I-1. PROJECT RESEARCHES

Project 2

PR2 Project Research of Accelerator-Driven System with Spallation Neutrons at Kyoto University Critical Assembly

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INTRODUCTION: At the Kyoto University Critical Assembly (KUCA), a series of the accelerator-driven system (ADS) experiments [1]-[6] 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). In the project research organized by KURNS, the ADS core was comprised of two zones: test zone (f) of low-enriched uranium (LEU composed of highly-enriched uranium and natural uranium) modeling core and driver zone of normal core (F: 1/8"p60EUEU) core, as shown in Fig. 1. Also, 100 MeV protons generated by the FFAG accelerator were injected onto the lead-bismuth (Pb-Bi) target. The objectives of the project research were to examine experimentally neutron characteristics of the LEU modeling core in ADS, 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 of intermediate neutrons (Tohoku University)
- Am-243 irradiation (JAEA and Hokkaido University)
- On-line monitoring of kinetic parameters (Nagoya University)
- Neutronics of LEU modeling core in ADS (Kyoto University)

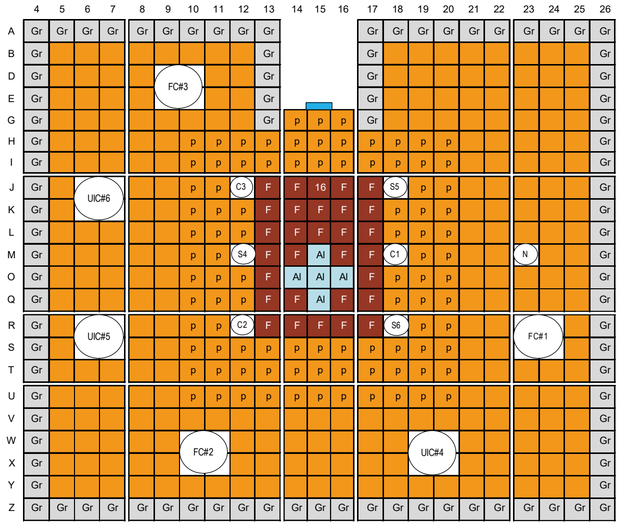

Fig. 1. Top view of core configuration with LEU test and EE1 driver zones at KUCA

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); effect of intermediate neutrons for reaction rates in ADS (Tohoku); feasibility study on Am-243 irradiation at a critical state (JAEA and Hokkaido); applicability of advanced measurement system with optical fibers to on-line monitoring of kinetic parameters (Nagoya); benchmarks on kinetic parameters in LEU modeling 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 LEU modeling 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.

REFERENCES:
[1] C. H. Pyeon, *et al.*, J. Nucl. Sci. Technol., **46**, (2009) 1091-1093.
[2] C. H. Pyeon, *et al.*, Nucl. Eng. Technol., **45**, (2013) 81-88.
[3] C. H. Pyeon, *et al.*, Nucl. Technol., **192**, (2013) 181-190.
[4] C. H. Pyeon, *et al.*, Ann. Nucl. Energy, **105**, (2017) 346-354.
[5] C. H. Pyeon, *et al.*, J. Nucl. Sci. Technol., **55**, (2018) 190-198.
[6] C. H. Pyeon, et al., J. Nucl. Sci. Technol., **57** (2020) 133-135.
[6] M. Yamanaka, et al., J. Nucl. Sci. Technol., **57** (2020) 205-215.

PR2-1 Subcriticality Monitoring for a Reactor System Driven by Spallation Source (III)

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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 some non-Poisson character of spallation neutron source.

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 referred to as A~F. The subcritical reactivity was adjusted by axial positions of 3 control rods, 3 safety rods and a central fuel loading.

RESULTS: Figure 1 shows a Feynman-α analysis result obtained from a counter B1 placed near the reactor core. The Degweker's formula [1] , where a non-Poisson character and a delayed neutron contribution were considered, were fitted to these Y data to determine the prompt-neutron decay constant α. These fitted curves are in very good agreement with the Y(T). As shown in Figure 2, the decay constants α determined by the present Feynman- α analysis is consistent with that obtained under stationary inherent neutron source, except for counter B4. Only the decay constant obtained by counter B4 has a large difference. This is because the counter B4 is placed far from the core and closely to a spallation target.

Figure 3 shows a subcriticality dependence of prompt correlation amplitudes obtained by respective Feynman-α analyses under stationary inherent source and spallation source. Clearly, the present non-Poisson spallation enhances the correlation amplitude, compared with the Poisson inherent source. A non-Poisson Character is responsible for this enhancement.

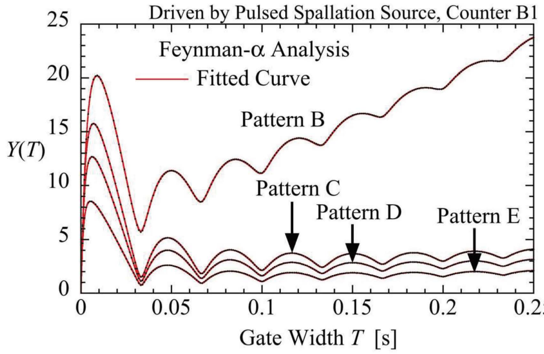

Fig.1. Y obtained by Feynman-α analysis.

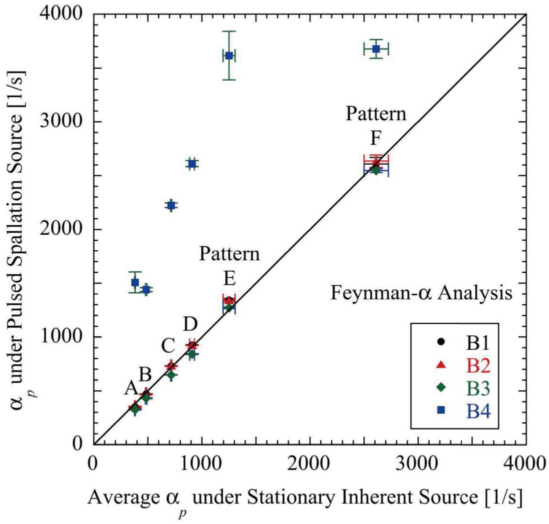

Fig.2. Prompt-neutron decay constant.

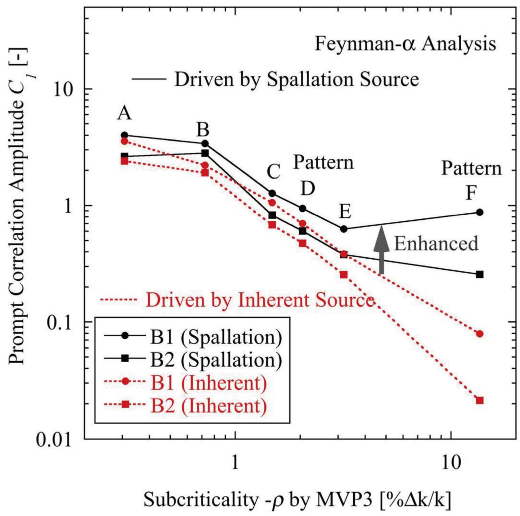

Fig.3. Feynman-α correlation amplitude enhanced by non-Poisson spallation source.

REFERENCES:

[1]Y. S. Rana, S.B. Degweker, Nucl. Sci. Eng., **162** (2009) 117-133.

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PR2-2 Measurement of Reaction Rates of Intermediate Neutrons on Accelerator-Driven System with Spallation Neutrons

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INTRODUCTION: The accelerator-driven system (ADS) has been studied for the transmutation of minor actinides. Besides, ADS has a potential to be applicable to a neutron irradiator for an effective production of useful nuclides by providing wide range of neutron energy from ultrafast to thermal. A neutron spectrum in ADS core depends on a core structure, a neutron source and neutron multiplication factor. The previous studies have carried out the measurement of neutron reaction rates for the activation foils with the threshold of reactions at several MeV energy in the Pb-Bi zoned core [1] and polyethylene (PE) moderated core [2] driven by spallation neutron source. These results indicated that the effect of fast neutrons was increased as subcriticality became deeper. In the present study, the measurements of reaction rates for intermediate neutrons were performed through the neutron irradiation experiments in ADS with different three subcriticality level, in order to clarify the effect of subcriticality on the reaction rates by intermediate neutrons.

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 was composed of the PE moderated highly-enriched uranium fuel and the low-enriched uranium mockup fuel. The activation foils of In, Ta, W and Cu employed in the experiment are sensitive to intermediate neutrons, and were set at (M-O, 15). The Au foils set at (O-P, 15) were for the measurement of thermal neutrons. The foils were set with and without Cd cover to examine the effect of thermal neutrons. The experiments were performed with one critical case and two subcritical cases (0.984 and 0.967 in k_{eff}) by changing the positions of control rods.

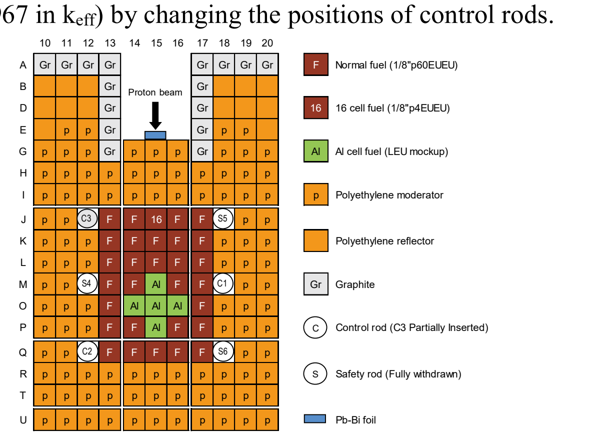
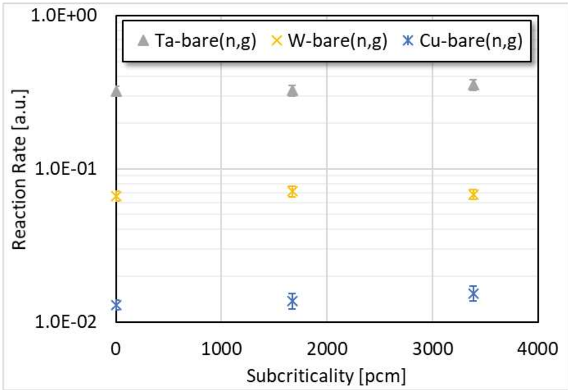
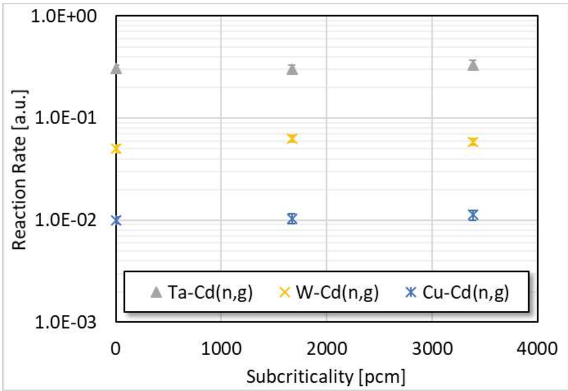


Fig. 1. Core configuration of KUCA A-core.

RESULTS: Figure 2 shows the reaction rates of Ta, W and Cu normalized by the Au(n,γ) reaction rates for three cases. The rates of In were excluded due to insufficient measurement accuracy. The reaction rates of bare Ta and Cu were increased slightly as subcriticality became deeper. The similar tendencies were observed in the measurement results of foils with Cd cover. The numerical calculations were also performed for the verification of the experimental results by the combined use of PHITS [3] and MVP [4]. The C/Es (the ratio of calculation result to experimental one) were almost the same values regardless of subcriticality, and the calculation results were confirmed to coincide with the measurement tendencies. These results indicated that the subcriticality change had a possibility to influence not only fast but also intermediate neutron spectrum. The tendency in the W reaction rates were remained unclear and the detailed analyses were underway.



(a) Bare foil



(b) Foil with Cd cover

Fig. 2. Reaction rates of activation foils without Cd cover normalized by Au(n,γ) reaction rate.

REFERENCES:

[1] C. H. Pyeon *et al.*, J. Nucl. Sci. Technol., **55 (2)** (2018) 190-198.
[2] N. Aizawa *et al.*, KURNS Progress Report 2018, PR4-2, (2018).
[3] T. Sato *et al.*, J. Nucl. Sci. Technol., **50 (9)** (2013) 913-923.
[4] Y. Nagaya *et al.*, JAERI 1348 (2005).

PR2-3

Measurement of ^{243}Am Fission Rates in Low-Enriched Uranium Region at A-core of KUCA

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INTRODUCTION: To transmute minor actinides (MAs) partitioned from the high-level wastes, the Japan Atomic Energy Agency has investigated neutronics of the 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. Previously, experiments of measuring fission rate ratio of neptunium-237 (^{237}Np) and americium-241 (^{241}Am) to fission rate of uranium-235 (^{235}U) were performed in a highly-enriched uranium (HEU) core [1, 2]. This study aims to measure the ratio of the americium-243 (^{243}Am) and ^{235}U fission reaction rates in low-enriched uranium (LEU) region at the Kyoto University Critical Assembly (KUCA).

EXPERIMENTS: The irradiation experiment of ^{243}Am and ^{235}U was conducted at A-core in KUCA. Fission reaction rates were measured by using single fission chamber (diameter: 48 mm, height: 120 mm) having a foil such as ^{235}U (10 μg) or ^{243}Am (12 μg). The simultaneous measurement of ^{243}Am and ^{235}U fission reaction rates was conducted at the center voided region surrounded by LEU rods as shown in Fig. 1. The LEU rod composed of HEU plates, aluminum (Al) plates, and natural uranium (NU) plates shown in in Fig. 2 has an averaged ^{235}U enrichment of about 17%. The pulse height distributions from the fission chambers were acquired under the condition of critical core corresponding to a reactor power of 3.5W. The irradiation time was almost 1 hour.

RESULTS: The distributions of pulse height of ^{243}Am and ^{235}U fission reactions were observed under the critical condition as shown in Fig. 3. The fission reaction signals need to be separated from noises due to α and γ rays in small pulse height. For example, the fission reaction events of ^{243}Am and ^{235}U in Fig. 3 were determined by integrating the counts at voltages greater than 0.589 and 0.592, respectively. As a result, the effective total fission counts of ^{243}Am and ^{235}U were estimated to be 5,208 and 118,664, respectively. Finally, the fission reaction rate ratio of ^{243}Am and ^{235}U was obtained by the total counts and the number of atoms, and a detection efficiency of the fission chamber was 0.042 ± 0.002. These measured value will be used for verification of evaluated nuclear data by conducting detailed analyses.

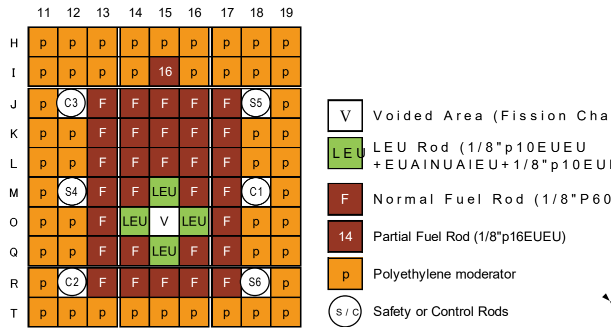

Figure 1. Loaded position of the fission chambers in the A-core of the KUCA.

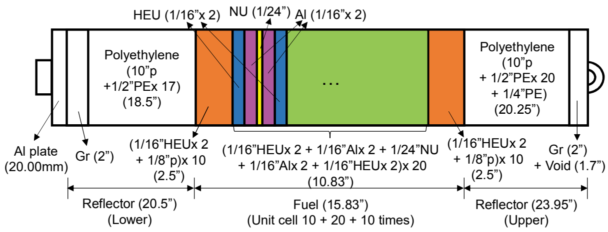

Figure 2. Schematic drawing of LEU rod in the KUCA-A core showing in Figure 1.

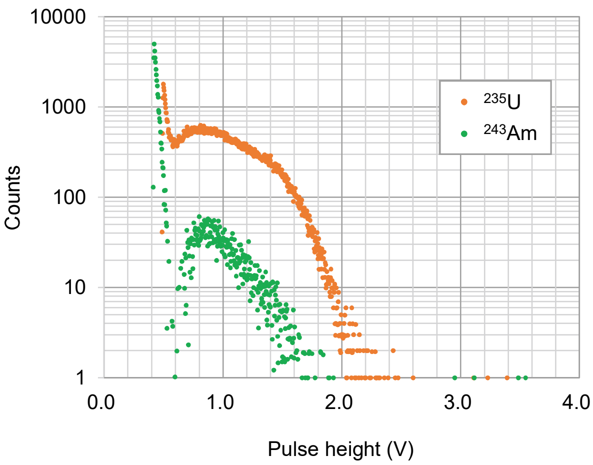

Figure 3. Fission signals of ^{243}Am and ^{235}U fission chambers.

REFERENCES:

[1] C. H. Pyeon, *et al.,* Nucl. Sci. Eng., **193**, pp.1023-1032 (2019).
[2] C. H. Pyeon, *et al.*, J. Nucl. Sci. Technol., **56**, 8, pp.684-689, (2019).

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 keep to be subcritical condition in any case. The subcriticality is desired to be monitored in real time. We are developing a real-time subcriticality monitoring system. This system can simultaneously apply two methods: the PNS and Rossi-α methods, to assure validity of the measured subcriticality. In this study, we performed the subcriticality measurement experiments using the fabricated subcriticality monitoring system. In addition, we considered the experimental conditions influencing the estimated subcriticality related parameters.

EXPERIMENTS: Subcriticality measurements were made in A-core of Kyoto University Critical Assembly (KUCA). A Pb-Bi target bombarded with 100 MeV protons from an FFAG proton accelerator, as a pulsed neutron source. The repetition rate of the pulsed proton beam was 20Hz. We used a new optical fiber type detector, in which small LiF/Eu:CaF_2 eutectics scintillators were dispersed on side surface of a wavelength shifting fiber. The optical fiber type detector was covered with a 2.5 mm dia. aluminum tube to protect the detection ele-ment. The PMT signal was digitized and the processed in a Field-Programmable Gate Array (FPGA). The in-formation on pulse height, rise time and detection timing were recorded and transferred to an analysis computer. In the analysis computer, these data were processed. Fi-nally, the subcriticality was calculated in the PC every seconds. The detector was placed in a core region. The subcriticality was changed by inserting control and safety rods.

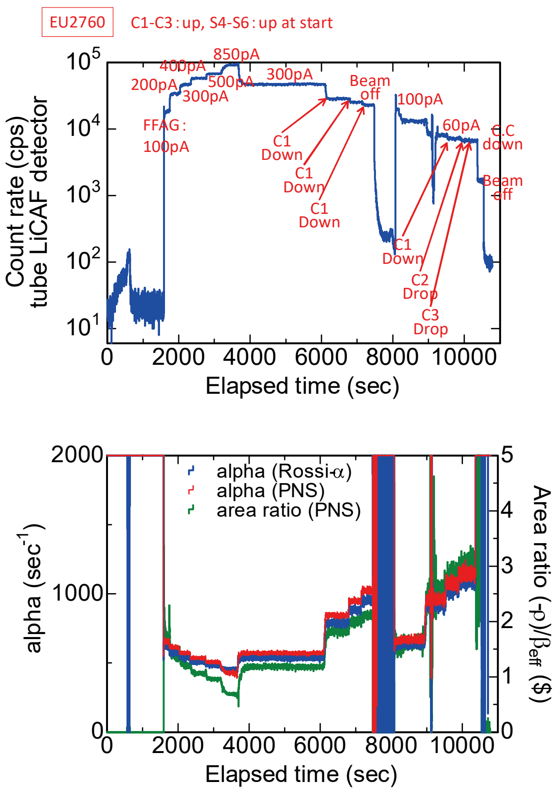

Fig. 1 Time trend of the measured neutron count rate(top) and the measured subcriticality (bottom).

RESULTS: Figure 1 shows the time trends of the measured neutron count rate and subcriticality measured by the fabricated subcriticality measurement system. The estimated prompt neutron decay constant α and area ratio were consistent with the reactor operation. Although the α and area ratio should not depend on the count rate, the measured values slightly depend on the count rate. Figure 2 shows the relation between the ratio of the experimentally estimated parameters and calculated values, E/C, and the detector count rate. The calculated values were obtained by Monte Carlo simulation with MCNP 6.1. Difference between the estimated α and area ratio and the calculated values increases with increasing the count rate. This is because the counting loss effect causes misestimation in determination of the subcliticality related parameters. Among three methods, Rossi-α ,α fitting and area ratio in the pulsed neutron source (PNS) methods, the α fitting method in the PNS took less influence compared with other methods. An error in the a fitting method is evaluated to be within 20% compared with the simulation values.

REFERENCES:

[1] C. H. Pyeon, J. Y. Lim, Y. Takemoto *et al.*, *Ann. Nucl. Energy,* **38** (2011) 2298–2302.

[2] C. H. Pyeon, T. Yagi, K. Sukawa *et al., Nucl. Sci. Energy,* **177** (2014) 156–168.

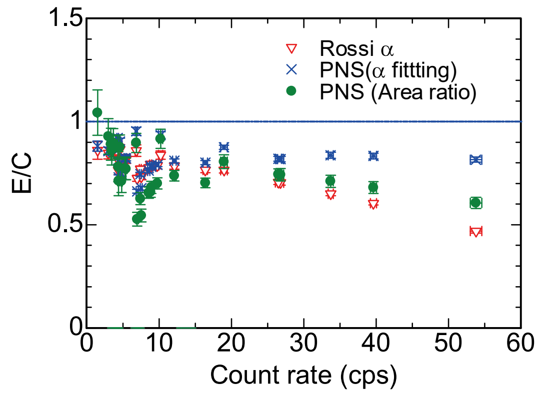

Fig. 2. Relation between the ratio of the experimentally estimated parameters and calculated values, E/C, and the detector count rate.