Demonstration experiment of detecting the HEU sample covered with lead using a neutron rotation machine and water Cherenkov neutron detector

M. Komeda[1], K. Tanabe[2], Y. Toh[1], Y. Kitamura[3] and T. Misawa[3]

[1]*Nuclear Science and Engineering Center, Japan Atomic Energy Agency*
[2]*National Research Institute of Police Science*
[3]*Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: A compact (transportable) and low-cost non-destructive inspection system to detect hidden nuclear material is required in the fields of nuclear security. We developed a new nuclear material detection method, called the active rotation method, using a neutron rotation machine that rotates a neutron source like Californium-252 at a speed of thousands of rpm. In addition to the rotation machine, we developed a water Cherenkov neutron detector (WCND) as a low-cost neutron detector. The system for detecting nuclear materials can be composed with the neutron rotation machine and WCND, leading to a compact and low-cost. In previous studies, we accomplished to detect a few grams of high enriched uranium (HEU) using the system. Incidentally, gamma ray measurements are common for detecting nuclear materials due to its ease of measurement. However, it is easy to shield gamma rays from HEU with thin lead plates since those gamma rays are low energy. The purpose of this year is to detect the HEU covered with lead plates that cannot be detected by a gamma ray detector.

EXPERIMENTS: The HEU is surrounded by lead plates, and covered polyethylene blocks around it. The experimental setup is shown in Fig.1. Note that the lead plates inside the polyethylene blocks are visible, but in the experiment, they are covered with the entire blocks and inside is not visible. The dimensions of the neutron rotation machine are approximately 60cm in width, depth, and height. The rotation machine can rotate the disk (diameter 32cm), where a neutron source is installed at its outer periphery, at a rotation speed between 0 and 4000 rpm. A neutron source of Californium-252 is set in the disk, the radioactivity was 2.2 MBq. In this experiment, we used approximately 4 g of HEU. The WCND basically consists of an aquarium (30x25x30cm), four PMTs (Photomultiplier tube) and boron rubber. The PMT diameter is 2 inches. The boron rubber is attached on the surface of the aquarium to prevent thermal neutrons from entering. The neutron time distributions were measured by a multi-channel scaler (MCS) that was synchronized with the disc rotation signal from the servomotor.

RESULTS: It was confirmed that low-energy gamma rays generated from HEU were effectively blocked by lead plates by measurements using a Ge detector. We successfully detected its HEU shielded with lead plates using a neutron rotation machine and WCND. Then, we estimated whether the object included the nuclear material by a comparison between the time-distribution spectra at 4000 rpm and 300 rpm. The measurement time for each speed was 10 minutes. Figure 2 shows an example of measurement result (time-distribution spectrum) at the rotation speed of 4000 rpm. As a next step for our study, we are going to work on detecting unevenly distributed nuclear materials inside the container.

Fig. 1 The rotation machine (left), the water Cherenkov detector (right), and measurement object (middle). The center part of the object is HEU covered with lead plates.

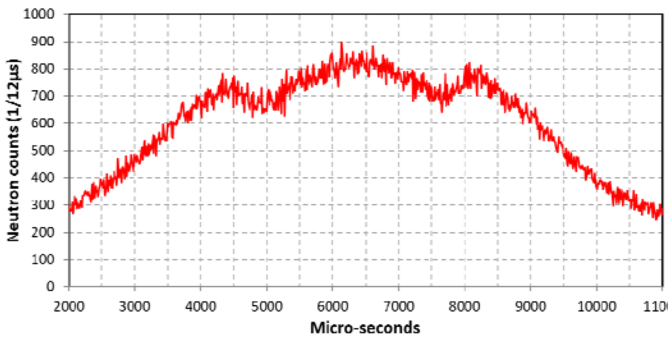

Fig. 2 Neutron events distribution in the case of HEU covered with lead plates. The measurement time was 10 minutes with the rotation speed of 4000 rpm.

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Establishment of a novel mutation breeding using Boron Neutron Capture Reaction (BNCR)

M. Kirihata, S. Segami[1], Y. Hattori, T. Kinouchi[2], Y. Kinashi[2]

Research Center of BNCT, Osaka Prefecture University
[1]Research Institute of Environment, Agriculture and Fisheries, Osaka Prefecture
[2]Research Reactor Institute, Kyoto University

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). As a new utilization method of BNCR, this study aims to establish a novel mutation breeding using BNCR. The method attempts 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. Previously, we tested ^{10}B-enriched boric acid ($H_3{}^{10}BO_3$), ^{10}B-enriched *p*-boronophenylalanine (BPA), and mercaptododecaborate (BSH) as boron compounds for treating rice seeds. In this report, two new experiments were performed. The first was the experiment using C12-BSH. This compound introduced an alkyl chain on the thiol group of BSH to enhance the hydrophobicity, which has a higher internalization amount than BSH into cells in animal cells. The second evaluated the effects of $H_3{}^{10}BO_3$ treatments at low concentrations below 10 mM.

EXPERIMENTS: The experimental material used *Oryza sativa* L. cv. Nipponbare. The dry seeds were immersed into different boron concentrations (0, 10, 100, 1000, 2000 ppm) of ^{10}B-enriched C12-BSH and 0, 0.5, 1, 2.5, 5, 7.5, 10 mM $H_3{}^{10}BO_3$ for 24 h. The solvents were distilled water and PBS buffer for C12-BSH and $H_3{}^{10}BO_3$, respectively. The samples were washed with water and re-dried. The seeds in 6-mL tubes were irradiated with thermal neutron for 90 minutes. After the irradiation treatment, the seeds were cultured in Petri dishes with continual moistening of filter paper at 25℃ under a photoperiod of 16 h light and 8 h dark. The germination rate was examined 7 days after sowing (DAS) and growth 14 DAS. As a control experiment, seeds only treated with $H_3{}^{10}BO_3$ soaking and not irradiated with thermal neutrons were sown using the same method, and germination rates were investigated.

Fig.1 Comparison of growth 14DAS
Left：Control (10 mM $H_3{}^{10}BO_3$ treatment and no irradiation)
Right：10 mM $H_3{}^{10}BO_3$ treatment and irradiation

RESULTS: The C12-BSH treatment did not decrease the germination rate and growth in any of the concentrations. This result is similar to the result of the BSH treatment, and it is not clear at this time whether it is not taken up by seeds, whether there is no difference in the internalization amount into cells in the plant cells, or whether the selective uptake has no effect on the germination rate. For the $H_3{}^{10}BO_3$ experiment, the germination rate at 7 DAS was not decreased in any concentrations. On the other hand, at 14 DAS, no effects were observed at 5mM or less on growth, but shoot length and root volume varied at 7.5 mM treatment, and shoot less than 1 cm and no rooting were observed in all individuals at 10 mM treatment, indicating a strong effect of BNCR (Fig.1). These effects and the decreased germination rate at higher concentrations were not seen without neutron irradiation at the same concentration of immersion treatment, suggesting that BNCR caused it. The germination rate was consistent with previous results over a wide range of treatments and did not decrease with treatments below 10 mM. However, this observation confirmed that treatments above 7.5 mM affected growth. For mutagenesis, 10 mM treatment, where severe effects on growth are observed, should be avoided, and 7.5 mM or less is considered preferred.