CO2-1　Neutron Flux Measurements of Newly Developed Neutron Collimator

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INTRODUCTION: Precisely measured prompt γ-ray intensities are widely used for activation analyses (PGAA). Using the B-4 tube at KUR, we measured prompt γ-ray intensities of ^{14}N(n,γ) [1], ^{35}Cl(n,γ) [2], and so on. Generally, these light nuclei had relatively simple level schemes, but heavier ones have highly-complex level schemes. To measure these heavier isotopes, we are developing a new measurement system using a true-coaxial-type HPGe detector [3] coupled with another HPGe detector to get coincidence information. Samples are put into the through-hole of the HPGe detector, and neutrons for irradiations are also introduced to the hole. The emitted prompt γ-rays are measured with HPGe detectors. Here, the true-coaxial-type HPGe detector can detect sum of the γ-rays, which reflect information of the level scheme. Using this measurement system, we expected to derive all energy levels and intensities of de-excitation γ-rays placed at these excited states to the ground state. In order to realize the measurement, a new collimator to guide neutrons and a γ-ray shield to reduce background γ-rays from the shutter unit of B-4 are needed. In this year, we made a new collimator and measured neutron fluxes and leakage neutrons.

EXPERIMENT: Figure 1 (a) and (b) show a photograph of an experimental set up and a schematic drawing of a newly developed collimator, respectively. The collimator has a cylindrical form having a total length of 445 mm. The sizes of an outer diameter and an inner through hole are 15 mm$^{\phi}$ and 5 mm$^{\phi}$, respectively. The compositions of this collimator are polytetrafluoroethylene (PTFE) and lithium fluoride (LiF) which contains one or three weight-% of ^{6}Li. The scattered neutrons are absorbed by ^{6}Li(n,α) reaction. To measure neutron fluxes at a measurement condition, the activation method was used. About 8-95 mg thin gold foils were mounted at positions "A" to "E" as shown in Fig.1 (b), and they were irradiated by two hours. Induced activities were measured with an HPGe detector.

RESULT: Measured neutron fluxes were plotted in Fig. 2 as a function of distances from a position "A" (an entrance of the collimator). The sample-irradiated position of "B" had a neutron flux of 7.6×10^{5} n/cm^{2}/s. The position "E" shows a neutron flux at the Ge crystal. By comparisons between "B" and "E", we evaluate that the collimator having 5 mm thickness wall can reduce scattered neutrons with an absorption rate of approximately 10^{-3}. The values are enough for our experiment.

CONCLUSIONS AND FUTURE PLANS: A neutron collimator was newly developed, and neutron fluxes at the irradiated position and those at the outsides were measured. These fluxes satisfy our demand. For the next step of our experiment, we plan to develop a new shield to reduce the background γ-rays from the shutter unit of B-4.

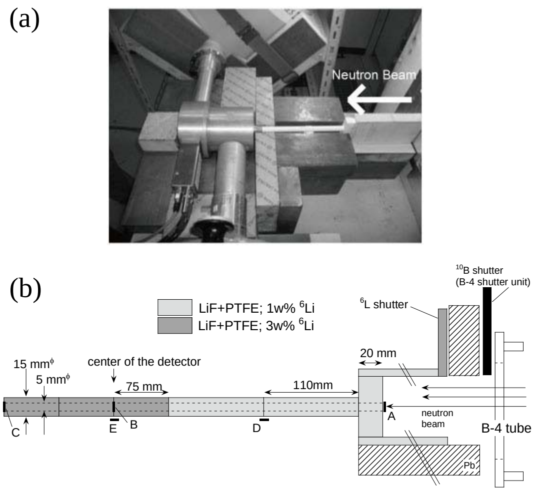

Fig. 1. (a) A photograph of our experiment at the B-4 experimental room. (b) A schematic drawing of a developed collimator. Positions of "A" to "C" are used to measure neutron fluxes in the beam axis, and those of "D" and "E" are used to evaluate the leakage ones.

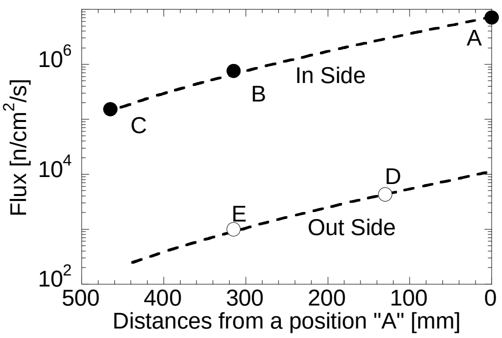

Fig. 2. Results of flux measurements in our measurement condition. Notations of "A" to "E" are represented in Fig.1 (b).

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[2] I. Miyazaki *et al.*, KURRI Prog. Rep., **2005** (2005) 148.
[3] H. Hayashi *et al.*, Nucl. Instr. And Meth., A **606** (2009) 484-489.

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採択課題番号 22018　全吸収検出器を用いた即発ガンマ線強度決定法の開発　共同通常

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CO2-2 Characterization of a White Neutron Beam from Thermal to 10 keV for Calibration of Neutron Detectors

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INTRODUCTION: Precise determination of epithermal neutron fluence is important in various studies such as characterization of a neutron detector and irradiation dose evaluation in a boron neutron capture therapy [1]. In the present study, we have developed a new calibration method for neutron detectors using a white neutron source with energy range from thermal to 10 keV at KURRI. In this calibration method, precise detection efficiency curve of the neutron detector is experimentally determined by two-dimensional simultaneous measurements of the pulse height of detector outputs with the time of flight (TOF). Then, characteristics of the white neutron source were experimentally evaluated. We also developed an epithermal neutron camera consisting of GEMs and resonance filters for neutrons up to 10 keV.

EXPERIMENTS: Neutrons were obtained by the photoneutron reaction using a water-cooled tantalum target at the KURRI Linac [2]. Neutrons above 10 keV were also produced by the photoneutron reaction. These neutrons are also backgrounds in calibration test from thermal to 10 keV for a neutron detector. The neutron spectrum and fluence were measured with a ^{6}Li-glass scintillation detector for keV region, a 2”×2” NE213 liquid scintillation detector for MeV region and a total absorption BGO detector by means of the TOF method for thermal region.

The response function of a prototype of epithermal neutron camera was measured using the white neutrons. The prototype detector consists of a Silver plate as a resonance filter, a B_4C thermal neutron absorber, and a GEM with a neutron converter of ^{10}B as shown in fig. 1. The response function was obtained from the TOF method.

RESULTS: Figure 2 shows observed neutron spectra at KURRI. The result shows that the neutrons from thermal up to 10 keV are efficiently obtained by using the moderator around the target. Moreover, fig. 2 indicates that thermal peak around 0.02 eV and typical evaporated spectrum due to the photonuclear reaction around 1 MeV are clearly observed. The feature of result is that the smooth neutron spectrum was obtained using tree neutron detectors with different efficiencies. The present result is thought to be reliable.

As for the epithermal neutron camera, the response function was obtained as shown in fig. 3. Difference in the response function between with and without the silver resonance filter was observed as a clear dip.

A part of this study is the result of “Study on a progressive calibration method for neutron dosimeters using white neutrons” carried out under the Strategic Promotion Program for Basic Nuclear Research by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

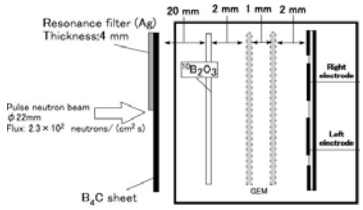

Fig. 1. Schematic view of the prototype of epithermal neutron camera and the experimental setup at KURRI.

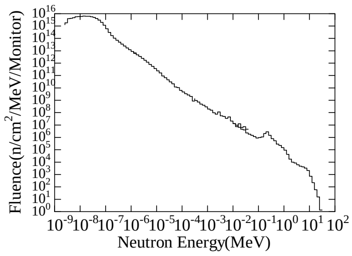

Fig. 2. White neutron spectrum at KURRI measured with the ^{6}Li-glass scintillation detector, the NE213 liquid scintillation detector and the total absorption BGO detector.

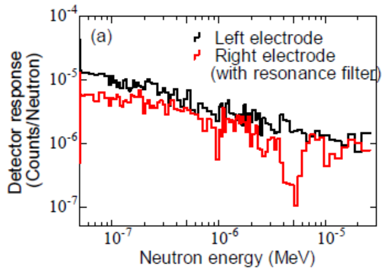

Fig. 3. Response function of the prototype detector measured with and without the silver filter.

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採択課題番号 22034　　熱中性子フルエンス率の測定の高度化と
その国際標準化に関する研究　　共同通常

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渡辺賢一、富田英生、照田千尋、早川 輝、能仕琢磨（放医研）高田真志、鎌田創
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CO2-3 Study on The Neutron Capture Cross Sections of Fission Product Nuclei

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INTRODUCTION: Recently, a great interest has been taken in burn-up credit for criticality safety in the transportation, storage and treatment of spent nuclear fuel. Burn-up credit is a concept in criticality safety evaluation that takes into account for the reduction in reactivity of spent fuel due to the composition change during irradiation. Neutron capture cross section data of fission product (FP) play an important role in burn-up credit. According to the reference [1], twelve FP isotopes (^{95}Mo, ^{99}Tc, ^{103}Rh, ^{133}Cs, $^{143, 145}$Nd, $^{147, 149, 150, 152}$Sm, ^{153}Eu, ^{155}Gd) are recommended to be considered in burn-up credit. The objective of this work is to measure neutron capture cross sections of ^{153}Eu and ^{151}Eu. ^{153}Eu is one of the most important FPs for burn-up credit application. ^{151}Eu has a large capture cross section and is contained in the sample of enriched ^{153}Eu that used in this work. Therefore, the experimental data of ^{151}Eu are also necessary to correct the ^{153}Eu capture yield including the effect of ^{151}Eu as an impurity in the sample.

EXPERIMENTS: The capture cross section measurements were carried out by the TOF method using the linac at the KURRI-LINAC. A photo-neutron target of Ta was adopted as a pulsed neutron source for the neutron TOF measurement. We employed a pair of C_6D_6 liquid scintillators for the capture γ ray measurement. The distance between the sample and the neutron source was 12.1±0.02 m. Output signals from the scintillators were summed up and stored with the Yokogawa's WE7562 multi channel analyzer as a two dimensional data of pulse height(PH) and TOF.

The samples of ^{151}Eu and ^{153}Eu were packed in aluminum foils 20 mm in diameter and 0.08 mm in thickness. The enriched ^{10}B sample was used for the measurement of the incident neutron flux on the sample. The sample of ^{10}B was also packed in an aluminum case.

The energy dependent neutron flux was derived with the standard cross sections of the ^{10}B(n,$\alpha\gamma$) reaction. A pulse-height weighting technique [2] was applied to observed γ-ray spectra to determined the capture yields of $^{151, 153}$Eu. The weighting functions were obtained using the response functions of a pair of C_6D_6 liquid scintillators that were calculated with a Monte Carlo simulation code EGS5[3].

RESULTS: The absolute neutron capture cross sections of ^{151}Eu were obtained in the neutron energy region from 0.03 eV to 100 keV as shown in Fig. 1. As for ^{151}Eu, a number of experiments were reported. The present results are in general agreement with the previous experimental data. The validity of the weighting function derived in this work was confirmed by the experiment.

The absolute neutron capture cross sections of ^{153}Eu were obtained in the neutron energy region from 0.03 eV and 4 keV tentatively as shown in Fig. 2. In the energy region below 0.1 eV, the present data agree well with the evaluated values of JENDL-4.0 [4] although the data by Widder [5] are larger than the present results by about 20 %. The undesirable structure is clearly observed around 0.6 eV. There is a possibility that the correction for impurities was not completely made. Further analyses are necessary in future work.

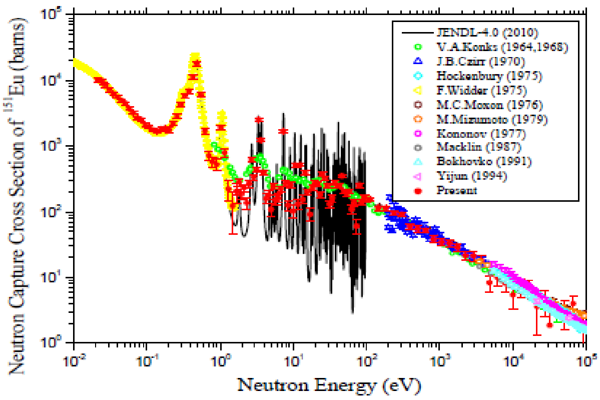

Fig. 1. Neutron capture cross sections of ^{151}Eu

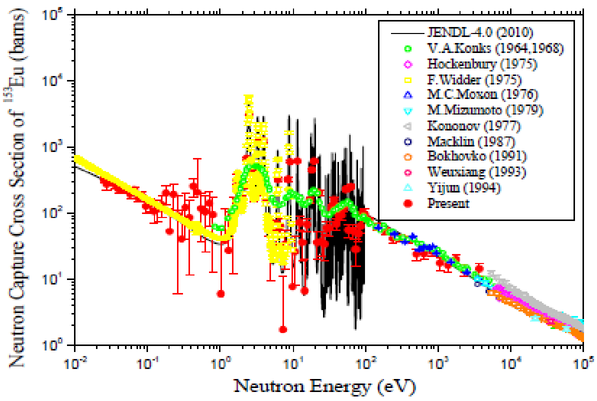

Fig. 2. Neutron capture cross sections of ^{153}Eu

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[1] Nuclear Fuel Cycle Facility Safety Research Committee, JAERI-Tech 2001-055, 2001[in Japanese].
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採択課題番号22035　　核分裂生成核種の中性子捕獲断面積に関する研究　　プロジェクト
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CO2-4 **Measurement of the Photofission Cross-Section of Pa-231 by the Fission Track Method**

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INTRODUCTION: Fission track methods have been applied to detection of the fission fragments from photofission of ^{231}Pa ($T_{1/2}$=3.28×10^{4}y), receiving attention as a product in the thorium nuclear fuel cycle. The nuclide, however, lacks sufficient data in nuclear property due to its own high dose rate of γ-rays. In the present study, the photofission probabilities of ^{231}Pa relative to those of ^{nat}U and ^{232}Th were measured with the techniques.

EXPERIMENTS: Samples from the target material of ^{231}Pa, Pa-a and Pa-b, were prepared through different purification processes and were sandwiched between pieces of quartz and muscovite, used as solid state track detectors, for irradiation with bremsstrahlung at Linac facility of Tohoku University together with the natural uranium (^{nat}U) and ^{232}Th targets used as references. The maximum energies of bremsstrahlung applied in the experiments were 18MeV, 20MeV, and 22MeV. After the irradiation, the detectors were subjected to chemical etching and observed for track counting using a microscope in order to evaluate the photofission cross-section of ^{231}Pa.
The same target stacks were prepared for another irradiation with thermal neutrons at KURRI, which was performed to evaluate the possible background events from fissile impurities in target and references with thermal neutrons in the irradiation of bremsstrahlung.

RESULTS: The result from the irradiation with thermal neutrons lets us know that the background fragments are negligible. In Table 1 are listed the fission probabilities of ^{231}Pa relative to ^{238}U, while those relative to ^{232}Th in Table 2. The former values and the latter values were determined to be around 2 and around 6, respectively, at more than 18 MeV of the maximum bremsstrahlung energy. It exhibits a saturation behavior of the process.
The data are also compared with the TALYS calculation [1] in Table 3 and found out to be fairly well reproduced if the values by the calculation are multiplied by a scaling factor of 1.9.

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Table1. The fission probabilities of ^{231}Pa relative to ^{238}U

E_{max}	Pa-a	Pa-b
18 MeV	1.8 ± 0.3	1.4 ± 0.2
20 MeV	1.4 ± 0.2	1.6 ± 0.2
22 MeV	1.6 ± 0.2	1.7 ± 0.2

Table 2. The fission probabilities of ^{231}Pa relative to ^{232}Th.

E_{max}	Pa-a	Pa-b
18 MeV	6.0 ± 0.7	4.6 ± 0.4
20 MeV	5.7 ± 0.6	6.5 ± 0.7
22 MeV	5.6 ± 0.4	6.2 ± 0.4

Table 3. Comparison of the data to the calculation by TALYS.

Target nuclide	E_{max}	Fission Events(TALYS)	Fission Events (EXPL)	Fission events (EXPL)／ Fission events(TALYS)	Average
^{231}Pa	18 MeV	65	133 ± 16	2.0 ± 0.2	1.9 ± 0.1
	20 MeV	123	208 ± 23	1.7 ± 0.2	
	22 MeV	126	245 ± 25	1.9 ± 0.2	

採択課題番号 22039　フィッション・トラック法による Pa-231 光核分裂反応断面積の測定　共同通常

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CO2-5 Test Measurement for Investigating Fast Neutron Capture Reaction with a $LaBr_3$ Detector

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INTRODUCTION: A time-of-flight (TOF) method is used to deduce differential neutron capture cross sections. Linear pulses from a γ-ray spectrometer are measured to determine the gamma ray energy. These pulses are also processed to obtain the neutron time-of-flight (or the neutron energy). Therefore, properties of γ-ray spectrometers on both time resolution and energy resolution are important elements in the TOF measurements. In this work, we applied a $LaBr_3$ detector to the TOF measurements. The $LaBr_3$(Ce) scintillator has the properties of fast decay time and very high light outputs, and therefore, are an attracting device for γ-spectroscopy measurements. In this study, we have applied the gating technique to the photomultiplier tube (PMT) attached to the $LaBr_3$ detector in order to test how the affect of intense "gamma flash" removed.

EXPERIMENTS: An experimental set-up is shown in Fig.1. For fast neutron capture reaction, the TOF measurement was performed by using the 46-MeV electron linear accelerator (linac) at the Kyoto University Research Reactor Institute (KURRI). The linac was operated with repetition rate of 200 Hz, pulse width of 100 ns, peak current of ~4 A, and electron energy of 30 MeV. The electron beam irradiated a tantalum target and induced bremsstrahlung photon. The pulsed neutron beam was produced by the photoneutron reaction and passed along a 12-m flight path from the tantalum target to a sample. NaCl powder put in an aluminum case and an aluminum tablet were used as sample. An aluminum case and a carbon block were also used to evaluate background. To cutoff thermal neutron, a cadmium sheet of 0.5 mm thick was placed on the way of flight path. As shown in Fig.1, a $LaBr_3$ detector was set near the sample. The detector consisted of a 1.5 in. × 1.5 in. $LaBr_3$(Ce) crystal (Saint-Gobain crystal BrilLanCe380) [1], a PMT (Hamamatsu R329-02), and a gated voltage divider (Hamamatsu C1392-11MOD) [2]. The energy resolution (FWHM) of the $LaBr_3$ detector was about 3% at 1.3 MeV, when the PMT was biased at -750 V. This PMT bias was chosen in view of the dynamic range and the energy resolution, while it was lower than the nominal voltage. A positive TTL pulse derived from the accelerator trigger was used for the gated voltage divider as the external gating signal to turn off the PMT gain.

RESULTS: The measured TOF spectra are shown in Fig. 2, where the horizontal axis is the neutron energy and the vertical axis is the number of counts normalized by arbitrarily unit. The dotted line and the solid line correspond to the TOF spectra for the NaCl sample. The peaks of ^{23}Na, ^{35,37}Cl, and ^{27}Al(n,γ) reactions are observed. The dotted line shows the case of the PMT gate "OFF". It is strongly affected by gamma flash and the upper energy of the measured TOF spectrum is less than ~70 keV. The solid line shows the case of the PMT gate "ON". In this case, the PMT gain operation was turned off by the external gating signal before and during gamma flash. In comparison with the dotted line, the solid line indicates that measureable energy region extends to the energy region of ~300 keV. Detail analysis is in progress.

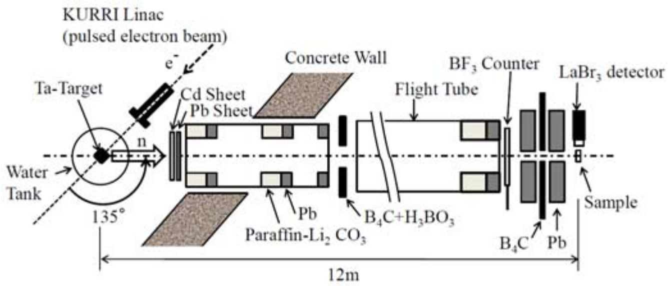

Fig. 1. Experimental set-up at linac of KURRI.

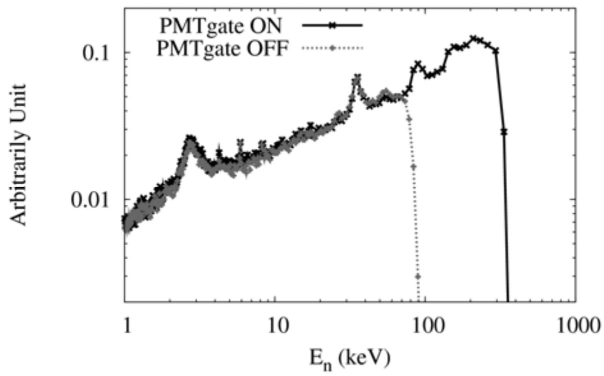

Fig. 2. TOF spectrum for the NaCl sample.

REFERENCES:

[1] http://www.detectors.saint-gobain.com
[2] http://www.hamamatsu.com

採択課題番号 22065　　LaBr$_3$(Ce)シンチレーション検出器を用いた　　共同通常
高速中性子捕獲反応の測定技術開発
（原子力機構）原　かおる、原田秀郎、藤　暢輔（京大・原子炉）堀　順一

CO2-6 Experiments on Reaction Rates in the Accelerator-Driven System (ADS) with 14 MeV Neutrons at the Kyoto University Critical Assembly (KUCA)

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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 accelerator. 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 with 14 MeV neutrons,[1]-[3] the experiments of gold (Au) reaction rate were carried out in the KUCA A-core. The comparison between the results in experiments and calculations revealed the good agreement with each other, and the numerical precision by the MCNPX calculations was confirmed to be valid in the reaction rates in the subcritical system.

Results and Discussion: The KUCA A-core (Fig. 1) was composed of the high-enriched uranium and the polyethylene as the moderator and reflector. The cell configuration in the A-core was comprised of 1/8”P60EU-EU, and two partial fuel rods were loaded in the core. Th Au wire was set in the region of (11-19, Q-R) shown in Fig. 1, and 14 MeV neutrons were injected into the core, under the condition of subcriticality 0.124 %$\Delta k/k$ attained by a full insertion of C1, C2 and C3 rods. The results in the eigenvalue calculations by MCNPX were found to be within the statistical errors in experiments and calculations. The comparison (Fig. 2) between the results in experiments and calculations of Au reaction rates revealed the good agreement with each other. From these results, the numerical precision by the MCNPX eigenvalue and source calculations with nuclear data library ENDF/B-VII was confirmed to be valid in the reaction rates in the subcritical system. Finally, the numerical methodology is expected to be applied to the analyses for the neutron spectrum by using the foil activation method.

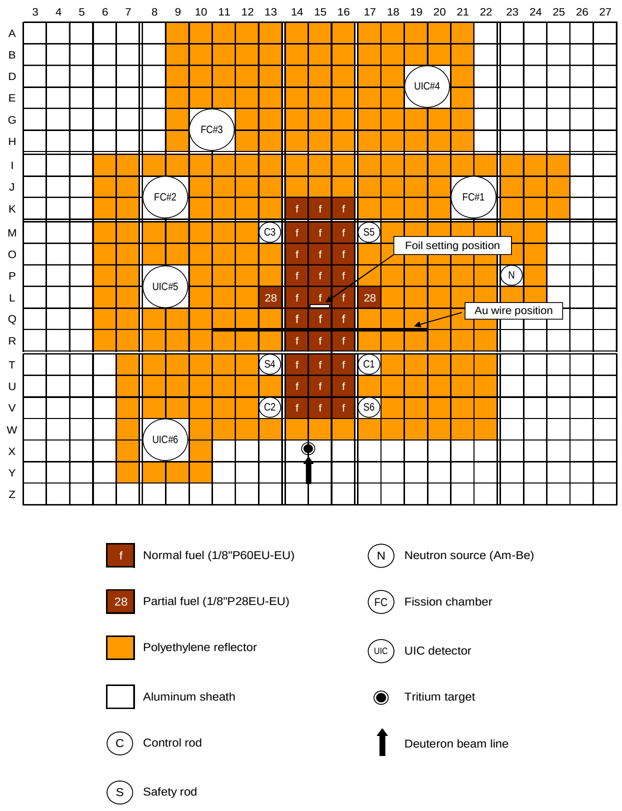

Fig. 1. Top view of A-core configuration.

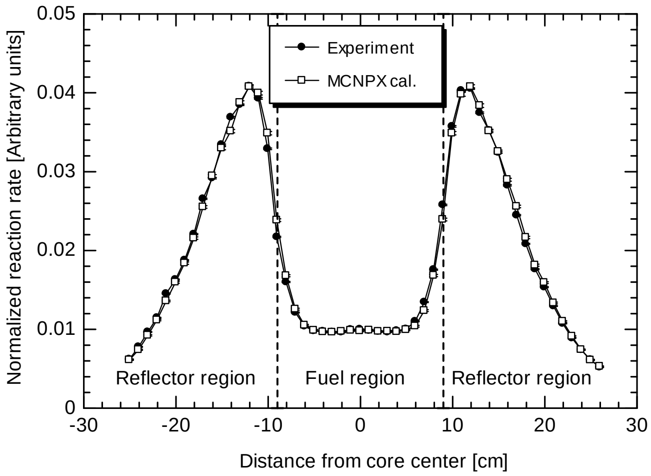

Fig. 2. Comparison between the results in experiments and calculations (MCNPX) of Au reaction rates.

References:

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[2] C. H. Pyeon, *et al.*, *J. Nucl. Sci. Technol.*, **45** (2008) 1171.

採択課題番号CA22101 加速器駆動未臨界炉の基礎実験 共同通常
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