I-1. PROJECT RESEARCHES

Project 4

PR4

Project Research of Accelerator-Driven System with Spallation Neutrons at Kyoto University Critical Assemly

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INTRODUCTION: At the Kyoto University Critical Assembly (KUCA), a series of the accelerator-driven system (ADS) experiments [1]-[5] had been carried out with the combined use of A core (solid-moderated and -reflected core) and the fixed-field alternating gradient (FFAG) accelerator. Project research of “Accelerator-Driven System with Spallation Neutrons at Kyoto University Critical Assembly” was composed of six research teams in domestic: Kindai University; Tohoku University; Japan Atomic Energy Agency (JAEA); Hokkaido University, Nagoya University; Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS; former the Kyoto University Research Reactor Institute). In the project research organized by KURNS, the ADS core was comprised of EE1 (1/8”p60EUEU) core shown in Fig. 1, and 100 MeV protons generated by the FFAG accelerator was injected onto the lead-bismuth (Pb-Bi) target. For an injection of 100 MeV protons onto the Pb-Bi target, spallation neutrons were observed with a hard spectrum by high-energy neutrons, and were contributed to neutron multiplication of the EE1 core. The objectives of the project research were to examine experimentally neutron characteristics of the EE1 core modeling actual ADS experimental facilities, and to investigate applicability of current measurement technologies to kinetic parameters and numerical methodologies to deterministic and stochastic calculations, in the ADS experiments with spallation neutrons at KUCA.

EXPERIMENTS: In the ADS experiments with spallation neutrons, main characteristic of proton beams by the FFAG accelerator were shown as follows: 100 MeV energy; 30 Hz frequency; 100 ns repetition rate; 30 pA to 1 nA intensity; 40 mm diameter beam spot. The research topics were revealed in each research team as follows:

- Subcriticality measurement by the Noise method (Kindai University)
- Measurement of reaction rate distribution (Tohoku University)
- Minor Actinide irradiation (JAEA and Hokkaido University)
- On-line monitoring of kinetic parameters (Nagoya University)
- Neutronics of EE1 core in ADS (Kyoto University)

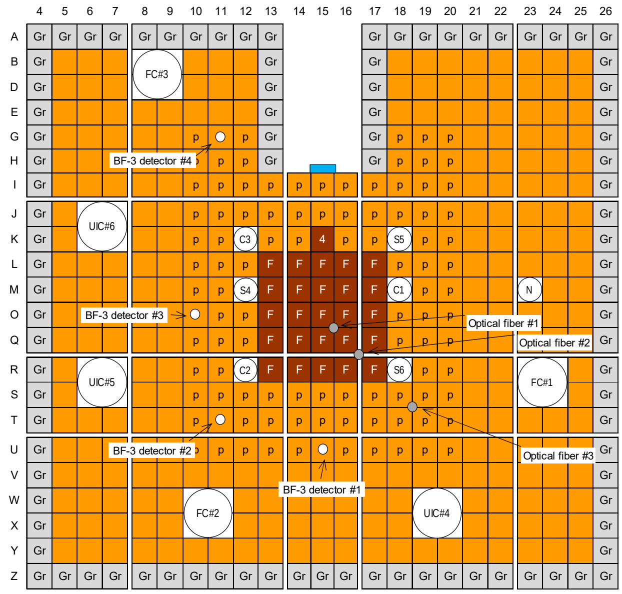

Fig. 1. Top view of EE1 core configuration at KUCA.

RESULTS: From the results of a series of ADS experiments, special attention was made to the following items: applicability of the Noise method to subcriticality measurement in ADS with spallation neutrons (Kindai); subcriticality dependency on reaction rate distributions (Tohoku); feasibility study on MA irradiation by spallation neutrons (JAEA and Hokkaido); applicability of advanced measurement system with optical fibers to on-line monitoring of kinetic parameters (Nagoya); benchmarks on kinetic parameters in EE1 core of ADS with spallation neutrons (Kyoto).

CONCLUSION: The project research of ADS with spallation neutrons at KUCA was successfully conducted with the combined use of EE1 core and FFAG accelerator at KUCA. A series of static and kinetic ADS experiments revealed importantly applicability of current measurement methodologies to upcoming actual ADS facilities in the future, demonstrating remarkable reconstruction of ADS experiments by numerical calculations.

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PR4-1 Subcriticality Monitoring for a Reactor System Driven by Spallation Source (II)

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INTRODUCTION: Feynman-α and Rossi- α Methods have been frequently employed to determine subcritical reactivity of nuclear reactor systems driven by Poisson source such as Am-Be neutron source. Recently many advanced formulas for a pulsed non-Poisson source such as spallation source have been derived. The objectives of this study are to confirm experimentally an applicability of these formulas for a subcritical reactor system driven by a spallation source and to investigate the multiplicity information of neutrons emitted by spallation reaction.

EXPERIMENTS: A subcritical system was constructed on the A loading of the Kyoto University Critical Assembly. The system had a lead-bismuth target, to which 100Mev proton beam was drawn to cause spallation reactions. The repetition frequency of the proton pulse beam was 30Hz. Time-sequence counts data from four BF_3 proportional counters were acquired for 30 minutes at several subcritical states. The subcritical reactivity was adjusted by axial positions of control and safety rods.

RESULTS: Figure 1 and 2 show a Feynman-α and Rossi-α analysis result obtained from a counter BF_3#1 placed near the reactor core, where all control and safety rods are completely inserted. The Degweker's formulas [1] with a delayed neutron contribution were fitted to these data to determine the prompt-neutron decay constant α. These fitted curves are in very good agreement with the Y(T) and the P(τ) data, respectively. The decay constants α determined by the Feynman- α and the Rossi-a analyses are consistent with each other.

Figure 3 and 4 show another Feynman-α and Rossi-α result obtained from a counter BF_3#4 placed near the lead-bismuth target and far from the core. These distributions of the Y(T) and the P(τ) are significantly different from those of Figure 1 and 2. The decay constants are significantly larger than those determined from BF_3#1 data. This is because BF_3#4 counter detects spallation source neutrons but no fission neutrons. Therefore, the distributions of Figure 3 and 4 must have only the correlation information of spallation neutrons. However, the decay constant determined by the Feynman-α analysis is significantly different from that by the Rossi-α analysis. The further advancement of data analysis is in progress.

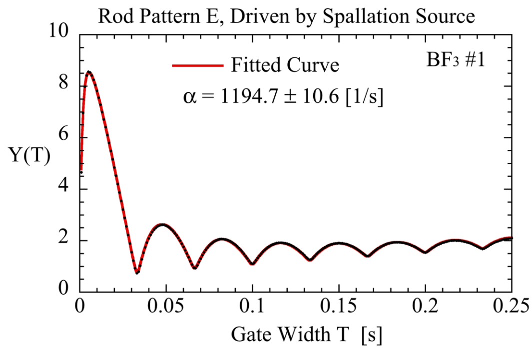

Fig.1. Feynman-α result obtained from BF_3#1.

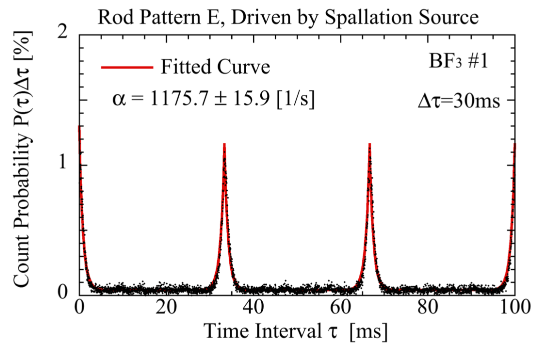

Fig.2. Rossi-α result obtained from BF_3#1.

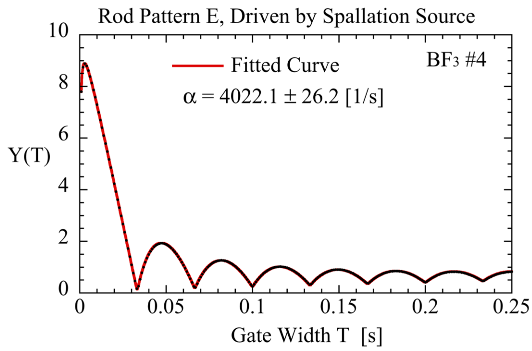

Fig.3. Feynman-α result obtained from BF_3#4.

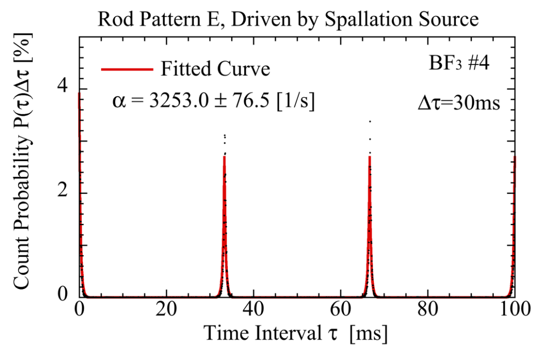

Fig.4. Rossi- α result obtained from BF_3#4.

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PR4-2 Reaction Rate of Accelerator-Driven System with Spallation Neutrons

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INTRODUCTION: An accelerator-driven system (ADS) has been investigated for the effective minor actinide transmuter. The neutron reactions in the ADS core are dominated by neutrons with several MeV energy, but the contribution of several tens MeV neutrons to the reactions is not negligible. The experimental studies of the neutron reaction rates in the core region had been carried out in the previous study with the use of the Pb-Bi zoned core with the spallation neutron source generated by 100 MeV protons [1]. In the previous study, the accuracy of the reaction rates in the fixed-source calculation was presented as an important issue. The purpose of the present study is to examine the cause of the calculation accuracy through the measurement of the neutron reaction rates in the different core system with spallation neutron source.

EXPERIMENTS: The ADS experiment was performed in KUCA A-core combined with spallation neutron source generated by 100 MeV protons from FFAG accelerator. Figure 1 shows the core configuration. The core employed in the present study was 1/8"p60EUEU core, which was PE (polyethylene) moderated uranium core. The subcriticality was set from 1449 to 8820 pcm (0.986 to 0.929 in k_{eff}) by changing the number of fuel assembly. In, Al, Fe, Ni, Au foils were employed for the measurement of the neutron reaction rates on the basis of the various reaction threshold energies, and were set at (M-O, 15). In wire was set along (A-P, 13-14) to measure the reaction rate distributions of ^{115}In(n, γ) ^{116m}In and ^{115}In(n, n') ^{115m}In, which were sensitive to thermal and the fast neutrons, respectively.

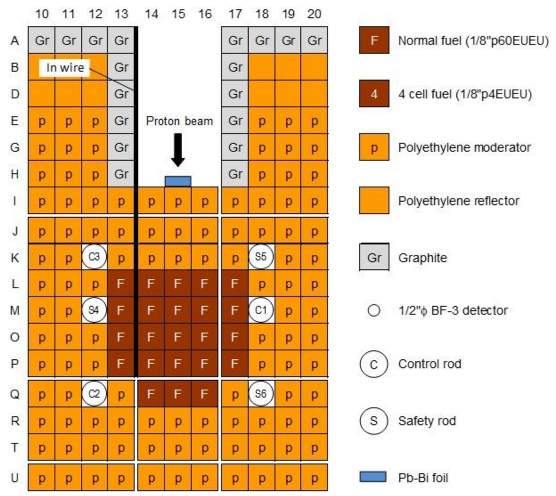

Fig. 1 Core configuration of KUCA A-core.

RESULTS: Figure 2 shows the variation of the reaction rates on each foils normalized by the reaction rates of Au(n,γ). The all reaction rates except for Al foil increased as the subcriticality became deeper, and the gradient of the Fe reaction rate whose reaction threshold was 5.0 MeV was the largest. These trends meant that the contribution of the fast neutrons, especially over 5.0 MeV neutrons, to the neutron reaction increased with increasing the subcriticality level. The discrepancies between experiments and Monte Carlo calculations were seen but the same trends were also obtained in the calculations. The reaction rate distributions of ^{115}In(n, γ) ^{116m}In and ^{115}In(n, n') ^{115m}In were also measured, and the ratios of ^{115}In(n, n') ^{115m}In to ^{115}In(n, γ) ^{116m}In were derived as shown in Fig. 3. The calculated ratios also had the similar distributions, and the spectrum information at the wire positions was considered to be available from the measured reaction rates.

In the future work, the cause of the discrepancies between the experiments and calculations will be analyzed in detail.

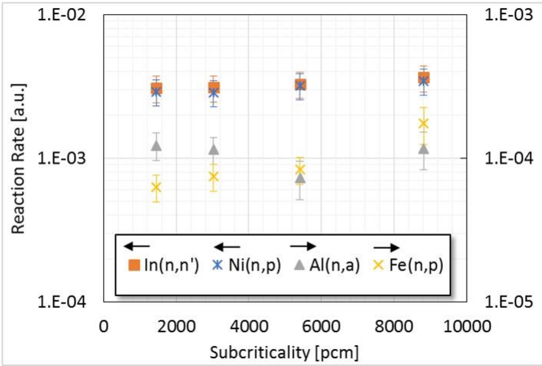

Fig. 2 Reaction rates of activation foils normalized by Au reaction rate.

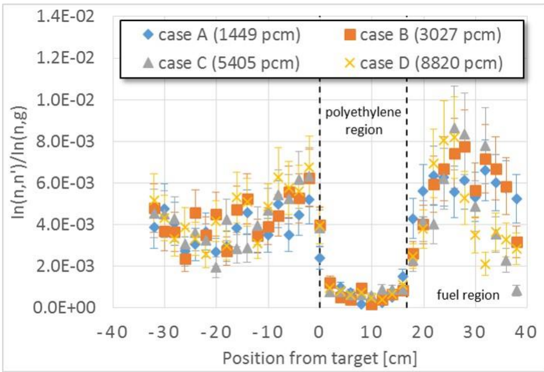

Fig. 3 Distributions of ^{115}In(n,n')/ ^{115}In(n,γ) ratio.

REFERENCES:

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PR4-3

Measurement of MA Reaction Rates Under Sub-Critical Condition with Spallation Neutron Source in A-core of KUCA for ADS

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INTRODUCTION: In order to transmute minor actinides (MAs) partitioned from the High-level waste, the Japan Atomic Energy Agency (JAEA) has investigated neutronics of an accelerator-driven system (ADS). In the nuclear transmutation system such as ADS, the nuclear data validation of MA is required to reduce the uncertainty caused by the nuclear data of MA. To validate the nuclear data, many independent experimental data need to be mutually compared. An expansion of integral experimental data is the important issue since there is a limited number of experimental data of MA. The Kyoto University Critical Assembly (KUCA) has a potential capability to perform simulated experiments of ADS with injection of spallation neutron sources into a subcritical core. This study aims to measure the reaction rates of neptunium-237 (^{237}Np) and americium-241 (^{241}Am) under the sub-critical condition using the spallation neutron source in KUCA.

EXPERIMENTS: The MA irradiation experiments were conducted at A-core in KUCA with the fixed-field alternating gradient (FFAG) proton accelerator. Fission reaction rates were measured by using a back-to-back (BTB) fission chamber (diameter: 40mm, height: 42mm). The BTB fission chamber having two foils (mass: 10μg/nuclide) such as uranium-235 (^{235}U) and MA (^{237}Np or ^{241}Am) was installed at the center of the core as shown in Figure 1. The pulsed-height distribution from the BTB fission chamber was acquired under the condition of sub-critical core (k_{eff} = 0.998) with proton beam injection, such as 100 MeV energy, 30 Hz period, 100ns beam width, and 0.5 nA current, which corresponds to a reactor power of 1.5W. The measurement times were 112 min for ^{237}Np/^{235}U and 98 min for ^{241}Am/^{235}U.

RESULTS: The distributions of pulse height of ^{237}Np, ^{241}Am, and ^{235}U fission reactions were observed under the sub-critical condition as shown in Figure 2. The fission reaction signals have to be separated from noises due to α and γ rays in small channels. For example, the fission reaction events of ^{237}Np and ^{235}U in Figure 2(a) were determined by integrating the signals from 59 and 51 to 250 and 255 channels, respectively. Similarly, the fission reaction counts of ^{241}Am and ^{235}U in Figure 2(b) were obtained from 45 and 30 to 215 and 240 channels, respectively. Finally, the fission reaction rate ratios of ^{237}Np/^{235}U and ^{241}Am/^{235}U calculated from the each total count using the above method and the number of atoms were 0.014±0.002 and 0.023±0.005, respectively. These measured values will be used for verification of evaluated nuclear data by conducting detailed analyses.

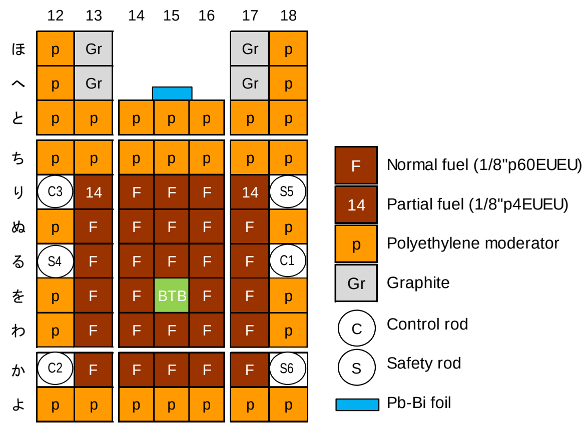
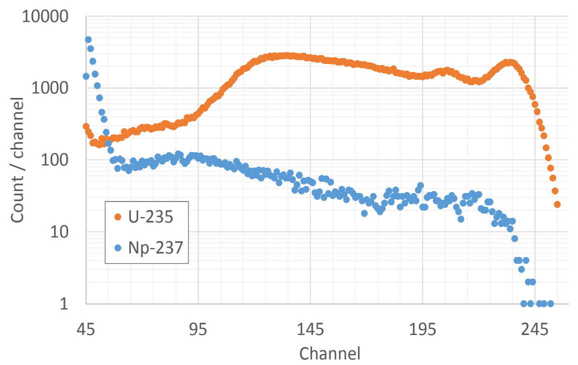
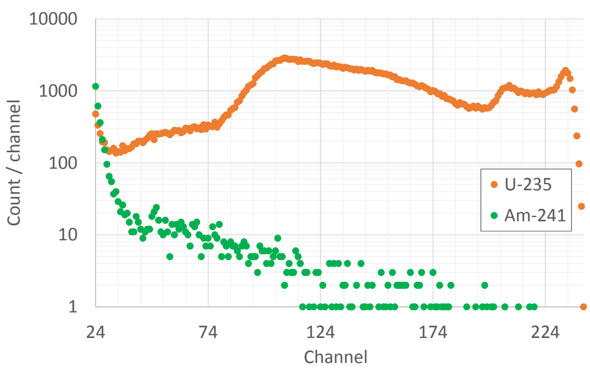


Figure 1. Loaded position of the BTB fission chamber in the A-core of the KUCA.



(a)^{237}Np and ^{235}U



(b) ^{241}Am and ^{235}U

Figure 2. Signals from BTB fission chamber.

Development of Real-time Subcriticality Monitor

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INTRODUCTION: The accelerator-driven subcritical (ADS) system has been developed for transmuting minor actinides and long-lived fission products [1-2]. The ADS system should be designed to be subcritical condition in any case and the subcriticality should be monitored in real time. Iwamoto et al. already demonstrated real-time subcriticality monitoring for ADS system, in which they used only a pulsed neutron source (PNS) method [3]. So far, we also developed a real-time subcriticality monitoring system. This system uses two methods simultaneously, the PNS and Rossi-α method, to assure validity of the measured subcriticality. In this study, we attempt to improve the detector performance and time resolution of the subcriticality measurements.

EXPERIMENTS: Subcriticality measurement experiments were conducted in A-core of Kyoto University Critical Assembly (KUCA). As a pulsed neutron source, a Pb-Bi target bombarded with 100 MeV protons from a FFAG proton accelerator. The repetition rate of the pulsed proton beam was 20Hz. We fabricated a new optical fiber type detector. Figure 1 shows the fabricated detector. Small LiF/Eu:CaF2 eutectics scintillators were dispersed on side surface of a wavelength shifting fiber. These scintillators were wrapped with Teflon tape reflector and covered with a 2.5 mm dia. aluminum tube to protect the detection element. The PMT signal was digitized and processed with a Field-Programmable Gate Array (FPGA). The information of pulse height, rise time and detection timing were extracted by FPGA and transferred to an analysis computer. The analysis computer processed these data and calculated the subcriticality every seconds. The detector was placed in a core region. The subcriticality was changed by inserting control and safety rods.

RESULTS: Figure 2 shows the time trends of the measured neutron count rate and measured subcriticality. To determine the prompt neutron decay constant α, Levenberg-Marquardt algorithm, which is non-linear least square fitting method, was used for the both of PNS and Rossi-α method. The estimated α and area ratio were consistent with the reactor operation, such as a control rod insertion. Our system was confirmed to be able to determine the subcriticality every second. This means that the time resolution of this system is one second. This fast response is achieved by highly sensitive optical fiber type neutron detector developed in this study.

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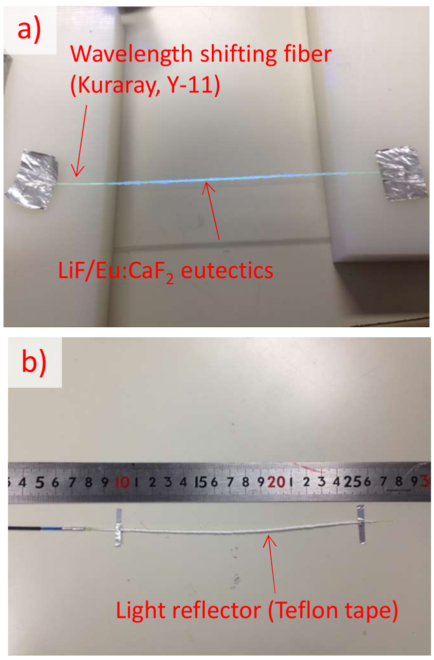

Fig. 1 Photograph of the fabricated new detector. a) Small LiF/Eu:CaF_2 eutectics scintillators were dispersed on side surface of WLSF. b)After wrapped by Teflon tape reflector.

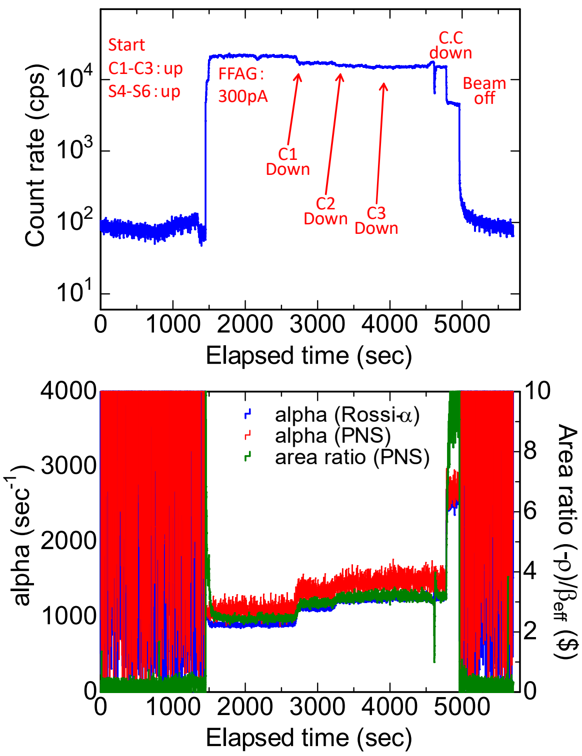

Fig. 2 Time trend of the measured neutron count rate(top) and the measured subcriticality (bottom).