Radiation Evaluation in RIBF

RIKEN Nishina Center

K. Tanaka, N. Inabe, K. Yoshida K. Kusaka, T. Kubo, A. Akashio,
and Y. Uwamino

Outline

Introduction: RIBF accelerator facility

  Radioactive Isotope beam production

  Measurement and PHITS calc.

Radiation evaluation and comparison with PHITS calc.:

  A, Neutron dose

  B, Heat load

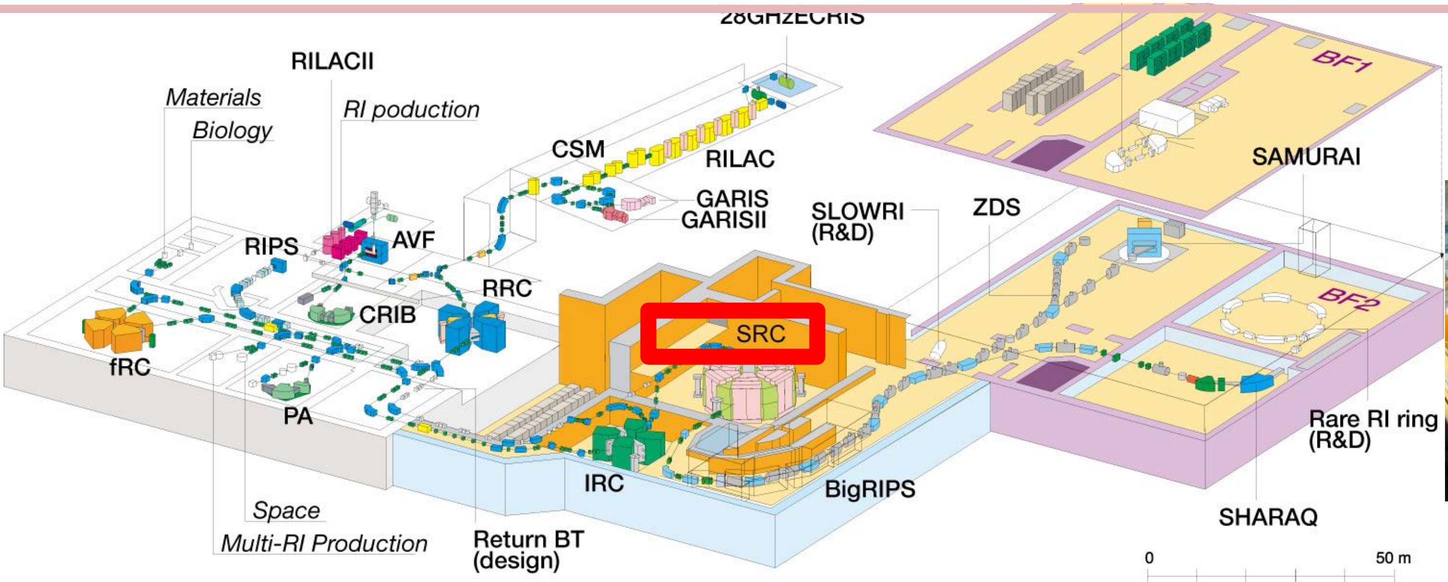
  C, Residual radioactivity

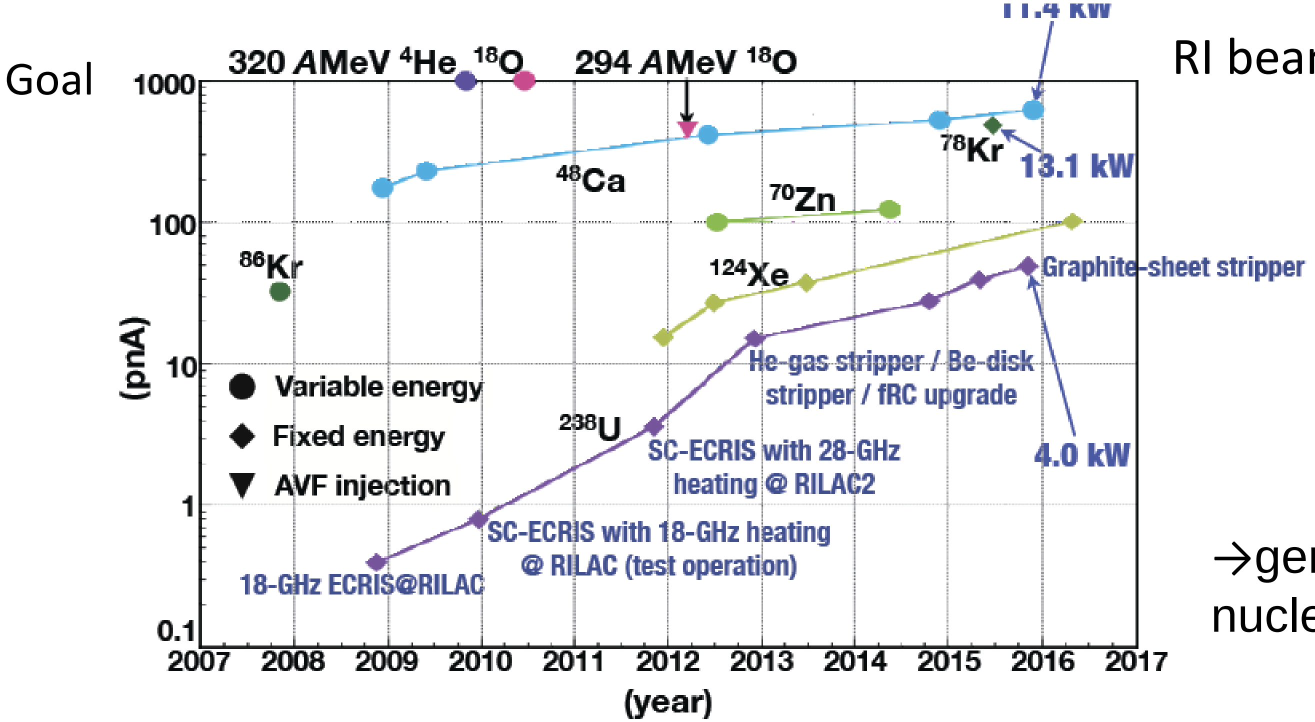
High energy beam

  D, Radioactivity at low energy beam

Future plan

Radioactive Isotope Beam Factory (RIBF)



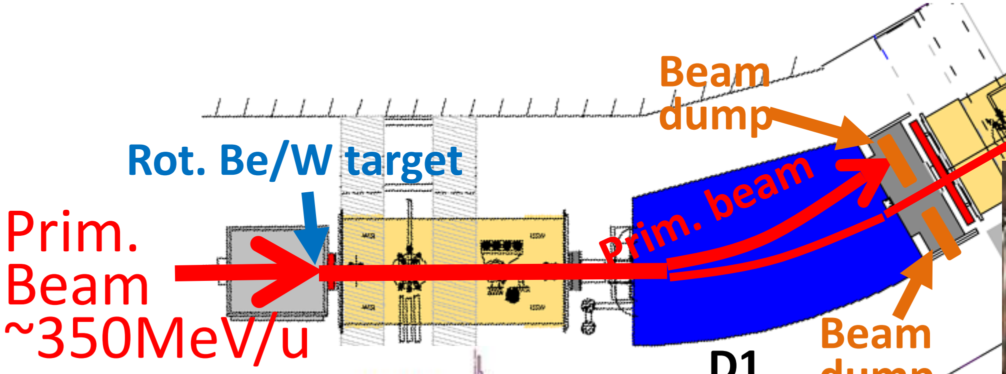


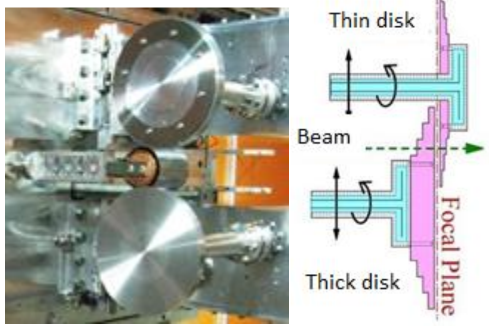
RI beam facility using Superconducting Ring Cyclotron (SRC).

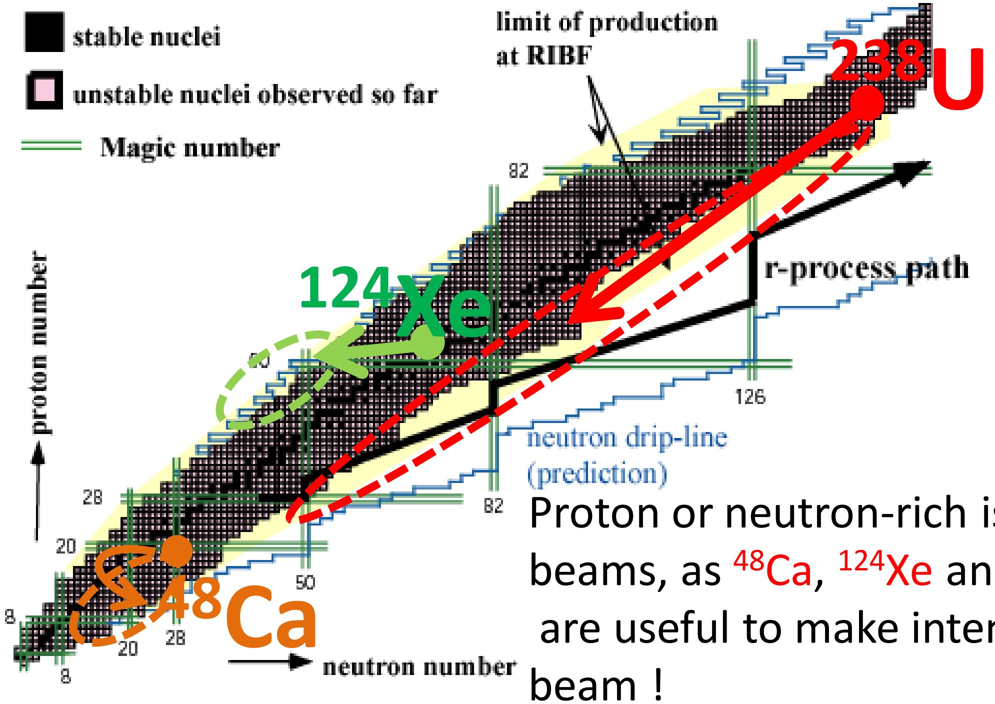
- Operation of RIBF started in 2007.
- Maximum energy is ~350MeV/n for heavy ions up to ^{238}U
- Goal intensity is 1 pμA (82kW at ^{238}U) for all ions.
- Beam intensities increase year by year.
- 1/6 of Goal beam power is achieved.

→generate variety of radioactive isotopes (RIs) to study nuclear, nuclear astrophysics and etc.

RI beam production

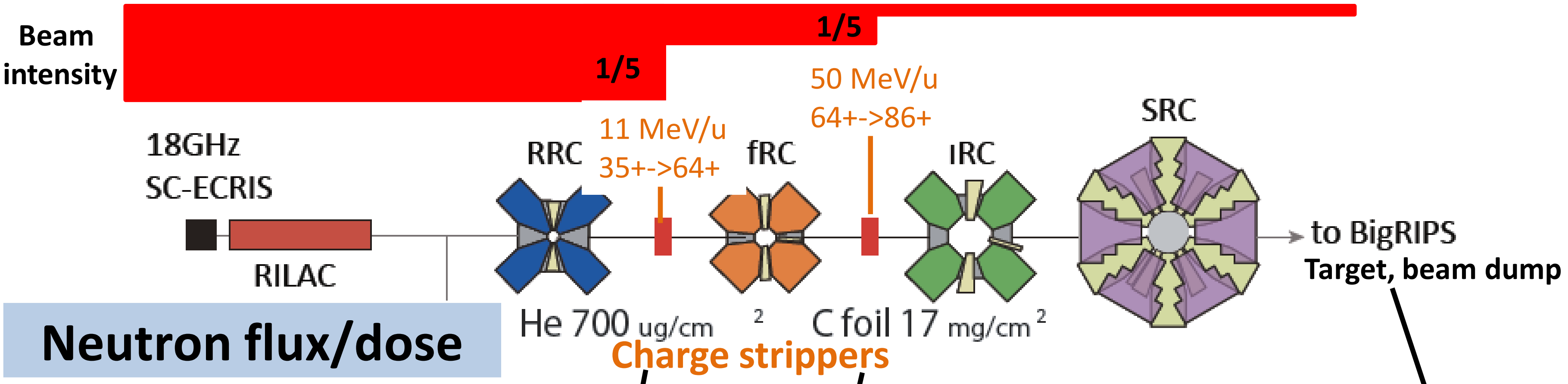






Proton or neutron-rich isotope beams, as ^{48}Ca, ^{124}Xe and ^{238}U are useful to make intense RI beam !

Radiation Evaluation at RIBF over the past decade



Neutron flux/dose

Heat Load

Activation/residual dose

11 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{238}U + He gas stripper	**Neutron flux (Bi sample)**	**~1**
	Activation	**0.5~2**

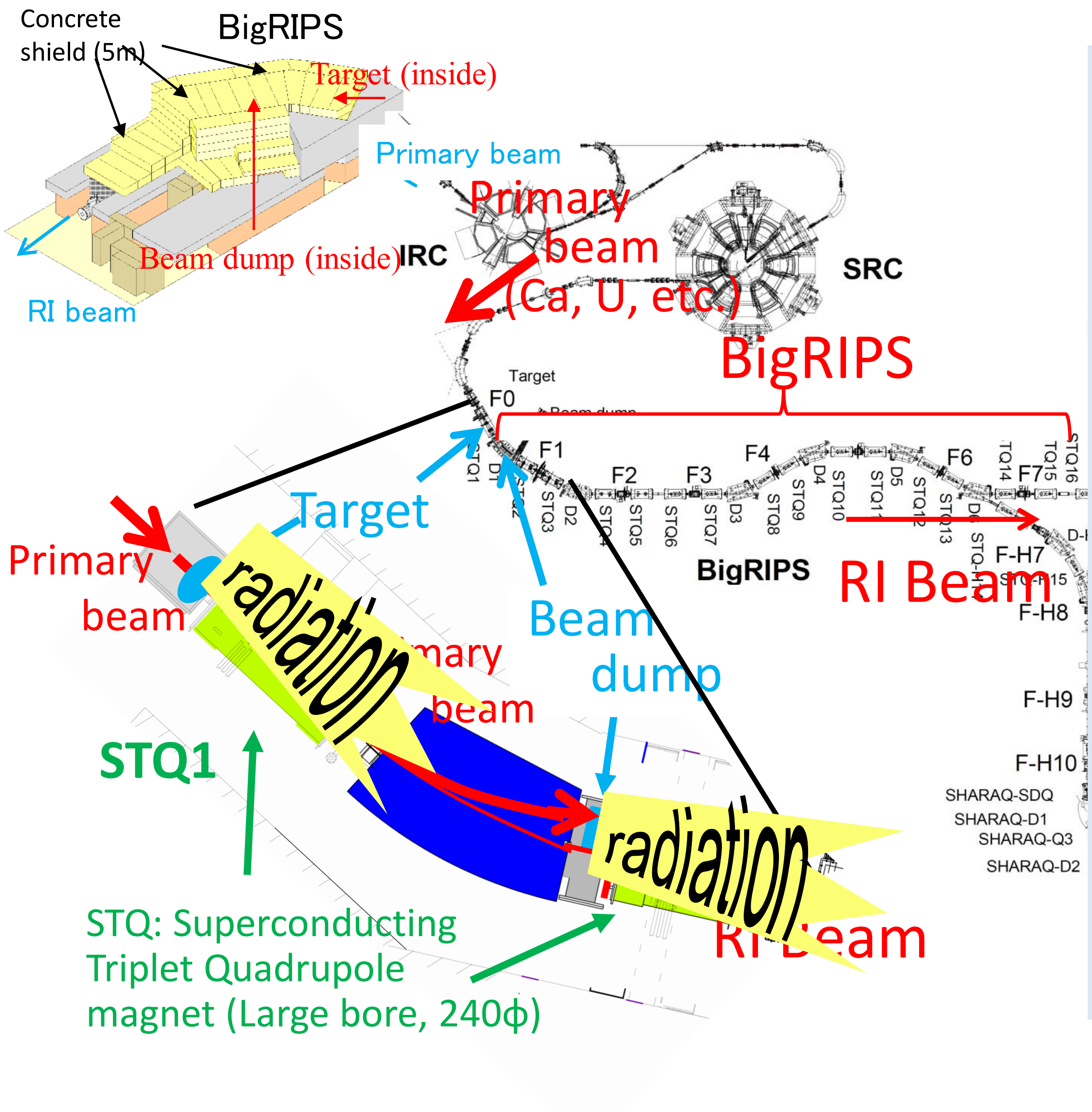
50 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{238}U + Be, C	**Neutron flux (Bi sample)**	**2~3 (H.Lee et al.)**

350 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{48}Ca+Be, Cu dump	**Neutron dose (survey meter)**	**2.1**
^{124}Xe+ Be, Cu dump		**1.4**
^{238}U + Be, Cu dump		**1.2**
^{238}U + Be	**Neutron flux (Bi sample 60,90 degree)**	**~1**
^{48}Ca+Be	**Heat load (Superconducting magnet)**	**1~1.5**
^{238}U+Be		**1.2**
^{48}Ca+Cu dump	**Activation**	**2~3**
^{238}U, ^{124}Xe+Cu dump		**~1**

Radiation measurement : High energy 350MeV/u



STQ: Superconducting Triplet Quadrupole magnet (Large bore, 240ϕ)

Radiation measurement:

A, Neutron dose
outside of shield

B, Heat load on STQ1

C, Radioactivity using
samples near
beam dump

Results are compared
with PHITS calculation !

PHITS calculation ("Particle and Heavy Ion Transport code System", Monte-Carlo code)

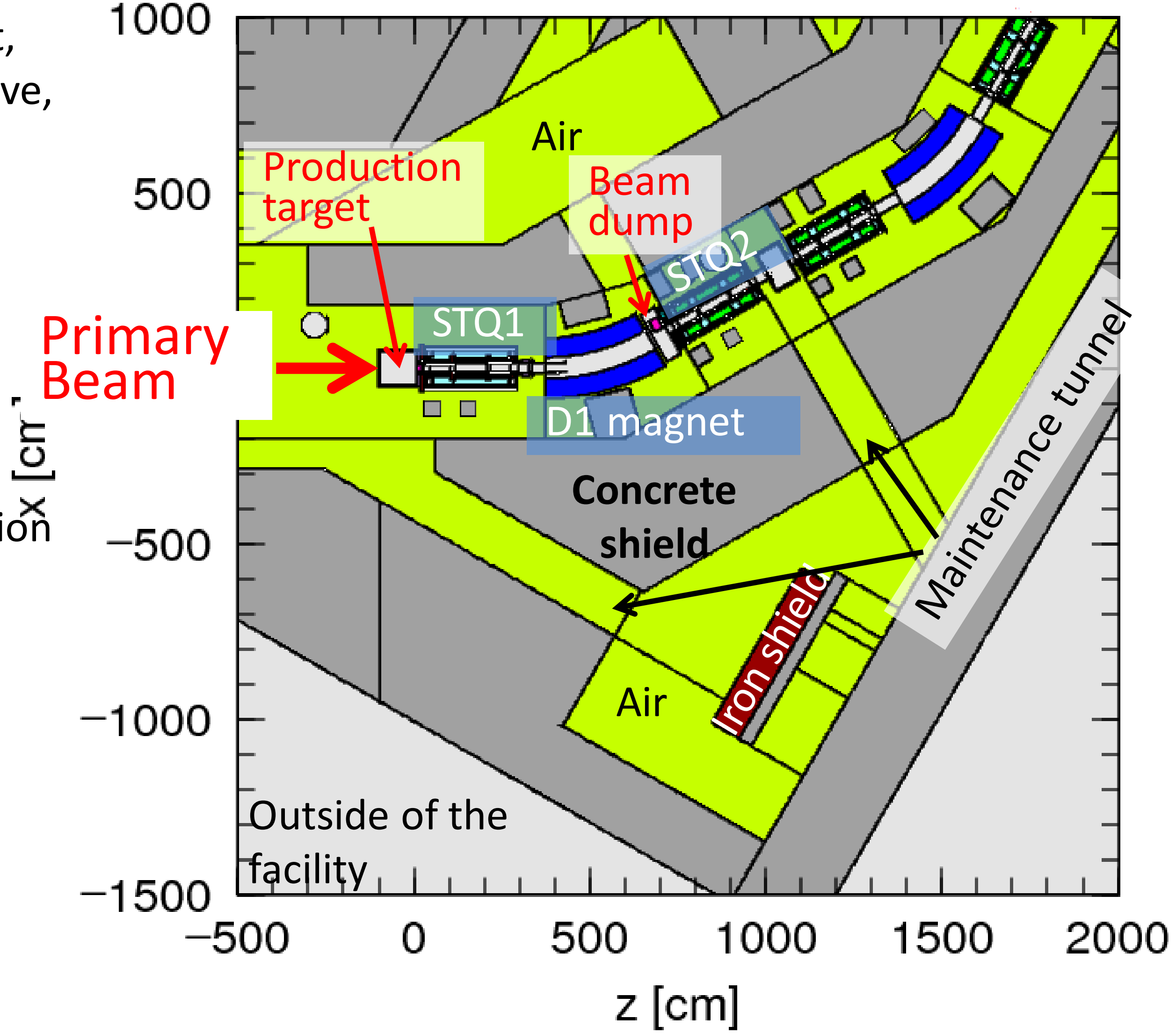
Calculation (PHITS ver 2.30-2.86)

Event :1-10M ions irradiate target,
100~500 core, HOKUSAI GreatWave,
34560core 1.0PFLOPS)
time : 0.5~1 day

Condition

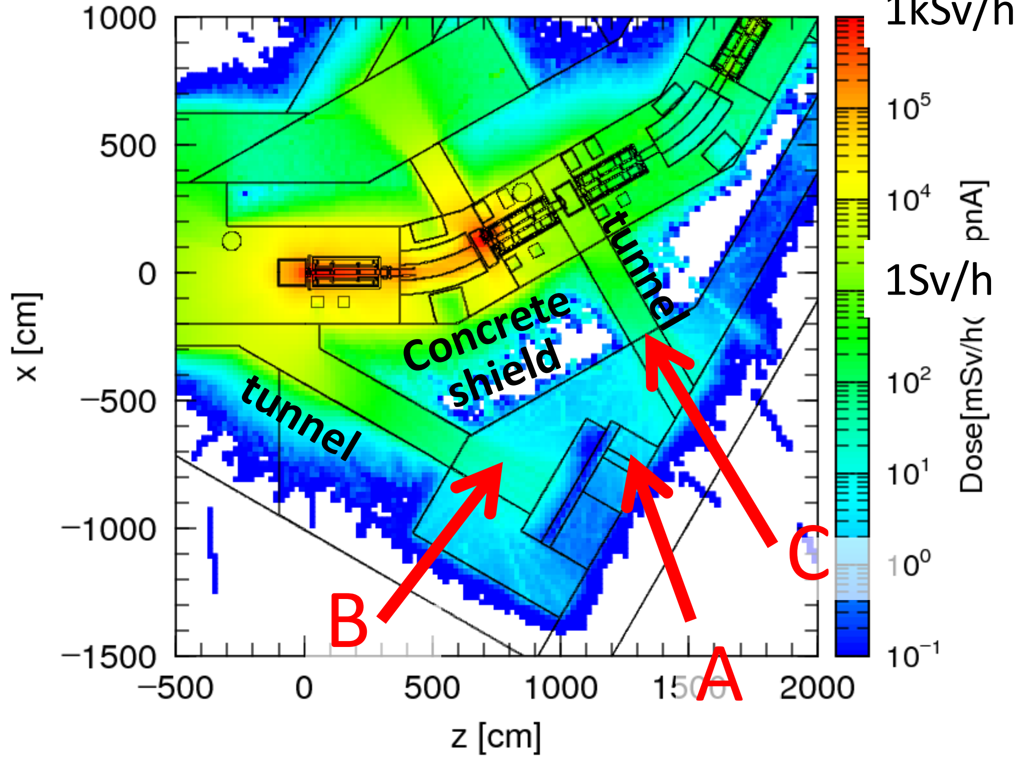
Collision:
Heavy ion
JQMD1 + GEM (General Evaporation Model)
INCL+GEM for ^{238}U + He

Neutron
E > 20MeV, JAM or INCL+GEM
E≦20MeV, nuclear data
ENDF/B-VII



A, Neutron dose

Ex, ^{48}Ca 100pnA+Be15mm



Beam, target, Bρ 1	Spot	Dose rate (mSv/h) PHITS/exp.	Ratio PHITS /exp.
^{48}Ca 100pnA + Be 15 mm,	A	4 / 1.7	2.4
8.100Tm	B	50 / 27	1.9
	C	50 / 25	2.0
^{124}Xe, 10pnA + Be 4 mm, 7.645Tm	A	0.5 / 0.36	1.4
^{238}U, 1pnA + Be 5 mm, 6.950Tm	A	0.15 / 0.13	1.2

Measurement

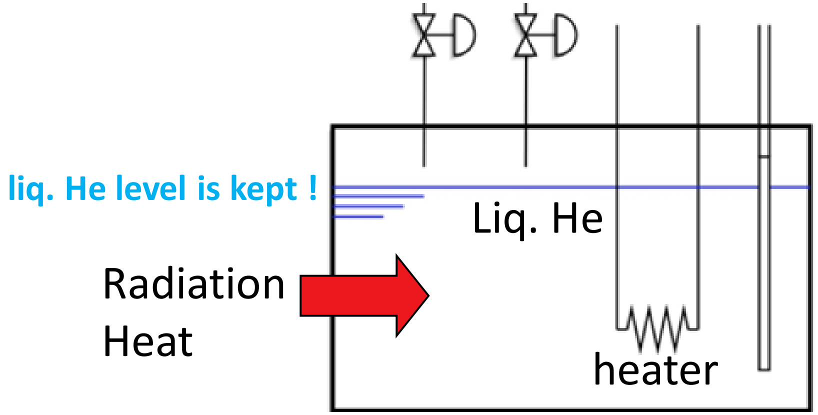
ALOKA, TPS-451C (Polyethylene moderated ^{3}He neutron detector, E=0.025eV-15MeV)

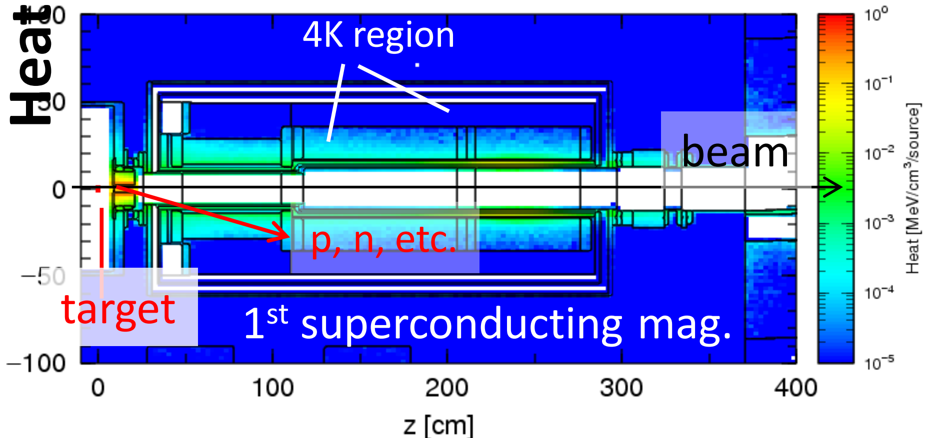
B, Heat load

Radiation heat load on cryogenic region of the superconducting magnet can be measured !

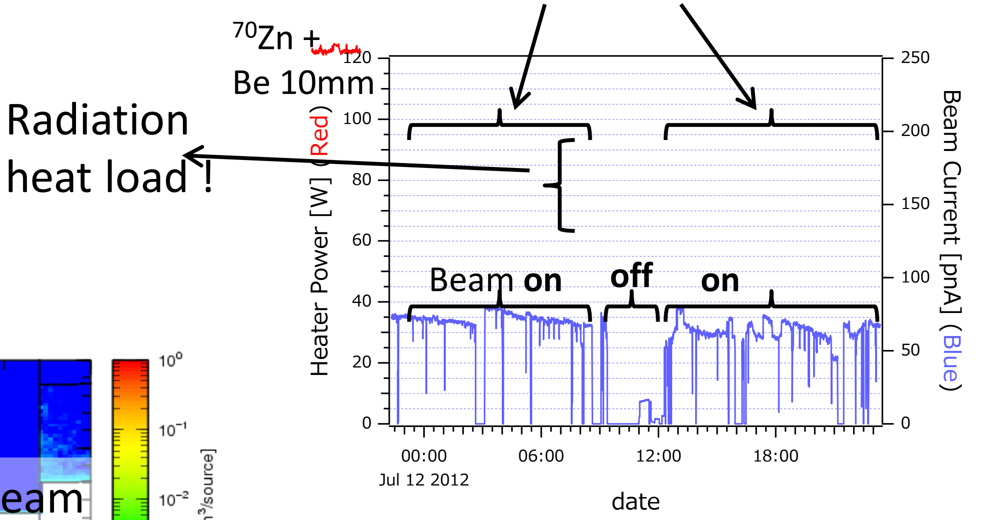
(K. Kusaka et al., IEEE Trans. Appl. Supercond. Vol.21, 1696 (2011))

- Liq. He level is kept constant by varying the heater power with fixed supply and return valves
- Radiation heat load fluctuation is compensated by the heater power.
- Thus, the radiation heat load can be deduced by comparison of heater power for beam on / off

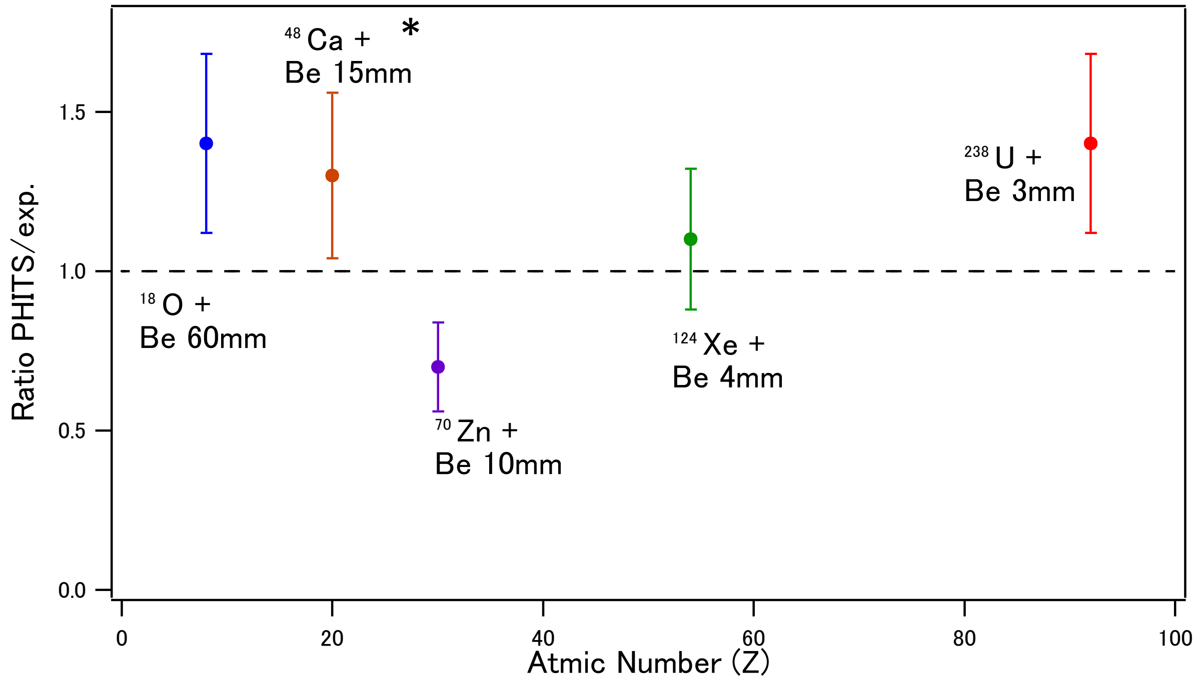




Beam on: heater power become low to keep liq. He level



B, Heat load



Error: 20%
mainly from beam current uncertainty

*T. Ohnish et al., Prog. Nucl. Sci. Tech. 2(2011) 416

Beam, target	Heat on Superconducting magnet (W) PHITS/exp.	Ratio PHITS/exp.
^{18}O 190pnA + Be 60 mm	54 / 39	1.3
^{48}Ca 175pnA + Be 15 mm*	43 / 33	1.3
^{70}Zn 70pnA + Be 10 mm	17 / 25	0.7
^{124}Xe 10pnA + Be 4 mm	6.4 / 6	1.1
^{238}U 10pnA + Be 3 mm	4.2 / 3	1.4

C, Activation of sample materials

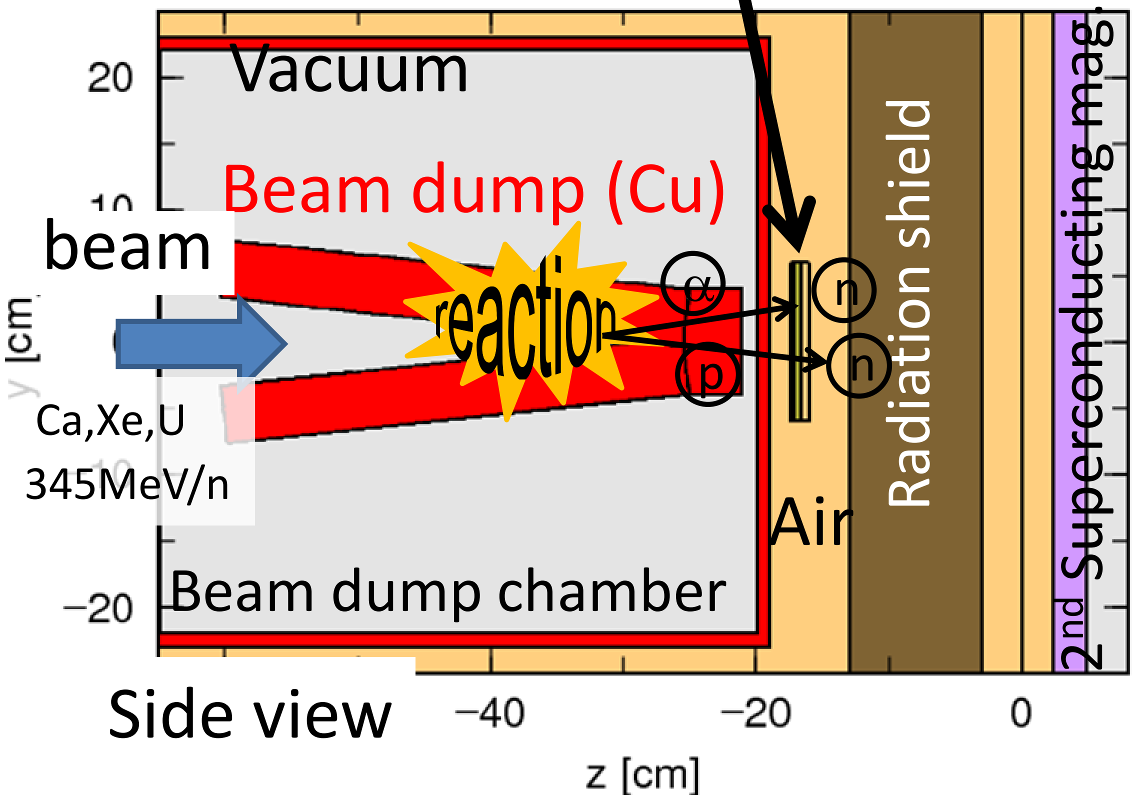
Radiation samples were set downward of the Cu beam dump, in the forward direction of the beam.

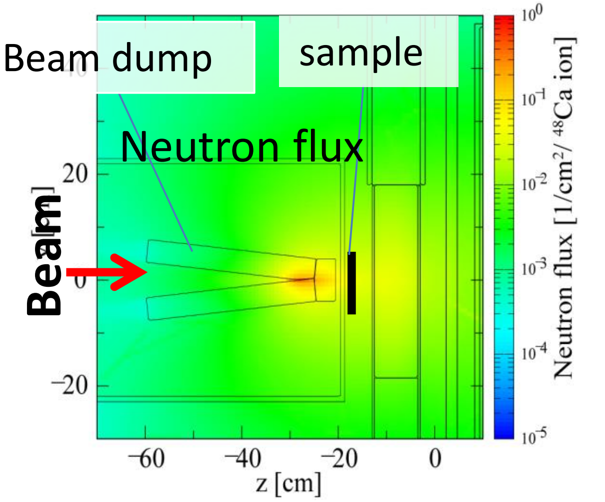
Neutrons come from the beam dump, and samples were irradiated.

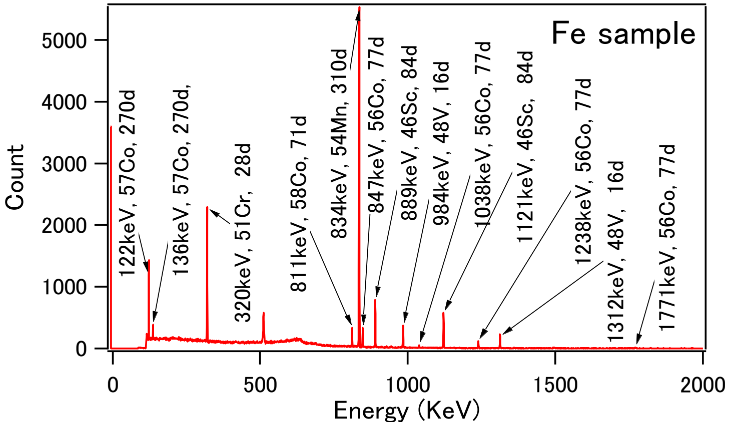
Generated radioactive nuclide in samples were identified using a Ge detector and compared with PHITS calculation.

Radiation sample

(Fe, Cu, Al, Ni, Cr (stainless steel ~Fe+Cr+Ni))



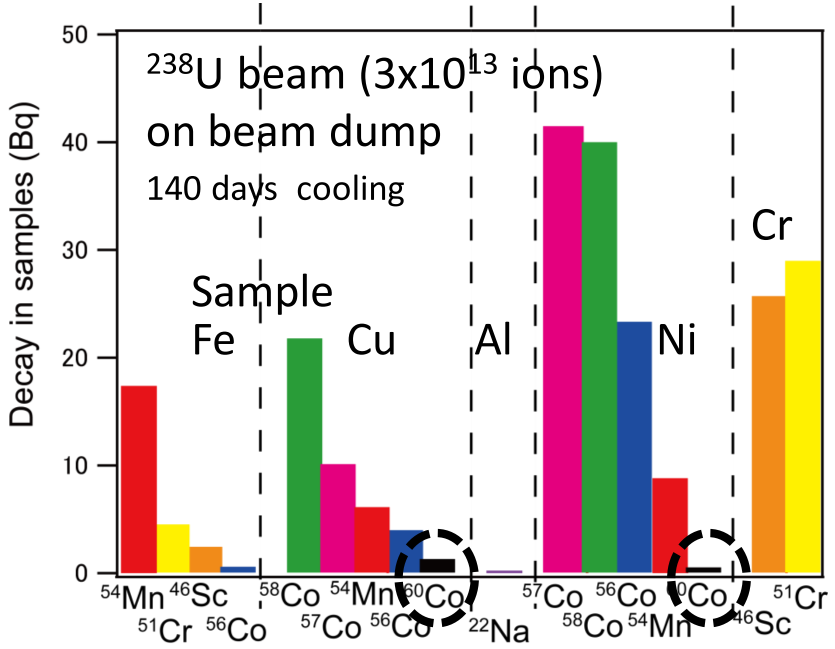


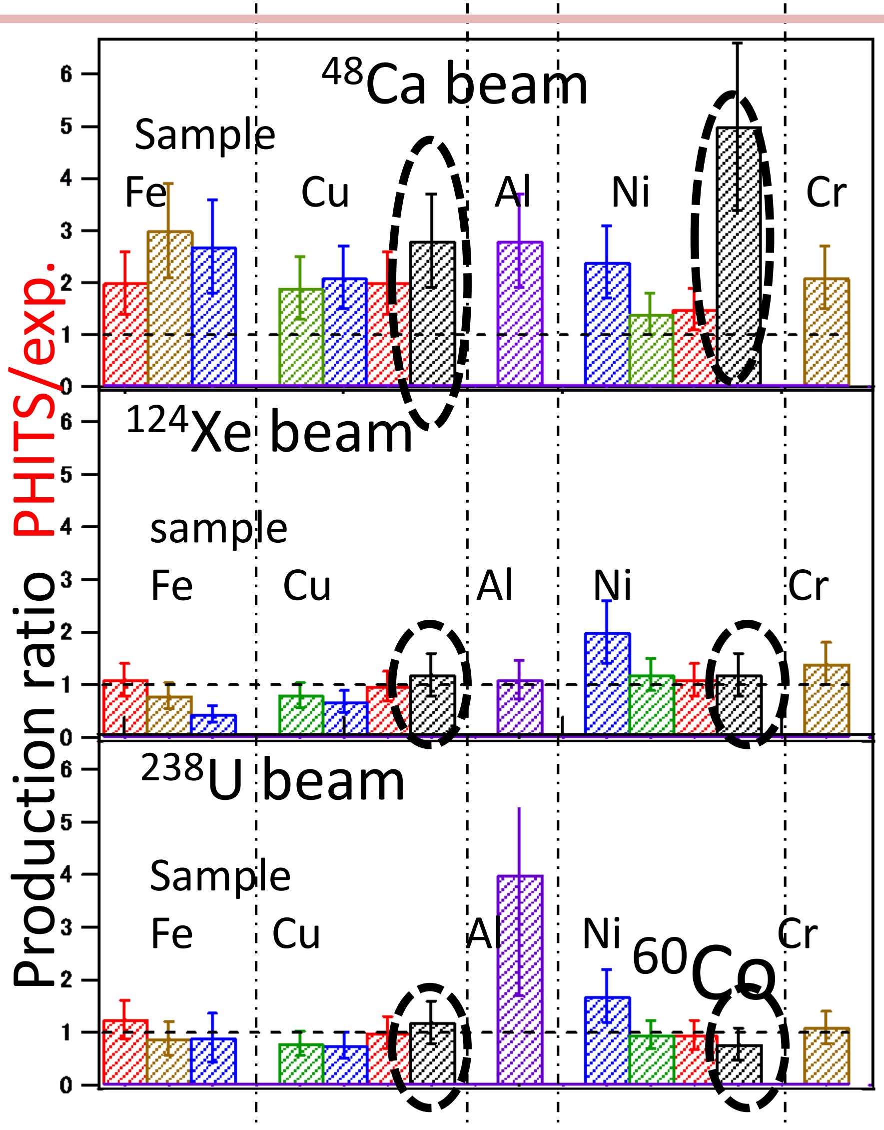


Produced long lived nuclides

To eliminate background of short life RI, Radioactivities were measured after 90~140 days cooling

🟥 ^{54}Mn $T_{1/2}$=312d
🟫 ^{46}Sc $T_{1/2}$=84d
■ ^{57}Co $T_{1/2}$=272d
⬛ ^{60}Co $T_{1/2}$=5.3y
🟨 ^{51}Cr $T_{1/2}$=28d
🟦 ^{56}Co $T_{1/2}$=77d
🟩 ^{58}Co $T_{1/2}$=71d
🟪 ^{22}Na $T_{1/2}$=2.6y



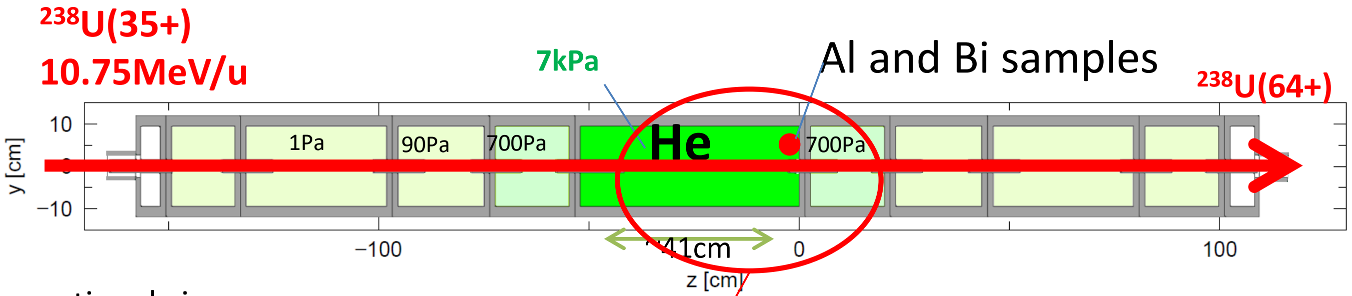


Ratio for ^{48}Ca ~2-3

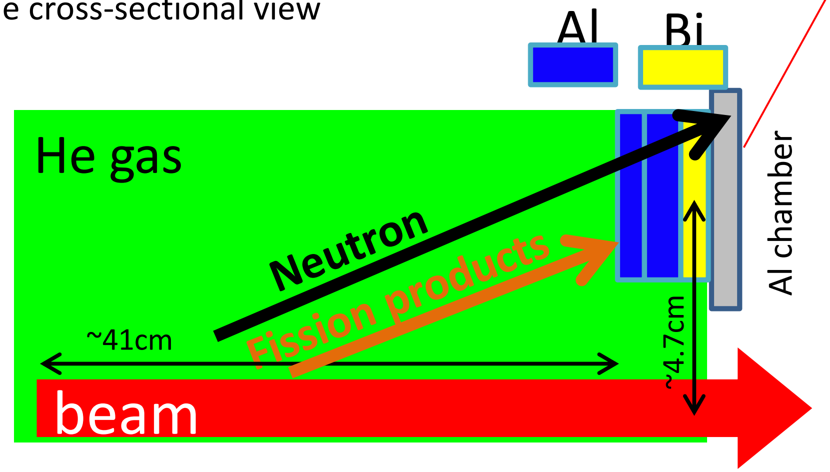
^{124}Xe, ^{238}U ~ 1

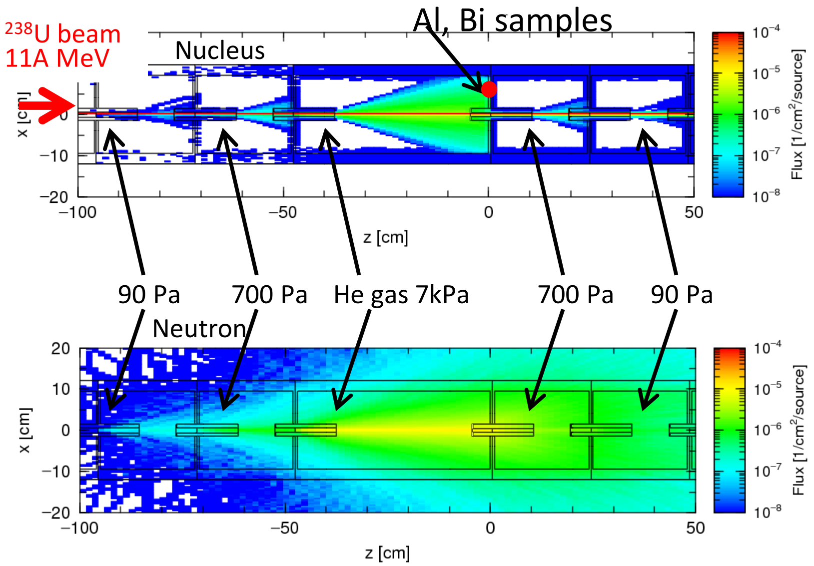
D, Residual radioactivity at low energy to plan maintenance

11 MeV/u ^{238}U beam + He gas



Side cross-sectional view





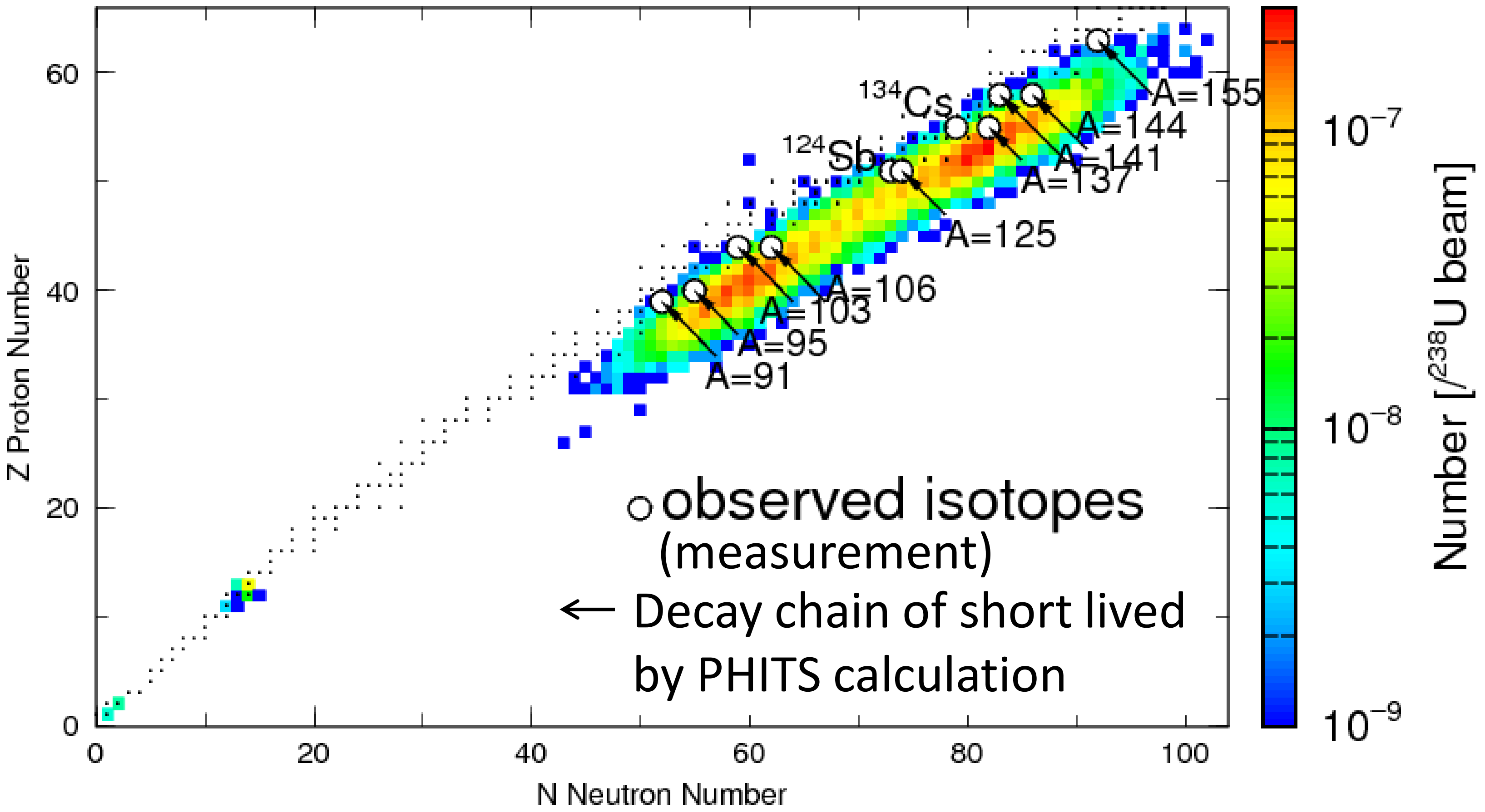
Al sample (chamber material) activation

First layer: fission product catcher

Second layer : Al activation by neutron from U beam

Third layer : Radioactive Bi isotopes corresponds to energy dependence of neutron flux

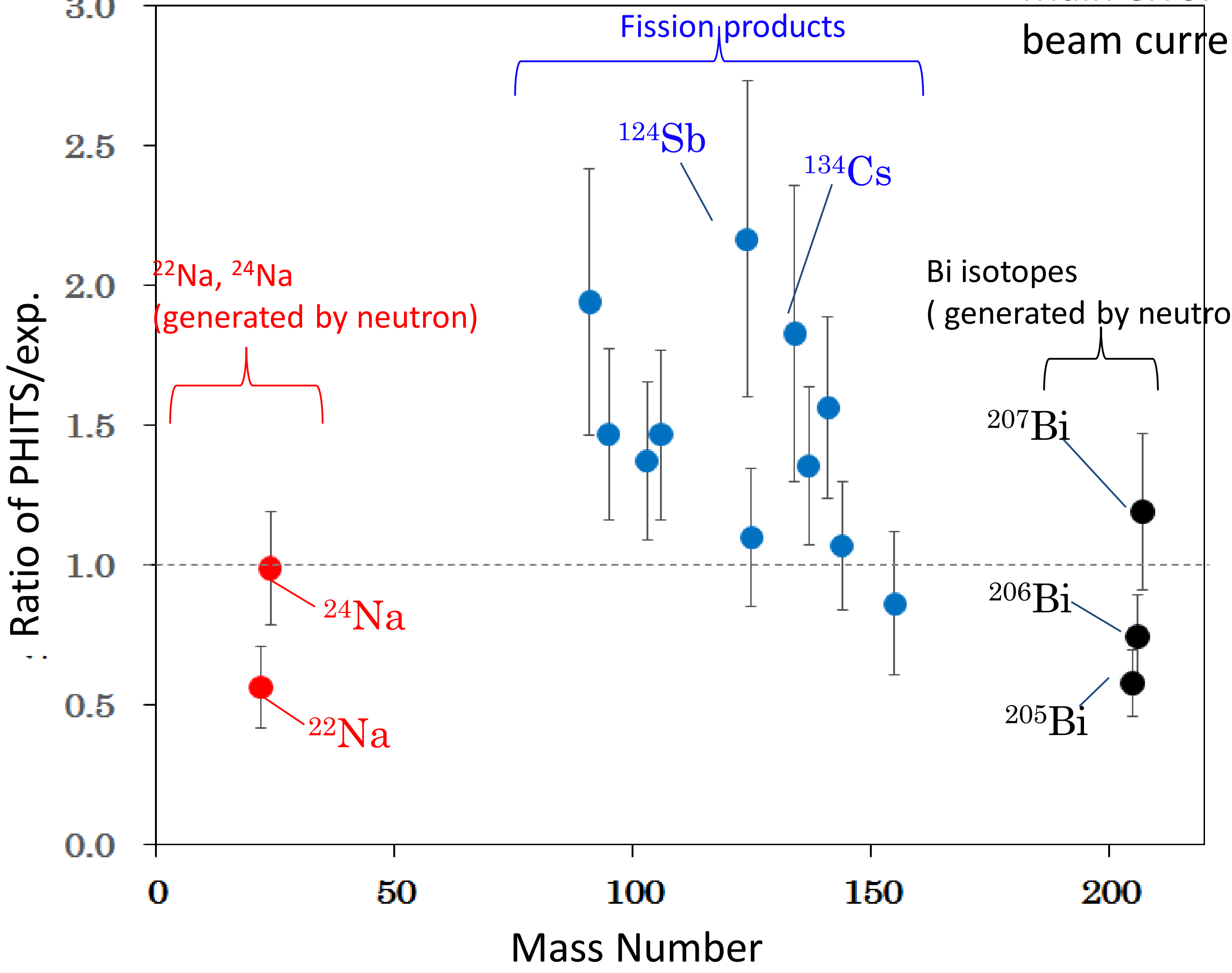
Production rate of nuclide

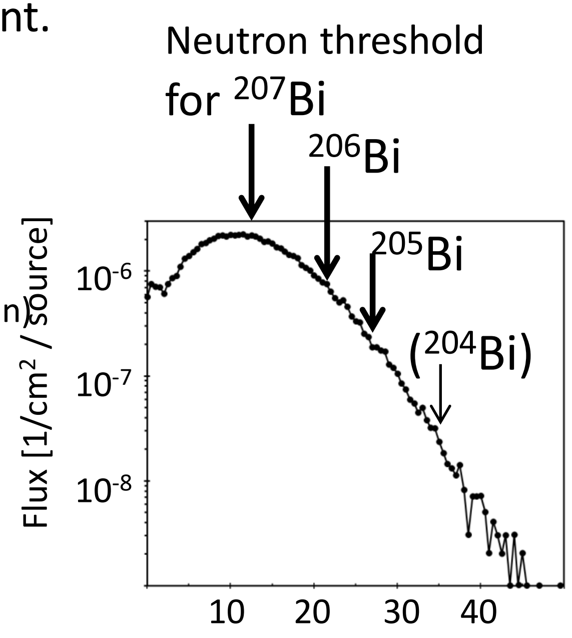


By PHITS calculation, both long and short lived nuclides were generated.
But only long lived nuclides were observed by measurement.
To compare the PHITS calc. result to exp. result, short lived were summed to long lived in calculation.
^{134}Cs and ^{124}Sb could be compared without other nuclides, respectively, because they don’t have parent nuclides.

Ratio of the produced nuclides to PHITS/exp.

Main error are 20% of beam current.



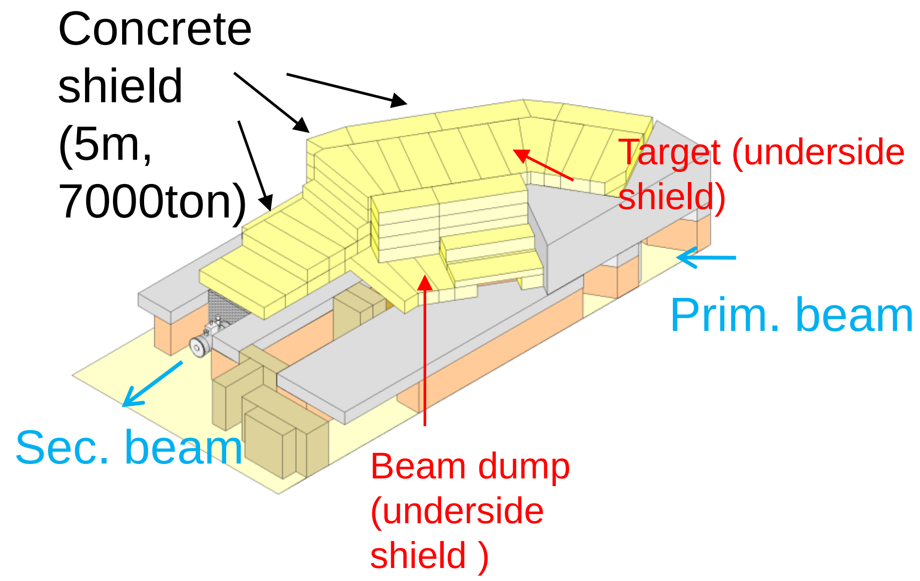


Neutron energy[MeV] by PHITS calculation

Nuclide	Threshold (MeV)	Reaction
^{207}Bi	14.12	(n,3n)
^{206}Bi	22.55	(n,4n)
^{205}Bi	29.62	(n,5n)
^{204}Bi	38.13	(n,6n)

Future plan for radiation evaluation in RIBF

Precise measurement of neuron yield for more high intense beam



RIBF shield design(~1999)
simple formula (*E* >150MeV)

$$E=\frac{E_0(\theta)\times\exp\{-t/\lambda\}}{L^2}$$

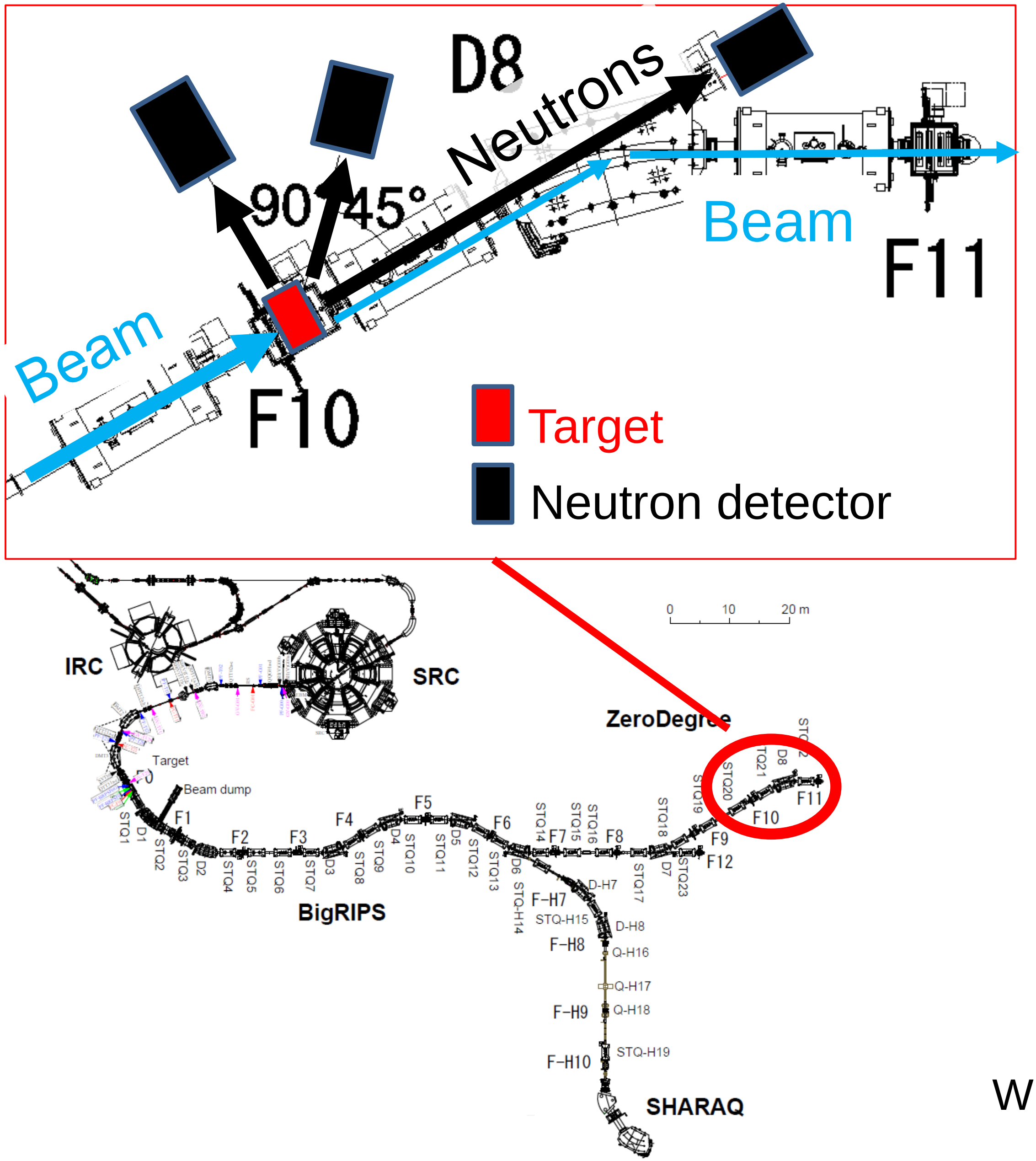
$E, E_0(\theta)$: neutron dose rate

t: shield thickness λ: shield capacity

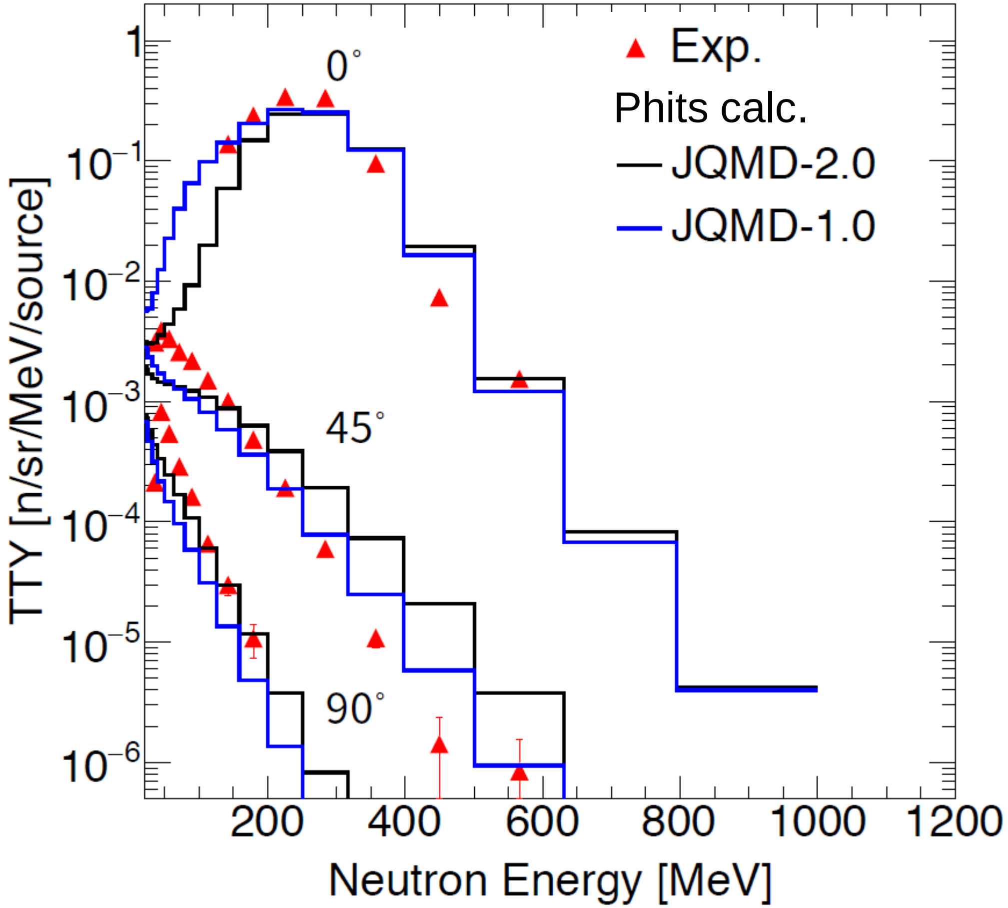
L: distance from source point

- Current intensity of uranium beam is **70 pnA**.
- **Permission for uranium beam: 300 pnA**. **Goal: 1000 pnA.** Future･･･?
- RIBF shield was designed at 1999 by empirical formula of mass dependence of “A*E^2” with ^{20}Ne + Cu 400MeV/u measurement.
- More than ten times surplus shield were applied.
- RIBF is in underground. Neuron yield for side direction as 45, 90 degrees are also necessary.

Neutron yield measurement using TOF



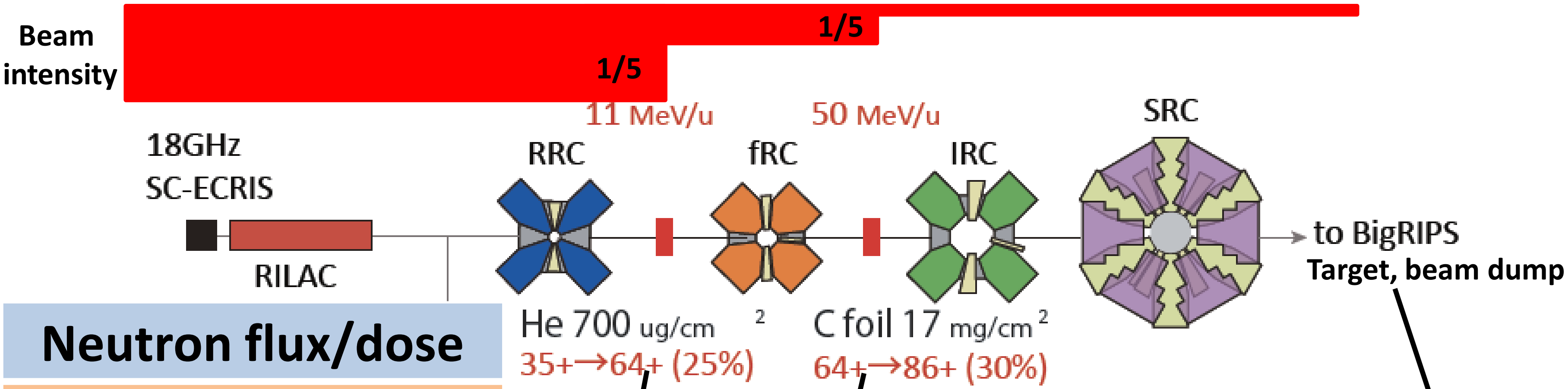
Preliminary result for ^{238}U + thick Cu target at 345 MeV/u.



K. Sugihara and Kyushu univ.

We will measure for thin Be, W target (RIBF target materials)

Summary : Radiation Evaluation at RIBF over the past decade



Neutron flux/dose

Heat Load

Activation/residual dose

11 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{238}U + He gas stripper	**Neutron flux (Bi sample)**	**~1**
	Activation	**0.5~2**

50 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{238}U + Be, C	**Neutron flux (Bi sample)**	**2~3 (H.Lee et al.)**

350 MeV/u

Beam, target	Evaluation	PHITS/exp.
^{48}Ca+Be, Cu dump	**Neutron dose (survey meter)**	**2.1**
^{124}Xe+ Be, Cu dump		**1.4**
^{238}U + Be, Cu dump		**1.2**
^{238}U + Be	**Neutron flux (Bi sample 60,90 degree)**	**~1**
^{48}Ca+Be	**Heat load (Superconducting magnet)**	**1~1.5**
^{238}U+Be		**1.2**
^{48}Ca+Cu dump	**Activation**	**2~3**
^{238}U, ^{124}Xe+Cu dump		**~1**

Thank you for attention