Measurement of temperature-dependent thermal neutron spectrum in CaH_2 moderator material for space reactor

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Abstract. In order to accurately design a CaH_2 moderated small high-temperature reactor, it is necessary to experimentally confirm the temperature-dependent thermal neutron spectrum in the CaH_2 moderator material. To obtain the temperature-dependent thermal neutron spectrum in the CaH_2, we have carried out the neutron scattering experiment using the TOF method at the Kyoto University Institute for Integrated Radiation and Nuclear Science - Linear Accelerator (KURNS-LINAC). In present experiment, we raised the temperature of the CaH_2 from a room temperature 294 k to 392 K and 565 K, and obtained the change of the thermal neutron TOF spectrum for the increase of temperature. The obtained thermal neutron TOF spectra in the CaH_2 are compared with the calculated results using the Monte-Carlo simulation code MCNP-6.2.

1 Introduction

In order to provide reliable energy for the space exploration such as human missions to the moon and Mars, the nuclear reactor has been proposed as a space power system. To achieve the small, lightweight and high-power energy in a space reactor, a new concept of the small high-temperature nuclear reactor using the solid moderator has been studied by Toshiba Energy Systems and Solutions Corporation (Toshiba ESS) [1]. As the solid moderator to use a new space reactor, the calcium-hydride (CaH_2), which is one of moderator materials to produce a thermal neutron spectrum and have a high decomposition temperature, 1273 K, was selected for the high-temperature operation.

Because the nominal operation temperature of the reactor core is raised to about 1073 K in the new concept design, the reactivity of the CaH_2 moderated reactor is greatly contributed to the temperature-dependent thermal neutron spectrum in the moderator [2]. In order to accurately design and develop the CaH_2 moderated reactor, it is necessary to experimentally confirm the temperature-dependent thermal neutron spectrum in the CaH_2 moderator material.

In order to measure the temperature-dependent thermal neutron spectrum, we have carried out the neutron scattering experiment using the time-of-flight (TOF) method at the Kyoto University Institute for Integrated Radiation and Nuclear Science - Linear Accelerator (KURNS-LINAC). A gas electron multiplier (GEM) detector was used to detect the scattered neutrons. In present measurement, we raised the temperature of the CaH_2 from a room temperature 294 k to 392 K and 565 K. We confirmed the change of the thermal neutron TOF spectrum for the increase of temperature. Then, the obtained TOF spectra are compared with the calculated results using the Monte-Carlo simulation code MCNP-6.2 [3].

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2 Experiment

2.1 Experimental arrangement

We have carried out the neutron scattering experiment of CaH_2 using TOF method at the KURNS-LINAC. The experimental arrangement is shown in **Figure 1**. The present measurement was performed in the new TOF measurement conditions. In conventional nuclear data measurements using TOF method, the Ta-target was set at the center of a moderator. In the present measurement, a moderator was installed in 12 m detection room because to install a temperature raising device with a moderator. A more detailed explanations of the experimental arrangement are shown below.

The KURNS-LINAC was operated with an electron energy of about 30 MeV, a pulse width of 3 μs, a repetition rate of 35 and 40 Hz, an average current of 48 and 56 μA. Pulsed fast neutrons are produced from a water-cooled Ta-target [4] set in the target room. In order to increase the number of fast neutrons passing through the neutron flight tube, the Ta-target was set at the center of a graphite reflector [5], which has 50cm in width, 40cm in height and thickness. The two-dimensional GEM detector (detection area 10x10 cm^2) was used as a neutron detector.

A thin-film ^{10}B converter is installed in the GEM detector. A temperature raising device (heater) was set in the 12 m measurement room, and the CaH_2 with size 7x7x6 cm^3 was set at the center of the heater. The fast neutrons are slowed down to the thermal neutron energy by the CaH_2. The neutron flight length between the CaH_2 and the GEM detector was 90 cm.

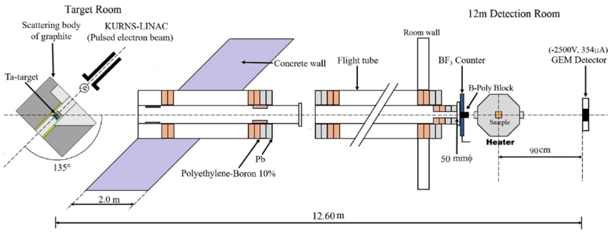

Figure 1. Experimental arrangement for the neutron scattering measurement.

2.2 Sample heating system

In order to raise the temperature of the CaH_2, an octagonal heater with 32 cm diameter and 28 cm height was used as shown in **Figure 2**. In the heater, four halogen heaters are set at 90 degrees rotation from the center of the sample to raise the sample temperature evenly. The vacuum pump is used to remove moisture and air in the heater. In present experiment, we raised the temperature of the CaH_2 from a room temperature 294 k to about 392 K and 565 K.

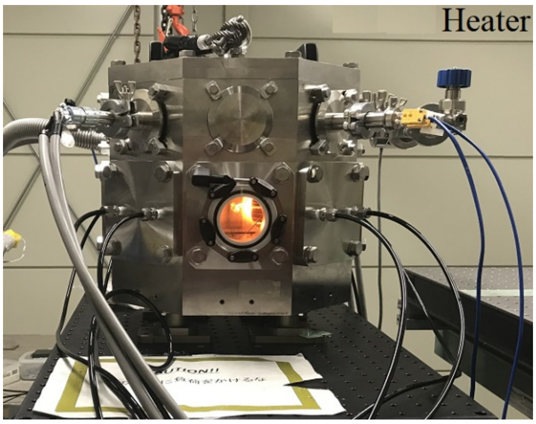

Figure 2. Temperature raising device used in the present experiment.

3 Measurement data analysis

The data analysis was conducted mainly by the following two steps. The first step is a background subtraction. In order to obtain the net TOF spectrum of CaH_2, the background was subtracted from the foreground TOF spectrum of CaH_2. The background TOF spectrum was obtained by a B-Poly block measurement data (CaH_2 + B-Ploy run). The B-Poly block was set at exit of the neutron flight tube as shown in **Figure 1**. The second step is an evaluation of detection efficiency. In the present experiment, the relative detection efficiency of the GEM detector was determined by calculation of the reaction yield YB = (1-exp($-n\sigma_B$)). where, σ_B is the ^{10}B(n,α)^{7}Li reaction cross section (b) and n is the ^{10}B convertor thickness (atoms/b).

4 Monte-Carlo simulation

The calculation of the thermal neutron spectrum in the CaH_2 at a room temperature 294 k, 392 K and 565 K was performed by a Monte-Carlo simulation code MCNP-6.2 [3] with the evaluated cross sections in the JEFF-3.3 [6]. Additionally, JEFF-3.2 thermal scattering law S(α,β) of CaH_2 at 293 K, 400 K and 600 K was used in the calculation.The heater and calculational geometry are shown in **Figure 3** and **Figure 4**. The calculation geometry was designed by taking into account of the experimental arrangement.

In the calculation, we used the incident neutron spectrum from Ta-target with graphite reflector [5] calculated by PHITS code [7] with JENDL-4.0 [8]. A time tally was set at a position 90 cm away from the center of the CaH_2, and the surface of the time tally was 10 cm in diameter. We have evaluated the scattered neutrons passing the surface of the time tally. The generated histories in the calculation were 9,000,000. The standard deviations of the simulation in the spectra were less than 0.02 percent below 800 μsec.

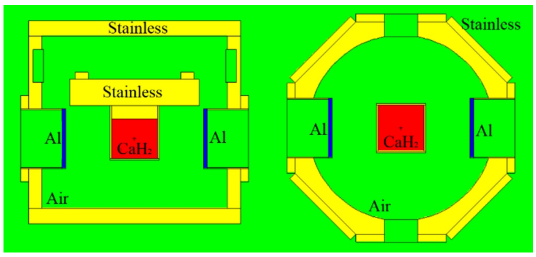

Figure 3. Heater geometry.

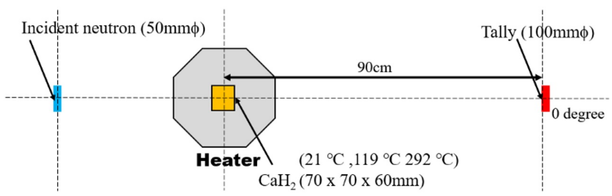

Figure 4. Calculational geometry.

5 Discussions

The obtained thermal neutron TOF spectra of CaH_2 at room temperature 294 k, 392 K, 565 K are shown in **Figure 5**. The ratio is the comparison between the TOF spectrum of the room temperature 294 K and the 392 K or 565

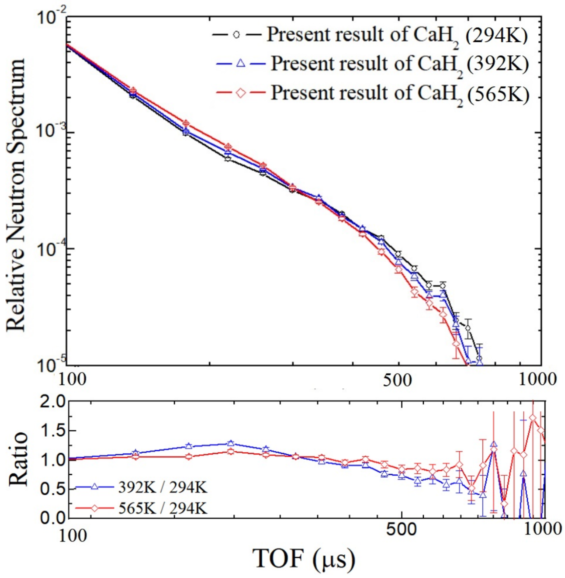

Figure 5. Temperature-dependent thermal neutron TOF spectrum in the CaH_2.

K. The calculated temperature-dependent thermal neutron TOF spectra of CaH_2 including S(α,β) of H or not are also shown in **Figure 6**. In order to compare the measured results with calculated data, the calculated spectra were normalized to the obtained thermal neutron TOF spectrum area of CaH_2 at room temperature 294 k above the 300 μsec.

In the present measurements at room temperature 294 k, 392 K and 565 K, we have obtained the thermal neutron TOF spectra at the region around 250 - 750 μsec as shown in **Figure 5**. Then, we were able to confirm the shift of the thermal neutron spectrum for the increase of the CaH_2 temperature. As can be seen in **Figure 6**, as the temperature increases, the calculated thermal neutron TOF spectra are different from the obtained results. Especially, the calculated data using S(α,β) of CaH_2 are largely different from the obtained results at all measurement temperatures.

The present experiment was carried out in the new TOF measurement conditions. We succeeded in experimentally observing the temperature-dependent thermal neutron spectrum of CaH_2.

6 Summary

To obtain the temperature-dependent thermal neutron spectrum in the CaH_2, we have carried out the neutron scattering experiment using the TOF method at the KURNS-LINAC. We raised the temperature of the CaH_2 from a room temperature 294 k to 392 K and 565 K. The obtained results are compared with the calculated data using the Monte-Carlo simulation.

In the present experiments, we succeeded in experimentally observing the thermal neutron spectrum of the CaH_2 in new measurement conditions. In addition, we were able to confirm the shift of the thermal neutron spectrum in the CaH_2 for the increase of the temperature.

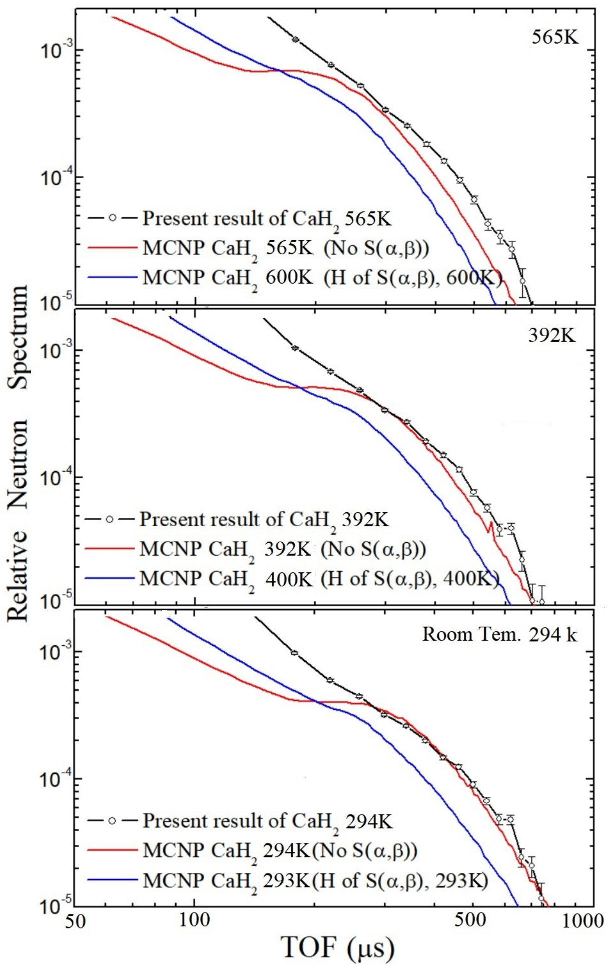

Figure 6. Comparison of the obtained results with the calculated data for the temperature-dependent thermal neutron TOF spectrum.

In future work, we will measure the temperature-dependent thermal neutron spectrum in the CaH_2 one more time with the aim of getting more accurate measurement data. In future measurement, in order to reduce the background, we will set the neutron shields and neutron collimators around the heater and the GEM detector.

Acknowledgement

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