Monte Carlo Simulation for Measurement of Hydrogen Void Fraction in Hydrogen Moderator for HANARO Cold Neutron Source

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1. Introduction

Design and installation of a cold neutron source (CNS) facility for the HANARO, a 30 MW research reactor, is in progress [1,2]. Liquid hydrogen has been selected as moderator to slow down neutrons extracted from the reactor. As shown in Fig. 1, liquid hydrogen density can be varied according to the production of voids due to the temperature rise. If the temperature rises in the hydrogen moderator, the liquid hydrogen locally boils and becomes to gas and make voids in the liquid. It is important to measure the void fraction in hydrogen moderator in order to guarantee the design concept of the HANARO CNS system. In present wok, we simulate transmitting photons with various energies from point source to detector over hydrogen moderator to search an optimized experimental condition to estimate the production of void in liquid hydrogen.

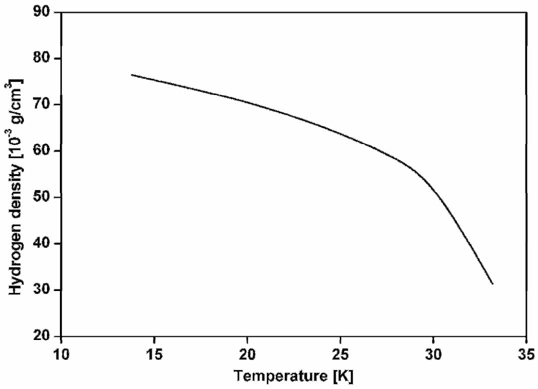

Figure 1. Hydrogen density according to temperature.

2. Simulation

An in-pool assembly (IPA) of HANARO CNS facility consists of a vacuum vessel, a moderator cell, a transfer tube, a heat exchanger and the related piping, and several sensors and heaters. IPA is connected to a hydrogen buffer tank and a vacuum system and a helium refrigeration system. The full description for this system has been done elsewhere [1], so only a brief description of it is included here for continuity. The moderator cell is made of 6061 aluminum alloy. The outer shell, which is isolated by narrow vacuum space with 6 mm thickness, is filled with liquid hydrogen through transfer tube. Its inner diameter and wall thickness are 130.0 mm and 1.0 mm, respectively. The simulation setup used in this work is shown in Fig. 2. Lead collimators are located between a gamma-ray source and a detector to reduce the scattered backgrounds. The events of transmitting photons over the hydrogen moderator were simulated using the MCNP5 code.

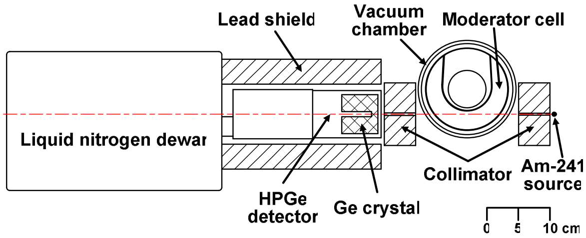

Figure 2. Schematic diagram of the hydrogen void fraction measurement around a hydrogen moderator (favored by M.S. Kim) [1]

3. Result and discussion

Fig. 3 shows particle displays to trace the particle's flight and interactions with each component according to the radius, respectively, of the lead collimator in front of source (r_s) and of that in front of detector (r_d). The photon energy in use is 60 keV.

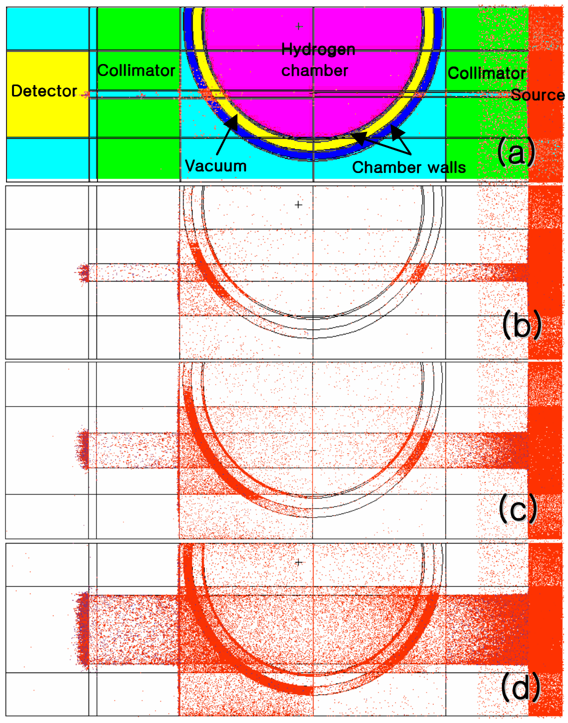

Figure 3. The particle displays. (a) r_s = 0.15 cm and r_d = 0.2 cm, (b) r_s = 0.5 cm and r_d = 0.5 cm, (c) r_s = 1.0 cm and r_d = 1.0 cm, and (d) r_s = 2.0 cm and r_d = 2.0 cm.

Most of photons are scattered by the chamber walls and collimator materials before entering the detector cell while just small portions of photons undergo the interactions with hydrogen moderator. Fig. 4 shows a fluence averaged over detector cell as a function of a detector collimator radius in case of r_s = 0.15 cm. The fluence at the detector cell was saturated at the collimator radius over about 1.0 cm. Fig. 5 shows the fluence averaged over detector cell as a function of a source collimator radius in case of r_d = 0.2 cm. The fluence at the detector cell saturated at the collimator radius over about 0.7 cm. From the figures, it is confirmed that no more improvement in the counting statistics is expected over the detector and source collimators of 1.0 and 0.7 cm, respectively.

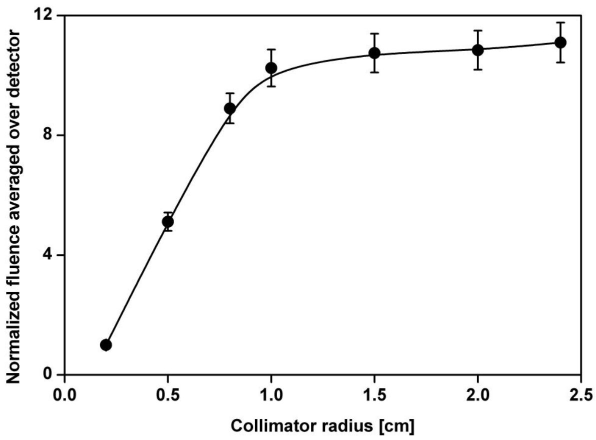

Figure 4. Normalized fluence averaged over detector according to the radius of a collimator in front of the detector.

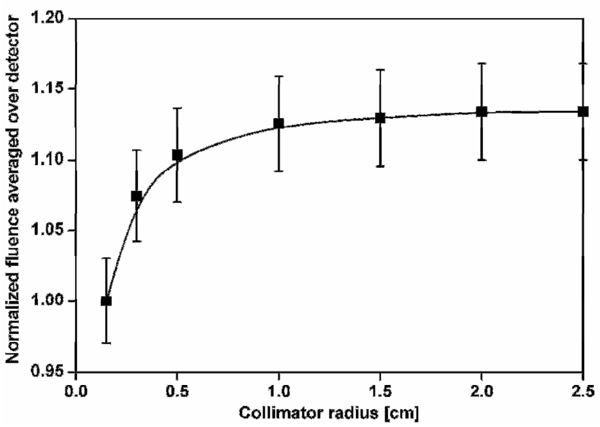

Figure 5. Normalized fluence averaged over detector according to the radius of a collimator in front of the source.

Fig. 6 shows a ratio of fluence calculated for the case of hydrogen density of $8x10^{-5}$ g/cm^3 to $8x10^{-2}$ g/cm^3 according to the photon energy to investigate the sensitivity of the photon energy. As shown in the figure, the ratio has minimum between 60 and 100 keV, which represents that the gamma-rays with these energies will be useful to indicate the variation of hydrogen density clearly.

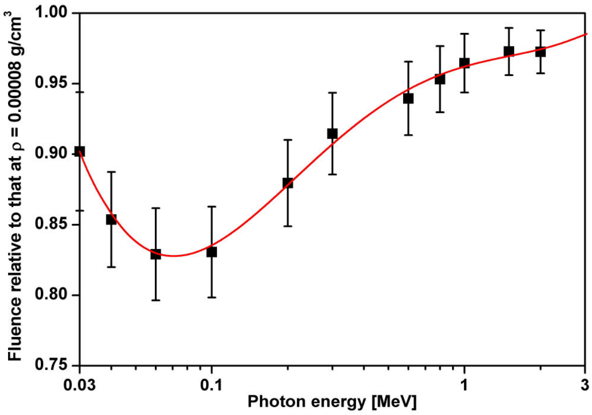

Figure 6. Fluence relative to that at $\rho = 8x10^{-5}$ g/cm^3 according to the variation of the photon energy.

3. Conclusion

According to the simulations, the experimental setup parameters can be determined to measure the void fraction in the hydrogen moderator, which is one of the important parameters for the operation of the moderator cell in the cold neutron source. The radii of the collimators in front of the source and detector can be set as 1.0 cm and 0.7, respectively and an Am-241 gamma-ray source with energy of 59.5 keV will be used to measure the liquid hydrogen density. Feadback information of the attenuation of the photons over the hydrogen moderator will make the temperature in the hydrogen moderator constant and refill the liquid hydrogen to stabilize the cold neutron energy distribution through the in-pool assembly.

REFERENCES

[1] M.S. Kim, J.W. Choi, Y.C. Kim, D.G. Hwang, S.B. Hong and K.H. Lee, “Measurement of Void Fraction in Hydrogen Moderator used for Moderator Cell of HANARO Cold Neutron Source ”, Proceedings of RRFM 2007 and IGORR transactions, 2007.

[2] J.H. Park, K.H. Lee and D.G. Hwang, “Estimation of non-nuclear Heat Load in Cold Neutron Source of HANARO”, Proceedings of Korean Society of Mechnical Engineer spring-conference, 2006.