Application of Gamma Densitometer Technique to Investigation of Characteristics of the Moderator Cell in HANARO Cold Neutron Source

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1. Introduction

In order to validate the design concept of the cold neutron source (CNS) facility for HANARO, a thermo-siphon mock-up test was conducted. A mock-up of the CNS facility was installed with an electrical heating system as the heat source instead of radiations. One of the major purposes of this mock-up test was to provide information related to the two-phase hydrogen moderator to confirm the performance of the CNS facility.

Various methods have been proposed for the measurement of a void fraction, and among these methods, the most widely used ones are the volumetric, electrical, ultrasonic, and radiation attenuation techniques. The radiation attenuation technique, especially, the gamma densitometer technique is widely applied for the measurement of the void fraction of various systems including a cryogenic two-phase system because it is non-intrusive, and in general, quite reliable and easy to apply [1,2].

In this work, we measured several characteristics related to the void fraction in the hydrogen moderator in the moderator cell of the mock-up for the HANARO in-pool assembly by using a gamma densitometer technique. We designed and installed a densitometer by using an HPGe detector and an Am-241 gamma-ray source, and measured the void fraction and its distribution in the moderator cell. These measurements will be very useful for a characterization of the HANARO cold neutron facility.

2. Experimental Setup

Figure 1 shows a schematic diagram of the experimental setup. The selection of the gamma-ray source depends on the characteristics of the test section such as the pipe material, detection sensitivity, and shielding considerations. Cs-137 isotope is usually utilized in a conventional gamma densitometer for a water flow system. However, it is very difficult to detect a void fraction change in the hydrogen medium with a transmission length of about 10 cm by using the 662 keV gamma-rays from the Cs-137 isotope. The smaller the gamma-ray energy is, the better the sensitivity for a void fraction change is. Therefore, in this work, 59.5 keV gamma-rays from the Am-241 isotope were utilized as the test gamma-rays.

In order to detect transmitted gamma-rays, NaI(Tl) scintillation detectors are commonly used due to their superior detection efficiency. But, we used an HPGe detector with a greater superiority for the energy resolution to reduce an uncertainty due to the peak area determination. In the analysis for the 59.5 keV gamma-ray peak area, a straight-line shaped background was assumed and subtracted. The detector used in this work is a 171 cm^3 coaxial HPGe detector with a detection efficiency of 40% of the 3″×3″ NaI(Tl) detector. The gamma-ray spectroscopy system was set-up, and the shaping time of the amplifier was set at 6 μsec.

The diameter of the source side collimator is 3 mm, and that of the detector side one is 4 mm. The counting rates of the transmitted gamma-rays were measured at several experimental conditions. The pathlength of the gamma-rays transmitted through the test section of the hydrogen medium was 102.5 mm.

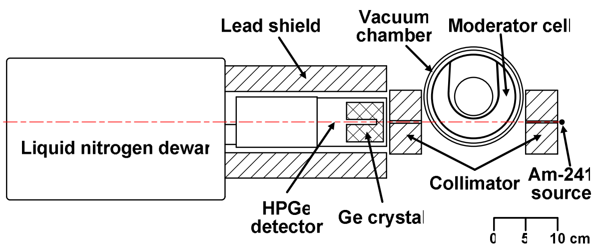

Fig. 1. Schematic diagram of the experimental setup to measure the void fraction.

3. Results

Figure 2 represents the result of the void fraction determination for the entire hydrogen medium inside the moderator cell. For the basic design procedure of the cold neutron research facility in HANARO, the heat load for the in-pile assembly was determined, and the nuclear heating rate for the moderator cell was estimated to be about 470 W. As shown in the figure, we assumed a linear relationship between the void fraction and the applied heating power. The void fraction at a heating power of 470 W was determined to be about 20% by using a fitting line for the measurements with the heating power.

The uncertainty in the void fraction determination by using a gamma densitometer is 2~3% in terms of the void fraction unit for a hydrogen medium of about 10 cm. This uncertainty value is quite big for the case of a small void fraction of less than 10%. The uncertainty of the determined void fraction is closely dependent on the uncertainty in the determination of the count rates of the transmitted gamma-rays through the test section. And, the count rate determination is directly related to the gamma-ray peak area. Therefore, in order to reduce the uncertainty of the determined void fraction, the gamma-ray peak area should be increased. With no change for the detection system, reducing the uncertainty of the measurements by half requires an increase of the detection time by a factor of 4. Otherwise, the use of a gamma-ray source with a bigger activity or a detector with a bigger efficiency would be useful for reducing the uncertainty. At any rate, when the void fraction for the hydrogen medium is near 20%, the uncertainty in the void fraction determination by using a gamma densitometer is relatively small, and it can be regarded as an acceptable level.

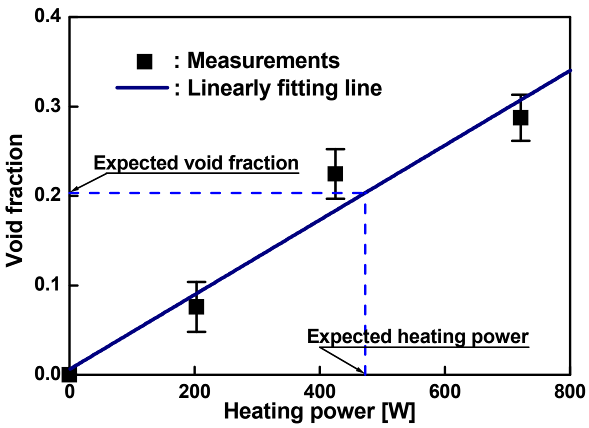

Fig. 2. Determined void fraction of the moderator cell.

Figure 3 represents the result of the measurement for the level of the liquid hydrogen in the moderator cell. As shown in the figure, the relative count rates of the gamma-rays transmitted through the liquid hydrogen are discriminated well from ones through the gaseous hydrogen. From the figure, the level of the liquid hydrogen can be determined to be 151 mm. This is consistent with the calculation with an assumption for the quantity of the liquid hydrogen remaining in the transfer tube and heat exchanger.

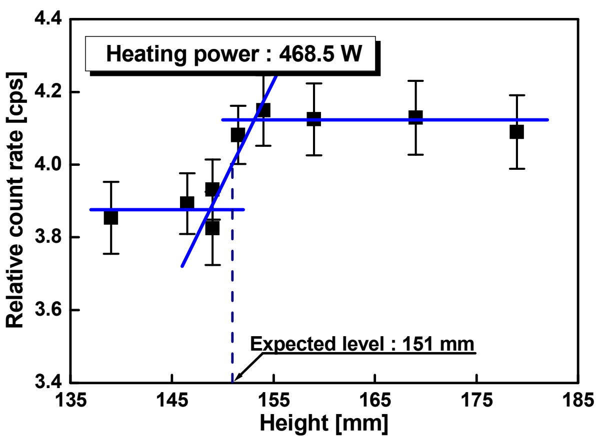

Fig. 3. Determined level of liquid hydrogen in the moderator cell.

Conclusively, the gamma-densitometer technique can be very useful for the measurement of the properties related to the void fraction in a cryogenic liquid such as hydrogen which is used in a cold neutron source system.

REFERENCES

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