CO2-1

Measurement system requirements for photofission signal detection with coincidence neutron counting method

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INTRODUCTION: This work focuses on numerical simulation on design of coincidence neutron counting system to detect photofission signal coming from uranium target consisting of ^{235}U and ^{238}U with in the experimental condition of LINAC Kyoto University. The information of photofission by two different energy beams can lead to the different enrichment of these two isotopes or multi-nuclide of nuclear material using the Photofission Reaction Ratio (PFRR) methodology. Photofission signal detection via neutron detection encounters difficulties of background by not only the bremsstrahlung converter target, the surrounding structural material and collimator which could contribute photo-neutrons as background. Another challenge is the separation of neutrons signal by photonuclear reactions from photofission reactions. This work proposes coincidence counting method for the neutron signal separation, and qualitative assessment on background reduction of neutrons. The coincidence counting method is a technique for separating.
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METHODOLOGY: With MCNP code, bremsstrahlung photon source by Tantalum target with LINAC and the photo-nuclear reactions of uranium and structure materials were simulated including the neutron detector response by He-3 tubes for coincidence counting method with neutron multiplicity. The photonuclear data library used in this work is the ENDF/B-VII.0.
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RESULTS: The impact analysis was performed on the measurement possibility with accidental injections of single neutrons coming from mainly background neutron collision in nuclear material, and background neutron reduction requirement and possible neutron absorber designing were finally deduced. The existence of the neutron absorber such as pure ^{10}B and High Density Poly Ethylene (HDPE) with 10% of fully enriched ^{10}B with certain length of thicknesses have successfully reduced the accidental injection noise down to the measurement goal defined as 1% of the total doubles of photofission neutrons, also improved the distinguishability of photofission neutrons from the background neutrons by about four orders magnitude difference (Fig. 1).
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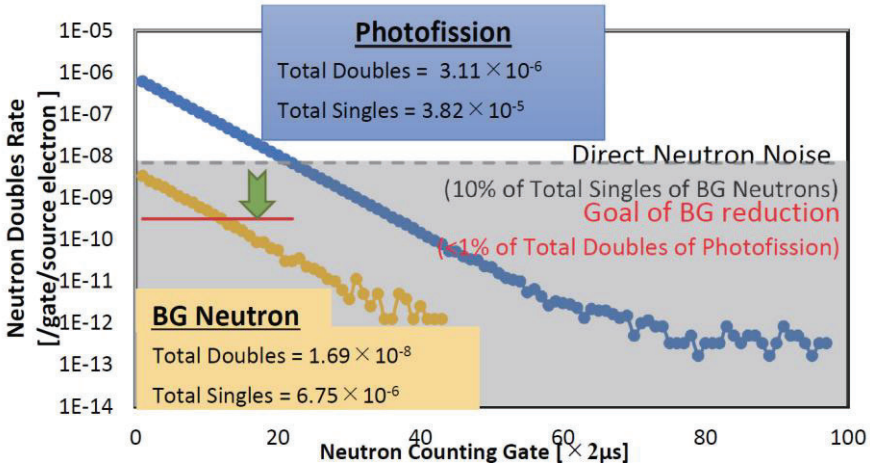

Fig. 1 Accidental neutron injection noise reduction goal.[1]

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CO2-2

Measurement of Th-232 Capture Cross Section for Thorium Reactor System

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INTRODUCTION: In thorium fuel loaded nuclear reactor systems, it is important to have reliable evaluated nuclear data on the neutron capture reaction of the parent material Th-232 and the fission reaction of U-233. The authors have previously carried out differential experiments using the electron linear accelerator at the Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS-LINAC) to measure the fission cross section of U-233 and the neutron capture cross section of Th-232. In the FY2024, shielding of gamma-ray and X-ray from photonuclear reaction in a Ta target was improvement and Th-232 capture cross sections were measured.

EXPERIMENTS: The experiment was performed on the 12 m neutron flight path shown in Figure 1. The samples were Th-232 and B-10 for neutron flux measurement. Th-232 and its daughter nuclides emitted γ rays as background. To reduce the background γ rays, a 10-mm-thick piece of lead was placed between the Th-232 sample and the BGO detector. In the measurement of B-10 for neutron measurement, a single γ ray of 478 keV emitted by the (n,α) reaction between the B-10 sample and neutrons was measured, and the TOF information was observed with the Ta target incident of accelerated electrons as the start signal and the prompt gamma ray emitted by the reaction be-tween the sample and neutrons as the stop signal.

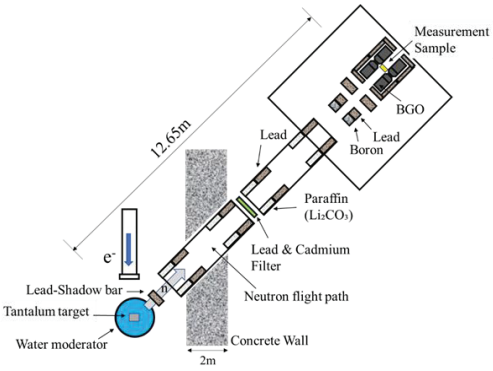

Fig.1 Experimental geometry

RESULTS: Table 1 shows the observed Th-232 resonances in this work. In this measurement, 17 resonances in the 10-350 eV energy region were observed. Compared with the evaluated values after correcting for the neutron self-shielding effect using the cross section of JENDL-5[3], the C/E values were ± 20 % except for the fourth resonance (69.2 eV). On the other hand, the C/E of the 4th resonance was clearly excessive compared to that of JENDL-5. Therefore, more detailed measurement of the 4th resonance is needed.

Table 1. Observed resonances

No.	Peak energy (eV)	No.	Peak energy (eV)	No.	Peak energy (eV)		Peak energy (eV)
1	21.80	6	120.89	11	221.33	16	329.16
2	23.47	7	129.21	12	251.69	17	342.07
3	59.53	8	170.42	13	263.28		
4	69.24	9	192.76	14	285.97		
5	113.06	10	199.45	15	305.69		

ACKNOWLEDGMENT: A part of this study was supported by CHUBU Electric Power Co., Inc.

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CO2-3

Analysis of Tetraneutron Search Experiment by the (^{4}n, n) Reaction in KUR

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INTRODUCTION: Tetraneutron is a nucleus that is composed of four neutrons. It is not clear whether it exists from theoretical calculations, but recent experimental studies have suggested its existence. For example, M. Duer et al. reported the discovery of a tetraneutron in a resonant state [1], and T. Faestermann et al. claimed the observation of a bound tetraneutron [2]. We have conducted a tetraneutron search experiment by the (^{4}n,n) reaction in KUR, assuming that bound tetraneutrons are emitted by fission of uranium in a nuclear reactor. As the first step, an experiment with $^{88}SrCO_3$ was conducted in FY2022, and an upper limit of the emission rate of tetraneutron was determined [3]. In this experiment, we performed a similar irradiation experiment with mononuclidic elements.

EXPERIMENTS: We used the (^{4}n,n) reaction on ^{93}Nb or ^{127}I to detect long-lived tetraneutrons from the fuel. High purity niobium metal and NH_4I samples were placed near the reactor core through hydraulic (Hyd) and pneumatic (Pn-2) transport tubes. They were irradiated for 4 hours and 1 hour, respectively, at a thermal power of the reactor of 5 MW. Then, we measured the gamma rays emitted from the samples with a germanium detector. If tetraneutrons reacted with ^{93}Nb or ^{127}I, γ-rays from ^{96}Nb or ^{130}I are expected to be observed.

RESULTS: As shown in Figs. 1 and 2, photopeaks originating from various nuclides were identified. In Fig. 1, we identified photopeaks not only from niobium, but also from tantalum, which was contained in the sample. In Fig. 2, we identified γ-rays from the silica tube in which NH_4I was sealed as well.

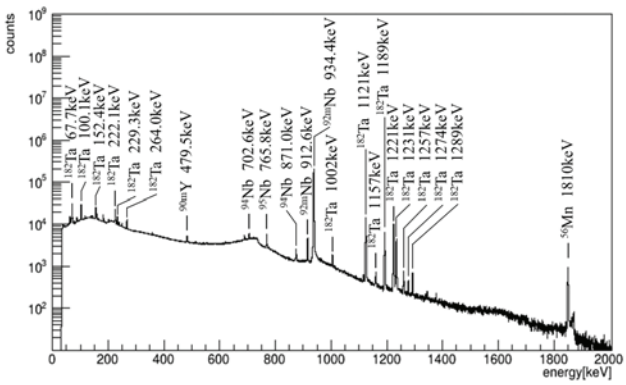

Fig. 1. Spectrum measured for 30 minutes from niobium metal about 70 hours after irradiation.

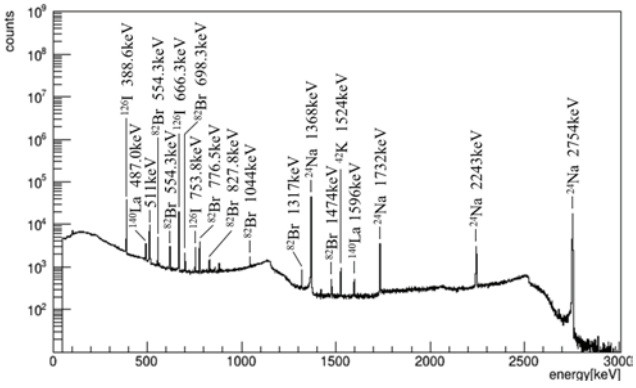

Fig. 2. Spectrum measured for 30 minutes from NH_4I about 69 hours after irradiation.

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CO2-4

Effects of lead addition on tritium recovery for advanced Li_2TiO_3-Li_4SiO_4 mixed breeder material

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INTRODUCTION: Tritium will be produced by (n, α) reaction with lithium (Li) in the fusion reactor because the amount of tritium in nature is limited. Tritium breeder requires good chemical stability and ease of tritium recovery. Lithium silicate (Li_4SiO_4) and lithium titanate (Li_2TiO_3) have different characteristics. For example, lithium silicate has a high lithium density, while lithium titanate is good chemical stability and has a good crushing load. Advanced tritium breeder materials should have both of higher tritium production rate and recovery efficiency. LTO-LSO mixed ceramic materials are expected to have both advantages. Lead (Pb) is a neutron multiplier that contributes to the improvement of the tritium breeding ratio and has a lower affinity with tritium. The addition of Pb into Li ceramics is expected to have a potential advantage for efficient tritium recovery.

EXPERIMENTS: LTO-LSO-x wt.%Pb, a powder sample of lithium titanate and lithium silicate mixture with 2, 5, 25wt.%Pb addition, was prepared at Wuhan University of Technology. Those samples were irradiated by neutron at Kyoto University Research Reactor (KUR) with the neutron fluence of 8.0×10^{15} n cm^{-2} and 8.0×10^{16} n cm^{-2}. After the neutron irradiation, tritium release behavior was evaluated by Tritium-thermal desorption spectroscopy (T-TDS) system by heating the samples separately from R.T. to 1113 K with the heating rates of 10, 20, and 30 K min^{-1}. Liquid scintillation counter (LSC) was used to measure the total T amount trapped by the water bubbler at Shizuoka University. For each sample, the surface chemical states were characterized by X-ray Photoelectron Spectroscopy (XPS), and the bandgap was evaluated using Reflection Electron Energy Loss Spectroscopy (REELS).

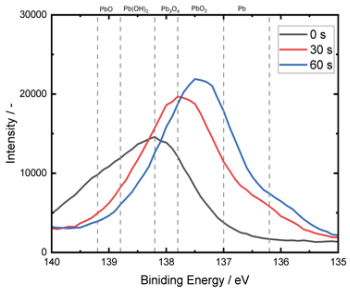

Fig. 1 XPS spectra of Pb-4f in LTO-LSO-20 wt.% Pb.

RESULTS: Fig. 1 shows the XPS spectra of Pb-4f for LTO-LSO-20 wt.%Pb. It was found that the oxidation state of Pb increased with depth from the surface. This suggests that Pb forms oxides with LTO and LSO. The bandgap of LTO-LSO was found to be 2.78 eV, whereas that of LTO-LSO-20 wt.%Pb increased to 4.53 eV, as determined from REELS measurements. This increase can be attributed to the larger energy difference between the conduction band of Pb and the valence band of highly electronegative oxygen. These results suggest that the Pb-added sample is more resistant to external influences such as radiation and exhibits better thermal stability. Fig. 2 shows the T-TDS spectra for LTO-LSO and LTO-LSO-5 wt.%Pb with different LTO/LSO compositional ratios. The addition of Pb caused the shift of major tritium desorption toward lower temperature side. The T release behavior also varied depending on the relative proportions of the two oxides. Therefore, it is considered necessary to investigate not only the Pb content but also their mixing ratio.

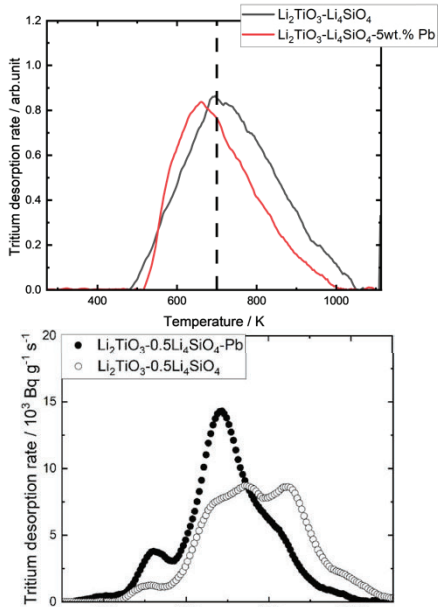

Fig. 2 TDS spectra of samples with different LTO/LSO ratios (top: LTO-LSO, bottom : LTO-0.5LSO).

CO2-5

Development of neutron resonance analysis technique in neutron time-of-flight for fissile material identification and quantification

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INTRODUCTION: The Japan Atomic Energy Agency (JAEA) has been developing a neutron resonance analysis (NRA) technique as an active neutron non-destructive assay for the identification and quantification of fissile materials. NRA combines neutron resonance transmission analysis (NRTA), neutron resonance capture analysis (NRCA), and neutron resonance fission neutron analysis (NRFNA) [1]. In the JAEA NRA system, we employed EJ-276D plastic scintillators, which allow for pulse shape discrimination (PSD) of gamma rays and fast neutrons for NRCA and NRFNA. Additionally, we used the GS20 lithium glass scintillator for NRTA [2]. An NRA experiment was conducted at the neutron time-of-flight (TOF) beamline of the KURNS-LINAC using enriched uranium (EU) samples. This paper reports the measurement results and discusses the NRA system's ability to identify and quantify fissile materials.

EXPERIMENTS: **Fig. 1** shows the experimental setup. The KURNS-LINAC was operated with a pulse width of 2 μs, a repetition rate of 50 Hz, an average current of 47.5 μA, and a beam energy of 31.5 MeV. The pulsed neutrons were collimated using lead and borated polyethylene and directed toward the sample. In this experiment, three EU samples with different thicknesses (1, 2, and 3 mm) were used, each containing approximately 93.14 wt% of ^{235}U. The EU samples were placed at the center of the two EJ-276D detectors, which detected fast fission neutrons and gamma rays emitted by the EU sample. A 6-mm-thick GS20 detector was used to measure the neutrons transmitted through the EU samples.

RESULTS: **Fig. 2** shows the obtained TOF spectra for the 3-mm-thick EU sample. The resonance dips and peaks corresponding to the ^{235}U(n, tot) and the ^{235}U(n, γ) reactions (in blue and black respectively) were observed in the TOF range of 170–450 μs. Additionally, the resonance peaks from the ^{235}U(n, f) reactions (in red) were observed in the TOF range of 100–2000 μs. These results indicate that the JAEA NRA system is sufficiently capable of identifying fissile materials. Currently, analysis is ongoing to quantify the fissile material using data obtained from the EU samples of different thicknesses.

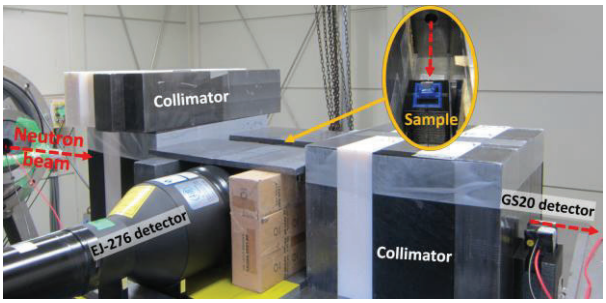

Fig. 1. Experimental setup.

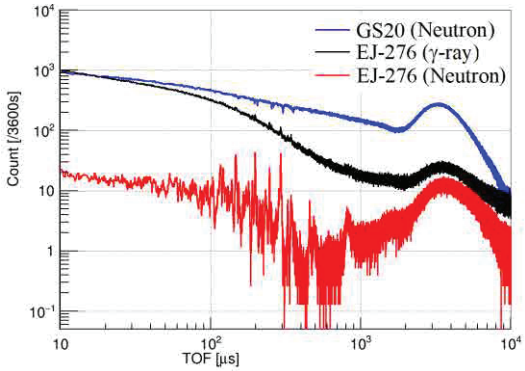

Fig. 2 Obtained TOF spectra of 3-mm-thick EU.

ACKNOWLEDGEMENTS: This research was implemented under a subsidy for "promotion of strengthening nuclear security and the like" of the Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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CO2-6

Measurements of neutron capture cross sections of P-31

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INTRODUCTION: The thermal neutron capture cross section data of ^{31}P are scarce, as it has only been measured by Salama et al [1]. This is because it was not regarded as an important nuclide in the applications of nuclear power and stellar nucleosynthesis. The evaluations of JENDL-5 [2] and ENDF-B/VIII.0 [3] are 16% and 18% larger than that of Salama et al. Therefore, we measured neutron capture cross sections of ^{31}P at the thermal energy with the Kyoto University Institute for Integrated Radiation and Nuclear Science-Linear Accelerator (KURNS-LINAC).

EXPERIMENTS: The KURNS-LINAC is an L-band electron linear accelerator having a maxi-mum acceleration voltage of 46 MeV and a beam power of 10 kW. Accelerated electron beams with a repetition rate of 50 Hz, an energy of 31 MeV, and an average beam current of 60 μA are bom-barded to a water-cooled Ta target, generating bremsstrahlung X-rays. Neutrons produced via (γ, n) reactions are moderated by light water sealed in the tank with a diameter of 20 cm and a height of 30 cm. 6.935 g of red phosphorus powder was sealed in an aluminum container with a diameter of 30.0 mm and a thickness of 16.5 mm. Furthermore, we measured a dummy case to subtract sam-ple-dependent background. The measurement was performed using a time-of-flight (TOF) method. The distance between the sample and the neutron source was 12.7 m. Neutron capture gamma-rays from the ^{31}P sample were measured with twelve BGO detectors. Signals from the detectors were recorded event-by-event as two-dimensional data of TOF and pulse height data. Incident neutron energy distribution was determined by measuring 478 keV gamma-rays via ^{10}B(n, γα) reactions. Figure 1 shows the obtained TOF spectra of the ^{31}P sample and the dummy case. The net TOF spec-trum of ^{31}P was determined by subtracting the sample-dependent and sample-independent back-ground. Finally, the neutron capture cross sections of ^{31}P was derived.

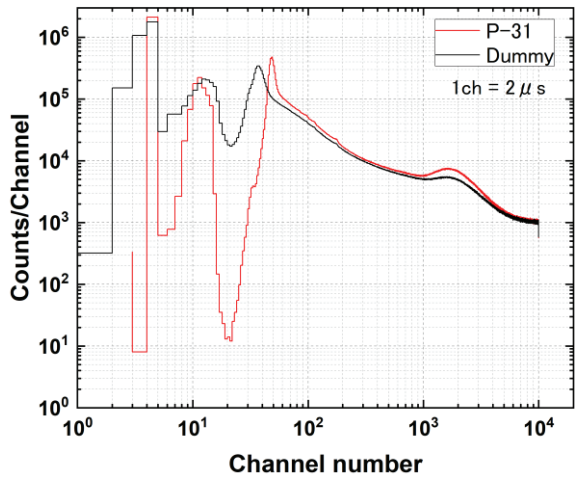

Figure 1. Measured TOF spectra were shown. The red line is the ^{31}P TOF spectrum. The black line is the Dummy TOF spectrum. 1 ch is 2μs.

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CO2-7

Neutron cross-section measurement of molybdenum

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INTRODUCTION:

The Kyoto University Critical Assembly (KUCA) is preparing to adopt a new reactor fuel composed of uranium-molybdenum (UMo). This will be the first reactor in the world to utilize this type of fuel, which is expected to be widely used in research reactors in the future. While the reliability of nuclear data has been sufficiently validated for conventional uranium-aluminum alloy fuel, core analysis using UMo fuel, particularly for molybdenum, remains insufficient. Therefore, improving the nuclear data related to molybdenum is essential.

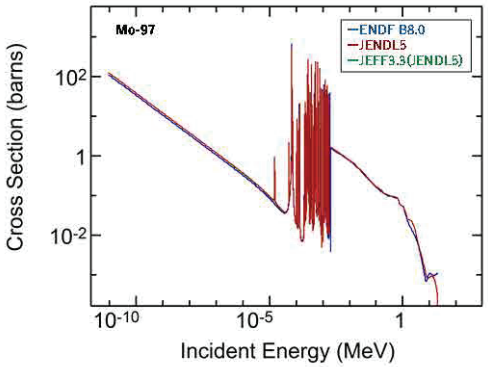

Fig. 1. Cross-section of Mo-97

Figure 1 shows a comparison of Mo-97 data in JENDL-5 and ENDF/B-VIII.0, revealing some discrepancies. This study aims to contribute to the improvement of molybdenum nuclear data by measuring neutron cross-sections of selected molybdenum isotopes using the KURNS-Linac, thereby enhancing the accuracy of KUCA core analyses.

EXPERIMENTS:

For the preliminary test, a natural molybdenum plate was used as the sample. The plate was 3.0 mm thick, with dimensions of 15 × 15 mm. In the time-of-flight (TOF) setup, the sample was placed 12 meters from the target at a 135-degree angle. The target was surrounded by a carbon moderator. A total of 12 BGO scintillators were arranged around the sample to measure the total energy of absorbed gamma rays. No shielding materials were used. The accelerator operated in short-pulse mode with the following parameters: average beam current of 17 μA, frequency of 200 Hz, pulse width of 33 ns, and beam diameter of 50 mm. The measurement time was 1 hour for both the sample and the blank.

RESULTS:

Figure 2 presents the TOF measurement results for both the sample and the blank (no sample). The data are normalized to measurement time. One channel corresponds to 100 ns. For example, a difference was observed in the TOF region between 10 and 50 μs, which was attributed to hydrogen capture gamma rays. Several peaks were clearly detected, and further analysis will be necessary.

In future experiments, cross-section measurements will be conducted using thinner samples, with the sample thicknesses determined through preliminary calculations

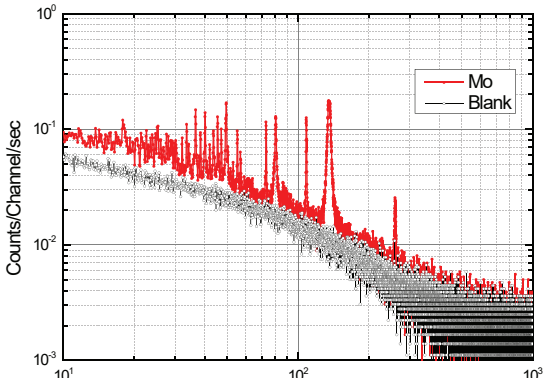

Fig. 2 Result of TOF