CO8-1 Demonstration experiment of nuclear material detection using a low-cost assay system

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INTRODUCTION: 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. In this method, a neutron source is rotated at a speed of thousands of rpm nearby a measurement object. Meanwhile, it is possible to detect nuclear materials by confirming the deformation of the time-distribution spectrum obtained by a neutron detector near the object. The machine to rotate the neutron source is quite compact that its width, depth, and height is approximately 60 cm each. In the previous studies, we have accomplished following two objectives. One is that this new method was verified with a neutron detector bank composed of He-3 proportional counters. Another is that a low-cost assay system setup was completed with the rotation machine and water Cherenkov detector. The water Cherenkov detector is much lower in cost than He-3 counters. The purpose of this year was to detect nuclear materials by using the low-cost assay system in KUCA.

EXPERIMENTS: Figure 1 shows the experimental setup of the low-cost assay system and a measurement object. The water Cherenkov detector basically consists of four PMTs (Photomultiplier tube) and an aquarium (30x25x30cm). The back of the aquarium is covered with PTFE diffuse reflective sheets.
Black sheet and boron sheet are covered with the surface in order to prevent light and thermal neutrons. The aquarium is filled with the gadolinium aqueous solution of approximately 0.5wt%. The gadolinium was added in order to increase the amount of the Cherenkov light. To detect more Cherenkov light emission, a wavelength converter is added. Since high energy gamma ray also causes the Cherenkov light in water, we discriminate neutron signal by pulse height difference. A measurement object is put between the aquarium and the rotation machine. In this experiment, we used approximately 60 g of U-235 surrounded by polyethylene blocks. Measurements of the neutron time distribution were performed by a multi-channel scaler (MCS) that is synchronized with the disc rotation. The rotation machine can rotate a neutron source at a rotation speed between 0 and 4000 rpm. The neutron source was installed at the outer periphery of the disc of 32 cm diameter.

RESULTS: Figure 2 shows an example of experimental results of a sample including uranium when the rotation speed is 3000 rpm. The left edge near 6000 micro seconds is higher than the right edge near 11000 micro seconds due to the geometric condition. Comparing the deformation of the time-distribution spectrum at 3000 rpm with that at 600 rpm, it was observed that the integrated value after the center, which is near 9000 micro-seconds, increased while the integrated value did not increase in the case not containing nuclear materials. We have confirmed detecting nuclear material by using the low-cost assay system composed of the rotation machine and water Cherenkov detector.

Fig. 1 Arrangement of the assay system: The water Cherenkov detector (left), measurement object containing uranium (middle) and the rotation machine (right).

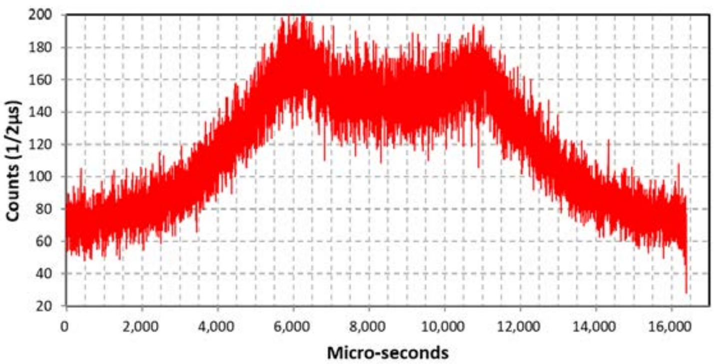

Fig. 2 Neutron events distribution of the uranium sample. The measurement time was 15 minutes with the rotation speed of 3000 rpm.

CO8-2 Neutron efficiency of a GEM-based detector

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INTRODUCTION: A two-dimensional neutron detector with a gas electron multiplier (GEM) has been developed [1]. The GEM-based detector is called "nGEM" [2]. The nGEM is a gas-flow radiation detector having a 7:3 gas mixture of Ar and CO_2. It has a compact body (52 × 25 × 5 cm) that includes a gas chamber and onboard electronics. In the onboard electronics, an application-specific integrated circuit for pulse shaping and a field-programmable gate array for online processing are also installed. The measurement data are transferred directly to a computer through a network. The data transfer capability is limited by the Gigabit Ethernet. The hit information, such as time of flight (TOF), hit position, and pulse width, is included in the 8-byte data format. The active area is 100 × 100 mm. For neutron detection, nGEM can be used to measure the number of charged particles originating from the n(^{10}B, α)^{7}Li nuclear reaction. The thermal neutron efficiency of nGEM depends on the thickness of the enriched-boron layer on cathode aluminum plate. The thermal neutron efficiency simulated by Geant4 [3] is shown in Figure 1. The maximum neutron efficiency is expected to be approximately 5% with a 2–3-μm-thick ^{10}B layer. Above the thicker layer region, the charged particles cannot come out from the ^{10}B layer because the particles from the n(^{10}B, α)^{7}Li nuclear reaction have a shorter range. Therefore, the thermal neutron efficiency decreases. In the thinner layer region, because it is difficult to control the layer thickness, the film formation accuracy becomes worse. To perform absolute measurements in some neutron experiments, neutron detectors must first evaluate the neutron efficiencies. In this article, the experimental results of neutron efficiency for nGEM are described. The neutron irradiation test was carried out using CN-3 [4] at the Kyoto University Reactor (KUR).

EXPERIMENTS AND RESULTS: The neutron efficiency of nGEM was studied through a comparison with the measurement data of helium-3 proportional counter (^{3}He-PC). ^{3}He-PC covered with B_4C resin shield was used to measure the TOF. The counter had a gas mixture of ^{3}He and CO_2 (99:1), and the total pressure was 1003.19 kPa. The counter was cylindrical with a 1-inch diameter. The opening area of the B_4C resin shield was 10 × 10 mm. A disk chopper was operated at 30 Hz to obtain the neutron wavelength dependence. Neutrons from 1.5 to 6 Å passed through the disk chopper. The ^{3}He-PC was set downstream at a distance of 2.154 m from the disk chopper. After the operation condition of the ^{3}He-PC was defined, the beam center was scanned using CN-3. The relationship between the TOF and detector position was measured by moving the detector position. The neutron intensity in CN-3 was derived from the measurement data of the ^{3}He-PN with the absorption correction of the SUS detector housing. After the estimation of the absorption correction with Geant4, the measurement data were converted to the neutron intensity. The expected neutron intensity at CN-3 with a KUR beam power of 5 MW was approximately 2016.1 ± 1.4 neutrons/s·cm^2. Furthermore, the counting rate of nGEM was measured by replacing ^{3}He-PC.

The neutron efficiency is defined as the ratio of the nGEM counting rate and the expected neutron intensity in CN-3. The neutron efficiency of nGEM is shown in Figure 2. The results show that the nGEM has a thermal neutron efficiency of approximately 0.3%. The Geant4 simulation result with a 0.07-μm-thick ^{10}B layer is indicated as a blue line in the aforementioned figure. Because the measurement data are consistent with the simulation result, it can be concluded that the ^{10}B layer thickness is close to 0.07 μm.

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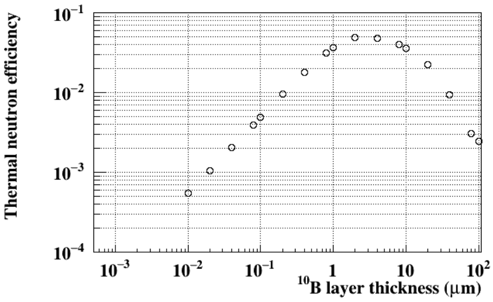

Figure 1. Thermal neutron efficiency with Geant4.

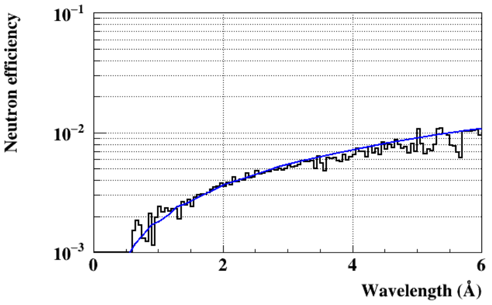

Figure 2. Neutron efficiency of nGEM.

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CO8-3 Establichment of a novel mutation breeding using Boron Neutron Capture Reaction (BNCR)

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INTRODUCTION: Boron Neutron Capture Reaction (BNCR) is based on the nuclear reaction of ^{10}B atom with thermal/epithermal neutron already applied to cancer treatment (BNCT) [1, 2]. As a new utilization method of BNCR, the purpose of this study is to establish a novel mutation breeding using BNCR.

The method attempts to mutagenesis by immersing plant seeds in a ^{10}B-enriched boron compound, re-drying, and then irradiating the seeds with thermal neutrons to induce BNCR. Its mutagenic effect depends on chemical and physical factors such as ^{10}B concentration, thermal neutron intensity, and irradiation time. In previous experiments, rice seeds were treated with ^{10}B-enriched *p*-boronophenylalanine (BPA) [3] or BPA-fructose complexes (BPA-Fc) at concentrations of 10-1000 ppm for 16, 24, or 48 hours, irradiated with thermal neutrons, and then examined for germination rate to evaluate mutagenicity. As a result, no decrease in germination rate was observed under these conditions; considering the solubility of BPA, 1000 ppm is considered to be the upper limit, and as for the immersion time, no relationship with BNCR was observed for the 48h treatment, and simply the immersion time decreased the germination rate, indicating that 48h or longer is not appropriate. In other words, it was difficult to achieve a stronger treatment with BPA. In order to investigate a stronger treatment method that would confirm a decrease in germination rate, the experiment was conducted this time by changing the boron compound used to ^{10}B-enriched boric acid ($H_3{}^{10}BO_3$).

EXPERIMENTS: The experimental material used *Oryza sativa* L. cv. Nipponbare. The dry seeds were immersed into different concentrations (0, 1, 10, 50, 100 mM) of ^{10}B-enriched boric acid for 24 h and 100mM $H_3{}^{10}BO_3$ for 36 h. Solvent was PBS buffer. The samples were washed with water and re-dried. The seeds in 6-mL tubes were irradiated with thermal neutron for 90 minutes in the Kyoto University Research Reactor (KUR). The irradiated seeds were sown in cell trays on May 13, 2021, germinated in a germination machine, grown outdoors, and the germination and survival rate was examined 14 and 21 days after sowing. As a control experiment, seeds that were only treated with $H_3{}^{10}BO_3$ immersing and not irradiated with thermal neutrons were sown on petri-dishes with continual moistening of filter paper to check germination rate after 7 days.

RESULTS: Germination rate decreased in a $H_3{}^{10}BO_3$ concentration-dependent manner (Fig. 1). This concentration-dependent decrease in germination rate was not observed in seeds that were not irradiated with thermal neutrons, suggesting that it was not due to immersion in $H_3{}^{10}BO_3$ solution, but rather to BNCR. As mentioned above, no reduction in germination rate was observed in previous experiments using BPA, so it is assumed that this result is due to differences in ^{10}B uptake in plant seeds caused by differences in boric acid compounds. This is an interesting finding regarding the uptake of boron by plant seeds. Based on the results of this study, the germination and survival rates of the 10B boric acid treatment were less than 50% after 24h treatment at 50 ppm, suggesting that 24h and 10 ppm is the most efficient treatment for mutagenesis. In the future, we would like to confirm the phenotype of M_1 and M_2 generations, evaluate the mutation spectrum, and conduct genetic analysis to discover the effectiveness of this method as mutation breeding.

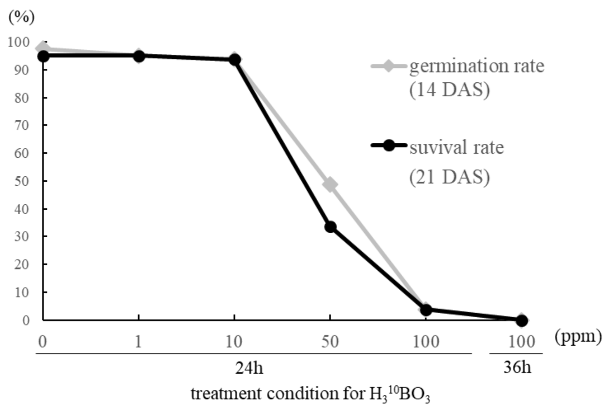

Fig.1 Relationship between treatment conditions and germination and survival rates.
*DAS : day after sowing

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