Experiments on the Accelerator-Driven System (ADS) in the Kyoto University Critical Assembly (KUCA)

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1. Introduction

The Kyoto University Research Reactor Institute is going ahead with an innovative research project on the accelerator-driven system (ADS) using a Fixed Field Alternating Gradient (FFAG) accelerator.[1] The goal of the research project was to demonstrate the basic feasibility of ADS as a next-generation neutron source using the Kyoto University Critical Assembly (KUCA) coupled with the FFAG accelerator. At the ADS using the FFAG accelerator, the high-energy neutrons generated by spallation reactions with 100 MeV protons, which had a few pA intensity at a tungsten target, were successfully injected into a highly-enriched uranium (U) and polyethylene-moderated core (Fig. 1) of thermal neutron field at KUCA in 2009.[2] In addition, the experiments on thorium (Th)-loaded ADS were also conducted by the injection of spallation neutrons generated by 100 MeV protons with 30 pA in 2010.

2. Uranium-Loaded ADS with 14 MeV Neutrons

In the ADS with 14 MeV neutrons,[3]-[8] numerical results of combined MCNP-4C2 and nuclear data libraries (JENDL-3.3, ENDF/B-VI.2 and JENDL/D-99) revealed good agreement with those of experiments, in terms of reactivity and reaction rate analyses. Then the foil activation method was found to be a useful measurement technique for the examination of neutronic properties of ADS with 14 MeV neutrons. The subcriticality was experimentally and numerically evaluated using several methods: pulsed neutron method; source neutron multiplication method; noise method (Feynman-α and Rossi-α methods); beam trip method within a wide range from 0.1 to 10 %$\Delta k/k$.

3. Uranium-Loaded ADS with 100 MeV Protons

The static and kinetic experiments on ADS with 100 MeV protons were conducted around 2 %$\Delta k/k$ (k_{eff} = 0.98), and the measurement methodology and the calculation precision were examined through the study of ADS at KUCA. The calculations were reliable in describing reaction rates: MCNPX with JENDL-3.3 and JENDL/D-99 were convenient for the estimation of reaction rates (Fig. 2; (O,A-13,14)) within an allowance of experimental errors. Here, while the tungsten target was also located outside the core as in 14 MeV neutrons, a neutron guide and beam duct were installed for directing the highest number possible of the high-energy neutrons generated at the target to the center of the core, and considered to be practical in an injection of high-energy proton beams.

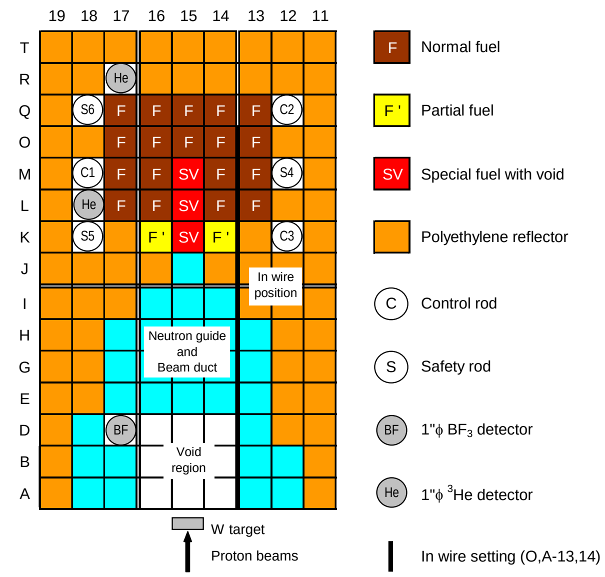

Fig. 1 Core configuration of U-ADS with protons

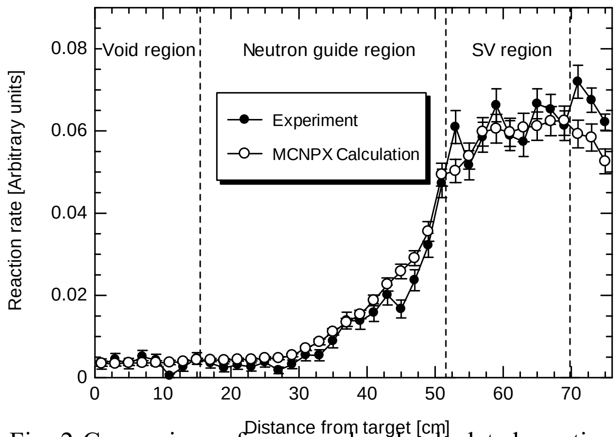

Fig. 2 Comparison of measured and calculated reaction rate distributions in U-ADS with protons

4. Thorium-Loaded ADS with 100 MeV Protons

By combining the FFAG accelerator with the thorium system (Fig. 3), a series of the ADS experiments were carried out under the condition that the spallation neutrons were generated by 100 MeV protons with 30 pA intensity and 30 Hz frequency at the tungsten target. A level of the neutron intensity generated at the tungsten target was around 1E+07 1/s. The objective of these experiments was to conduct a feasibility study on the thorium-loaded ADS from the viewpoint of reactor physics, such as the confirmation of thorium fission reactions by the spallation neutrons.

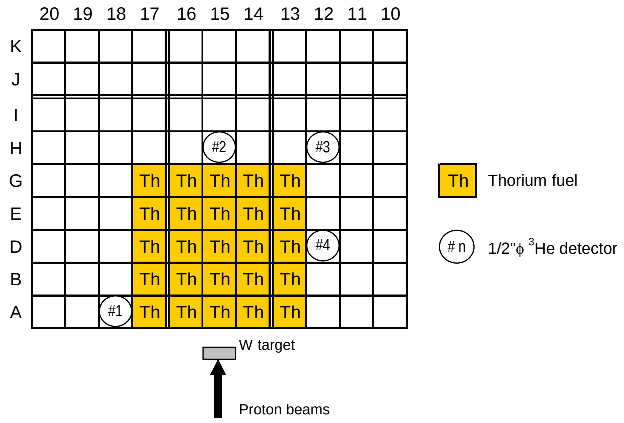

Fig. 3 Core configuration of Th-ADS with protons

From the results of reaction rate distribution in static experiments using ^{115}In(n, n')^{115m}In reactions (threshold energy of 0.5 MeV neutrons), the nuclear fission reactions by the thorium were not apparently observed to be happened in the core system. In the kinetic experiments, the subcriticality was not easily deduced from the prompt neutron decay constant used in the pulsed neutron method, and the behavior in the neutron decay (Fig. 4) was not found in the thorium system at the detector positions 2 through 4. This fact was attributable partly to the results of very small multiplication that the numerical evaluation of the effective multiplication factor k_{eff} obtained from MCNPX based on ENDF/B-VII was 0.03625±0.00001 (Fig. 3) and 0.02703±0.00001 in the thorium and thorium-graphite systems, respectively.

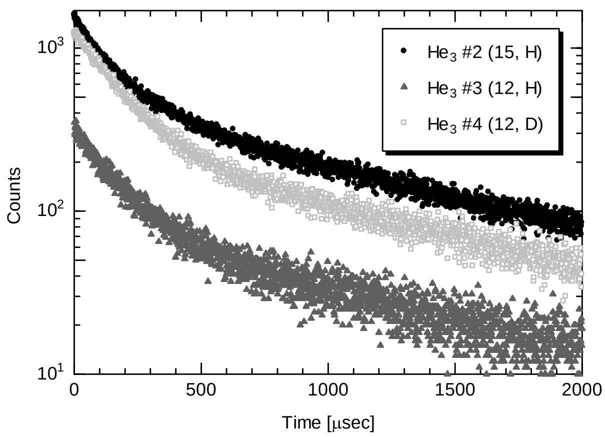

Fig. 4 Neutron decay behavior at several positions in the thorium system (Fig. 3)

An attractive knowledge, however, was importantly attained through the thorium-loaded ADS experiments: the intensity of proton beams should be improved to be high to generate the thorium fission reaction events in the core, and the combination of fuel (U and Th) and moderators (PE, C, Al and Be) should be considered to amplify the neutron multiplication further in the core.

5. Summary

At KUCA, the spallation neutrons generated by 100 MeV protons from the FFAG accelerator were injected onto the tungsten target. In the uranium-loaded ADS experiments, the reactor physics parameters were measured for examining the subcritical characteristics and the applicability of measurement methodologies through the comparison of experiments and calculations. Then these measurement methodologies were found to be useful in ADS experiments with high-energy protons. The thorium-loaded ADS experiments with 100 MeV protons were also conducted using the spallation neutrons. An attractive knowledge was importantly attained in view of neutron multiplication of the core.

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