Research and Development of a Neutron Two-dimensional Position Sensitive Detector System

S. Satoh, K. Mori[1], Y. Yoshino[1], M. Sakaguchi, T. Seya, T. Otomo and H. Oshita

Accelerator Laboratory, KEK
[1] Research Reactor Institute, Kyoto University

INTRODUCTION: In this research, we are developing two-dimensional position sensitive detector [1] and neutron scintillator detector [2] for neutron scattering experiments. We are also developing alternative detectors for a ^{3}He gas detector. In this fiscal year, a detector system combining neutron scintillator and wavelength shift fiber, which was a fundamental research, was verified.

A ZnS/^{6}LiF (ZnS) scintillator, which is most frequently used in neutron scintillators, has low gamma ray sensitivity with high light emission amount. However, because of an opaque scintillator, it is not made thick and has low detection efficiency. Because lights shining inside are difficult to emit outside, there are many attenuated small signals, which make a bad characteristic in a pulse height analyze (PHA) distribution. In order to solve these problems, we developed a fiber multilayer ZnS (FMZ) detector and evaluated effects of it.

EXPERIMENTS: Experiments of the FMZ detector were carried out using the B-3 beam line. A neutron efficiency of up to four sheets of ZnS which are sandwiched by five planes of wavelength sift fiver was evaluated. The efficiency compared to a standard ^{3}He detector was determined. An effect of both sides receiving of ZnS scintillator was also evaluated.

RESULTS: Figure 1 shows the neutron detection efficiency of the multilayer ZnS scintillator. The lines of 0.45 mm thick ZnS, 0.25 mm thick ZnS and these calculations are drawn. These lines of the ZnS are very good fitting with the calculated lines, assuming that the efficiency of the 0.45 mm thick is 33% and the 0.25 mm thick is 23%, respectively. The neutron detection efficiency of four sheets of the 0.45 mm thick has been obtained 82%, and the efficiency of the 0.25 mm thick has been obtained 64%.

Figure 2 shows a PHA distribution of both sides and single side receiving-lights of the 0.25 mm thick ZnS. It was confirmed that the PHA distribution of the opaque scintillator improves on the both sides receiving than on the single side receiving. The detection efficiency improved by 27%, and a clear bulge appeared in the PHA distribution.

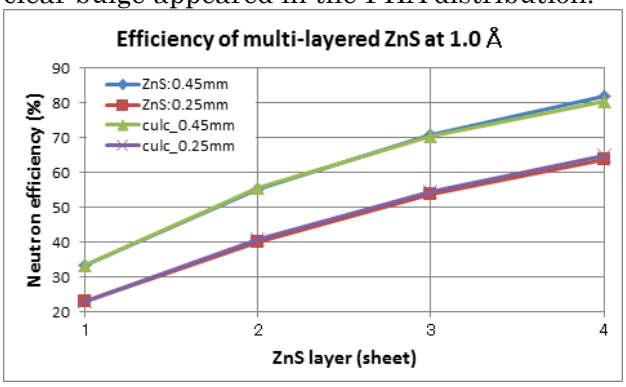

Fig. 1. Neutron detection efficiency of multi-layered ZnS scintillator.

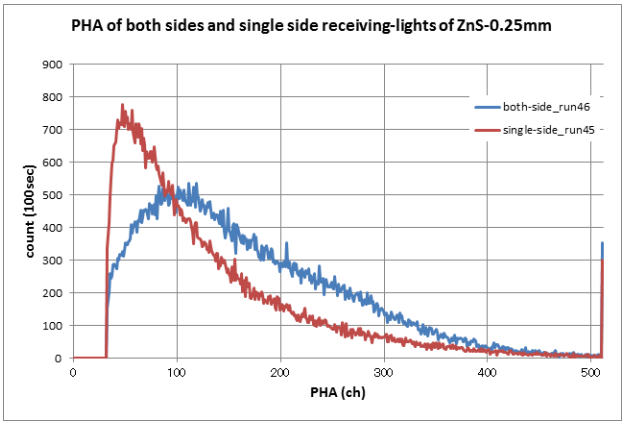

Fig. 2. PHA distributions of both sides and single side receiving-lights of a ZnS scintillator.

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CO8-2 Multi-element Analysis of Cultivated Oysters by Neutron Activation Analysis

M. Fukushima, A. Chatt[1], T. Maeda

Faculty of Science and Engineering, Ishinomaki Senshu University
[1] Trace Analysis Research Centre, Department of Chemistry, Dalhousie University

INTRODUCTION: Japanese cultivated oysters were collected from six different locations in Ishinomaki Bay in 2015 May. To study any possible seasonal variation, oyster samples were also collected every month from April to September from one of these cultivation areas. Bioaccessible trace element levels in soft tissues of oysters were also estimated by using an AOAC method.

EXPELIMENTAL: To study locational variation of trace elements, cultivated oysters were collected from six different bays in 2015 May; Takenoura Bay, Shizugawa Bay, Nagatsura-Hama, Ogatsu Bay, Ohishi-Hama, and Obuchi Bay in Miyagi Prefecture. Also, to study seasonal variation, one year old and two years old oysters were collected every month from April to September in 2015 from Higashimatsushima. Soft tissues were separated from shells of 5 oysters, washed with tap water, separated into gills, mantles, muscles, and hepatopancreas. Each organ was freeze dried, pulverized, and irradiated for 1 h in the Kyoto University Reactor, Japan. Gamma-ray spectra of the irradiated samples were recorded after one-month decay for 20-30 min using a Ge detector system. Levels of Ag, Co, Cr, Fe, Rb, Sc, Se, and Zn were obtained using ^{110m}Ag, ^{60}Co, ^{51}Cr, ^{59}Fe, ^{86}Rb, ^{46}Sc, ^{75}Se, and ^{65}Zn, respectively. The instrumental neutron activation analysis (INAA) method used was validated using NIST 1566b Oyster Tissue, NIST SRM 1573a Tomato Leaves, and NRCC TORT-1 Lobster Hepatopancreas certified reference materials.

Bioaccessible trace element levels in soft tissues of oysters were also estimated by using an AOAC method. Briefly, about 1 g of dried oyster soft tissue powders was incubated with α-amylase, protease, and amyloglucosidase one after another. Water soluble dietary fiber was filtered from the undigested residue after adding ethanol, and both fractions were analyzed by INAA.

RESULTS: Three SRMs and one CRM were analyzed and data for two materials are shown in Table 1 .

Table 1. Analysis of SRM and CRM.

Element	NIST SRM 1573a Tomato Leaves (mg/kg)		NRCC TORT-1 Lobster Hepatopancreas (mg/kg)	
	This work	Agency values	This work	Agency values
Ag	---	0.017*	9.82±1.03	---
Co	0.57±0.05	0.57±0.02	0.38±0.02	---
Cr	1.90±0.15	1.99±0.06	2.4±0.4	2.4±0.6
Fe	365±40	368±7	180±17	186±11
Se	---	0.054±0.003	6.86±0.5	6.88±0.4
Zn	29.7±4.1	30.9±0.7	160±2	177±10

* reference value.

All the results agreed well with agency values.

Mass fractions obtained for heaptopancreas from six different bays are shown in Fig. 1.

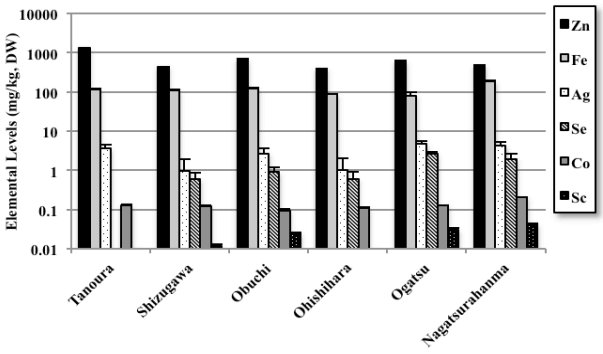

Fig.1 Mass fractions of elements in hepatopancreas from six different bays.

From all the results for hepatopancreas, mantle, gill, and muscle, Zn level was high in oysters from Tanoura and Fe was high in Nagatsura-Hama. Seasonal variations of total and bioaccessible Zn levels in oyster soft tissues are shown in Fig. 2. Both of 12 and 25 month old oysters were collected in July and total levels showed peak in July. July is mating season in Tohoku district. When the amount of Zn in whole soft tissues were calculated, it showed peak in June and decreased in July. Soft tissue weight decreased drastically in July, and it might be the reason that Zn level showed peak in July. Bioaccesble level of Zn was not same as total level and almost propotional to total levels in all seasons.

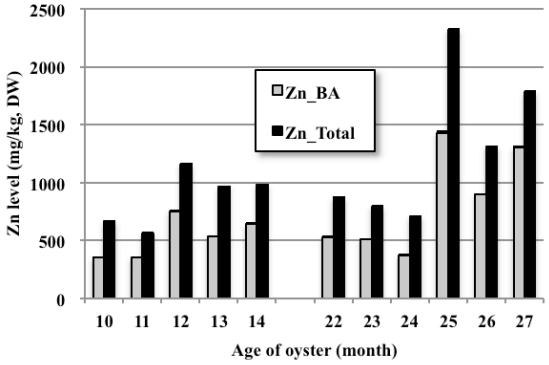

Fig. 2. Seasonal variations of total and bioavailable level of Zn in soft tissues from Higashimatsushima.

This tendency was same for Fe, Ag, and Sc. Se showed different tendency.

Conclusions: Eight selected trace elements in oyster soft tissues and separately in heaptopancreas, gill, mantle, and muscle were obtained by INAA. Seasonal and locational variation were observed for several elements.

CO8-3 First Result of Neutron Imaging at Reactor with Neutron Flat Panel Detector

T. Fujiwarwa and M. Hino[1]

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology

[1]*Research Reactor Institute, Kyoto University*

INTRODUCTION: Neutron imaging is powerful tool for observing inside an object without destructing the object. Although neutron imaging (neutron radiography) is one of the most traditional uses of neutrons, still there are rooms for improvement. Here, we report on the first neutron imaging result at reactor with our new neutron imaging detector based on Thin-Film-Transistor (TFT) technology, the neutron Flat Panel Detector. nFPD is tested at neutron beam port at KUR, and succeed in taking fine neutron image and 3D computed tomography (CT).

EXPERIMENTS: Experiments were held in CN-3 port at Kyoto University Reactor [1]. At this facility, approximately 20 × 100 mm^2 size cold neutron beam is available. Fig. 1 shows the outlook of the nFPD. The volume of the detector is remarkably compact and thin compared to the conventional neutron imagers. The size of this detector improves the flexibility for placing and it will be a great advantage for installation to various experiments. Meanwhile, nFPD only requires 5V (4W) single power supply, and simply connected to PC with USB cable. The detector has effective area with 512 × 512 pixels (200 mm pixel size).

In this experiment, we took various radiographs and 3D CT was performed with automated turntable.

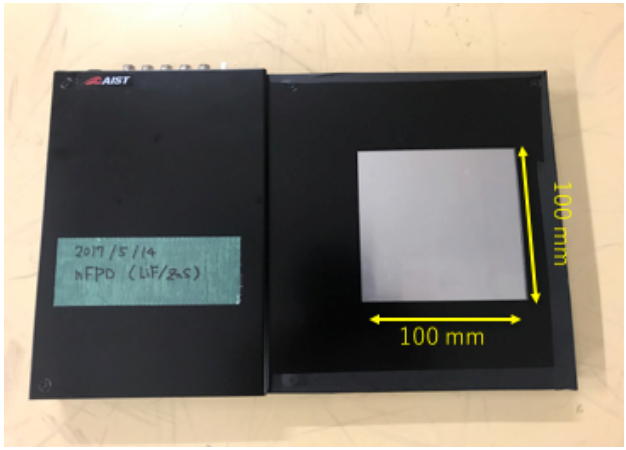

Fig. 1. Outlook of nFPD with 100 × 100 mm^2 effective area. For the neutron convertor, 320 mm thick LiF/ZnS(Ag) scintillator was used.

RESULTS: First, simple neutron imaging capability of nFPD was tested with Gd coated test chart developed at PSI [2]. As shown in Fig. 2, fine neutron radiograph was obtained. Fine structures less than 300 μm can be observed. From this result, spatial resolution of our nFPD is estimated as 200 μm.

Neutron CT was performed with automated turntable. The sample used here is an aluminum plate with screw holes and screwed with various material screws. Using this setup, the scanning sample was rotated in 1° pitch, and 360 images were obtained for 360° radioscopic image. The 3D image was reconstructed from those images by a filtered back-projection algorithm. The reconstructed 3D image is shown in Fig. 3. Fine structure of M4 screws can be clearly seen, and in addition, CT value of the objects agrees to theoretical neutron cross-section (Aluminum < Steel (Fe) < Plastics (Hydrogen)). Time for total scanning was less than 60 minutes.

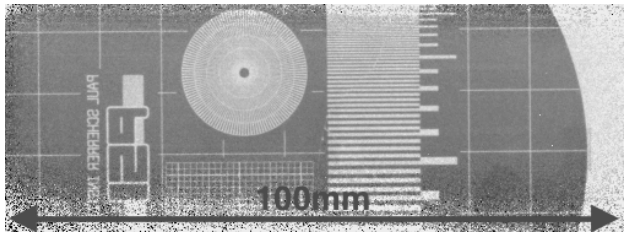

Fig. 2. Obtained neutron radiography of fine-structured Gd chart with nFPD. Integrating time was 5s at 1 MW operation. Fine patterns can be clearly observed.

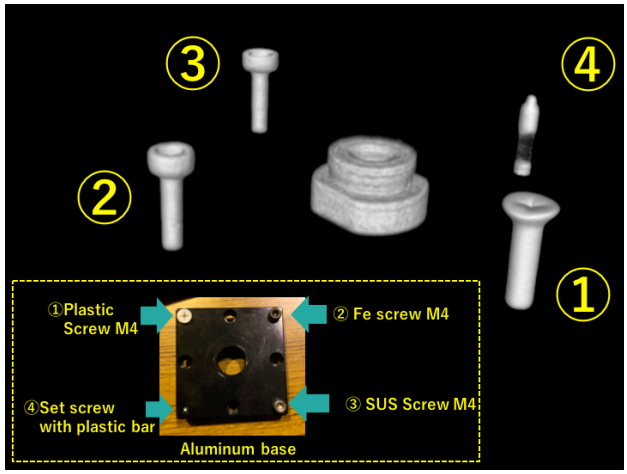

Fig. 3. Reconstructed 3D CT image of aluminum plate with various screws. Plastic screws and steel screws can be clearly seen while Aluminum part is almost transparent.

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[2] K.-U. Hess *et al.*, Geosphere **7** 6. (2011) 1294–130.

CO8-4

Development of Neutron Source and Neutron Detector for Non-destructive Assay of Nuclear Materials

Y. Takahashi, Y. Kiyanagi[1], J. Hori, T. Sano, D. Ito, H. Unesaki, K. Nakajima, T. Kamiyama[2], K. Mochiki[3]. N. Hagura[3] and S. Satou[4]

Institute for Integrated Radiation and Nuclear Science, Kyoto University,

[1]Nagoya University,

[2]Hokkaido University,

[3]Tokyo City University,

[4]High Energy Accelerator Research Organization

INTRODUCTION: The Kyoto University Research Reactor Institute electron linac, KURRI-LINAC, has been used for executing a project to develop methodolo-gy for the integrity evaluation of nuclear fuels, named the N-DeMAIN (Development of Non-Destructive Methods Adapted for Integrity test of Next generation nuclear fuels) project in Japan. As a non-destructive method, the neutron resonance transmission analysis was adopted for the identification and the quantification of nuclide in the fuels. Furthermore, determination of temperature distribution in the fuels based on Doppler broadening was also planned as well as traditional transmission imaging.

To obtain accurate data by these methods, high quality neutron beam regarding neutron flux, time resolution and spatial resolution is required. In order to satisfy the neutron beam quality required to successfully execute the experiments described above, the design of the neutron source, especially the moderator, reflector and collimator, should be improved and optimized. .In this project, a tar-get moderator reflector system (TMRS) and a beam collimator system have been redesigned to obtain the highest intensity and good spatial resolution with the use of simulation calculation. Then, the neutron source system including moderator and reflector was newly developed. The neutron beam line is placed at an angle of 135° with respect to the electron beam line and the collimator in 12 m beam line was also re-arranged. The characteristic of the TMRS was investigated experimentally.

EXPERIMENTS: A water-cooled photo-neutron target was set at the center of the neutron source system located in the target room. To enhance the neutron flux in thermal and epi-thermal regions, the size of the moderator of polyethylene was 5 cm thickness and 15 cm square. The collimators of polyethylene with 10% boron of 20 cm thickness were set at following positions; 15, 10 cm in inner diameter at 3, 9 m from the target, respectively. The conditions of the accelerator were as follows: average beam current was about 100 μA, frequency was 50 Hz and pulse width was 4 μs. For the evaluation of the spatial resolution of the TMRS, the dysprosium (Dy) foil transfer method was adopted in this study. The 6 Gd_2O_2S ceramic plates of 1 cm square and B_4C markers as shown in Fig. 1 are placed on the neutron beam line while shifting the position by 10 cm intervals. The Dy foil (110 mm width, 160 mm height, 0.1 mm thickness) was set at the end the Gd plate. The Dy foil was activated by the neutron passed through Gd plate and the Dy foil emitted beta ray. The beta ray emitted from Dy foil was transferred a neutron imaging plate and we obtained neutron imaging indirectly. After the Gd plate experiment, the neutron imaging with BPI and SI indicators was measured by Dy foil transfer method.

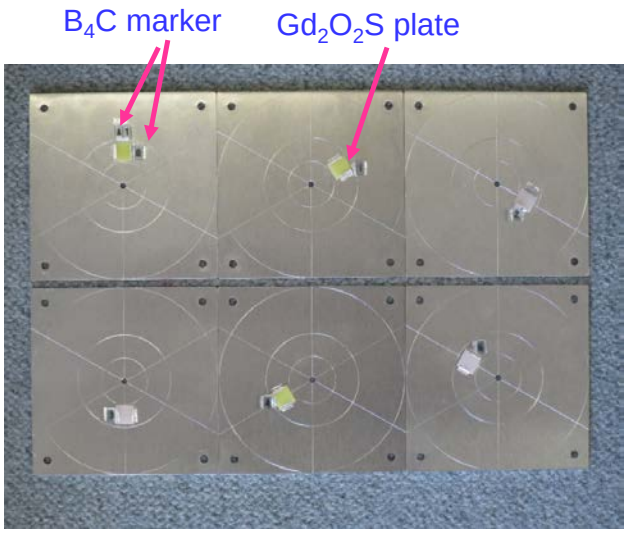


Fig. 1 Gd plates and B_4C marker for Dy foil transfer method

RESULTS: The results of neutron imaging by Dy foil transfer method are shown in Fig. 2. The modulation transfer function (MTF) on the results of Gd plate was well and it was found that the TMRS has good L/D. The boron point can be observed in BPI indicator and the 50 μm line is visible in SI indicator. From the results, it was found that we can obtain the enough neutron flux and our system is available for a neutron imaging with good spatial resolution.

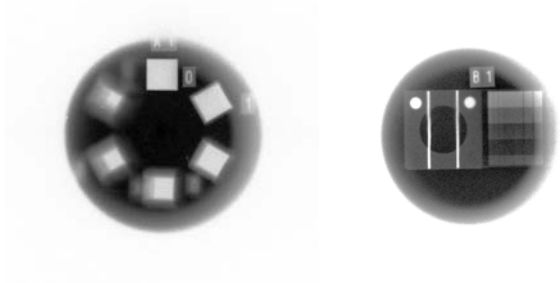


Fig.2 Results of neutron imaging by Dy foil transfer method
(left: Gd_2O_2S ceramic plates, right: Indicators)

Present study includes the result of “Development of Non-Destructive Methods Adapted for Integrity test of Next generation nuclear fuels” entrusted to the Kyoto University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT)

CO8-5 Integral Test for the Development of Nondestructive Methods Adopted for Integrity Test of Next Generation Nuclear Fuels (N-DeMAIN)

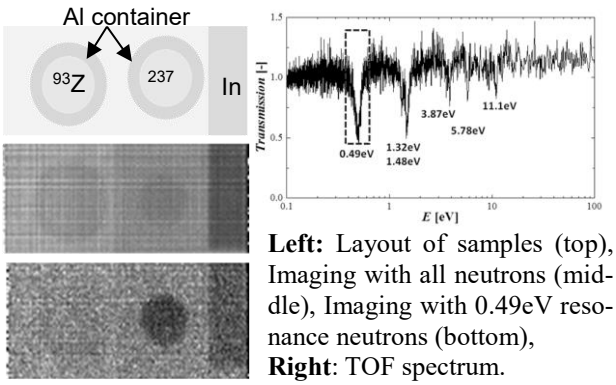
K. Nakajima, J. Hori, T. Sano, Y. Takahashi, H. Unesaki, D. Ito, T. Kamiyama[1], H. Hasemi[1], K. Mochiki[2], N. Hagura[2], Y. Kiyanagi[3], K. Koike[4] and S. Satoh[5]

Research Reactor Institute, Kyoto University
[1] Graduate School of Engineering, Hokkaido University
[2] Faculty of Engineering, Tokyo City University
[3] Graduate School of Engineering, Nagoya University
[4] R-Tech Corporation
[5] Institute of Material Structure Science, KEK

INTRODUCTION: TRU fuels containing MA will be used in a fast reactor system to reduce the high-level waste by the transmutation of long-lived minor actinides. It is important to test their integrity to confirm the fuel safety, however, such fuels have high radioactivity and high decay heat, thus the conventional techniques would be difficult to use. Therefore, we launched a new project, which named as "**N-DeMAIN**" (Development of **N**on-**De**structive **M**ethods **A**dopted for **I**ntegrity Test of **N**ext Generation Nuclear Fuels) in 2014, in order to develop the NDA techniques for Next generation fuels, i.e., TRU fuels containing MAs. In the project, the neutron resonance transmission analysis (NRTA) with the time-of-flight (TOF) measurement is adapted for the identification and quantification of nuclides in the fuels. In addition, the determination of temperature distribution in the fuels based on Doppler-effect and neutron imaging are conducted.
In the present study, we have performed the following measurements using the KURRI-LINAC as the integral test:1) Isotopic imaging of the sample containing a minor actinide and a long-lived fission product, 2) Geometry measurement by neutron beam and X-ray, 3) Temperature measurement using the Doppler effect.

EXPERIMENTS and RESULTS:

1) Isotopic imaging of the sample containing a minor actinide and a long-lived fission product: By selecting the specified resonance region in the TOF spectrum of a sample, we can obtain the 2D imaging of the isotope corresponding to the specified resonance. We have obtained the 2D imaging of the samples containing a minor actinide, ^{237}Np, and a long-lived fission product, ^{93}Zr, by the NRTA using the THIN-GEM detector. The samples are oxide powder of ^{93}Zr and ^{237}Np, and they were encapsulated in aluminum disk-shaped containers with 30mm diameter. Those samples have radioactivities, 47MBq for ^{93}Zr and 26Mbq for ^{237}Np. In addition to the samples, the indium foil was measured for th e reference. As shown in Fig.1, the 2D imaging of the samples is not clear when the all neutrons were detected, however, the shape of ^{237}Np can be observed by selecting the 0.49-eV resonance region in the TOF spectrum. Thus, it was confirmed that this technique would be applicable for the TRU fuel imaging with the high radioactivity.



Left: Layout of samples (top), Imaging with all neutrons (middle), Imaging with 0.49eV resonance neutrons (bottom), **Right**: TOF spectrum.

Fig.1. Result of 2D imaging for ^{237}Np.

2) Geometry measurement by neutron beam and X-ray: Since the X-ray imaging has a high spatial resolution, the obtained imaging data were combined with the neutron imaging which has a low resolution to improve the spatial resolution. The nuclide identification was performed by neutron imaging. As shown in Fig. 2, we succeeded in reconstructing synergy imaging by using X-ray and neutron imaging data.

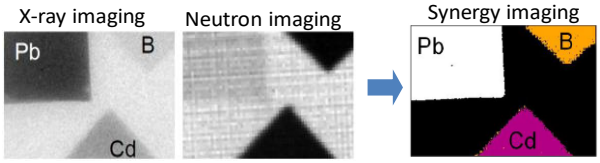


Fig.2. Synergy imaging for 2D-sample.

3) Temperature measurement using the Doppler effect: The temperature rise of a sample causes the Doppler broadening of the resonance peak, then, we can evaluate the temperature change by observing the change of resonance reactions. Because the TRU fuel containing MAs has high decay heat, it is important to monitor the fuel pellet temperature and keeps it to the proper range during the storage. Then, we tried to develop the nondestructive method to monitor the fuel pellet temperature. In the experiment, the temperature of a cylindrical Ta sample (10mmϕ×30mm) was controlled up to 350°C using the sample heating device. The transmitted neutrons were measured with the THIN-GEM detector. It was found that the ratios of resonance count ratios for high temperature to room temperature tend to decrease with temperature rise in the rate of about 0.01%/K as shown, and it was indicated that the change of temperature might be evaluated using the change of the ratio.

SUMMARY: Through the integral test, it was confirmed that the developed techniques satisfy our requirements.

ACKNOWLEDGMENT: Present study is performed under the entrustment to the Kyoto University by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).