## CO8-1 Developments for an innovative method to detect nuclear materials

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**INTRODUCTION:** Devices for detecting nuclear materials have become increasingly important with the increase of today's global terrorism. In particular, a compact and low-cost non-destructive assay system to detect hidden nuclear material is required in the fields of nuclear security. We have therefore developed an innovative nuclear material detection method by using a neutron source of Californium-252, which is capable to assemble such system. In this method, a neutron source is rotated at a speed of thousands of rpm nearby the target. Meanwhile, it is possible to detect nuclear materials by confirming the deformation of the time-distribution spectrum obtained by a neutron detector near the target. The machine to rotate the neutron source is quite compact that its width, depth, and height is 60 cm each. We have installed the machine at an experimental laboratory in the KUCA. In the previous study, we presented experimental verifications for this new method [1]. However, we used expensive detectors based on He-3, so that we have studied to develop a low-cost detector for this new method. A water Cherenkov detector has a potential ability as a low-cost neutron detector. Unfortunately, our experiments in this year are severely limited due to the influence of the COVID-19.

**EXPERIMENTS:** The left side of the Fig.1 shows a water Cherenkov detector. Four PMTs (Photomultiplier tube) are mounted on the aquarium. The diameter of the PMT is 2 inches. The aquarium (25x25x30cm) is a commercial item and reasonable price. It is covered with a black sheet and boron sheet in order to prevent light and thermal neutrons. The aquarium is filled with the gadolinium aqueous solution with approximately 0.5wt%. The gadolinium was added in order to increase the amount of the Cherenkov light. This detector can be constructed at a much lower cost than He-3 detectors. Since high energy gamma ray, for example from hydrogen in water, also causes the Cherenkov light, we discriminate neutron signal by using pulse height difference. Measurements of the neutron time distribution were performed by a multi-channel scaler (MCS) that is synchronized with the disc rotation. The right side of the Fig.1 shows a rotation machine to rotate a neutron source. The neutron source was installed at the outer periphery of a disc of 32 cm diameter. The maximum rotation speed is 4000 rpm.

**RESULTS:** Figure 2 shows an example of experimental results of a blank sample (only polyethylene blocks) under the condition that the rotation speed is 3000 rpm. The neutron source was closest to the polyethylene blocks approximately at 8500 micro-seconds in Fig. 2. Since the neutron source, the polyethylene blocks and the neutron detector system have a complicated geometry, the dips in the times spectrum appear before and after the peak. We have confirmed that this Cherenkov detector is able to measure as same as He-3 detectors. It means that we can construct a new detection system for nuclear materials that is low cost and transportable. Further improvement of the Cherenkov detector is possible and desirable. Therefore, more detailed experimental study with nuclear materials would be required.

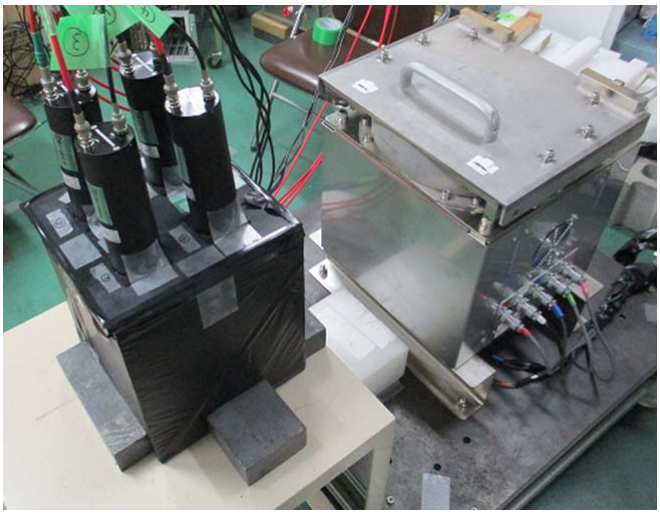

Fig. 1. Water Cherenkov detector (left) and rotation machine (right). A black sheet and boron sheet are covered over the detector in the neutron measurements.

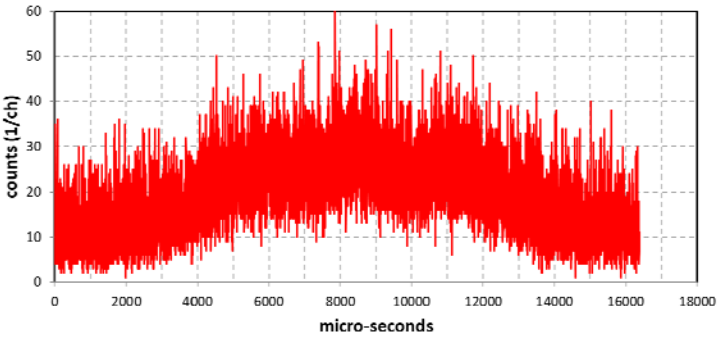


Fig. 2 Experimental examples of a blank sample. The measurement time was 30 minutes with the rotation speed of 3000 rpm.

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# CO8-2 Neutron Phase Imaging with Talbot-Lau Interferometer at CN-3

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**INTRODUCTION:**
Neutron phase imaging is a method which can directly access the phase information of the neutron wave function, and provide a higher sensitively to thinner objects than the conventional neutron imaging technique and a sensitivity of small structures in the sample, which can be analyzed by means of small-angle scattering technique. We have been developing neutron phase imaging technique with the Talbot-Lau interferometer consisting of three gratings [1, 2], that is, the most upstream absorption grating (G0), the middle phase grating (G1), and the most downstream absorption grating (G2). G0 works as a multi-slit and forms an array of spatially coherent line sources. Each source produces an interference pattern or a "moiré fringe" constructively through G1 grating and G2 grating. Based on the important characteristics of the Tal-bot-Lau interferometer such as availability for a relatively broad wavelength-range neutron beam and an adaptability to a low-coherent and low-intensity neutron beam, we have constructed a Talbot-Lau interferometry apparatus optimized to the KUR CN-3 port and conducted neutron phase imaging experiments.

**EXPERIMENTS:** For the neutron phase imaging experiments, three gratings optimized to the spectra of CN-3 beam port, the central wavelength was 2.4 Å, were fabricated. In addition, we have employed a new image detector system consisting of a CMOS camera and a LiF/ZnS scintillator screen. Using this new apparatus, we at first aligned all the gratings so as to maximize the visibility of moire pattern and then decided the fringe step condition. The fringe scan was conducted by moving G2 along horizontal axis, and one period of the grating was divided into 10 steps. The exposure time of one image was 10 sec and repeated by 5 times for each step. The samples used for the demonstration study were Fe-Si-Al magnetic alloy powder (average radius = 30 μm) and a mixture of powder and grains (average radius = 2 mm) filled in rectangular quartz cells. The samples were placed between G1 and G2 gratings.

**RESULTS:** Visibility image obtained without sample is shown in Fig. 1(a). There appeared a very strong visibility distribution ranging from 0.2 to 0.4 along horizontal axis. This is thought to come from the beam divergence due to the neutron guide tube installed in front of the G0 grating.
Fig.2 shows the results of sample measurements. The absorption image shown Fig.2 (a) indicated that the neutron transmission is high and there was very small difference between the powder and the mixture of powder and grains. On the other hand, the visibility image clearly displayed a contrast between them. This is the clear indication that visibility image obtained by the neutron phase imaging can distinguish micro-meter scale structure inside the object.

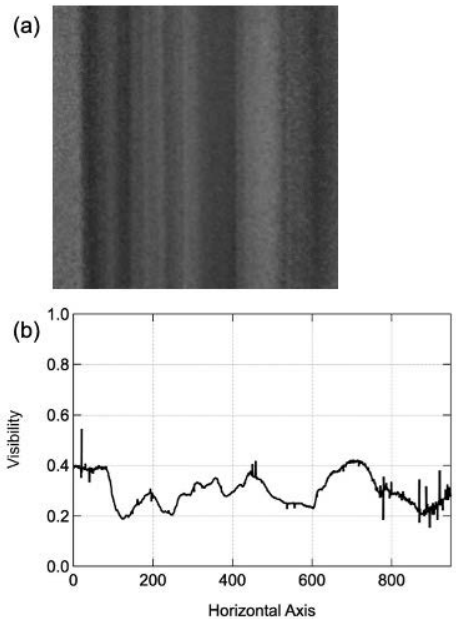


Fig. 1 Visibility of the direct beam. (a) Visibility image, (b) cross section profile along horizontal axis.

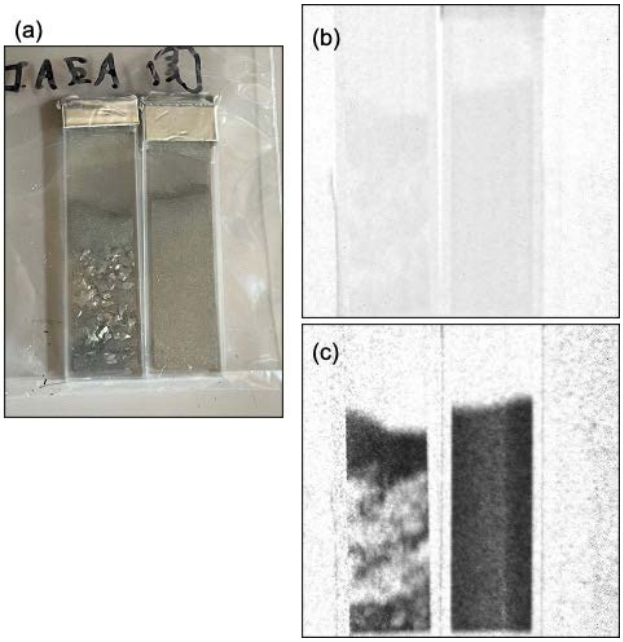


Fig. 2 Result of demonstration study using magnetic samples. (a) the photograph of the sample. (b) Absorption contrast image, (c) visibility image.

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# CO8-3 Neutron Resonance Spectrometry for Nuclear Security and Safeguards Education

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**INTRODUCTION:** In order to support nuclear facility regulations in Japan for safe use, it is necessary to develop educational training course with broad knowledge associated with nuclear engineering. Nuclear facilities include reprocessing, nuclear fuel factories, research facilities, etc. in addition to nuclear power plants, it is important to teach not only the knowledge of radiation, reactor physics, but also the physics of nuclear material itself at each stage of the nuclear fuel cycle. The knowledge of physical and chemical properties of nuclear material is also needed for effective regulation. As a part of this human resource development, we have proposed an isotope ratio measurement training program with uranium using pulsed neutron spectrometry as a candidate for the nuclear regulatory educational course to deepen the understanding of the nuclides in nuclear fuel cycle. Observation of the neutron resonance absorption phenomena of natural, enriched and depleted uranium will develop the understanding of the isotope itself and the properties of the nucleus of uranium. In this fiscal year, as the pandemic of Covid-19 limited our student to travel to Kyoto University, we attempted to establish an online experiment to acquire neutron resonance absorption spectra of various samples.

**EXPERIMENTS:** Metal plates of four different elements (Ag, Ta, Zr, Co) were irradiated at KURRI-LINAC to record neutron transmission spectrum. A $^{3}$He proportional counter followed by a multiple-stop time spectrometer (ORTEC EASY-MCS) was located just behind the sample at 13m experimental room and generated timing signal of neutron detection. A signal from the accelerator was used as the start signal of the time spectrometer. The timing calibration between start signal and output signal of the $^{3}$He proportional counter was performed with an oscilloscope by gamma-flash signal generated at the Ta target of the accelerator. Without and with Ta, Zr, Ag, Co plates was arranged at in front of the neutron irradiation port and time spectra of neutron transmission were recorded. Five students participated in the experiment over computer network by Zoom meeting software.

**RESULTS:** As shown in Fig. 1, a resonance dip of $^{109}$Ag was clearly observed in the time spectrum with the sample of silver plate (thickness: 0.05 mm) successfully, with measurement of 80,000 sweeps and 20 msec. range. The accelerometer was running at 50Hz with mode of 4 micro sec. per pulse. The time spectrum was recorded within about 27 minutes. The energy of this dip was estimated to be 5.3 eV derived from the source-detector distance of 12 m and dip position of 0.377 msec. The first energy level of $^{109}$Ag is 5.19 eV [1]. There is a good agreement between the experimental result and literature value. In Fig.2, time spectrum with Ta plate (thickness: 1 mm) were obtained. There were some resonance dips corresponding to $^{181}$Ta. We confirmed the dips corresponded to resonant absorption energies of 4.28 eV, 10.36 eV, 13.95eV, 20.29 eV and 22.72 eV [1]. Only two dips were observed for the resonance energies of 34.19 eV, 35.14 eV, 35.90 eV, because time resolution of our system was not enough to separate them. The screen of the PC acquiring these spectra was shared with online students through Zoom. The online students were able to observe the acquisition of neutron transmission spectra in real time. The experimental system and conditions were explained online with a video taken in the morning of the day when the experiment was carried out. Interviews with students after training showed that the content of the experiment could be understood online.

**CONCLUSION:** We proposed pulsed neutron spectrometry as a candidate for the nuclear regulatory educational course to deepen the understanding of the nuclides in nuclear fuel cycle and performed online training program. The results showed that online program was sufficient to understand the experiment. The next work is to establish the online program when the uranium is actually used as the measurement target and a larger number of students joint online at once.

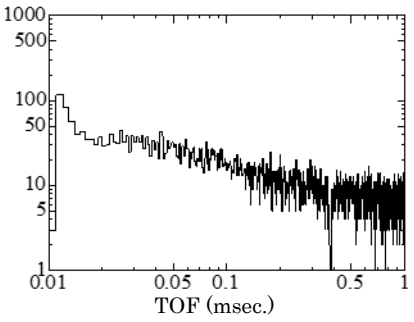


Fig. 1. ToF spectrum of Ag.

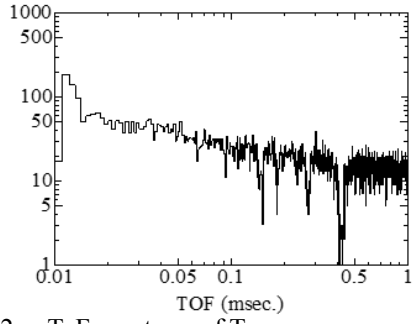


Fig. 2. ToF spectrum of Ta.

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# CO8-4 Coolant Visualization in the Accumulated Square Rod Arrays

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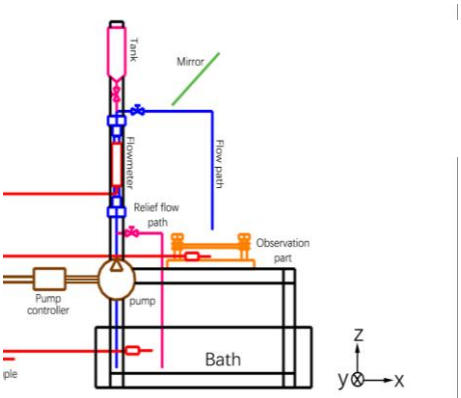
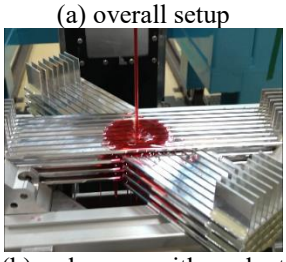
**INTRODUCTION:** Electric motors used in vehicles has been required to have high performance, more power, and compactness [1]. This results in the higher emission heat density from the motor package and the effective cooling scheme of the stator coil has been important. The actual vehicle stator coils are cooled by the coolant poured from a nozzle above. For the evaluation, the temperature measurement was carried out [2, 3]. However, the coolant profile inside the coil has not been clarified yet and the pouring conditions are decided empirically. In this study, therefore, the coolant profile inside the simplified stator system is studied by using the neutron radiography.

**EXPERIMENTS:** The schematic model of the experiment is shown in Fig.1(a). The stator coil is presumed by the accumulated square rod arrays shown in Fig.1(b) where the coolant is directly poured from above. Each square rod is made of aluminum and horizontally aligned with a gap of 1mm. This single layer is accumulated to four and bundled in the coolant circulation system consisted of a pump, flowmeter, temperature measurement devices, etc. The flow rate of the coolant is 0.5L/min. The neutron beam is in horizontal direction so does the coolant visualization. The experiment is carried out in the room temperature.




(a) overall setup



(b) rod arrays with coolant

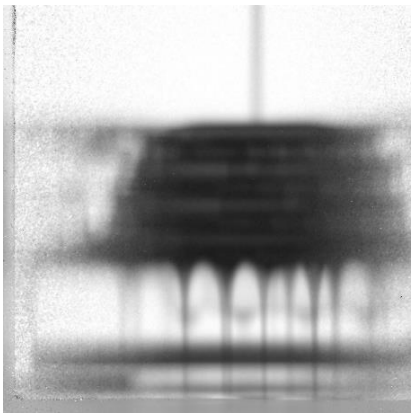
Fig. 1. Experimental setup.

**RESULTS:** First, for the evaluation, the visualization of the coolant between the two rods is carried out. The result is shown in Fig.2(a). As in the figure, the coolant can be visualized due to the large attenuation rate difference between the aluminum and coolant.

Next, the coolant in the accumulated rod arrays is visualized as shown in Fig.2(b). The coolant spreads in each array layer. It is found that the coolant in the below layer has larger area of coolant. This can be explained by the structure. At the top layer, the coolant can spread not only in the rod direction but also the spanwise direction due to the viscosity and the wettability of the coolant. The coolant escapes down and hit the lower layer. The coolant can spread in the same manner. Each array is accumulated with an angle. This suggests that the coolant is partially sandwiched by the above and below rods. This may induce the capillary effect and the horizontal spreading is enhanced. This is repeated as the coolant goes lower layer, resulting in the wider spread as it goes down.



(a) Between two horizontal aluminum rods.



(b) Inside the accumulated rod arrays

Fig. 2. Visualized coolant.

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