Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Research on Dynamic Neutron Radiography in HANARO

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1. Introduction

Neutron radiography is a non-destructive test method to examine a material by using the dependency of neutron attenuation on the nuclear characteristics of the atoms composing the object material. There are two categories of neutron radiography; static neutron radiography and dynamic neutron radiography. The static neutron radiography is a technique to observe a standing object by using a camera or a film cassette. The dynamic neutron radiography(DNR) is a technique to observe a moving object usually by using a camera. Depending on the camera frame rate, the dynamic neutron radiography is categorized into the real time neutron radiography(RTNR) and the high speed neutron radiography(HSNR). The frame rate for RTNR is 30 frames/s and that for HSNR is usually more that 500 frames/sec. Thus, RTNR is good for observing time-averaged phenomena and HSNR is good for observing instantaneous phenomena [1].

DNR is a powerful tool for fluid visualization as well as the multi-phase flow research [2,3,4]. This technique can be used to investigate the detail behavior of neutron-opaque fluid in metallic closure. Since 2001, the development of a DNR system in HANARO has been conducted and application studies have been performed. This paper describes the characteristics of DNR system in HANARO and the application study results.

2. DNR Facility in HANARO

HANARO has 7 beam tubes and the IR beam tube is used for the ENF facility(Ex-core Neutron-irradiation Facility). The inside of the shielding room in front of the IR beam exit is as shown in Fig. 1. Its floor area is 4x6 m^2 and the height is 3 m. The details for the arrangement of the shutter, filter and collimator are shown in Fig. 2. The beam-tube nose made from Zr-4 is located at the position of the peak thermal neutron flux in the D_2O reflector region. A long water cylinder is used as the beam shutter. By hydraulically moving in/out the water in the water cylinder, it plays the role of the beam shutter. A radiation filter for the ENF, whose main usage is BNCT(Boron Neutron Capture Therapy), should remove the fast neutrons and gammas but let more thermal neutrons pass. A feasibility study on the candidate materials for the filter was performed through a computer simulation and the silicon single crystal was chosen for filtering fast neutrons. Its cross section is high for the fast neutron and low for the thermal neutron. A bismuth single crystal was selected for filtering the gamma radiation, by considering the fact that its neutron absorption cross section is relatively low. To keep the radiation level low, auxiliary shields were added around the radiation filter and polyethylene, borated poly-ethylene and lead were used. Two exit collimators which are made from PE and $^6Li_2CO_3$ are available and their inside diameters are 15 cm and 10 cm, respectively. The neutron flux, L/D ratio, Cd ratio and n/γ ratio at various locations in the ENF shielding room are given in Table 1. The neutron fluxes and Cd ratios were measured by using the gold wire activation method. The n/γ ratios were obtained by simulations using MCNP4B. The L/D ratios were obtained by using the geometric information. If the Si filter is cooled by liquid nitrogen, the neutron flux increases by 40%. [1]

Fig.1 A view for the inside of ENF shielding room

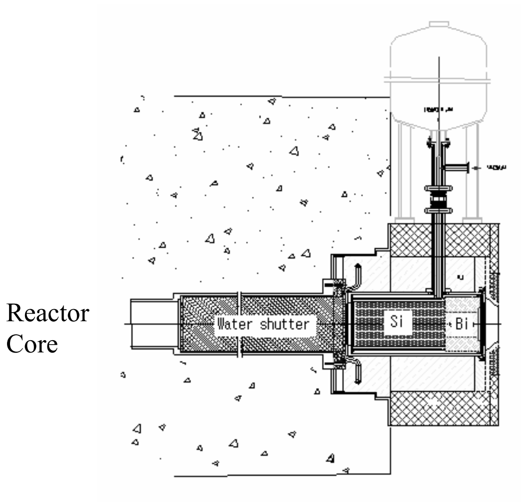

Fig.2 Beam shutter and filter for ENF

Table 1

Neutron beam characteristics of ENF beam in HANARO at 24 MW operation

Distance from beam exit(m)	0	1.05	2	3.57
Flux (n/cm^2s)	8.34E8	3.34E8	2.58E8	1.30E8
n/γ ratio ($n/mRcm^2$)	1.48E8	-	-	1.10E8
L/D ratio	38.5	47.3	55.2	68
Cd ratio	104	160	-	-

3. DNR Application Study

3.1. Application to two-phase flow study for nuclear reactor

The void fraction and two-phase flow pattern are important parameters required for the analysis of two-phase flow which may occur during the abnormal transient condition of a nuclear reactor. A test section simulating the fuel channel of HANARO was built and two-phase images were taken by using the HSNR technique. The camera frame rate was 1000 fps and the spatial resolution was 0.102 mm. By using the two-phase flow images, time-averaged void fraction, instantaneous void fraction and two-phase flow patterns were observed [1,5,6]. Pb-Bi is a candidate as a coolant for a fast reactor or an accelerator target. DNR is a good tool to visualize and investigate the two-phase flow in Pb-Bi. A study was conducted to investigate the two-phase flow behavior in a U-type channel simulating the air-driven natural circulation of Pb-Bi channel [7]. Also, the possibility to measure the 3D velocity distribution in a Pb-Bi channel was investigated taking advantage of the fact that the L/D value of neutron beam in ENF is very low [8].

3.2. Visualization of cavitation in a diesel engine fuel injection nozzle

Some optical visualization results have been conducted using nozzles made of glass. However, no visualization inside the real nozzle of a diesel engine has been conducted. Neutron radiography is a suitable tool for the visualization of fuel cavitation behavior inside the metallic nozzle and the test was conducted in ENF facility of HANARO [9]. The high neutron beam and a large shielding room in ENF of HANARO made it possible to perform this experiment.

3.3. Visualization of water generated in a fuel

The fuel cell will be an important energy source for a car in future and the visualization of water in a fuel cell is necessary for the development of a fuel cell. The water in a fuel cell was visualized by using the NR facility of NIST reactor. It was a preliminary study for a visualization of water generation in a fuel cell [10].

4. Future Works

For the completion of DNR system in the ENF of HANARO, more efforts are required in preparation of equipments as well as image process technique. The fuel cell visualization test facility will be installed in this year. These will help the further development of DNR technology in HANARO.

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