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Evaluation of Activated Areas in Electrostatic Accelerator Facilities

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Activated material control

In Japan, the clearance system was introduced for RI and accelerator facilities. (1) The clearance level (Bq/g) and (2) the control procedures, was introduced in this system.

In this regulation, (3) the definition of activated materials and (4) their handling rules were also defined. This system is very difficult, expensive and time consuming for small facilities to perform.

An acceptable proposal and manual for the decommissioning of various accelerator facilities have been expected by users.

Our strategy

(1) Classification of accelerators based on the activation condition (energy, power, use)
(2) Zoning activated/non-activated area
(3) Individual evaluation -> general guideline

To achieve above,

(1) Perform the evaluation procedure
(2) Evaluate activated area in various types of accelerators

Accelerators in Japan (2017)by JRIA

Category	Total	Hospitals &Clinics	Educational Institutions	Reseach Institutions	Private Companies	Other Organizations
Total (Ratio%)	1,711 (100%)	1,283 (75.0%)	66 (3.9%)	179 (10.5%)	150 (8.8%)	33 (1.9%)
Cyclotrons	236	157	4	23	50	2
Synchrotrons	46	12	3	27	4	–
Linear Accelerators	1,294	1,114	26	68	55	31
Betatrons	2	–	1	1	–	–
Van de Graaff Accelerators	35	–	13	21	1	–
Cockcroft-Walton Accelerators	78	–	17	29	32	–
Transformer-type Accelerators	14	–	–	6	8	–
Microtrons	4	–	2	2	–	–
Plasma Generators	2	–	–	2	–	–

Electrostatic Accelerators

- Targets accelerators
  - Van de Graaff and Cock-croft Walton

  ->acceleration type :Tandem or Single- end
  - Exclude neutron generators, electron acceleration type
- Uses
  - Old :Nuclear Physics
  - Now: Material analysis（Rutherford、ERA、NRA、PIXE)、AMS、Ion Implantation

If charged particle energy is higher than coulomb barrier and *Q*-value, nuclear reaction will occur.

- Activated area
  - Target, monitor, slit, dump are activated
  - Surroundings are also activated by secondary neutrons

Evaluation procedure

(1) Classify the operating conditions：usage. particle, energy, beam power, and beam loss

(2) Neutron monitoring during operation：Au-activation detector, TLD, Track detector CR-39

(3) Measure dose rate and gamma-ray spectra from accelerator and its surroundings before and after the operation

(4) Monte Carlo simulation for comparison

Preliminary survey

- Track detectors (CR-39) were set for 3 months in about 20 facilities.
- Tandem type

Terminal voltage	Number	N_{th} Detected
≦ 2MV	6 facilities	(1.7MV Kobe)
≦ 4MV	2 facilities	
≦ 6MV	5 facilities	(6MV Tsukuba)
> 6MV	1 facility	(20MV JAEA-Tokai)

- Single-end type

  3 facilities (2.5 MV Hiroshima、4.5MV Tohoku)

Detailed study

- Four facilities were selected
- In order to reproduce the neutron emission, we obtained the machine time for activation experiment

Table 1. Selected electrostatic accelerators and irradiation condition

	Institute	Type	Particles, Energy, Current	Target
1	Kobe Univ,	1.7MV, tandem	d, 3MeV, 0.25 μA	Be
2	Tohoku Univ.	4.5MV, single end	p, 2.5, 3MeV,5 μA	Li, Cu
3	Univ. Tsukuba	6MV, tandem	p, 6, 12 MeV, 1 μA	SUS, Ta
4	JAEA*	20MV, tandem	p, 30 MeV, 0.25 μA	SUS

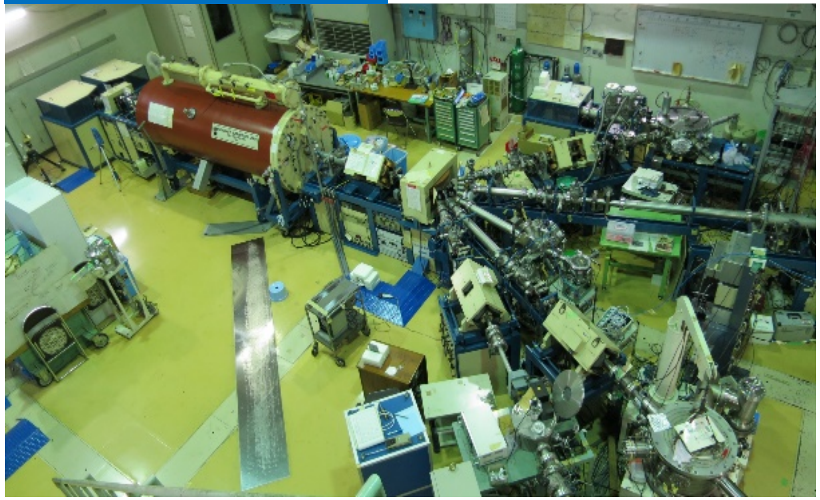
* Japan Atomic Energy Agency

Neutron detection using 3 types of passive detectors
Surface dose survey and gammma-ray spectrometry before and after experimant
Monte Carlo Calculation of neutron transport for the comparison of experimental results

Be（d，n）

Kobe

3MeVdeuteron



Li, Cu（p，n）

Tohoku

2.5MeV proton

Ta, SUS（p，n）

6 and 12MeV proton

Tsukuba

JAEA

30 MeV proton

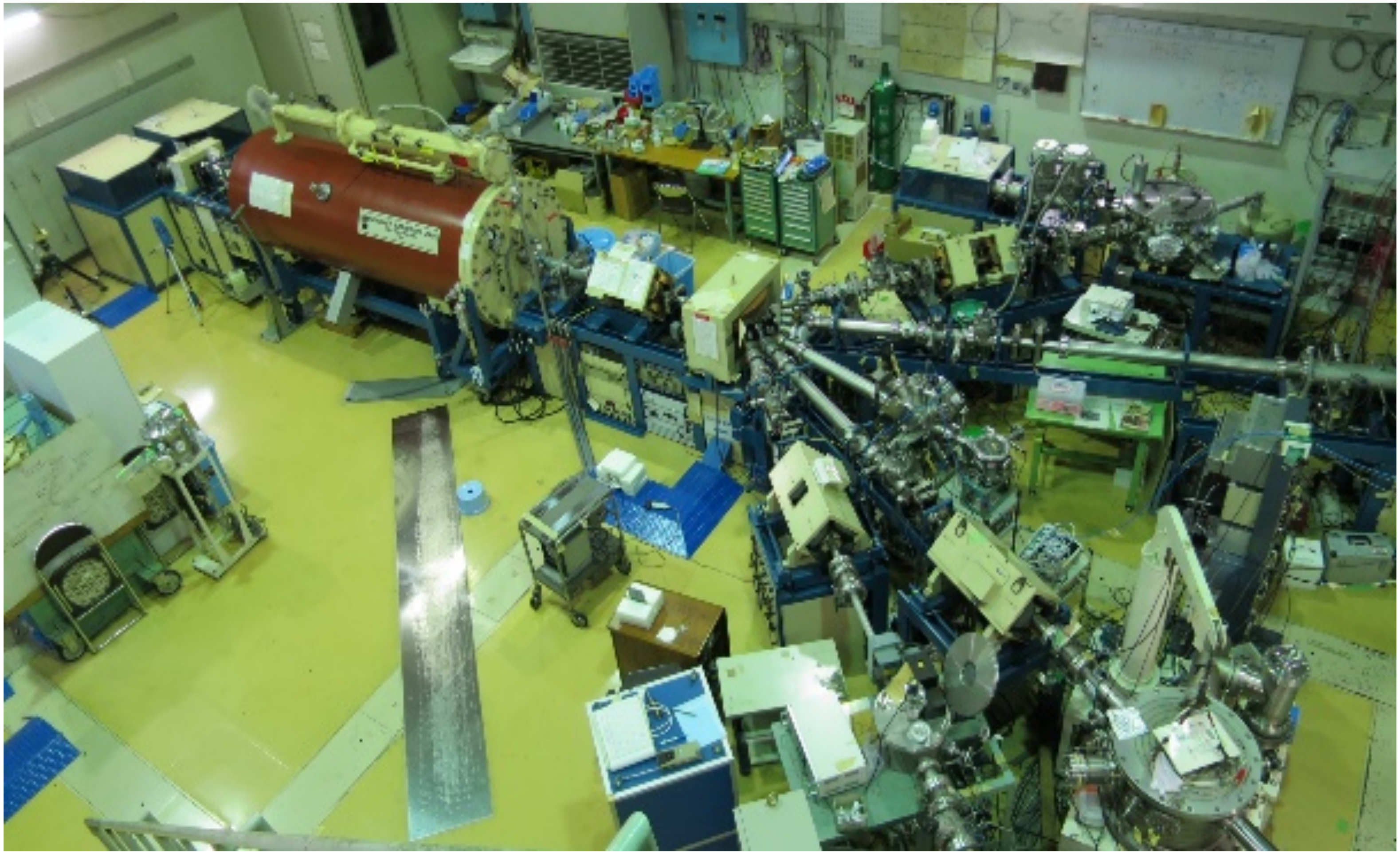
Neutron Monitoring Method

- Nuclear Track Detector (CR-39)
  - Polycarbonate plastic plate
  - Boron plate cover for α-particle radiator
  - Polyethylene plate cover for recoil proton radiator
- Activation detector
  - A pair of Au-foil(20μm) covered with and without Cd foil
  - Relative activity of all foils was measured by IP
  - Absolute activity of ^{198}Au in Au foil was measured by Ge
- TLD
  - Panasonic UD813PQ4
  - 2Elements: $^{6}Li_2{}^{10}B_4O_7(Cu)$ detection of Nth+Photon
  - 2Elements: $^{7}Li_2{}^{11}B_4O_7(Cu)$ detection of Photon only

Dose monitoring and spectrometry

- NaI(Tl) –scintillation survey meter
  - Hitachi ALOKA TCS-171 (1.5 inch ø)
- $LaBr_3$-scintillation spectrometer
  - Mirion Canberra InSpector-1000
- Portable Ge-detector
  - Canberra GR2018

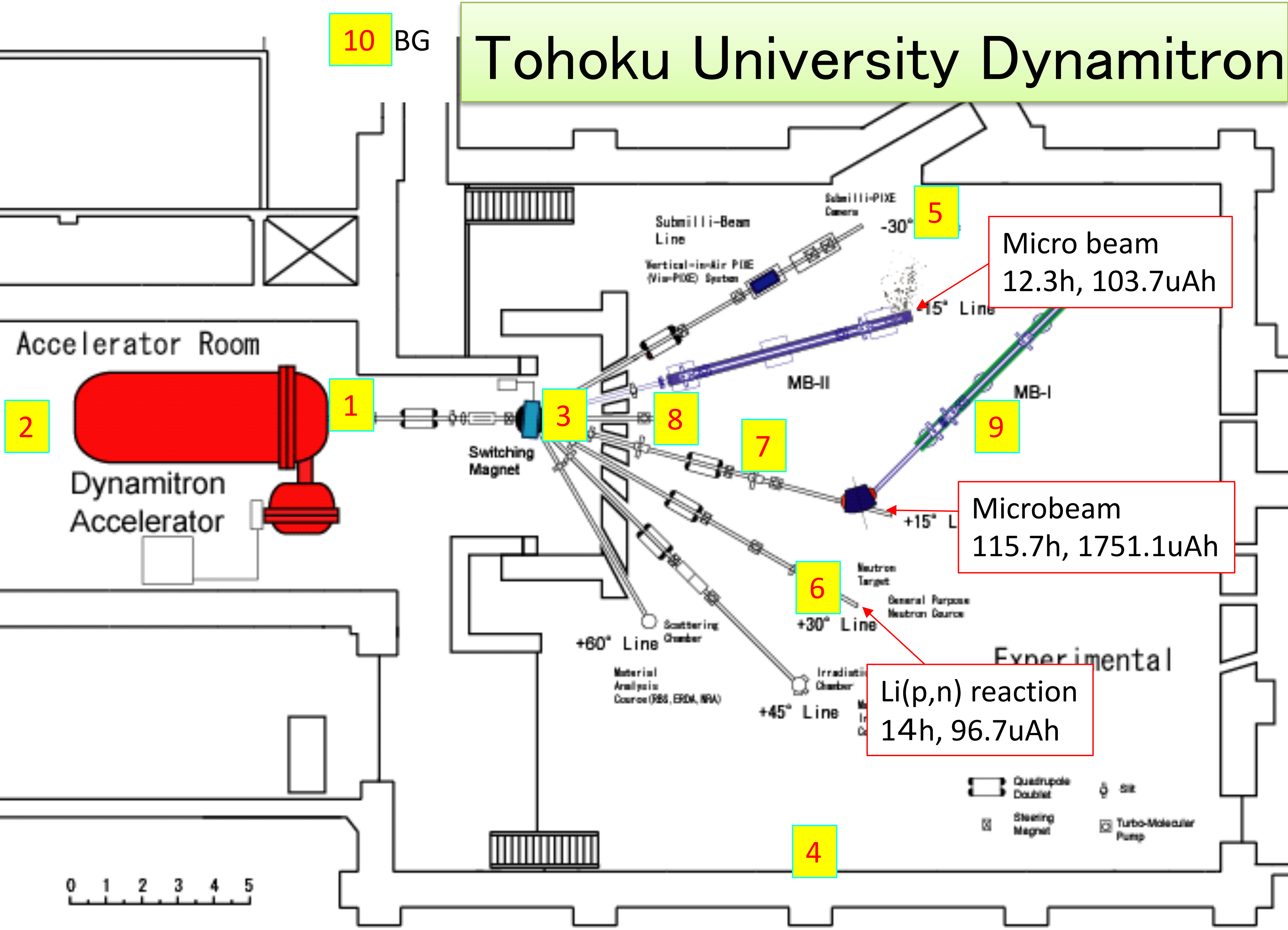
Kobe University 1.7MV Pelletron



Results

- Be target was used for the $^{9}Be(d,n)^{10}B$ reaction
- d : 3MeV, 0.26μA , 6.25hr
- Thermal neutron flux
  - Near the target : $5.7 \times 10^{3} cm^{-2}s^{-1}$
  - Surface of concrete floor : $10^{2} cm^{-2}s^{-1}$
- Ge-detector measurement
  - Major activity of concrete was natural RI (U, Th, ^{40}K)
  - Trace activity of ^{56}Mn (2.58h)、^{24}Na (15h)were detected after experiment. (by Matsumura)

Tohoku University Dynamitron



Results

- Li-Target : P 2.5MV, 5.5μA , 8hr
- Cu-Slit : P 3MV, 6μA , 7hr

- Maximum thermal neutron flux:$10^{2}cm^{-2}s^{-1}$
- Fast neutrons dose rate was high.
- Target (Li → ^{7}Be), Slit(Cu→ ^{65}Zn)

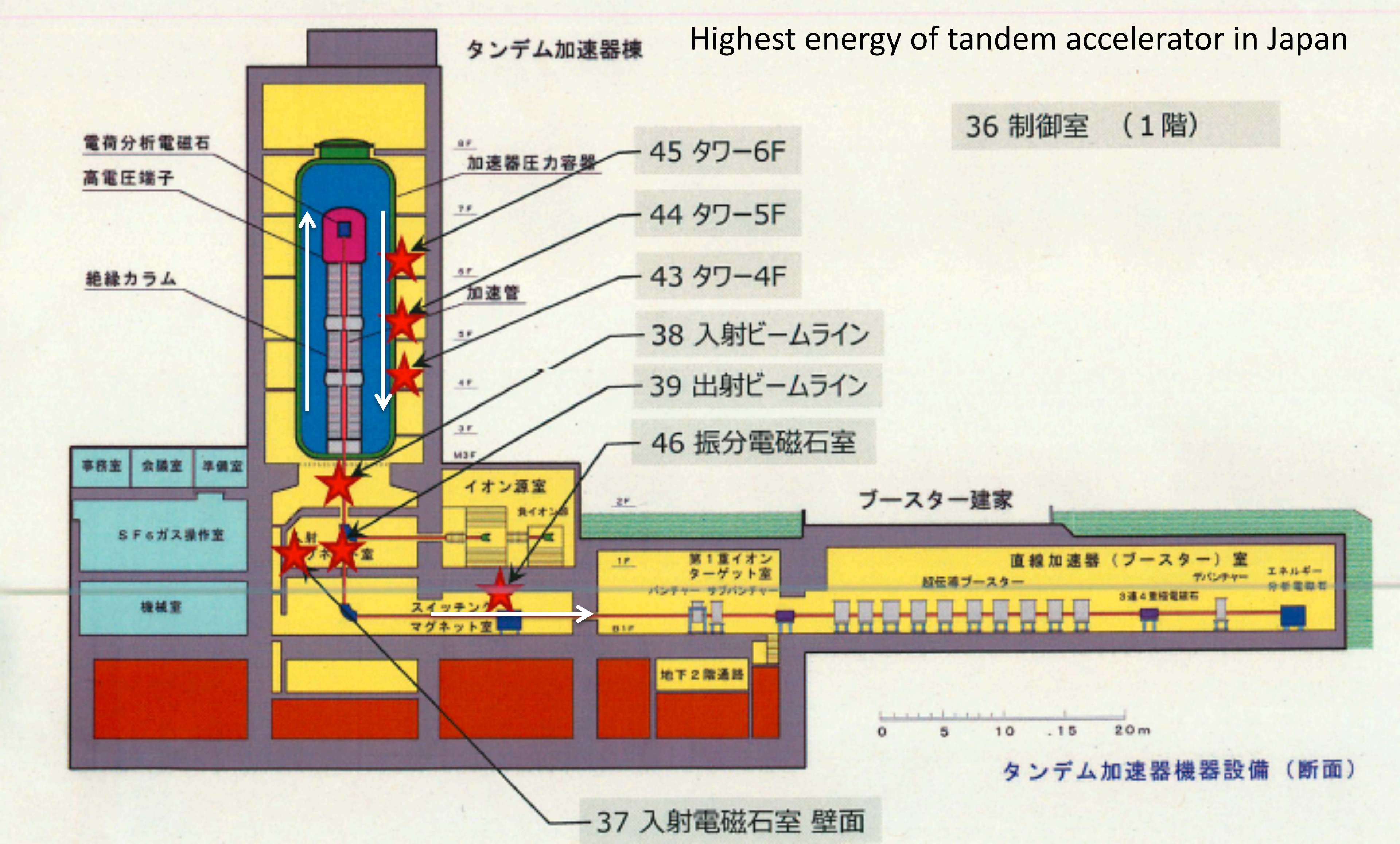
University of Tsukuba 6 MV Tandem

Results

- P 12MeV, 1μA , 2hr : Target-> SUS304, Ta
- P 6MeV, 1.2μA , 2hr : Target-> SUS304
- Maximum thermal neutron flux ($10^2 cm^{-2} s^{-1}$) was observed on the concrete floor just under the target chamber
- Ge-detector measurement on the concrete floor
  - Major activity of concrete was natural RI (U, Th, ^{40}K)
  - Trace activity of ^{56}Mn (2.58h)、^{24}Na (15h)were detected after experiment.

JAEA Tokai 20MV tandem

Highest energy of tandem accelerator in Japan



Results

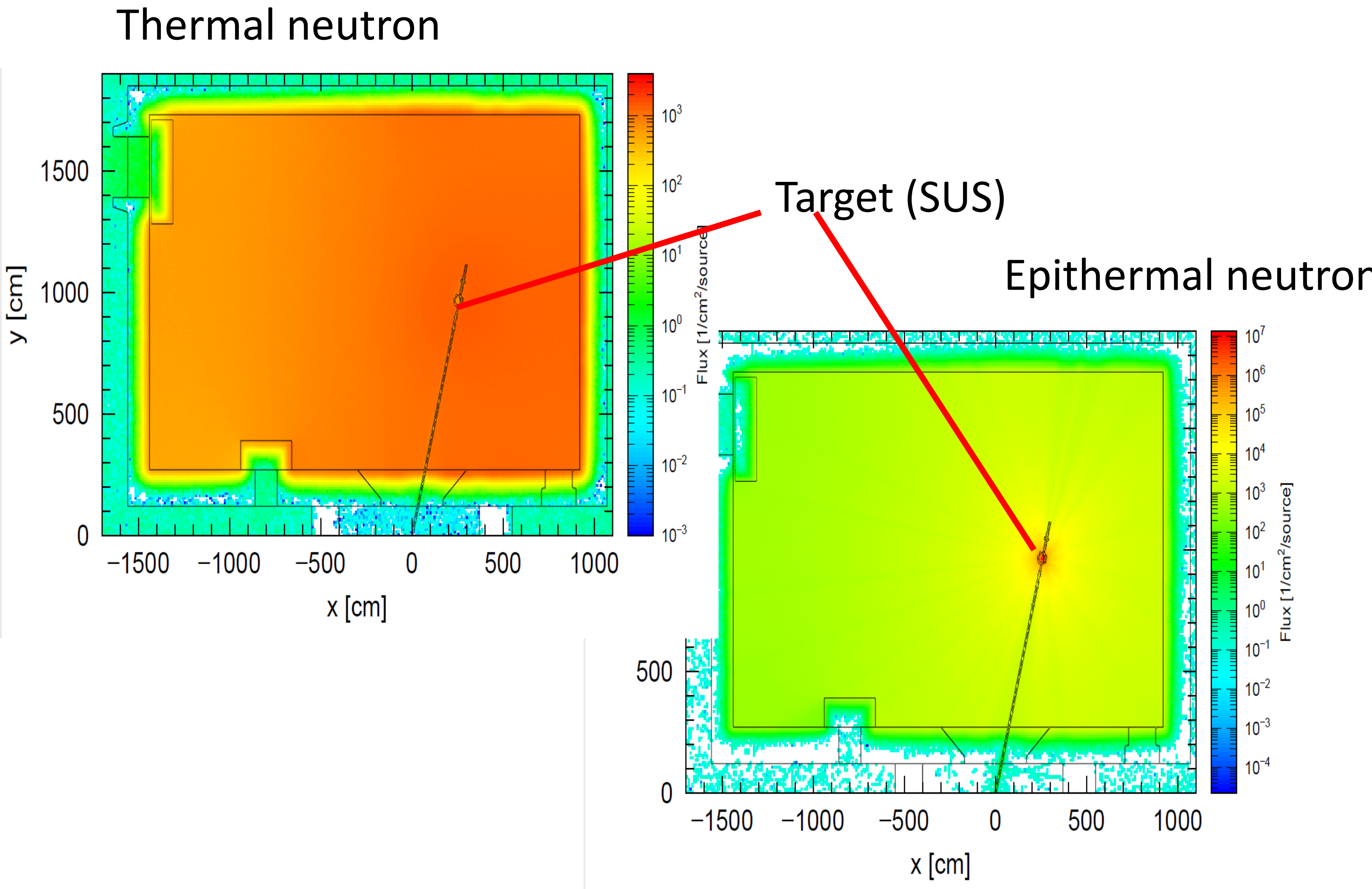
- Proton 30MeV, 0.25μA
- Measured in Accelerator room, Beam transport line, Irradiation room
- Accelerator room : N_{th}->$10^2 cm^{-2}s^{-1}$ at 5^{th}, 6^{th} floor and ^{56}Mn was detected at the tank surface
- Energy analyzer：N_{th}-Maximum $3X10^3 cm^{-2}s^{-1}$
- Irradiation room：$10^4 cm^{-2}s^{-1}$
  - Major activity of concrete was natural RI (U, Th, ^{40}K)
  - Trace activity of ^{56}Mn (2.58h)、^{24}Na (15h)were detected after experiment.

Monte Carlo simulation

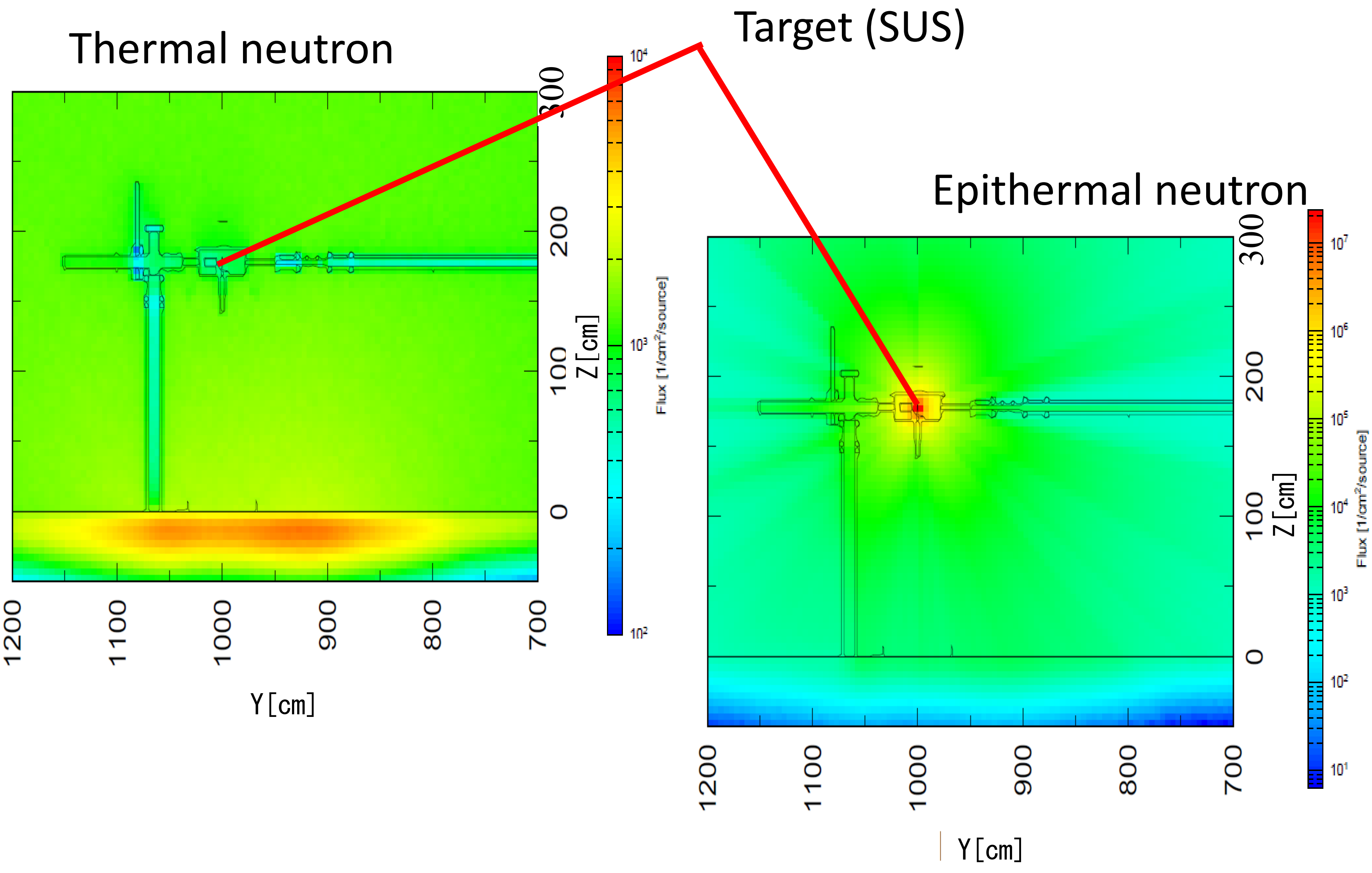
- The particle and heavy ion transport simulation code PHITS (v. 2.88)
  (1)Calculation of energy dependence of neutron emission was compared with the reported values
  (2)Neutron transport from target
- DCHAIN-SP (v. 2004) for activation calculations was also performed

  in case of proton and deuteron irradiation to 7 target materials from Li to Ta.

Neutron Distribution



Neutron Distribution



Conclusion (1)

- N_{th} monitoring in accelerator facilities
  - CR-39: Fast neutron effect is severe. Results of CR-39 were always higher than that of TLD and Au
  - Au: Cd-ratio approaches 1, error becomes large
  - TLD: Interference from high gamma dose is severe. Epithermal neutron effect can be cancelled by adding Cd-cover TLD
  - Cross check is important, Induced activity measurement is also useful sensitive for neutron flux monitoring
  - PHITS could be reproduced the experimental data .

Conclusion (2)

- Activated area
  - Almost all accelerators for analytical uses, such as AMS, were not activated by neutrons
  - At the facility performing the experiment of nuclear science using neutron emission experiment, activation were observed in the target, slit, and beam line. But, thermal neutron fluxes of $10^{2\text{-}3}cm^{-2}s^{-1}$ during operation on the floor concrete were very low. Activity of ^{60}Co from accelerator tank, and ^{60}Co, ^{152}Eu from floor concrete could not be detected.