Characteristics of Neutron Beam from IR Beam Port of HANARO for its Application to Dynamic Neutron Radiography

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ABSTRACT

The dynamic neutron radiography is a powerful tool for fluid flow visualization as well as multi-phase flow research. In HANARO, a BNCT facility was built at its IR beam port which could be used for neutron radiography as well. For neutron radiography, thermal neutron flux and L/D ratio are most important parameters. The neutron flux was measure by using gold wire activation analysis and the L/D ratio was measured by using ASTM E803-91 NU device. At the 2 m from the beam exit, the thermal neutron flux was found to be 2.58×10^8 n/cm^{2}s and L/D was 190. In addition, the shielded room at the beam port exit is very spacious, which is a merit for dynamic neutron radiography. From these, it is believed that the IR beam port in HANARO will act as a good source for dynamic neutron radiography.

1. INTRODUCTION

The dynamic neutron radiography is a powerful tool for fluid flow visualization as well as the multi-phase flow research[1,2,3]. This technique can be used to investigate the detail behavior of neutron-opaque fluid in metallic enclosure. For the dynamic neutron radiography, high thermal neutron flux, low neutron/gamma ratio and good sharpness are the key parameters.

HANARO is a open pool type research reactor operated by KAERI(Korea Atomic Energy Research Institute) and a BNCT(Boron Neutron capture Therapy) facility using the IR beam port has been installed. In the development of this facility, it was recognized that this facility could be well suited for dynamic neutron radiography considering its beam characteristics[4]. The construction of the beam facility and shielding room of the BNCT facility in HANARO was completed in 2001 and its beam characteristics in view of neutron radiography was measured.

In this paper, the measurement results on the IR beam characteristics are given with the calculation result. Also, they are compared with the characteristics of other beams for neutron radiography.

2. IR BEAM PORT IN HANARO

HANARO is an open-tank-in-pool type research reactor and it design power is 30 MW_{th}. It has 7 beam tubes and their arrangement is shown in Fig. 1. The IR beam tube was the only option for BNCT at HANARO because it was not considered at the design stage and any modification of the biological concrete shield was impossible[4]. The details for arrangement of shutter, filter and collimator is in Fig. 2. The beam tube nose is located at the position of the peak thermal neutron in D_2O reflector region. A long water cylinder plays the role of beam shutter. By hydraulically moving in/out the water in water cylinder, the shutter function is achieved. Radiation filter should remove fast neutrons and gammas but pass more thermal neutrons. Feasibility study for candidate materials of aluminum, silicon and bismuth was performed through computer simulation using the MCNP4B. It was found that if silicon and bismuth were crystallized, their cross section at thermal neutron energy range became lower. Thus, silicon single crystal was chosen for filtering fast neutrons. It has high fast neutron and low thermal neutron cross section. A bismuth single crystal was selected for filtering gammas, considering the relatively low neutron absorption cross section. The lengths of silicon and bismuth are 40 cm and 15 cm, respectively. To keep the radiation level low, auxiliary shields were added around the radiation filter. Polyethylene, borated polyethylene, lead and LiF were chosen. Also, the irradiation room was prepared with concrete shield for protecting radiation workers[4,5]. At present, the thickness of the lead shield is 20 cm and the diameter of collimator at exit is 15 cm.

3. IR BEAM CHARACTERISTICS

3.1 NUMERICAL CALCULATION OF NEUTRN FLUX AND GAMMA LEVEL

The particle flux distribution inside IR beam tube was calculated using the MCNP4B. Since the beam tube length was over 400cm, the calculation was divided into two steps to obtain the results with a reasonable statistical error from the Monte Carlo calculation. The flux at the beam tube nose was first calculated from a model containing the reactor core and a front part of beam tube. Next, the flux distribution inside the beam tube was calculated from a model of beam tube with a calculated source at the nose. For this model, the exact geometries of beam tube having water shutter and radiation filter were used. A Russian roulette with geometry splitting was utilized to direct more particles toward the beam tube exit as a variance reduction method. In the calculation model, the radiation filter of Si and Bi was at room temperature. The gamma distribution was calculated by using the same model.

3.2 MEASUREMENT OF BEAM CHARACTERISTICS

The neutron flux was measured by using gold wire activation analysis methods. Gold wires of 0.01" in diameter 20 mg in mass were attached on an aluminum plate and they were irradiated. The distance between gold wires were 4 cm and the area covered by wires were 16 to 144 cm^2 depending on the measurement locations. When measurement of the Cd ratio was required, gold wires were wrapped with Cd foil. The activities from the irradiated gold wires were measured by using a HPGe detector. Fig. 3 is the block diagram for the measurement system.

L/D is the parameter describing the angular spread of the emerging beam. The higher L/D value is, the sharper the image of an object is. For this measurement, ASTM E803-91 method was used[6].

In addition the beam characteristics were investigated by using the BPI(Beam Purity Indicator) and SI(Sensitivity Indicator) of ASTM E545-91[7].

3.3 RESULTS FROM CALCULATION AND MEASUREMENT

Fig. 4 shows the calculated thermal neutron flux distribution along the centerline of beam tube from the collimator exit at a reactor power of 24MW. This is the flux averaged over a disk of 2 cm in diameter. The statistical errors of the calculated thermal neutron fluxes were all within 20% and almost about 10%. The fast neutron fluxes are calculated to be less than 1/100 of the thermal neutron flux, and gamma fluxes are small compared with the thermal neutron fluxes.

In Table 1, the neutron fluxes and other characteristic parameters for IR beam tube are given and compared with those for JRR-3M[8], where multi-phase flow is performed by using the dynamic neutron radiography. This comparison shows that the thermal neutron flux at 2 m from collimator exit, where an imaging system is going to be installed, is high enough for dynamic neutron radiography. The measured fluxes were in good agreement with the calculated fluxes considering the errors in calculation and measurement. In Table 2, the beam quality and sensitivity of neutron beam from IR port obtained by using the BPI and SI of ASTM E545-91 were compared with those for neutron beam from NR port of HANARO[9]. This comparison shows that the thermal neutron content is less at the IR beam than at the NR beam. However, the sensitivity of IR beam at 2 m from the collimator is about the same as that of the existing NR beam. If the sensitivity would be measured at the farther location from the beam exit, the sensitivity would increase.

CONCLUSIONS

By using gold wire activation analysis and ASTM E803-91 NU device, the neutron fluxes from the IR beam port and L/D ratio were measured. At the 2 m from the beam exit where an imaging system is going to be installed, the thermal neutron flux was found to be 2.58×10^8 n/cm^{2}s and L/D was 190, respectively. The beam quality and sensitivity of neutron beam from IR port were also comparable to those of IR port which is being used for neutron radiography in HANARO. In addition, the shielded room at the beam port exit is very spacious, which is a merit for dynamic neutron radiography. From these, it is believed that IR beam port in HANARO will act as a good source for dynamic neutron radiography.

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Table 1. Comparison of neutron fluxes

		JRR-3M NR (20 MW)[8]	HANARO IR Beam Port (24 MW)			
Location		Specimen Table	Collimator exit	1.05 m from collimator exit	2.0 m from collimator exit	3.57 m from collimator exit
Flux (n/cm^2s)	Calculation	-	7.33E8	3.41E8	2.28E8	1.21E8
	Measurement	1.5E8	8.34E8	3.34E8	2.58E8	1.30E8
	Ratio	-	1.14	0.98	1.13	1.01
L/D ratio		153(Vertical)/ 176(Horizontal)	-	-	190	-
N/γ ratio ($n/mR\ cm^2$)		6.3E6	1.48E8	-	-	1.10E8
Cd ratio		130	104	160	-	-

Table 2. Comparison of neutron beam characteristics

	NC(%)	S(%)	γ(%)	P(%)	Sensitivity	
					Minimum gap Size (μm)	Minimum hole Size (μm)
2nd exposure room of HANARO NR	71.5	2.8	0.4	3.95	13	250
2 m from IR port collimator	62.2	3.2	0.8	1.2	13	250

NC : Effective thermal neutron content
S : Effective scattered neutron content
γ : Effective gamma content
P : Effective pair production content

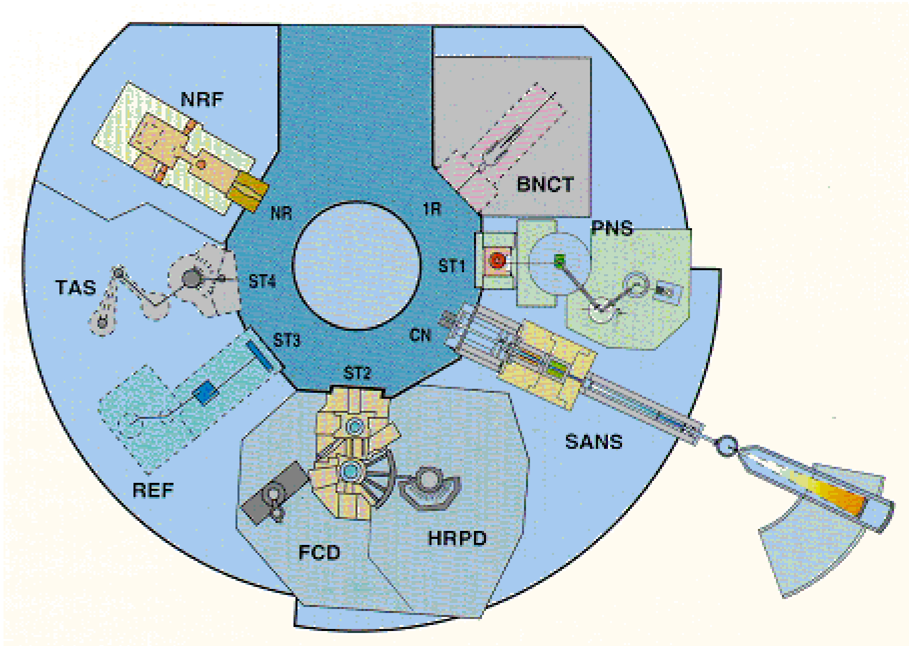

Figure 1. Arrangement of beam tubes in HANARO

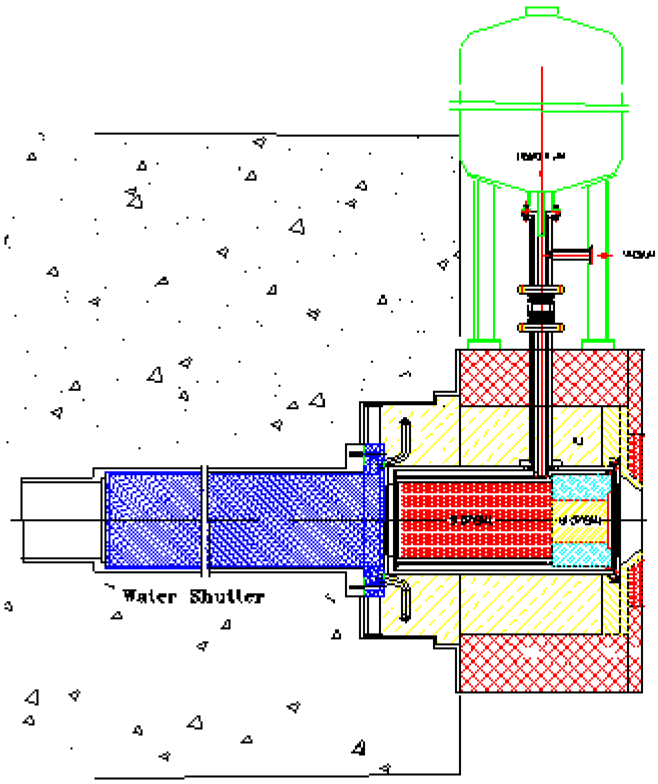

Figure 2. Water shutter, filter and collimator for IR beam port in HANARO

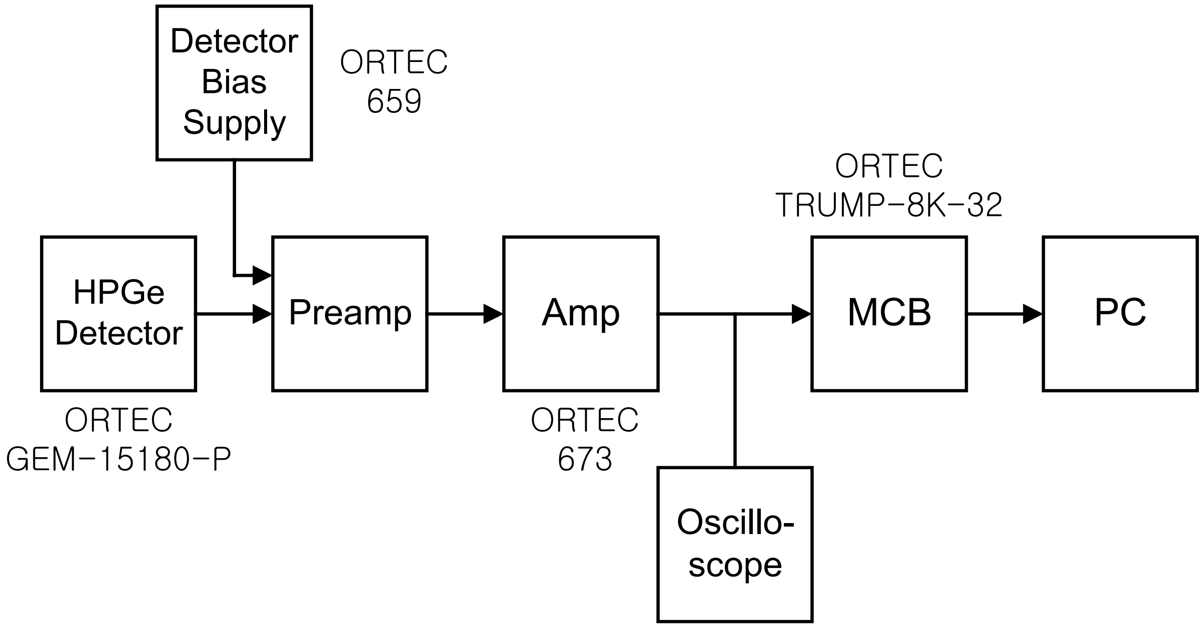

Figure 3.   Block Diagram for Gamma Spectroscopy

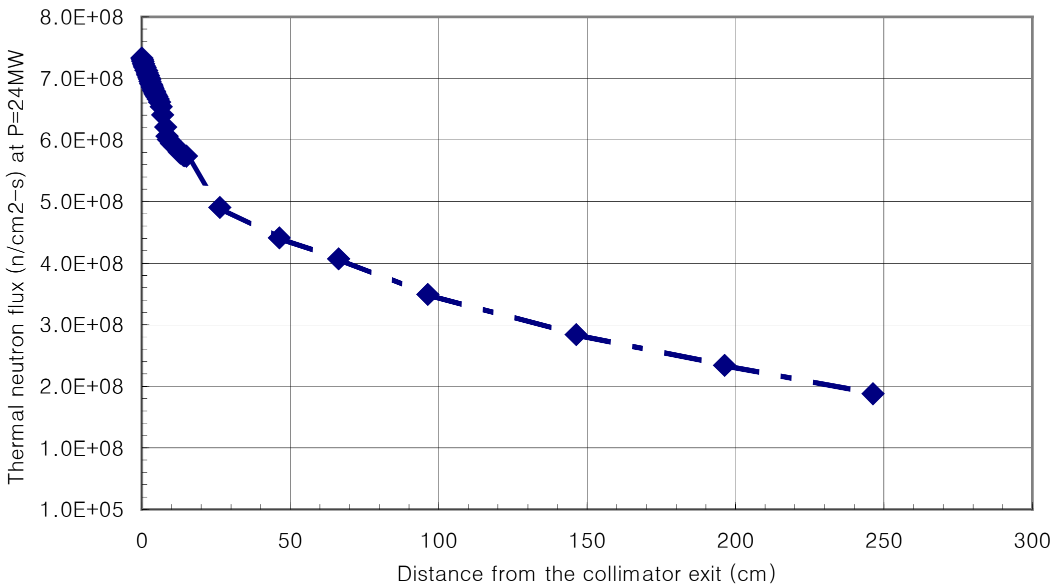

Figure 4. Calculated neutron flux distribution from the BNCT collimator exit at 24MW in HANARO