Progress of the Neutron Source Development Using an Electron linac for Bragg edge Imaging at Pohang Accelerator Laboratory

Mahdi Bakhtiari[a], Nam-Suk Jung[b], Wooyoung Um[a], Hee-Seock Lee[a,b*]

[a]*Division of Advanced Nuclear Engineering (DANE), POSTECH, Pohang, Korea*

[b]*Pohang Accelerator Laboratory (PAL), POSTECH, Pohang, Korea*

* *lee@postech.ac.kr*

Motivation & Objectives

❑ Motivation

- **Why a compact accelerator neutron source (CANS)?**
  - ✓ Future operation of nuclear reactor is uncertain due to public concerns or political issues
  - ✓ Spallation neutron sources are costly and it is hard to obtain beam time
  - ✓ CANSs have shown their abilities in Bragg edge imaging for material testing
  - ✓ More facilities needed to satisfy the needs of material analysis
  - ✓ CANSs are very useful since they exist usually near the users
  - ✓ **In Korea, there is a lack of this novel material testing technique based on small scale accelerator-driven neutron source**
- **CANS application: Bragg edge imaging**
  - ✓ Neutron imaging is nondestructive
  - ✓ Bulky sample can be probed
  - ✓ No pre-processing of the samples required
  - ✓ **Measuring texture orientation, phase volume fraction and crystalline size** of structural materials

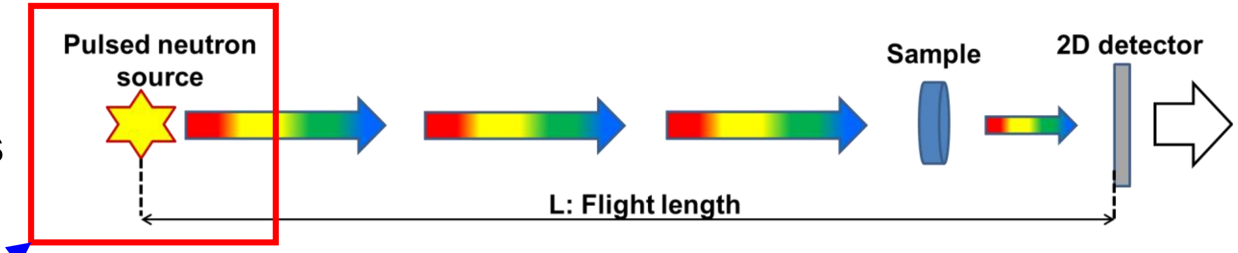
❑ Objectives

- This project aims to develop some parts required for Bragg edge imaging using CANS in Korea [1].
  - ✓ **Measurement of photoneutron production yields generated from a tungsten target→ Benchmarking Monte Carlo codes**
  - ✓ **Demonstrating the feasibility of cold neutron production→ Using polyethylene (PE)**

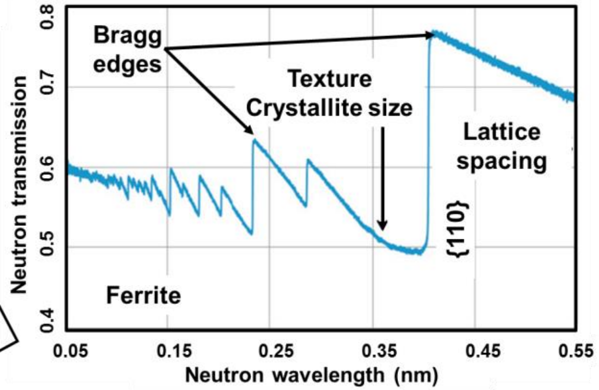
[1] C. H. Lee et al, Journal of Neutron Research, Preprint, 1 (2021).

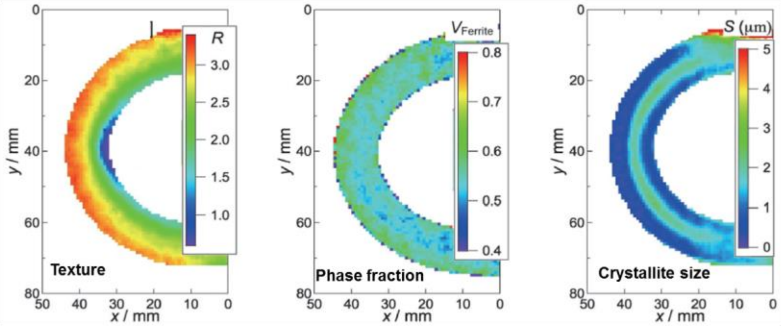
Elements for Bragg edge imaging

- **Pulsed neutron source**
  - ✓ A proton (several MeV) or **electron** beam (several ten MeV)
  - ✓ A target made of a material generating neutrons when interacting with protons or electrons
  - ✓ A moderator and reflector to thermalize the neutrons down to the requested energy (typically: **2 to 100 meV**)
  - ✓ Neutron beam line to bring the neutrons to the samples
- **Sample**
- **Detector**
- **Data acquisition systems**
- **Analyzing software**



Construction status of the neutron source is presented here.





For neutrons with wavelength of $\lambda > 2d$ (d is the interatomic distance) the transmitted intensity increases significantly. This increase in neutron transmission is called Bragg edge. **[2]**

[2] Material and Life Science Experimental Facility (MLF) Annual Report, page-46 (2016).

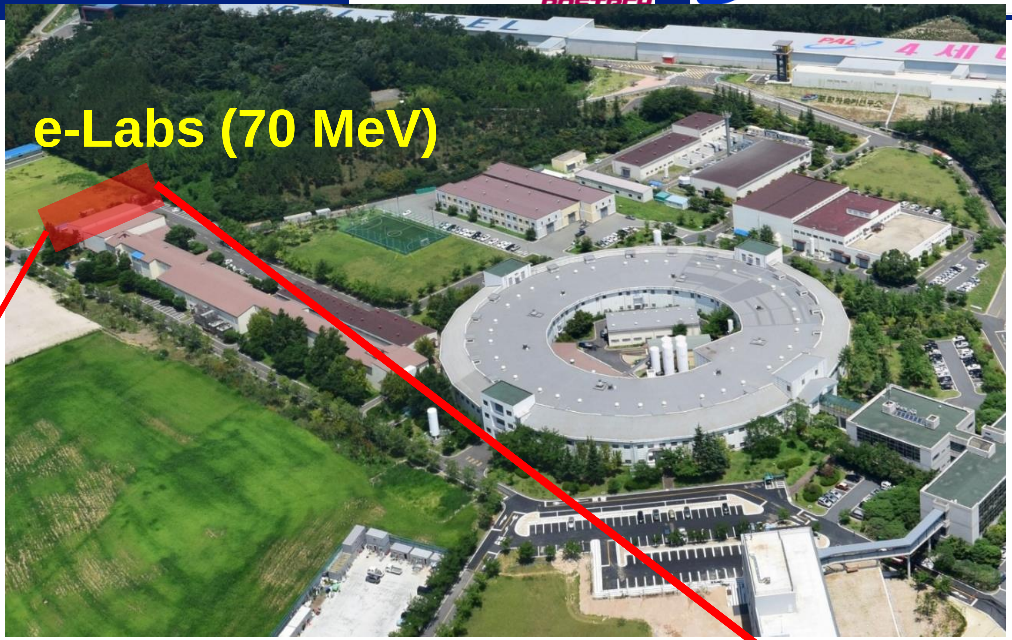
❑ Some CANS based on electron and proton linac

Facility	Accelerate particle	E [MeV]	beam current	Power [kW]	Target	Size [cm]	Neutron beam line angle [degrees]	Neutron yield [n/s]
Hokkaido University	electron	~ 45	33 uA (average) 50→100 pps	1→3.2	water cooled Pb	7 x 7x 7	90, 102.5, 115	1.6×10^{12} n/s
Kyoto University Research Reactor Institute LINAC (KURRI-LINAC)	electron	~max 46	8A (short pulse) 500 mA(long pulse)	6	Ta with H_2O moderator	12 sheets total thickness 29 mm in a cylindrical Ti case (Diamater=5 cm length = 6 cm)	90,135	8×10^{12} n/s
Bariloche Electron-linac (Argentina)	electron	25	25-30 uA	~0.8	Pb	cylindrical	90	6×10^{11} n/s
DAΦNE (Italy)	electron	max 500	Max 500 mA	0.04	W	Cylindrical: R = 3.5 cm, thickness: 6 cm	90	10^{11} n/s
AIST	electron	35	275 (average)	10	Ta	5 x 5 x 2.9	90	1.23×10^{13}
CPHS(China)	proton	13	max 50 mA	16	Be	1.2 mm thick	<90	5×10^{13} n/s
KUANS (Kyoto)	proton	3.5	max 10mA	16	Be	Φ= 6 cm Thickness= 40 um	90	10^{11} n/s

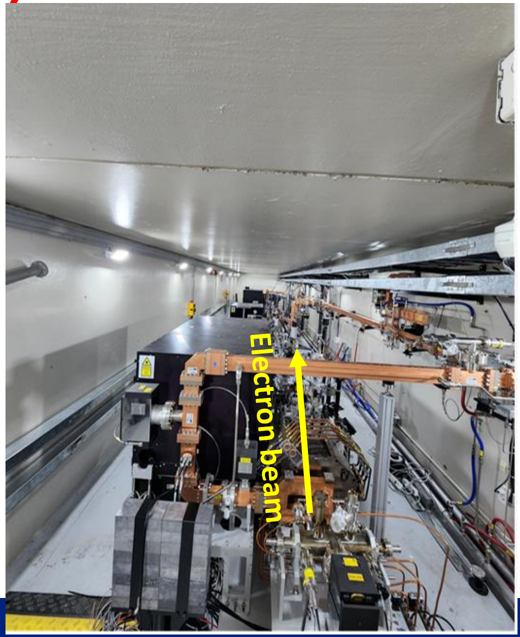
- **Dedicated small electron LINAC of 70 MeV for the development of the new neutron source.**

- **Electron linac for basic science (e-Labs):**
  - Electron energy: 70 MeV
  - Beam charge: 300 pC/pulse
  - Pulse width: 3 ps (FWHM)
  - Average beam current: 18 nA
  - Repetition rate: ~ 60 Hz
  - Total neutron yield : 1.55x10^9 n/s

* Expected neutron yield for Bragg edge imaging:
  2.15x10^{13} n/s
  (using 40 MeV and our designed TMR)



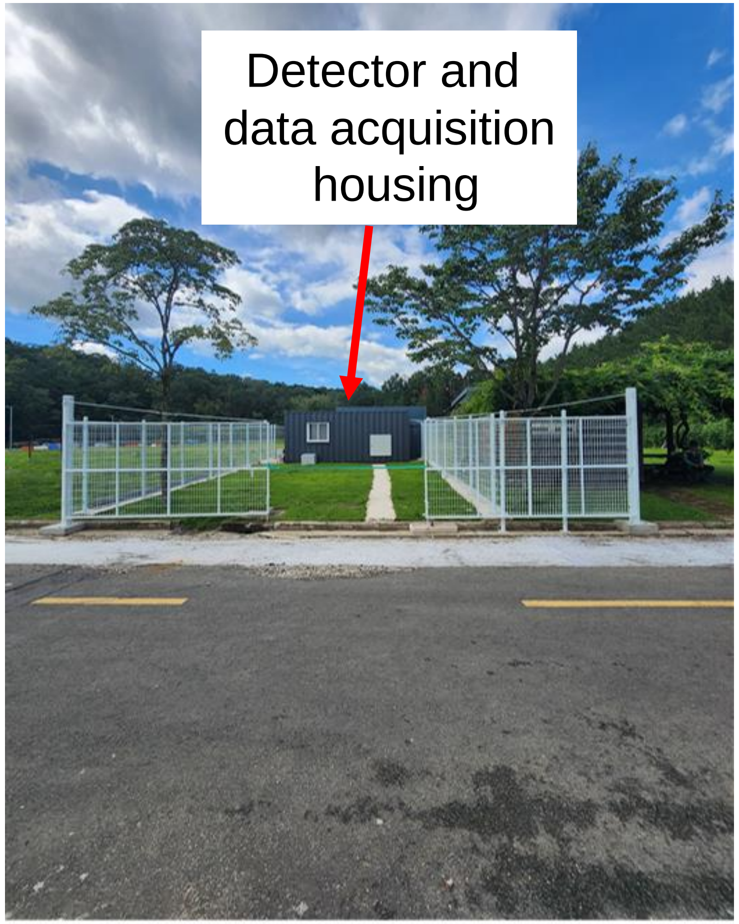
Tunnel

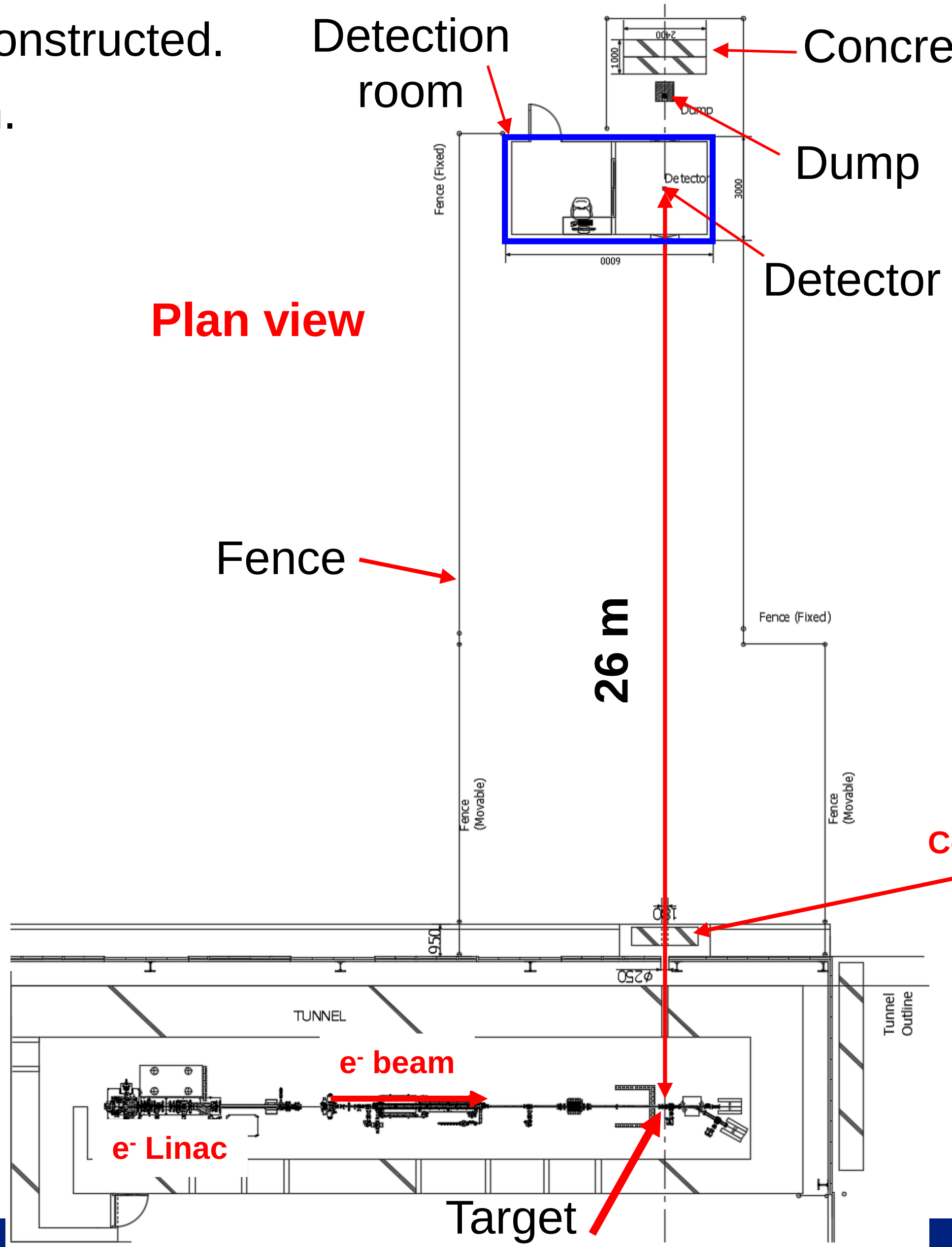


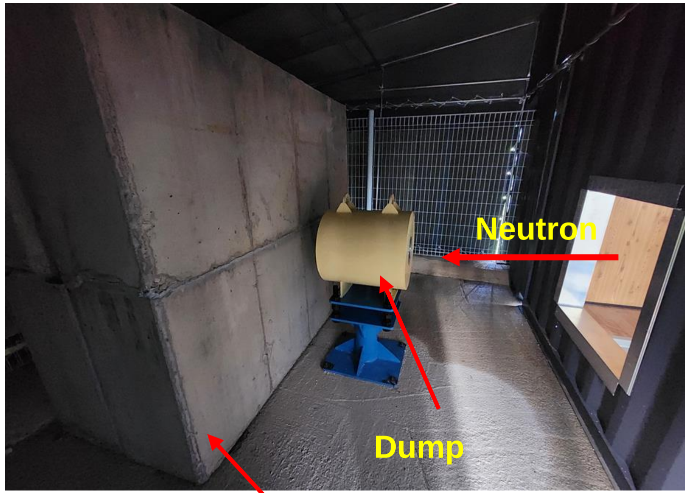
Gallery

Neutron measurement facility construction

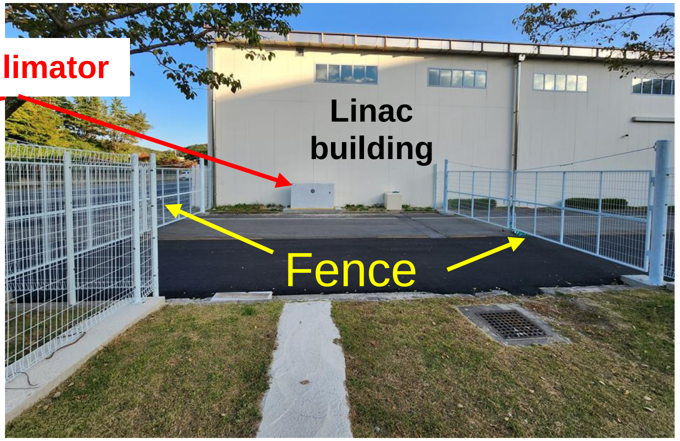
- A neutron detection room has been constructed.
- The target-detector distance is ~26 m.





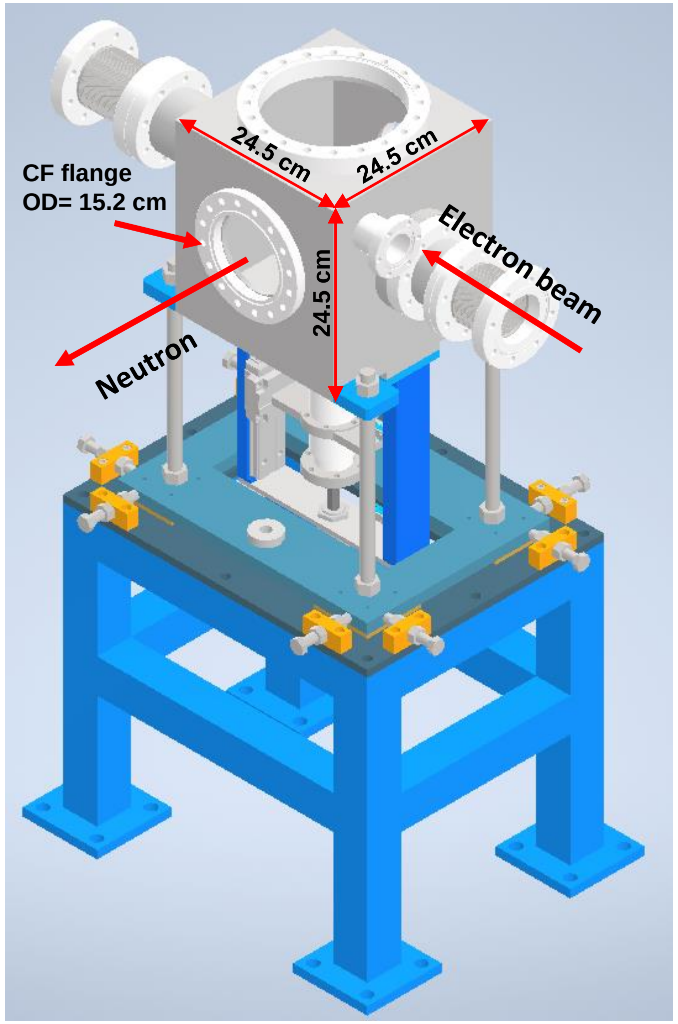


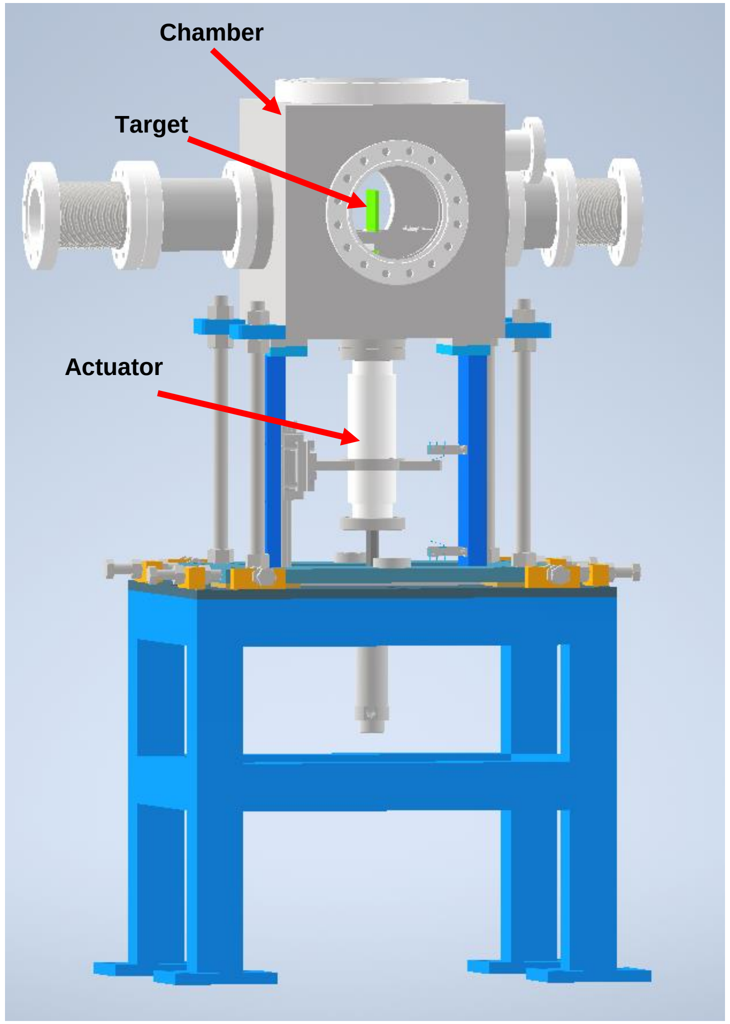
Concrete blocks: 1 m thick

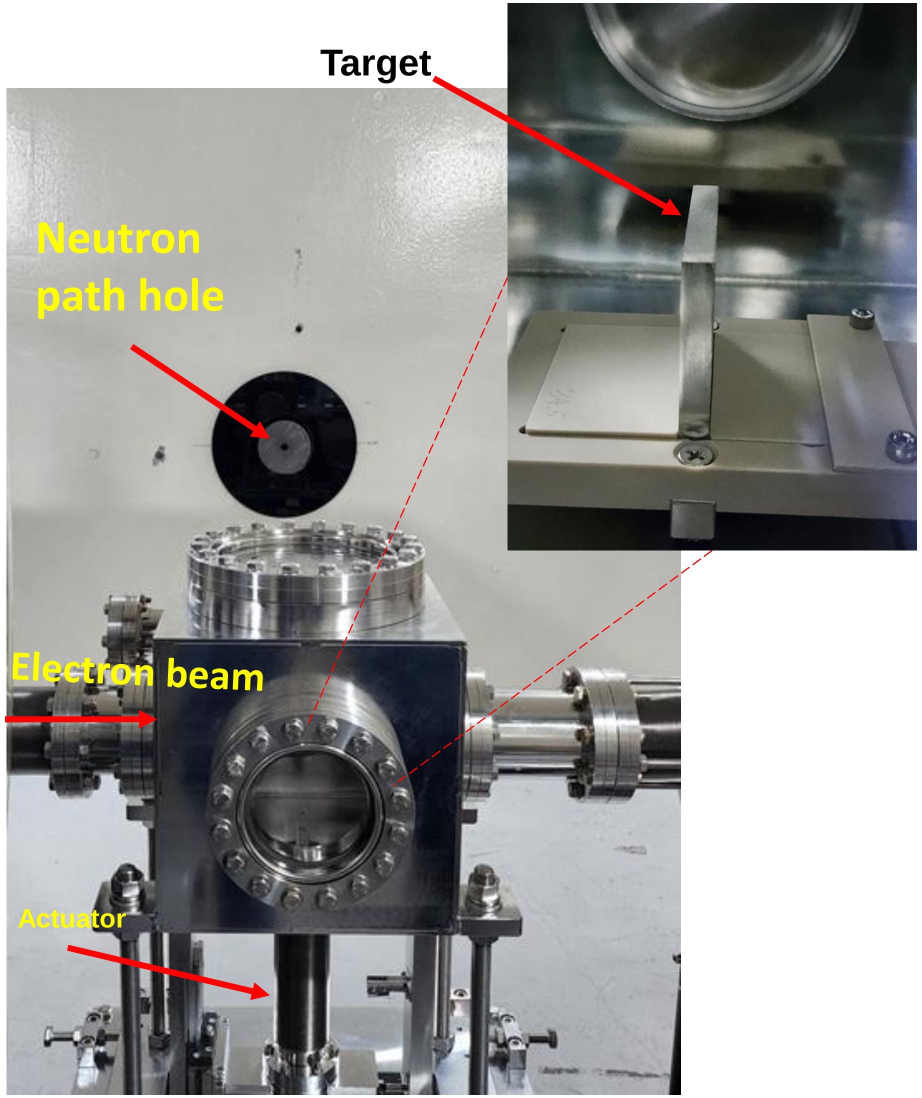


Neutron measurement facility construction

- A target chamber was designed, manufactured and installed in the ELABS linac.

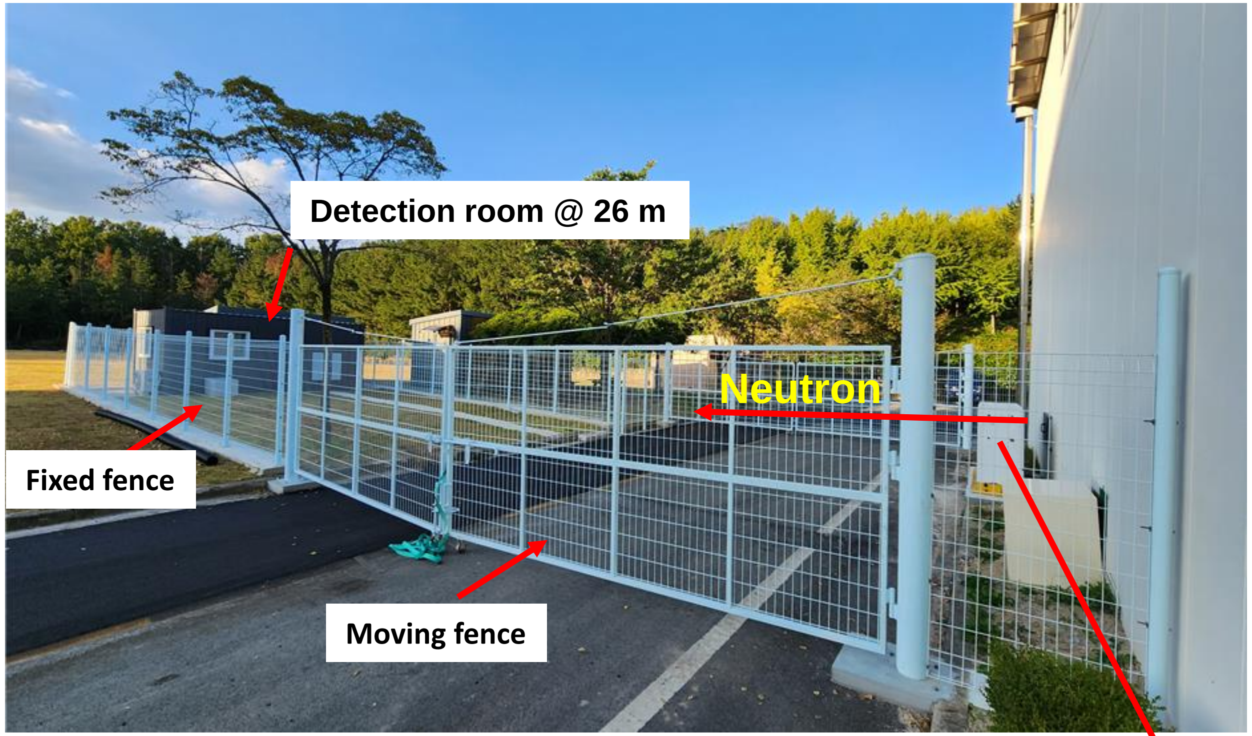




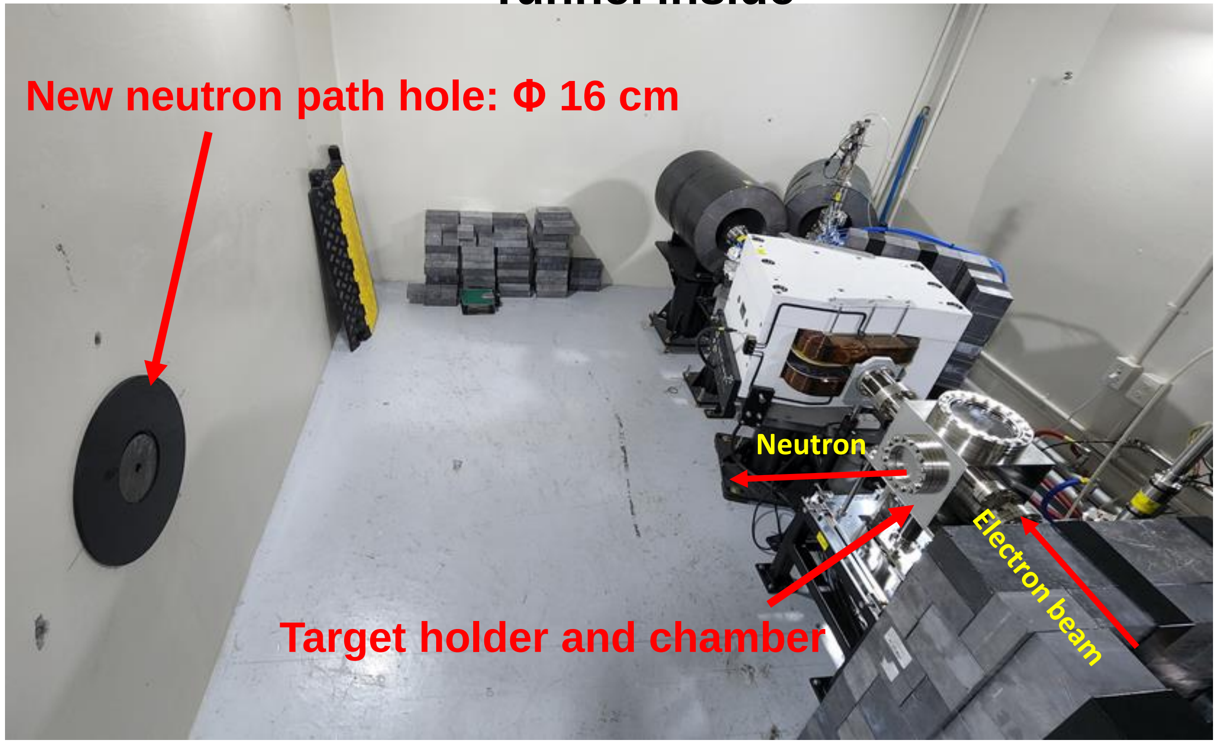


Neutron measurement facility construction

Outside



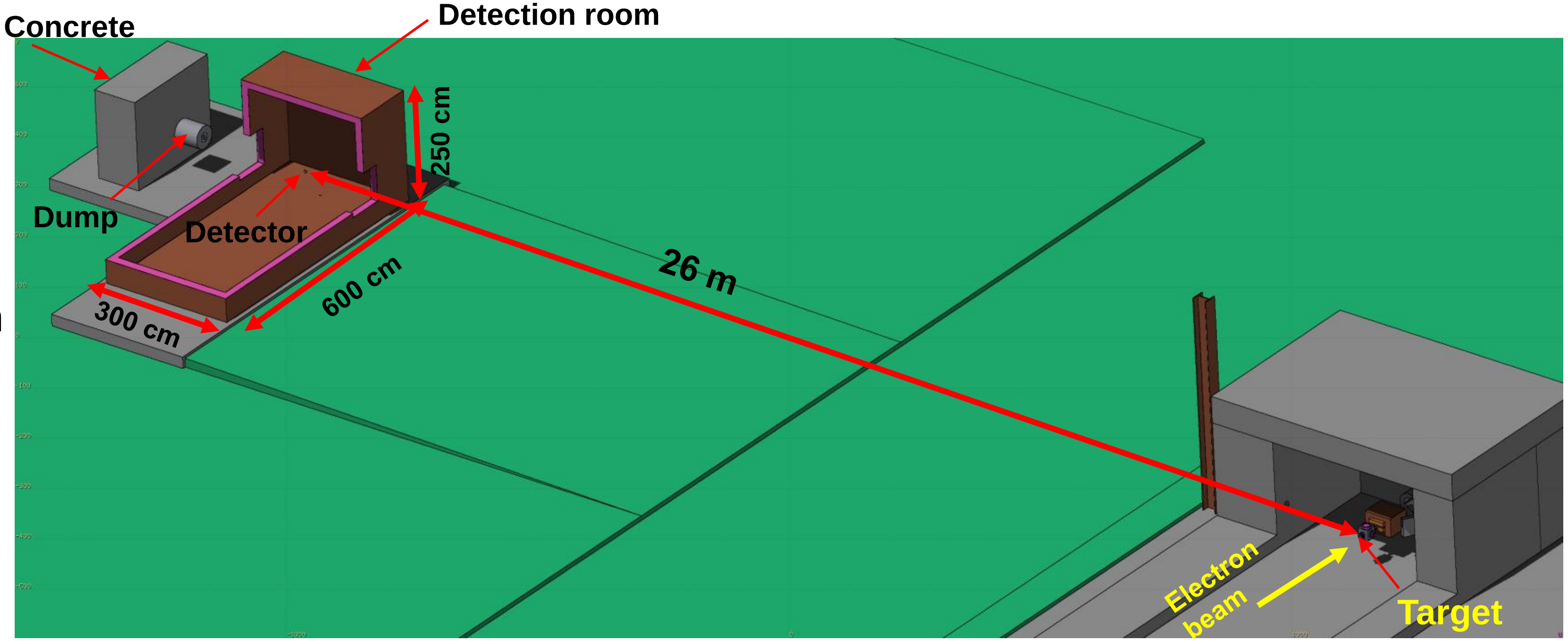
Tunnel inside



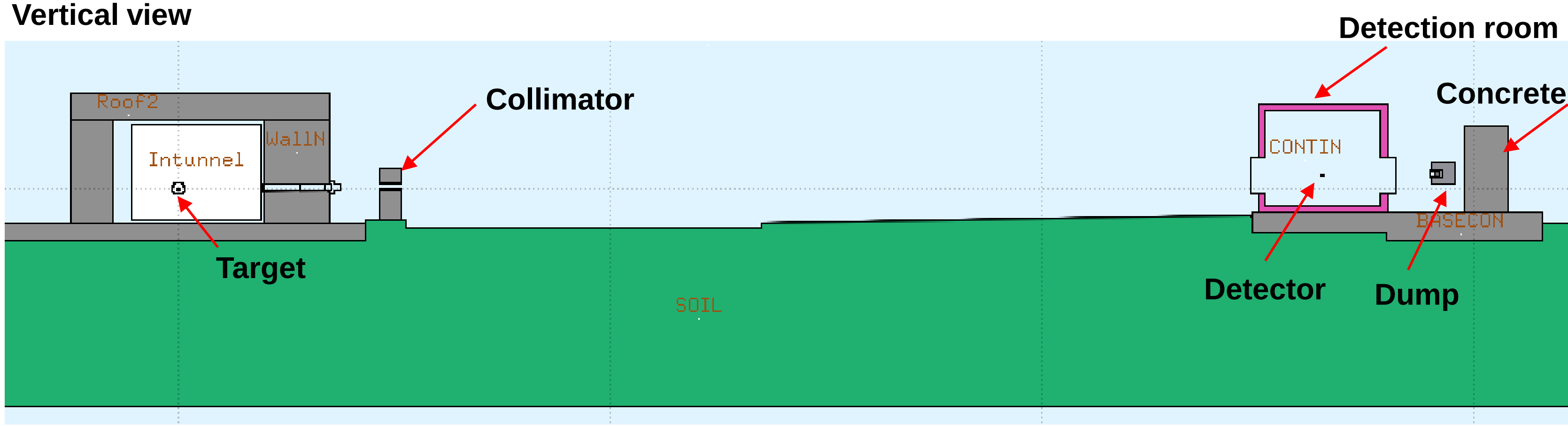
Collimator diameter will be reduced to 10 cm.

Dose estimation for radiation safety

- Neutron measurement facility was simulated in FLUKA [3] Monte Carlo code.
- Dose distribution was estimated:
  - Target: Tungsten, 5 cm× 5 cm × 1.75 cm
  - Electron energy: 70 MeV
  - Electron beam current: 18 nA



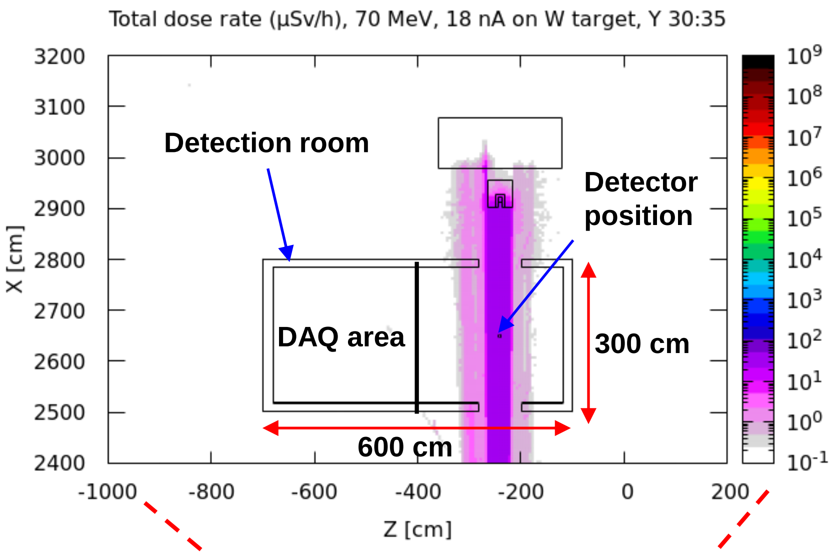
Vertical view



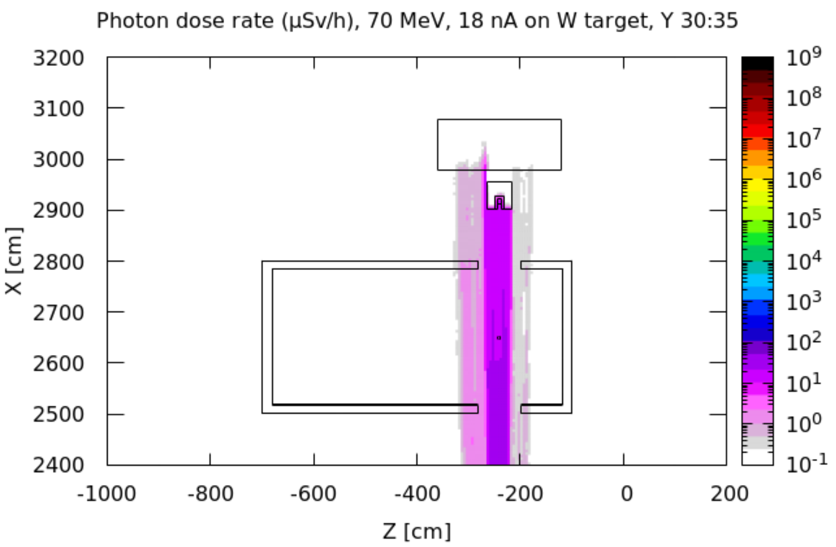
[3] G. Battistoni et al. Ann. Nucl. Energy. 82, 10 (2015).

Dose distribution - Top view

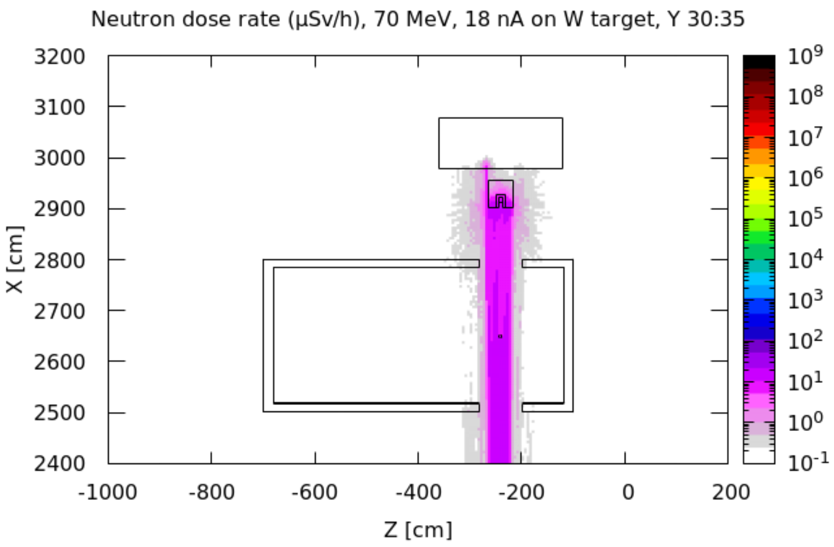
Total: White area <0.5 uSv/h

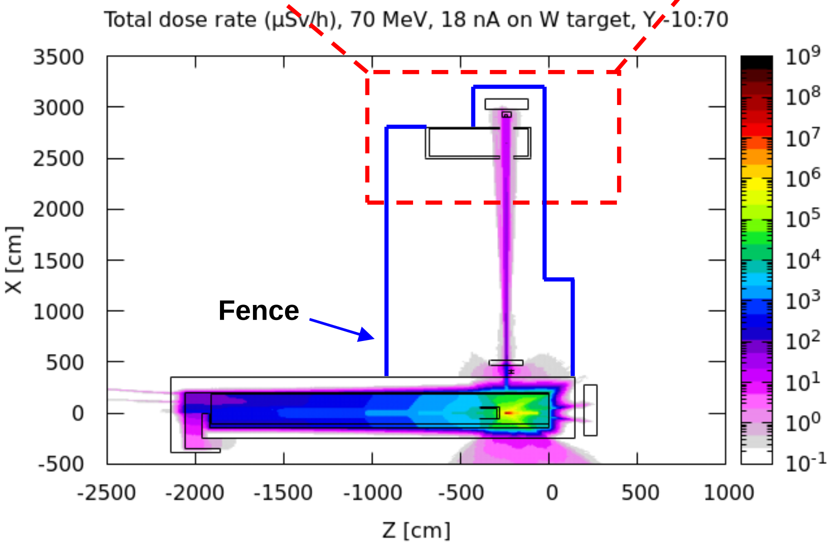


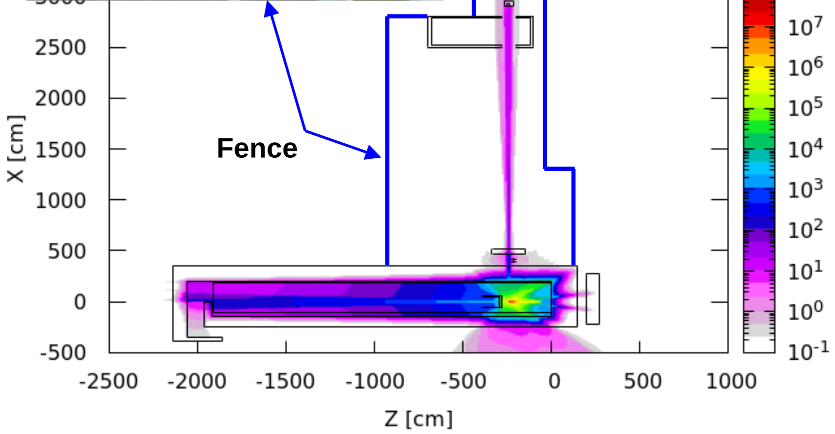
Photon

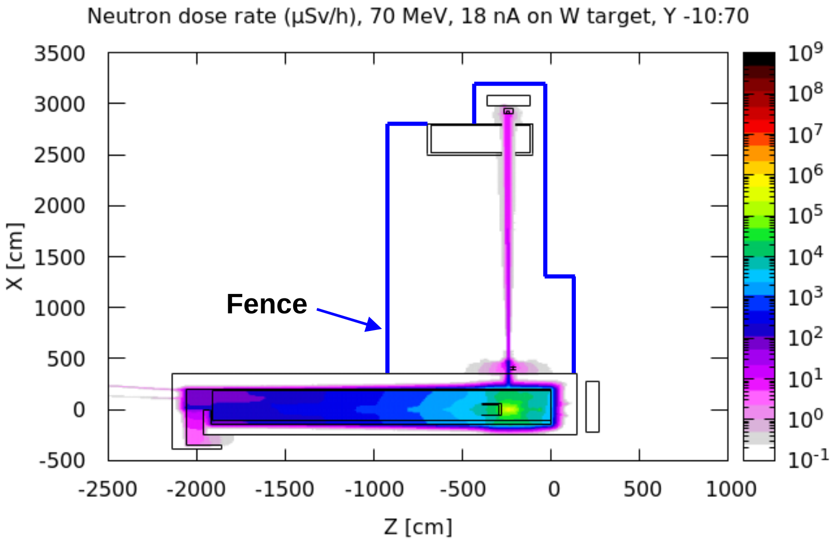


Neutron





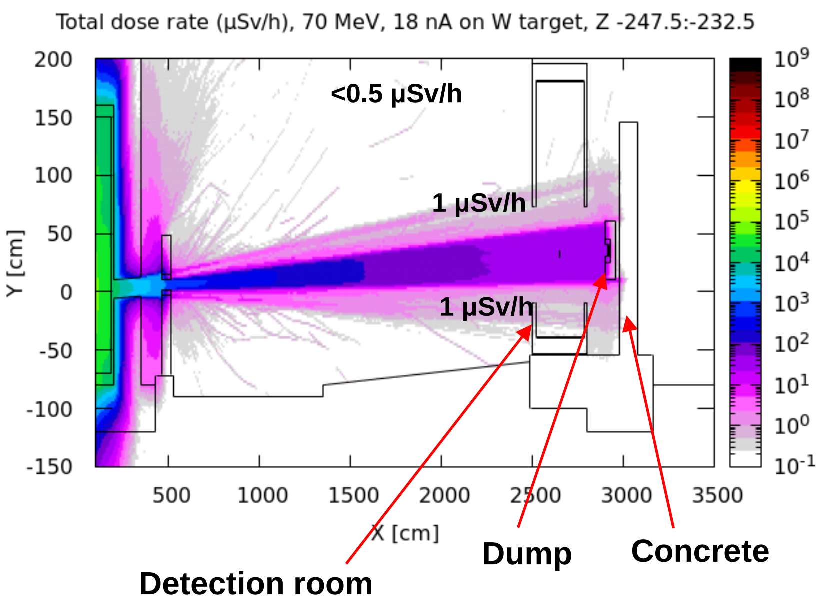




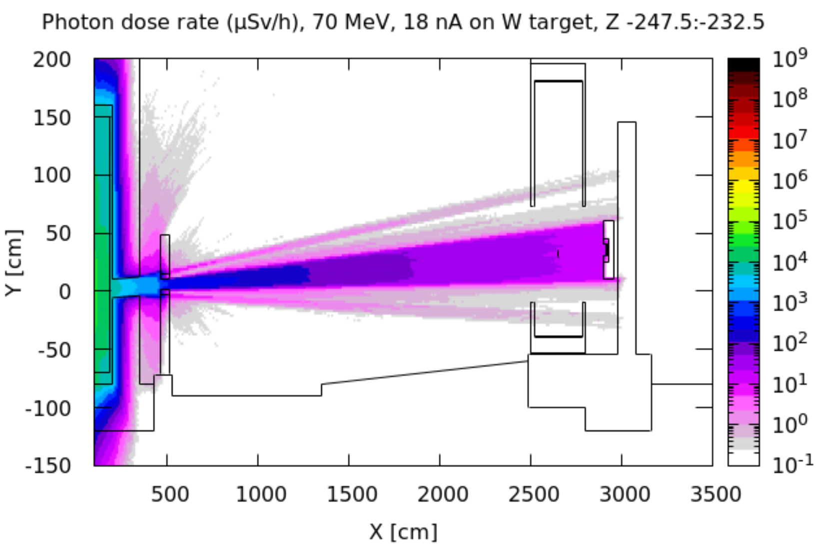
Dose distribution - Vertical view

DANE Division of Advanced Nuclear Engineering POSTECH | PAL 포항가속기연구소 POHANG ACCELERATOR LABORATORY

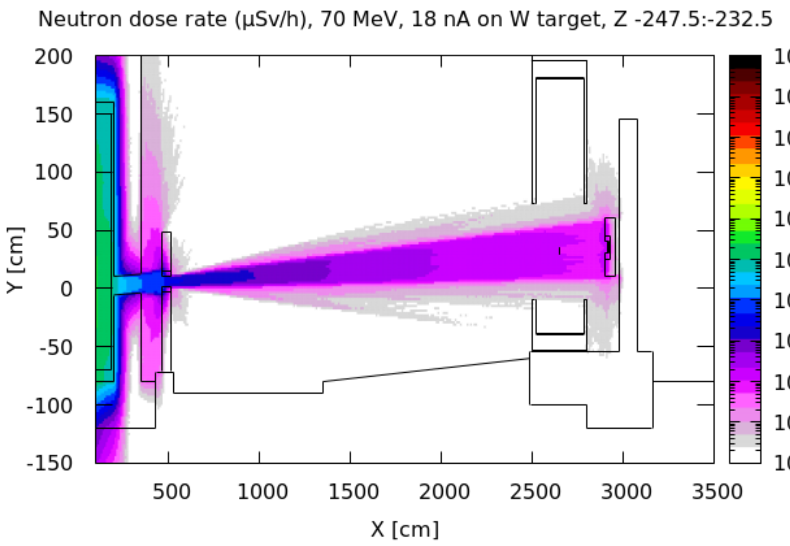
Total: White area <0.5 uSv/h



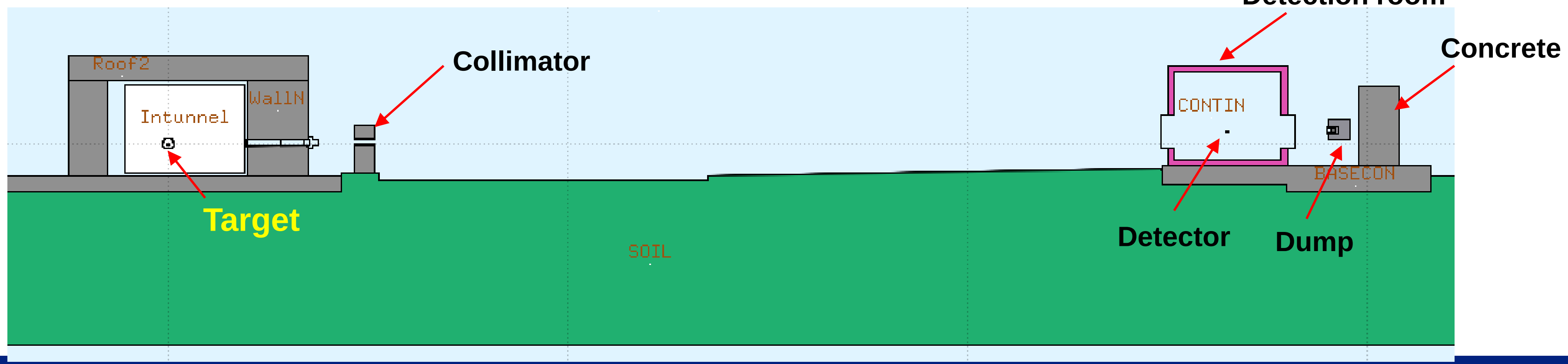
Photon



Neutron



Vertical view



Neutron detectors & Data Acquisition (DAQ) system

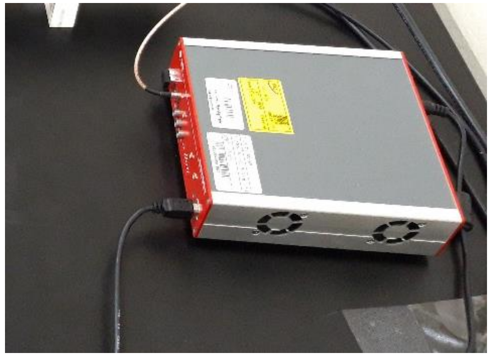
❑ Equipment for measuring fast and thermal neutrons

NIM-CAMAC modules

NE213 liquid scintillator 2 in × 2 in and 5 in × 5 in
→ Fast neutron measurement

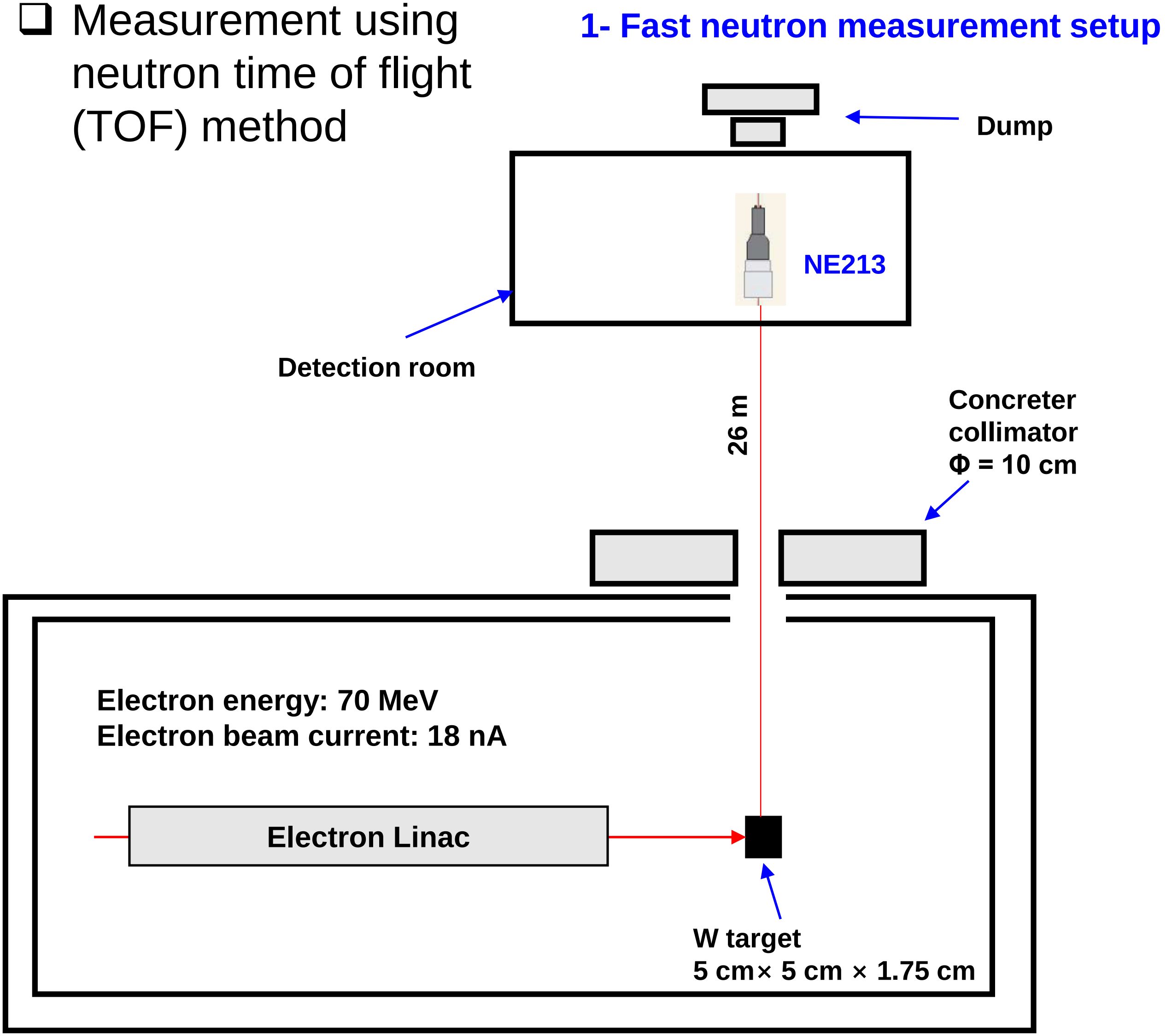
LiI(EU) detector 2 in × 3 in
→ Thermal neutron measurement

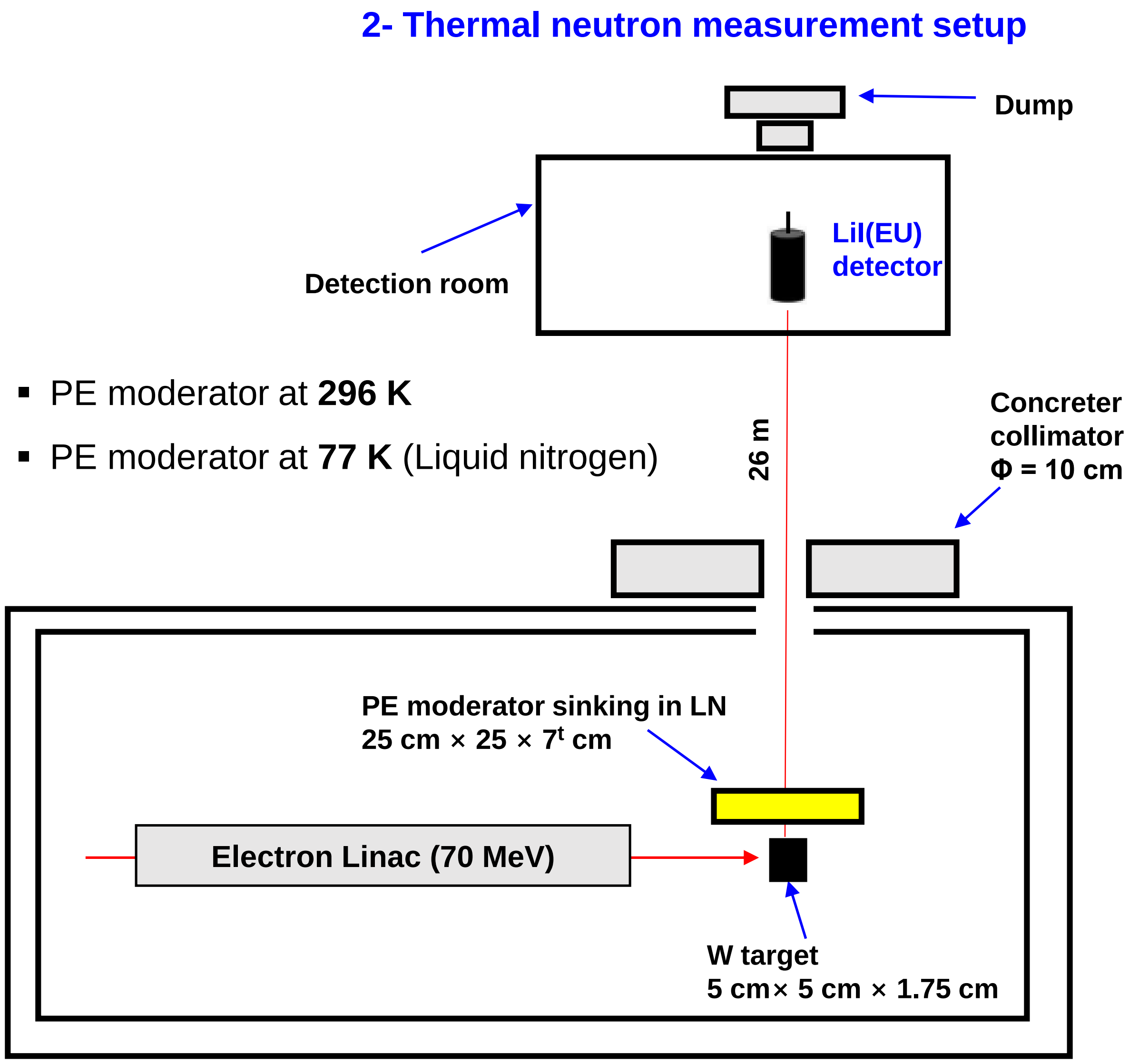
Desktop digitizer



Planned Experiments

- Measurement using neutron time of flight (TOF) method

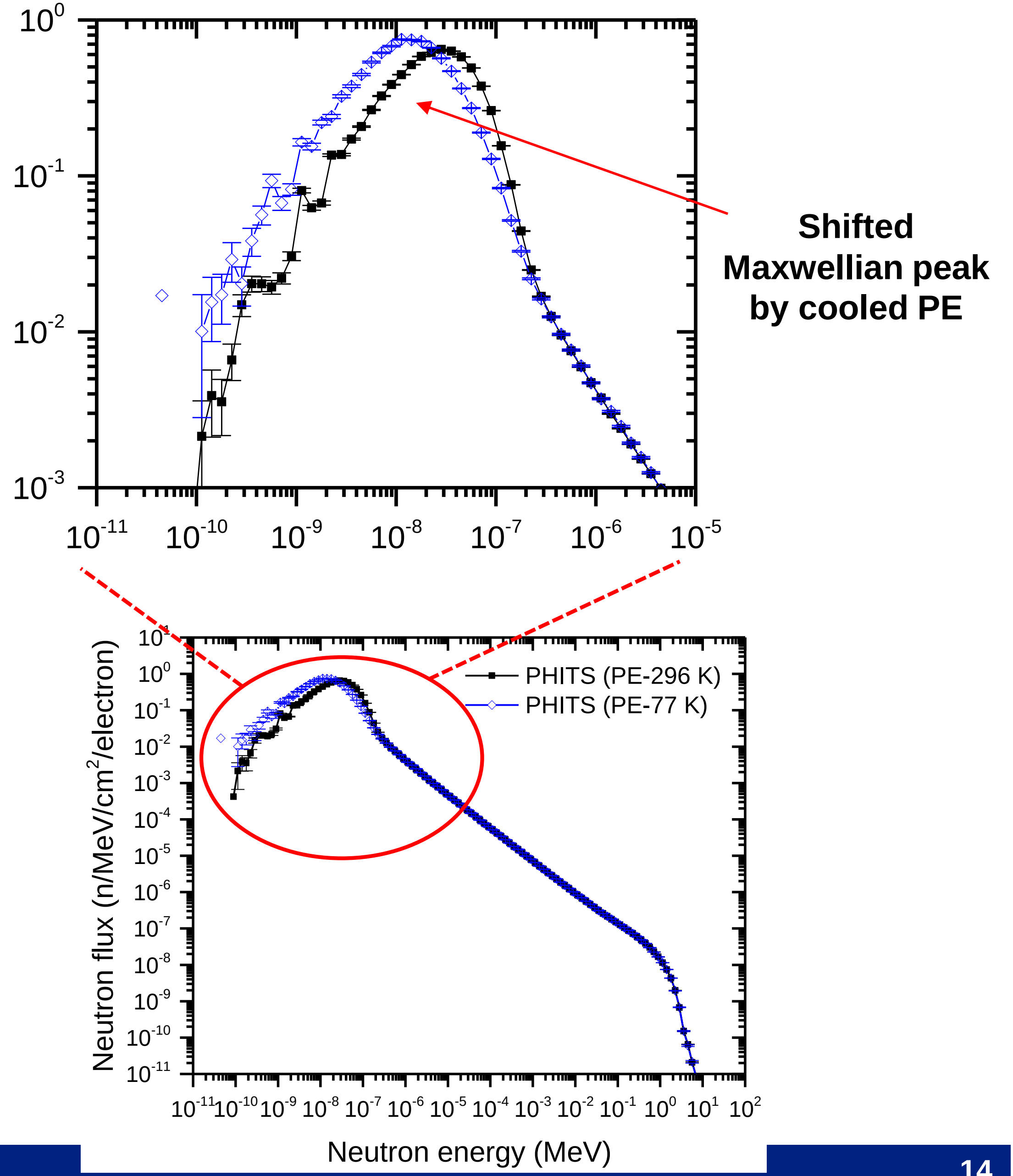




- PE moderator at **296 K**
- PE moderator at **77 K** (Liquid nitrogen)

Planned Experiments

- ❑ Measuring photoneutron production yields from a tungsten target using a small electron accelerator facility.
- ❑ Measuring cold neutron flux
  - Using PE at room temperature (~296 k)
  - Using PE cooled with liquid nitrogen (~77 K)
- ❑ Cooled PE shifts the Maxwellian peak to lower energies → Increasing cold neutron flux.
- ❑ Monte Carlo (PHITS) results can be benchmarked.
- ❑ Demonstrating the feasibility of cold neutron production.



PHITS [4] calculation.

[4] T. Sato et al, J. Nucl. Sci. Technol. 55 (2018).

Summary

- Compact Accelerator Neutron Sources can be used for Bragg edge imaging.
- A neutron source based on the electron linac (70 MeV) has been under development.
- The operation approval has already been given by NSSC in the view of radiation safety and field inspection will be done soon.
- The neutron measurement facility of TOF methods has been constructed for:
  - Fast photoneutron measurement
  - Cold neutron measurement
  - Other applications
- The experimental data will be useful for benchmarking Monte Carlo calculations
- This neutron source will show the feasibility of fast and cold neutron production.
- This neutron source will help for developing the Bragg edge imaging technique using the electron linac. (~ $1x10^4$ n/cm^2/sec at detector position)

Thank You for Your Attention