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Perspectives of research and development of accelerator-driven system in Kyoto University Research Reactor Institute

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ABSTRACT

The experimental studies on the accelerator-driven system (ADS) are being conducted for the basic research of nuclear transmutation analyses with the combined use of the core at the Kyoto University Critical Assembly (KUCA) and the fixed-field alternating gradient (FFAG; 100 MeV protons) accelerator, in the Kyoto University Research Reactor Institute. The ADS experiments with 100 MeV protons were carried out to investigate the neutronic characteristics of ADS, and the static and kinetic parameters were accurately analyzed through both the measurements and the Monte Carlo simulations of reactor physics parameters. An upcoming ADS at KUCA could be composed of highly-enriched uranium fueled and Pb–Bi zoned core, and the conversion analyses (^{237}Np and ^{241}Am) of nuclear transmutation could be conducted in ADS (hard spectrum core) at KUCA. Also, thermal hydraulics of liquid Pb–Bi are expected to be examined with the use of Pb–Bi test loop and test facilities for the investigation of Pb–Bi liquid characteristics from the viewpoints of single-phase heat transfer and two-phase flow.

1. Introduction

The experimental studies on the accelerator-driven system (ADS) are being conducted for nuclear transmutation analyses with the combined use of the Kyoto University Critical Assembly (KUCA; A-core: solid-moderated and -reflected core) and the fixed-field alternating gradient (FFAG) (Lagrange et al., 2013; Yamakawa et al., 2013) accelerator, in the Kyoto University Research Reactor Institute (KURRI). The ADS experiments (Lim et al., 2012; Pyeon et al., 2009, 2010, 2013a; Takahashi et al., 2013; Yagi et al., 2013) with 100 MeV protons obtained from the FFAG accelerator had been carried out to investigate the neutronic characteristics of ADS, and the static and kinetic parameters were accurately analyzed through both the measurements and the Monte Carlo simulations of reactor physics parameters, including the reaction rates, the neutron spectrum, the neutron multiplication, the neutron decay constants and the subcriticality. In addition to the uranium-loaded core, the spallation neutrons generated by 100 MeV proton beams from the FFAG accelerator had been also injected into the thorium-loaded core (Pyeon et al., 2011, 2013b) to conduct the feasibility studies on the thorium-loaded ADS through the experimental analyses of the static conditions and kinetic behaviors.

An upcoming ADS at KUCA could be composed of highly-enriched uranium (HEU) fueled and Pb–Bi zoned core, in consideration of an actual ADS designed by the Japan Atomic Energy Agency (JAEA). The neutronic characteristics of Pb–Bi are considered importantly analyzed experimentally from the viewpoint of reactor physics: neutron yield and neutron spectrum by Pb–Bi solid target; uncertainties of Pb–Bi cross sections in the core. Also, Pb–Bi liquid behaviors are expected to be examined with the use of Pb–Bi liquid loop equipments and test facilities for the investigation of Pb–Bi liquid characteristics from the viewpoints of heat transfer and thermal hydraulics in two-phase flow.

At KUCA, as preliminary study on the Pb–Bi solid characteristics, the critical mass and the sample worth experiments relating Pb–Bi could be conducted to investigate the uncertainties of Pb–Bi cross sections with the use of Pb–Bi solid plates, in addition to Pb and Bi solid plates. Furthermore, irradiation experiments of the minor actinides (^{237}Np and ^{241}Am) could be conducted in hard spectrum core at KUCA to examine the feasibility of conversion analyses (^{237}Np/^{238}U and ^{241}Am/^{235}U) of nuclear transmutation. The objective of this study was to review a series of previous ADS experiments with 100 MeV protons carried out at KUCA, and perspectives on upcoming ADS experiments with the use of HEU and Pb–Bi zoned core. The descriptions of the core configuration and

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experimental and numerical settings are shown in Sec. 2. The results of experiment and numerical simulations by Monte Carlo calculation code coupling with nuclear data libraries are presented in Sec. 3 and the conclusions are summarized in Sec. 4.

2. Experimental settings and numerical simulations

2.1. Experimental settings

At KUCA, A and B are polyethylene-moderated and -reflected cores, and C is a light water-moderated and -reflected one. The three cores are operated at a low mW power in the normal operating state, whereas the maximum power is 100 W. The ADS experiments were carried out in the A-core (Fig. 1) with the combined use of HEU fuel and polyethylene reflector rods. In the A-core, the fuel assembly is composed of 36 unit cells and upper and lower polyethylene blocks about 540 and 590 mm long, respectively, in an aluminum (Al) sheath 54 × 54 × 1520 mm. The target is located outside the core and is not easily moved to the center of the core, because control and safety rods are fixed in the core as the control driving system at KUCA.

In the ADS experiments at the A core, the neutron flux information was acquired from ^{115}In(n, γ)^{116m}In reactions using the indium (In) wire (1 mm diameter and 800 mm length), under the assumption that, in thermal region, the cross sections of ^{235}U(n, f) are proportional to those of ^{115}In(n, γ)^{116m}In. The In wire was set along the vertical direction (13–14, A–P) at the axial center position shown in Fig. 1. Another In foil (10 × 10 × 1 mm) was attached at the location of the target to obtain the spallation neutron information through ^{115}In(n, n')^{115m}In reactions (threshold energy of 0.3 MeV neutrons). The ^{115}In(n, γ)^{116m}In reaction rates normalized by ^{115}In(n, n')^{115m}In ones were estimated in the experiments, and interpreted as the actual values of reaction rates in consideration of the effect of external neutron source. The main characteristics of proton beams were shown as follows: 100 MeV energy, 10 pA intensity, 30 Hz repetition rate, 60 ns pulsed width and 1.0 × 10^6 1/s neutron yield. The irradiation time of the In wire was about 3 h. The subcriticality level 0.77 %$\Delta k/k$ (770 pcm) of the core was obtained by the full insertion of C1, C2 and C3 control rods and the full withdraw of S4, S5 and S6 safety rods shown in Fig. 1.

For optimizing the effect of moving the target from its original location outside the core shown in Fig. 1, additional experiments were carried out in the same core. The effect of moving the target was investigated through analyses of neutron multiplication, as in the previous study (Shahbunder et al., 2010) at KUCA. In the experiments, the ^{115}In(n, γ)^{116m}In reaction rates were measured in the core region, and neutron multiplication was deduced by the reaction rate distribution, when the tungsten target was moved from the original location to another one close to the core center. The subcriticality level was 0.75 %$\Delta k/k$ (750 pcm), and the protons were injected into a subcritical system under the following parameters: 100 MeV energy; 30 pA beam intensity; 30 Hz repetition rate; 200 ns pulsed width; 1.0 × 10^7 1/s neutron yield.

Another experiment was carried out separately at the original target location and the core target one (15, I), as shown in Fig. 1. And the combination of materials W and Be was selected as plural targets for the aim for accomplishment of the neutron spectrum in high-energy region and the neutron yield of high-energy neutrons in the core. The combined use of the heavy- (W, lead and bismuth) and the light-nuclide (Be and lithium) was considered useful for accomplishment of the research objectives relating the neutron spectrum and the neutron yield. Here the plural targets with the combined use of heavy- and light-nuclide were called “two-layer target” in this study.

In the thorium-loaded ADS with 100 MeV protons, the fuel rod was composed of a thorium (Th) metal plate and a polyethylene (PE), graphite (Gr) or beryllium (Be) moderator arranged as shown in Fig. 2. Other components were selected from HEU and natural

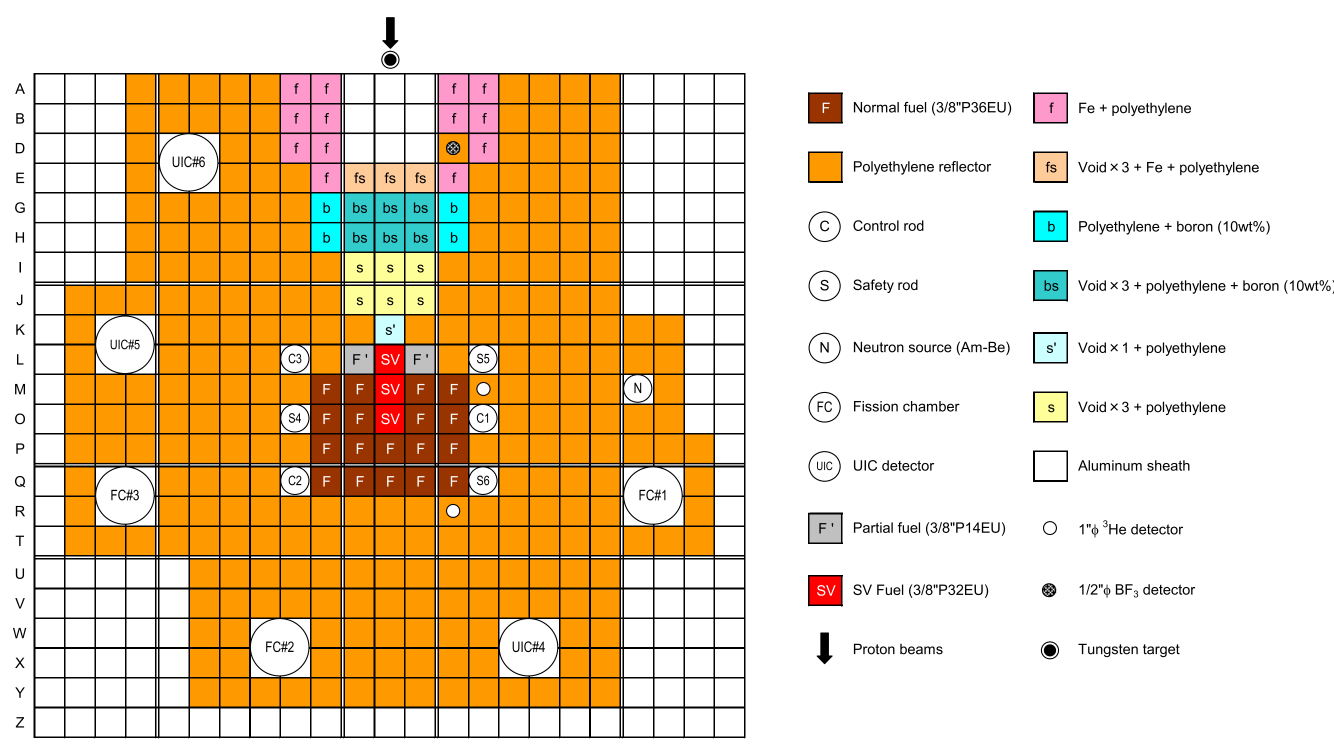

Fig. 1. Top view of the configuration of A-core in the ADS experiments with 100 MeV protons (Pyeon et al., 2009).