Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Performance Evaluation of Neutron Radiography Facility at Kyung Hee University Reactor, AGN-201K

Jong-Min Choi(1) *and Myung-Hyun Kim*(1)&(2)
(1) Department of Nuclear Engineering, Kyung Hee University, 446-701, Rep. of Korea
(2) Reactor Engineering Division, Argonne National Laboratory, IL 60439, USA
mhkim@khu.ac.kr

1. Introduction

Neutron radiography facility (NRF) is the non-destructive inspection equipment that utilizes intrinsic penetration property of neutrons. This technique is based on the interaction of thermal neutrons with nucleus instead of the electron as in X-ray radiography. Because of supplementary benefits to X-ray, NRFs have been widely used in the most of research reactors. In some facilities, NRF serves very critical service to many industries with high level of quality assurance; such as NDT for aerospace machine parts or on-line nano-scale monitoring research for a fuel cell.[1, 2]

As an enhancement program of Reactor Research and Education Center (RREC), NRF was designed and installed recently. In this paper, summary of design study for NRF at AGN-201K reactor was given with recent results from experimental test shots.

2. Methods and Results

2.1 AGN-201K Reactor

The AGN-201 reactor has been upgraded and refurbished two times. At the first period during 2004 through 2007, power was uprated and reactor equipments were upgraded for the establishment of experimental training courses; mainly focused on physics test. At the second stage from 2010 to this year, safety systems and detector systems were enhanced in accuracy and reliability. For the establishment of research tools, NRF was designed for real application with MCNP code. The only available area for NRF at AGN-201K was a thermal column part at the center-top of the reactor core. The flux level at this area with graphite is about 1.0×10^8#/㎠-sec. With a collimator in the center of graphite thermal column, we may have a high quality neutron beams. A preliminary study was done and showed a very flat beam intensities along the exit line of collimator.[3] At this study, various collimator designs were tested for feasibility and beam quality.

2.2 MCNP Simulation

For the design of collimator, K-code option was used in order to simulate a realistic neutron travelling to the target from the core. AGN-201K reactor is small and very sensitive to the surrounding environment. Even though structure of core with nine fuel disks is complex, it was assumed to be a single volume Cell. The different control rod locations were modeled as they are. The image shown on the image plate is simulated by mesh tally on the surface of image plate with 5% error tolerance. Because of enormous computing time, parallel computing was done on the 24 core Cluster PCs with LINUX MPI compiler. The following figure shows an example of geometrical model of AGN-201K reactor.

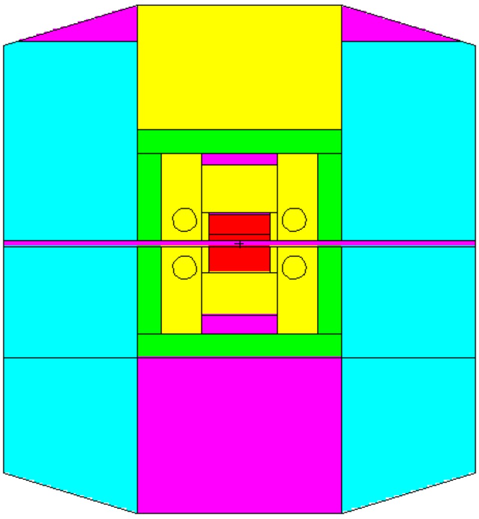


Fig. 1. AGN-201K model for MCNP code

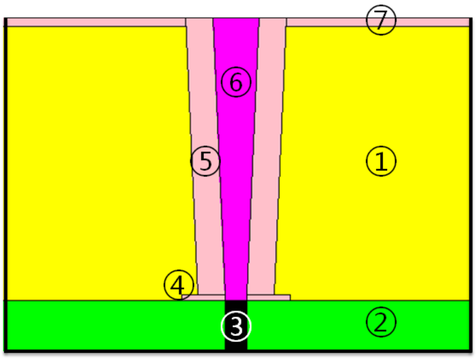
2.3 Collimator Design and Evaluation

The minimum thermal neutron flux of object needed in neutron radiography is known to be about 1.0×10^5#/㎠-sec. Based on the relation with neutron flux and L/D ratio, the thermal neutron flux is 1.0×10^8#/㎠-sec at the entrance of collimator where the collimator ratio can't exceed about 15. Collimator ratio is limited to 50, but Collimator ratio of AGN-201K reactor was designed less than 50 because of its low flux levels. For the same reason, the optimal entrance diameter of collimator was chosen by MCNP simulation. Table 1 shows the geometrical design data for collimator.[4]

In particular, to prevent interference of thermal neutron from graphite around the beam tube, B_4C lining layer was designed with a thickness of 5cm. A sapphire lens was installed as a fast neutron filter. Upper surface of thermal column was covered with a neutron shielding layer made of B_4C in order to protect image plate from backscattering neutrons and gammas. Fig. 2 shows layout of parts in AGN-201K collimator.

Table 1. Dimensions of AGN-201K Collimator

Entrance Diameter	40 mm
Collimator Length	500 mm
Collimator Ratio (L/D)	12.5
Divergence Angle (2θ)	5°



① Graphite ② Lead ③ Sapphire Filter ④ Aperture
⑤ Liner ⑥ Filling Gas ⑦ Neutron shielding material
Fig. 2. AGN-201K Collimator

2.4 Collimator Performance Evaluation

Performance evaluation of collimator was done with three parameters; neutron beam uniformity (NBU), thermal neutron content (TNC) and neutron beam linearity (NBL). Neutron beam uniformity of NRF should be less than 10%. Both TNC and NBL are aimed to be high without limit. Table 2 shows the performance of AGN-201K Collimator.

Table 2. AGN-201K Collimator Performance

Neutron Beam Uniformity	10%
Neutron Beam Linearity (Normal Direction)	78%
Thermal Neutron Content (TNC)	38.8%

The sapphire filter was not considered in this MCNP simulation, and performance of sapphire filter is consulted the N.C. State University PULSTAR reactor's NRF report. Based on this report, TNC of AGN-201K Collimator must be more than 80% with filter.[5]

2.5 Test Experiments

The digital radiography was done using the neutron sensitive Image Plate (IP-ND). These image plates are read by the FLA-7000 IP image scanner. The image plate is mounted on the image cassette as a darkroom. The sample is placed between collimator exit and the image cassette, irradiated during reactor operation. By changing the thickness and properties of the sample, operation time (irradiation time) and power (intensity), many trial shots were done for the search of optimal condition for each image. Following figure is the test sample of Zippo lighter, with exposure time of 2 hours, and power level of 4 watt.

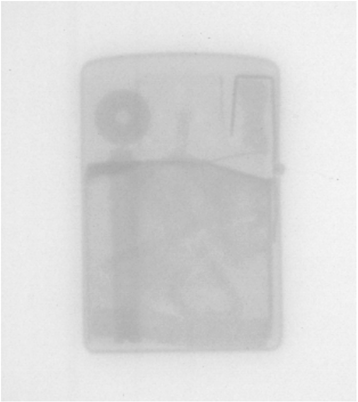


Fig. 3. NR Image of lighter from AGN-201K

Image shown in Fig.3 was one of successful shots during test experiments. At this time, quality was not good enough for non-destructive test. However, we can differentiate clearly parts of lighter such as flint and wick. By adjusting the L/D ratio and exposure time, we may get a better resolution.

3. Conclusions

Although most of NRF were installed only at high-power research reactors having reasonably high neutron fluxes, the feasibility of NRF installation in AGN-201K was shown in this paper. The resolution of image is highly dependent on experience as well as collimator design. More intensive test experiments should be followed during the research for the better image under the highly limited condition of AGN-201K.

REFERENCES

[1] Charles D. Harmon and Robert D. Busch, Criticality Calculations with MCNP: A Primer, Los Alamos National Laboratory, New Mexico, USA, 1994.

[2] P. Von Der Hardt and H. Rottger, Neutron Radiography Handbook, D. Reidel Publishing Company, Dordrecht, Holland, pp.2-20, 1979.

[3] J. Choi and M.H.Kim, "Neutron Beam Evaluation for NRF in AGN-201K Reactor Using MCNP Simulation," Transactions of the KNS Spring Meeting, Korea, May 27-28, 2010.

[4] J.C. Domanus, Collimator For Thermal Neutron Radiography An Overview, Riso National Laboratory, Roskilde, Denmark, pp.15-51, 1990.

[5] Kaushal Kishor Mishra, “Development of a Thermal Neutron Imaging Facility at the N.C. State University PULSTAR reactor”, NCSU report, 2005.