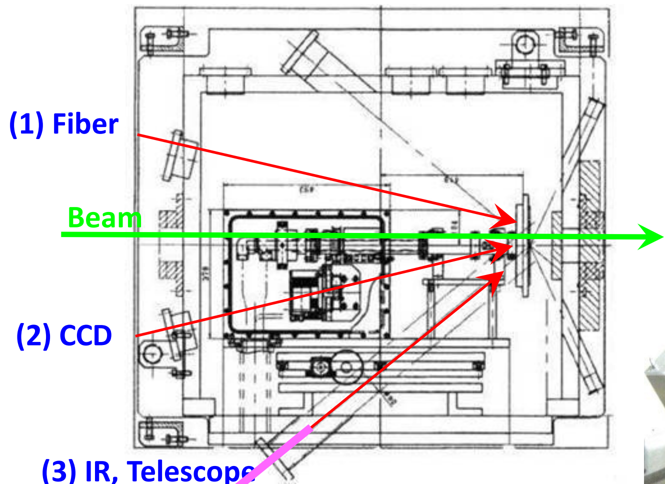
Vacuum UNIT
June 2017,
Feb. 2021

- Turbo-Molecular Pump of Target Chamber
  sensor failure May 2022

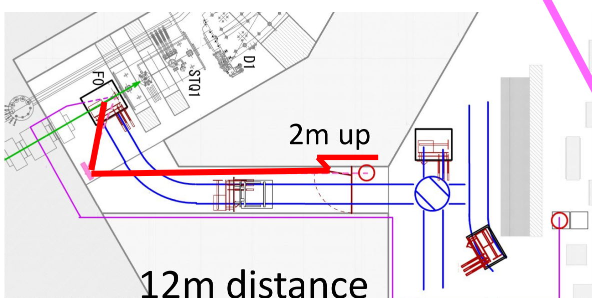
Beam-spot temperature measurement

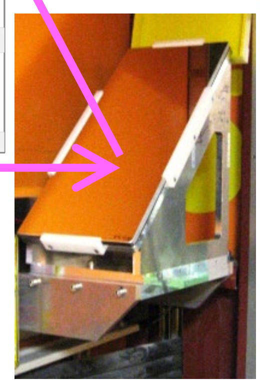
IR thermal image camera

Target chamber (upper view)

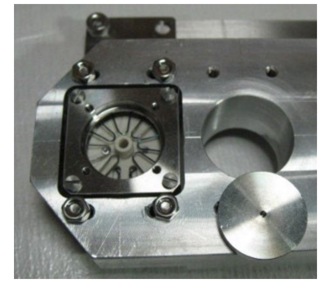


IR camera:
TVS-8500 AVIO (Japan)
Very weak for radiation
Can be used only for a short time.





Calibration of Temperatures
- Emissivity
- attenuation in window mirrors, air

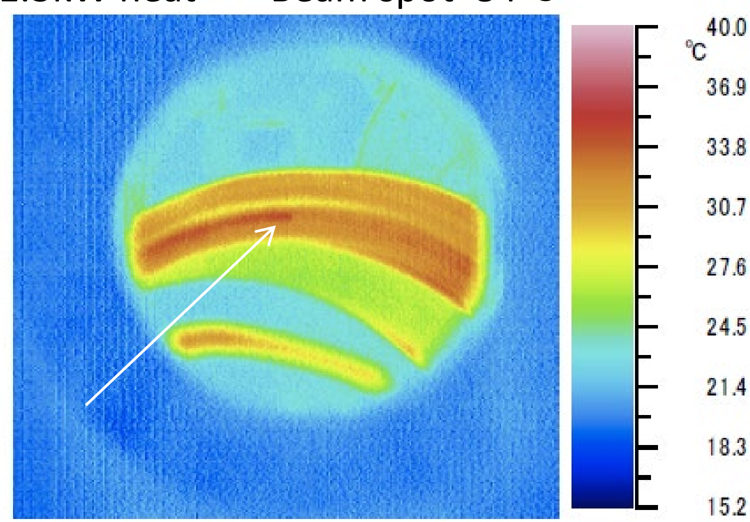


Heater + Be plate
+ Thermocouple

Rotating target

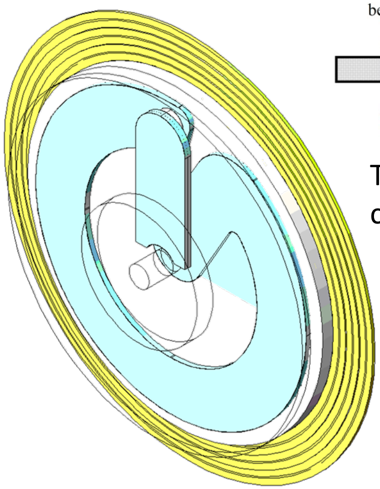
reduced rotation speed

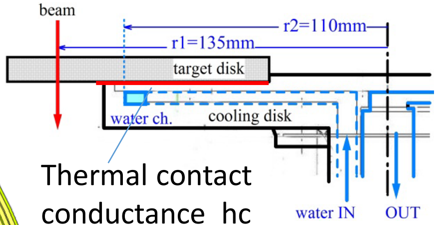
Be 15mm, 48Ca 420pnA, 100rpm
1.3kW heat -> Beam spot 84℃



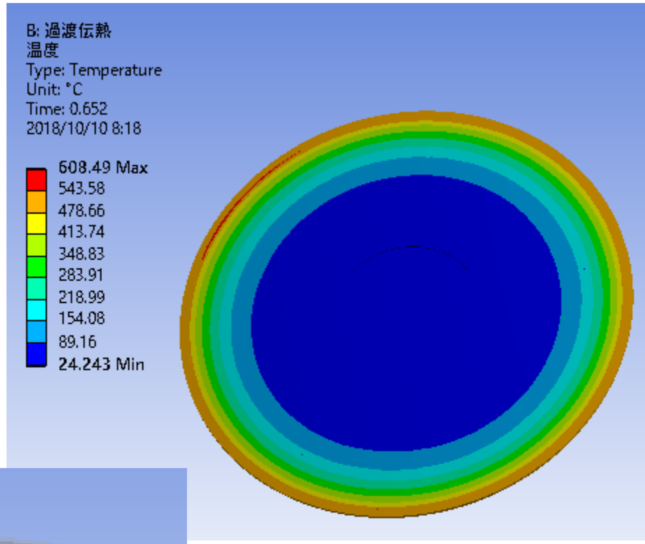
Simulation of Rotating target

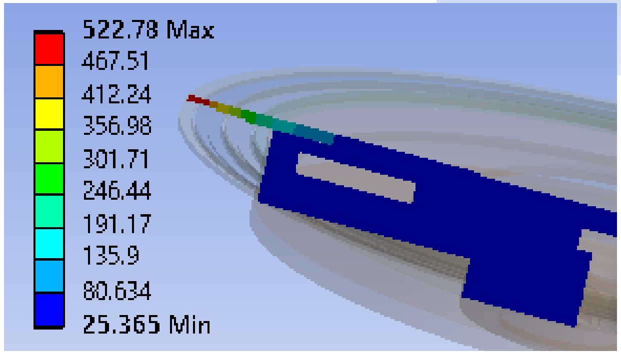
- ANSYS workbench is used for simulation.
- Moving source method was utilized for rotating motion.
- 1mm x 1mm Beam spot is assumed.
- Cooling-water channel is precisely described in the model.
- Heat transfer coefficient hw between cooling-water and wall of cooling channel
  Smooth tube with hydro-dynamic diameter, turbulence flow
  V= 1.5 m/s P= 0.4MPa, T=24℃
  -> hw = 7.2kW/m^2@25℃, 8.5kW/m^2@100℃
- Thermal contact conductance hc between Be target and cooling disk.
  Estimated from contact pressure between the target and the disk
  (fixed screw M6 x 8) hc = 3 kW/m^2
- Radiation cooling is considered. Emissivity 0.5





Thermal contact conductance hc

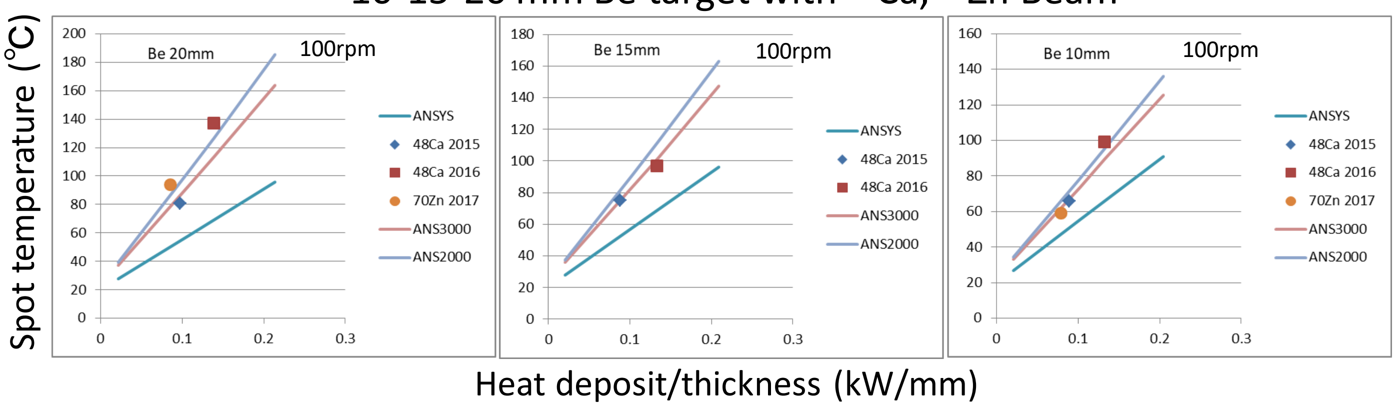




Spot temperature 608℃

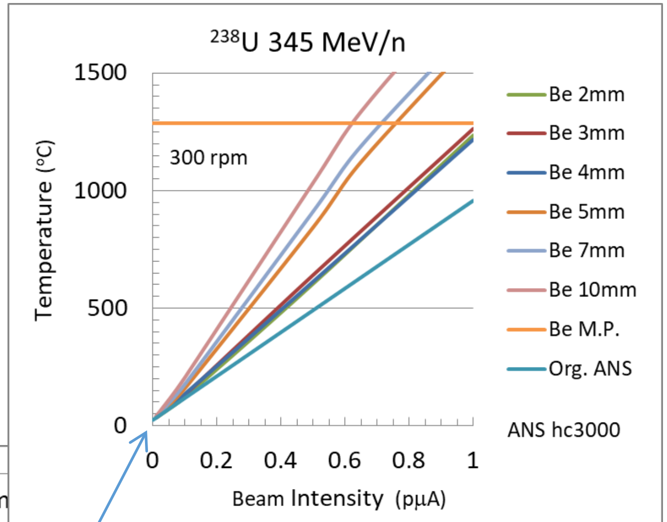
Be 2-3-4mm thick target,
300rpm rotation
^{238}U beam with 345MeV/u,
500 pnA irradiates 2 mm

Comparison of measured temperature
10-15-20 mm Be target with ^{48}Ca, ^{70}Zn Beam



Three Hc:
ANSYS no Hc effect
ANSYS2000 2kW/m^2
ANSYS3000 3kW/m^2

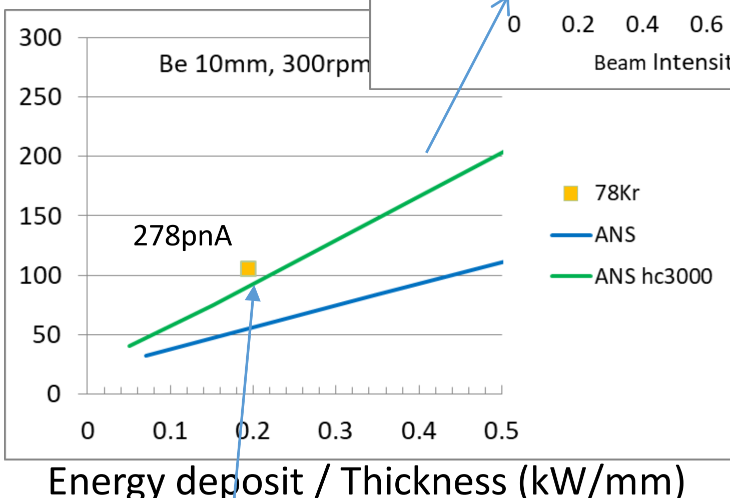
Cooling capacity of the rotating target

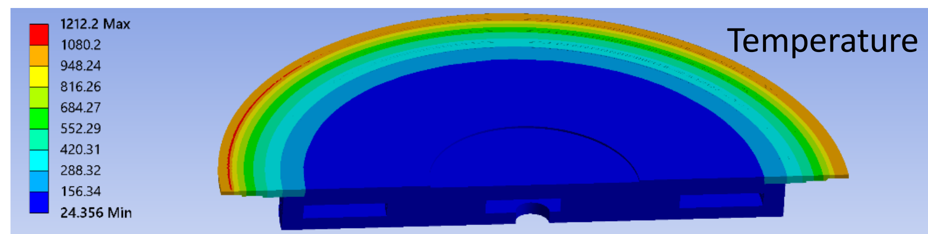


The target will be operated at 300 rpm for high Intensity beams.

2-3-4 mm Be target can barely withstand 1puA ^{238}U beam.

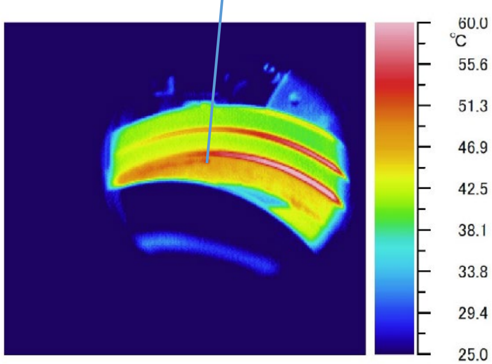
5-7-10 mm Be target max ~500pnA





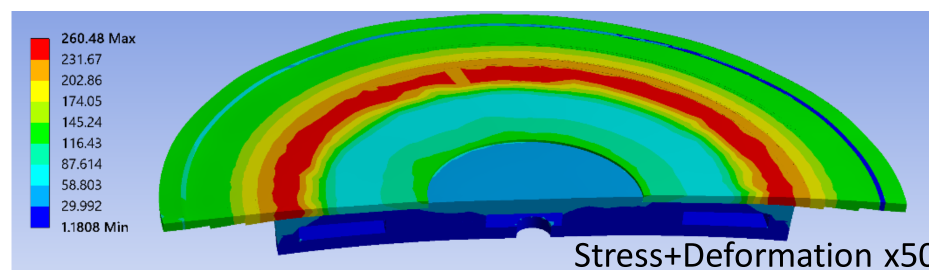
Max Temperature 1080 °C　　Melting Point 1280 °C

von Mises stress 260 MPa　　Ultimate tensile stress 440 MPa



^{78}Kr 278pnA on 10mm Be

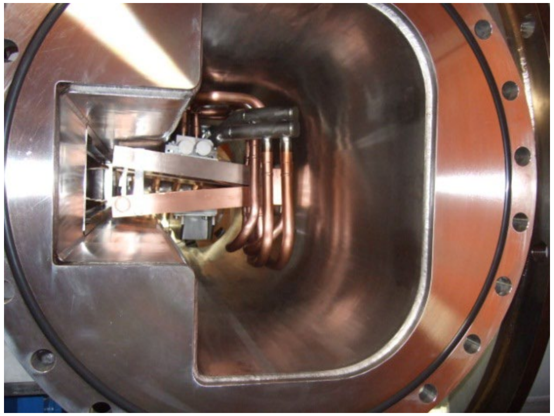
5-7-10 Be disk

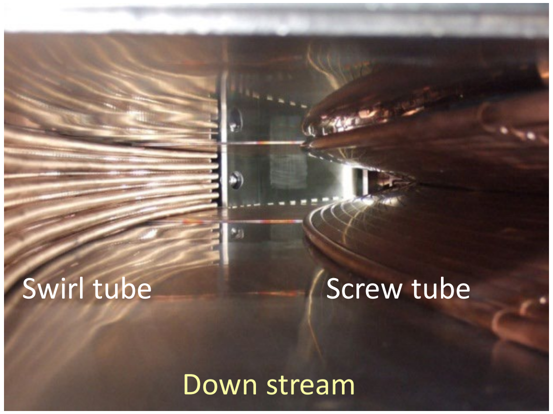


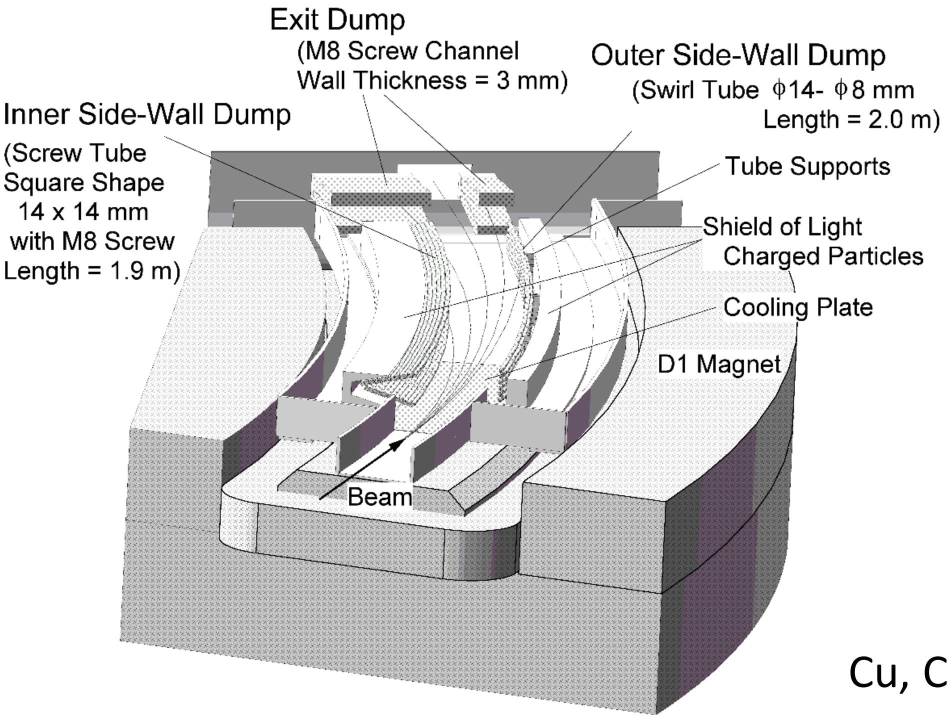
Need to check with higher intensity beam.

Water cooled stationary Beam Dump

Designed by T. Kubo, H. Mizoi, and N.Fukuda



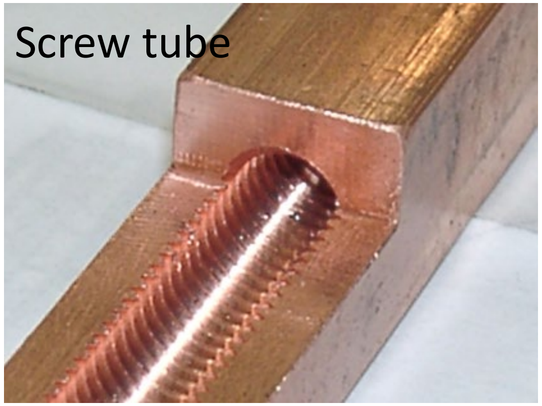




^{238}U 345MeV/n
1pμA
82kW
Max 1GW/m^2
Tilted Wall
100MW/m^2

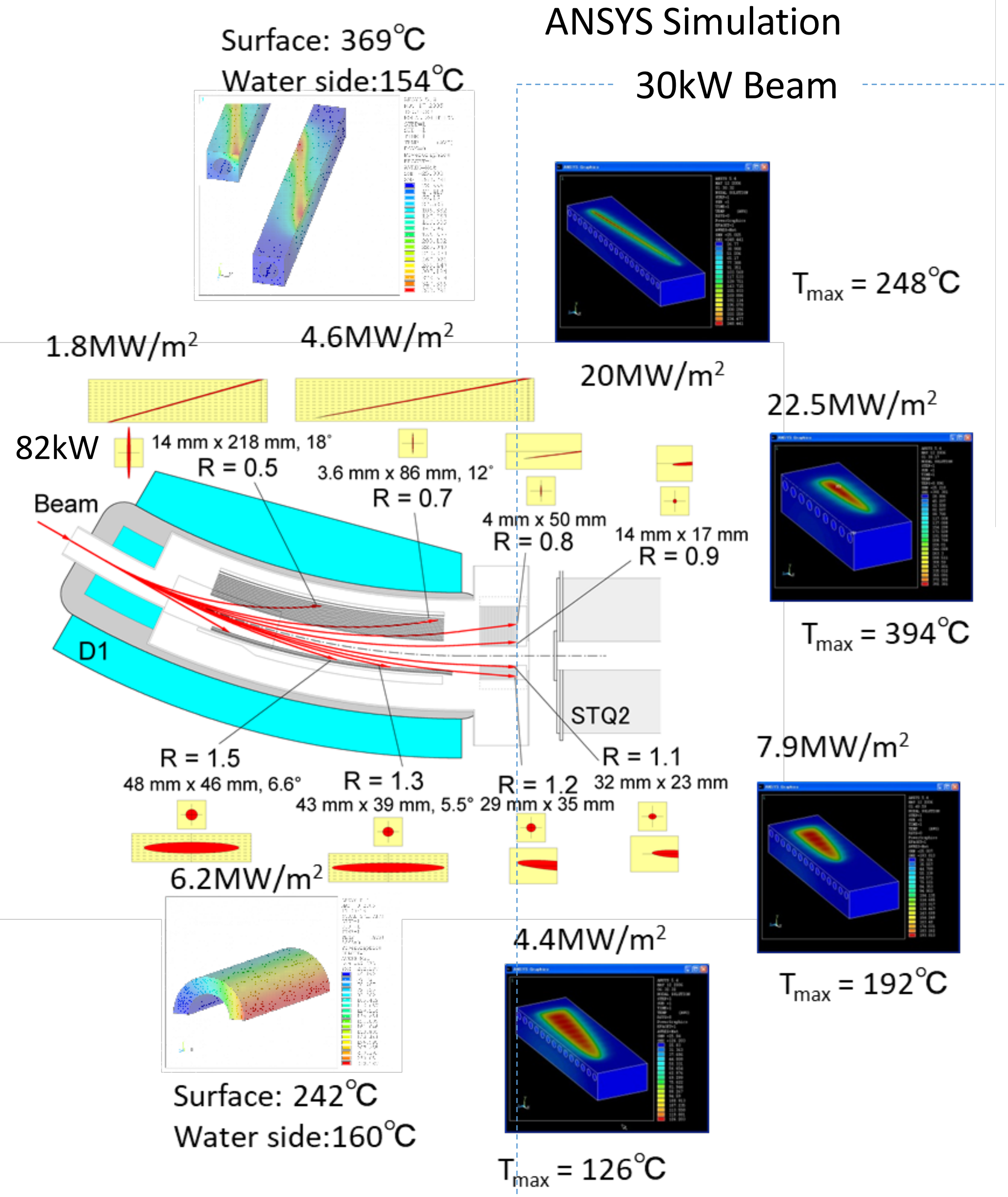
Cu, Cu-Ag, Cu-Cr-Zr

Cooling tubes with a high heat transfer coefficient.



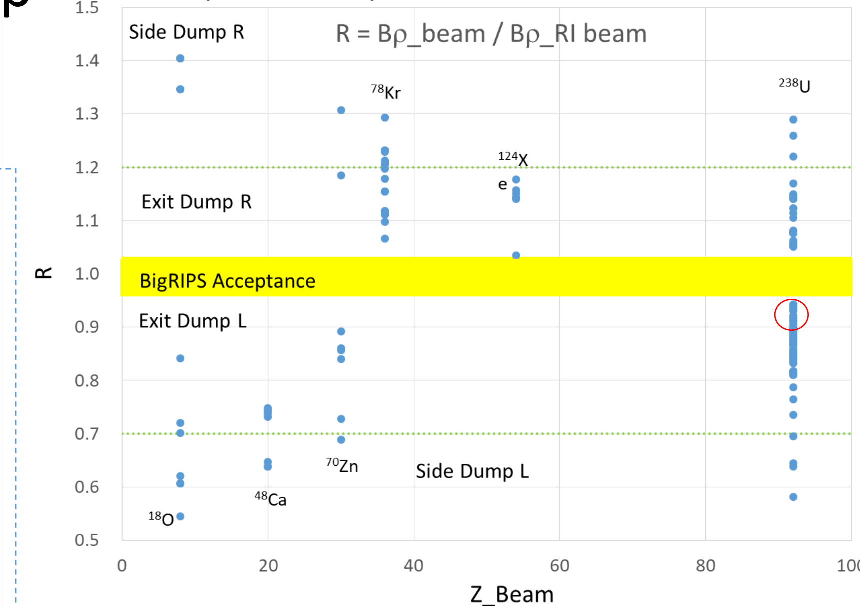
Cooling Capacity of the Beam Dump

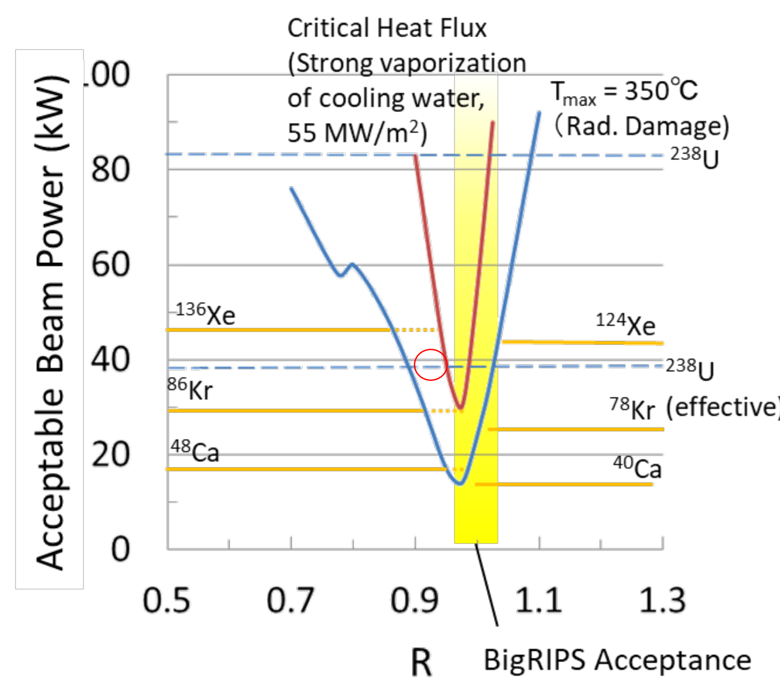
R = Bρ_beam / Bρ_RI Beam



Beam size at F0: ϕ 1mm, 3π mm mrad, 3mm wall thickness

Experiments performed in 2016-2022





^{238}U: Charge sate distribution 89+, 90+, 91+

^{48}Ca 345MeV 500pnA (8.3kW) Beam Test

Beam was stopped near the thermocopule mounted on exit beam dump.
(Beam Brho / D1 Brho =0.845)

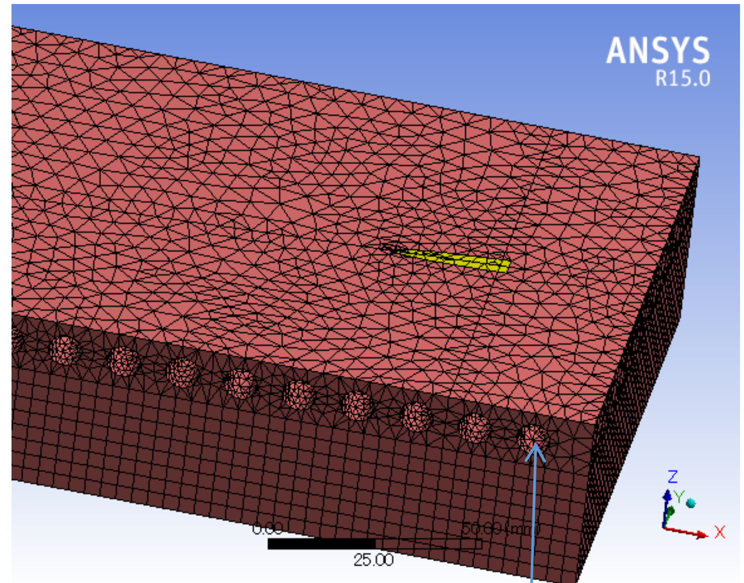
Beam Spot: estimated from the beam emittance measured at F2

F0 in σ x: 0.74mm, 3.3 π mm mrad

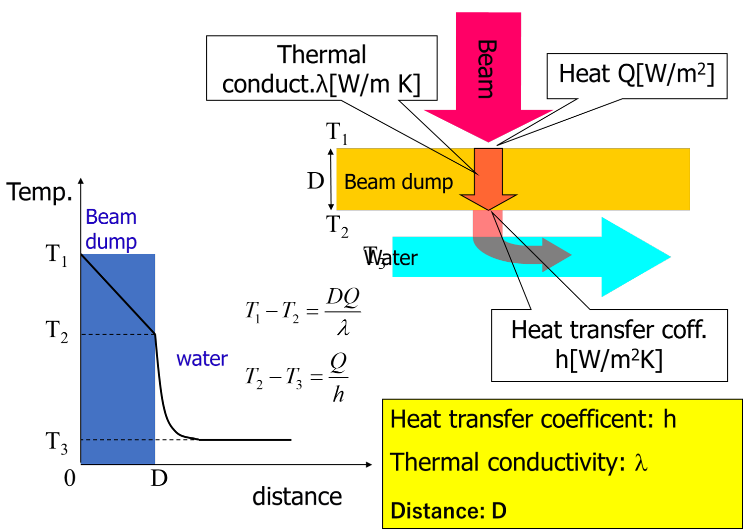
y: 0.45mm, 1.9 π mm mrad

Tuning STQ1 Field: three different spot sizes

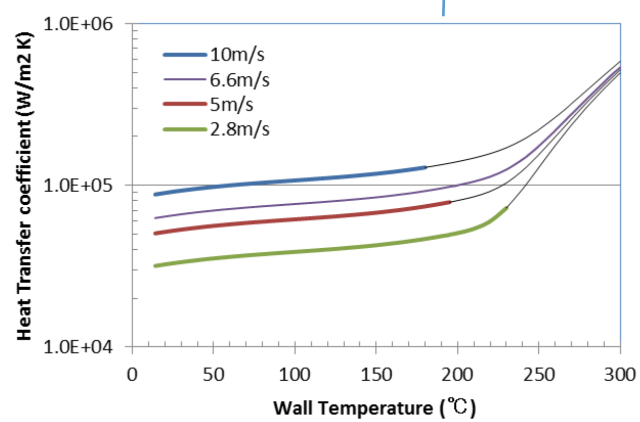
x x y : 4.5 x 141, 8.8 x 28.1, 1.9 x 23.6



Thermal Conductivity: Cu-Cr-Zr 320 W/m K
http://conductivity-app.org/



Heat Transfer Coefficients



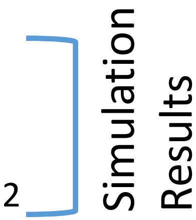
Heat transfer coefficients are calculated by using empirical formula.

J. Boscary et al., Fusion Eng. Des. 43 (1998) 147

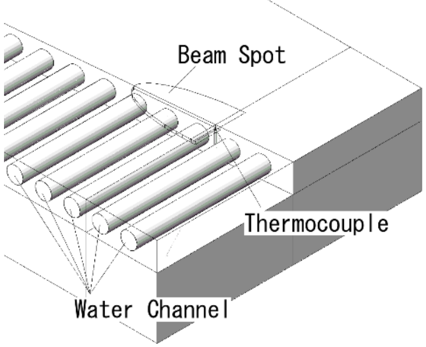
K. Masaki et al., Fusion Eng. Des. 61-62 (2002) 171

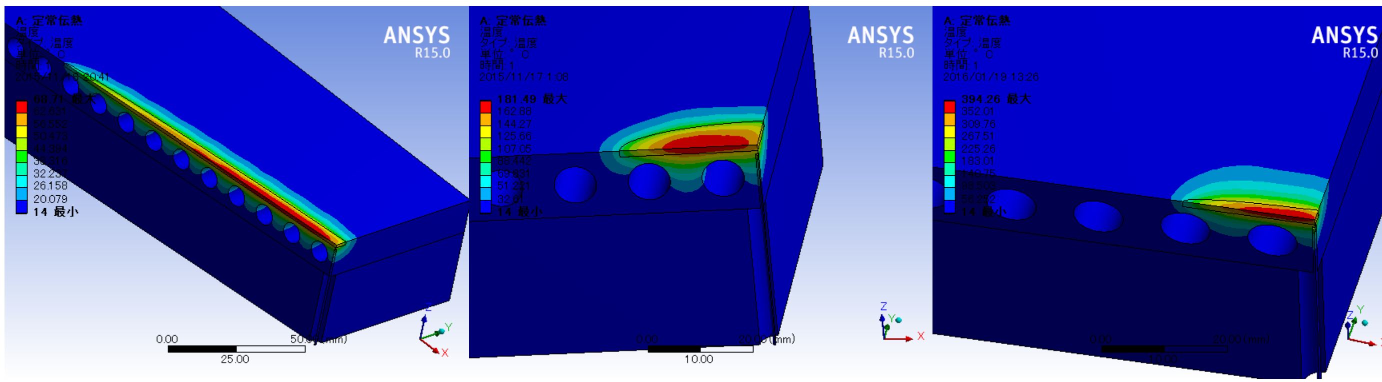
Temperature measurement with ^{48}Ca 345MeV/n 500pnA (8.3kW)

Beam spot size	4.5x141	8.8x28.1	1.9x23.6
Heat density (MW/m^2)	3.88	10.1	53.5
Cooling water speed (m/s)	10	10	10
Max. Temp (℃) :	68.7	182	394
Max. Temp at cooling channel(℃) :	44.2	129	179
Thermocouple Temp.(℃) :	37.43	96	168
Max heat flux at cooling channel(MW/m^2):	2.99	9.32	23.2

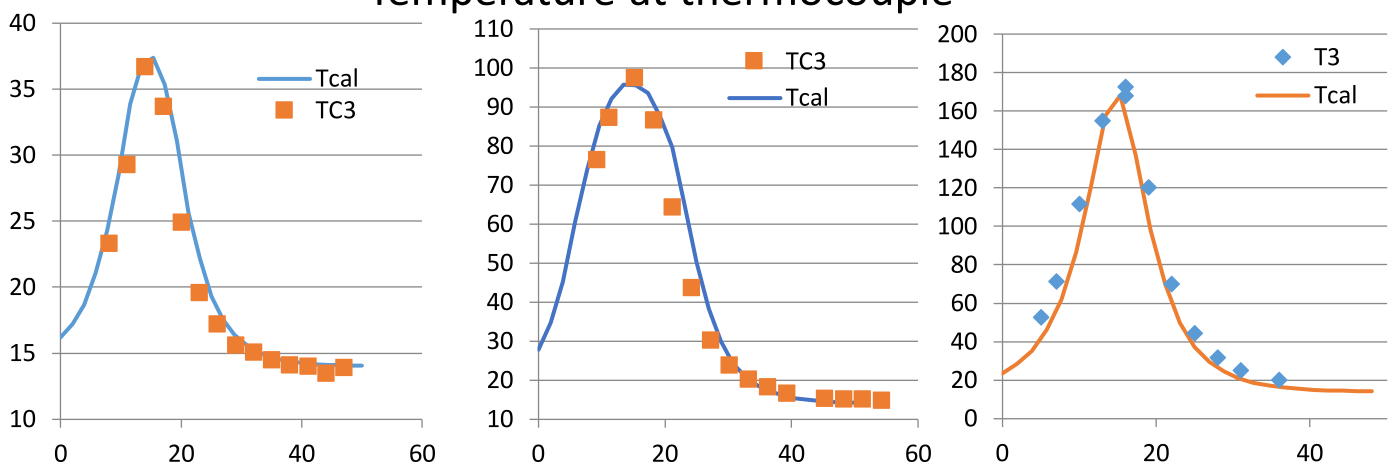


Thermo-couples mounted on the exit beam dump



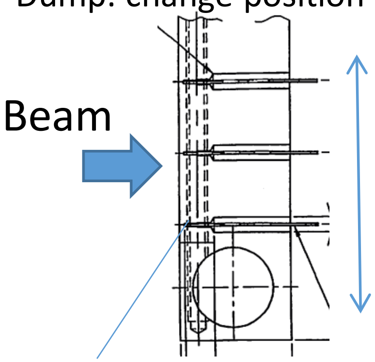


Temperature at thermocouple



Dump position

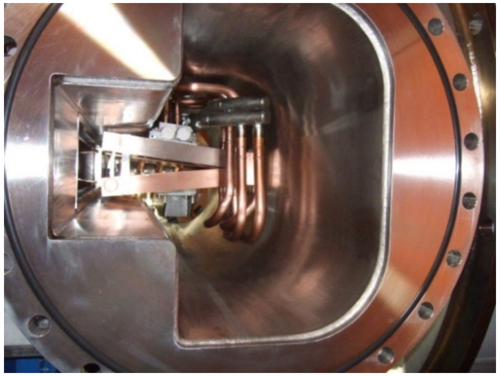
To get temperature profile,
Beam: fixed position
Dump: change position



3 mm behind the surface

Good agreement between the measurements and the simulations

Surface temperature measurement



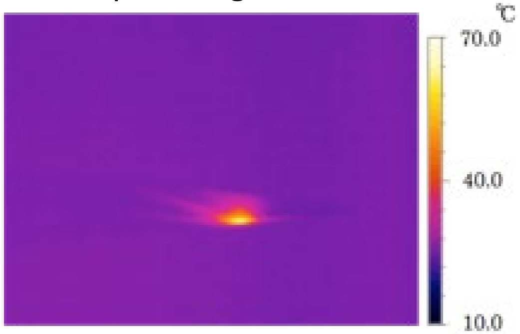
Exit beam dump
(Cooling water :10m/s 1MPa)

Surface temperature of the exit beam dump (highest temperature) was measured with the infrared thermal camera for ^{48}Ca beam with 345MeV/u, 0.5puA (8.3kW).

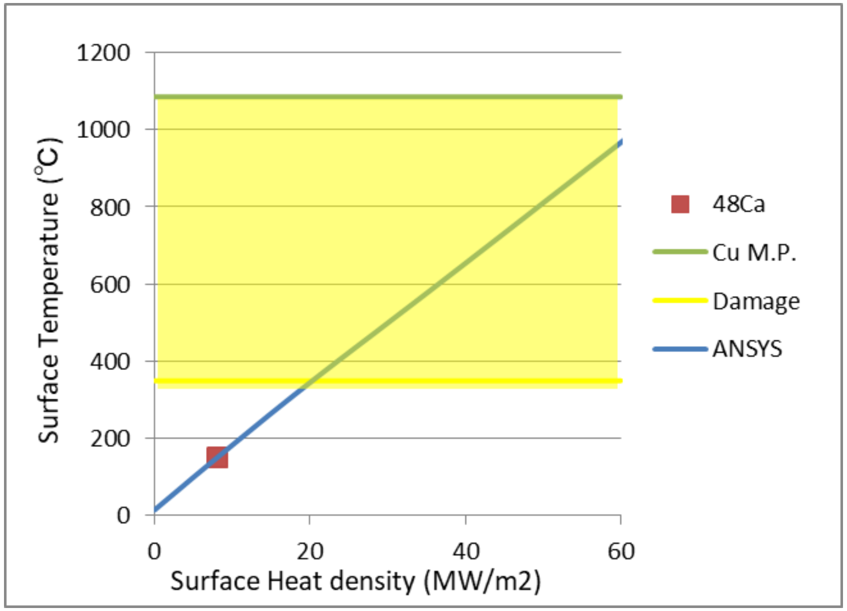
Due to the strong radiation from the dump, the camera only works within 1 min.

Observed temperature is well reproduced by the ANSYS beam dump model which used in the beam dump design.

Beam Spot Image of Therm. Cam.



^{48}Ca beam with 345MeV/u, 0.5puA



Spot size: X 30mm, Y 22mm

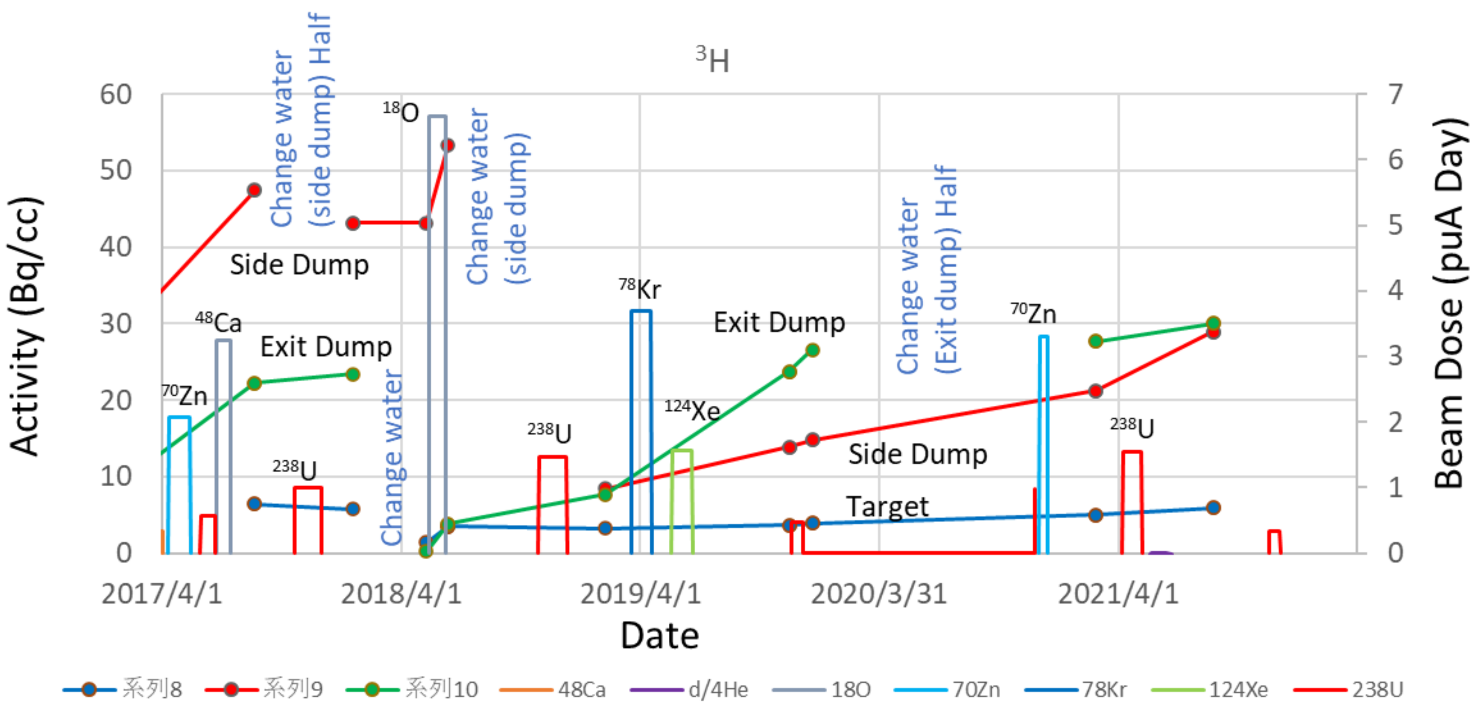
Max temp. 65℃(raw) → 150℃ (emissivity correction)

Heat density of 20 MW/m^2 corresponds to ^{238}U 345MeV/u 0.25 puA without target.
0.5 puA with a target

For 1puA ^{238}U beam, dedicate dump is necessary. (This is originally expected.)

Activation of Cooling water of target and beam dump

- Dedicated cooling water system for
  Target, Side Beam Dump, Exit Beam Dump
- They have own ion exchanger cell.
- De-oxygen system was installed in the Exit Beam Dump system to reduce erosion/corrosion
- Activity of the cooling water is measured by radiation control group.
  Main activity is ^3H.
- We change cooling water before ^3H activity exceeds 60 Bq/cc which corresponds the effluent limit of wastewater.



Summary

- Production Target
  - System structure is briefly reported.
  - Radiation Dose are estimated : Still small enough against the Radiation Damage
  - Measurement of Beam Spot Temperature and ANSYS simulation
  - Cooling Capacity :
    1-2-3mm Be target withstands ^{238}U 1pμA Beam
    To obtain the concrete result, test with higher beam intensity is necessary.
- Beam Dump
  - System structure and design are briefly reported
  - Cooling Capacity:
    Dump temperature were measured with thermocouple and infrared camera with ^{48}Ca 500 pnA beam. (8.2kW beam power)
    Results are well reproduced by ANSYS simulation.
    suggesting the beam dump has the cooling capacity as we designed.
- Activation Cooling water
  - Activation of cooling water of the target and beam dump is reported.