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Reactor Physics Experiment Programs for Students at Kyoto University Critical Assembly

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1. Introduction

A critical assembly is a nuclear facility for conducting mock-up and benchmark experiments in the field of nuclear reactor physics field. It is also one of the most effective facilities for the education related to nuclear engineering and technology, especially that students and engineers grasp the basic concepts of nuclear reactors by conducting experiments on and operating the reactor in person. Current computation technology of reactor simulator systems for reactor operation has made rapid progress, and most reactor operators at nuclear power stations have been trained through simulators, all of which contribute to safe operation of reactors. It follows, therefore, that for the education of students majoring in nuclear engineering, conducting experiments on actual reactors is a prerequisite to understanding the reactor itself. Furthermore, experiments on a critical assembly provide students and engineers valuable opportunities to appreciated safety regulations related to reactor facilities and the handling of nuclear materials.

The joint reactor-laboratory course[1]-[3] for Japanese students at the Kyoto University Critical Assembly (KUCA) was launched in 1975 and various experiments on reactor physics have been conducted since: approach to criticality, control rod calibration, measurement of neutron flux and power calibration, subcriticality measurements by the Feynman-α and the pulsed neutron methods, and instruction in reactor operation. These experiments were conducted in the KUCA C-core, which is a water-moderated- and -reflected-core with a plate-type fuel consisted of highly-enriched uranium and aluminum (Al) alloy. Until fiscal year 2014, over three thousand and six hundred undergraduate and graduate students (3,630) all over Japan attended this course as shown in **Table I**. The same course for Korean undergraduate students in the Kyoto University Critical Assembly (KUGSiKUCA) program was launched from 2003 to 2009 and founded by the Korean government. In addition to the Swedish students ranging between 2007 and 2009, the International Reactor Physics Experiment (IRPE) program was launched newly in 2012 for graduate students in Korea and China. From 2003 to 2015, a total of two hundred and thirty foreign students in overseas, including Korea, Sweden and China, took part in this program.

For the foreign students, in April 2010, Kyoto University Press published a textbook in English,[4] which was transcribed from the Japanese course work[5] comprising lectures, experiments, discussions and reports that had been prepared from English textbooks on nuclear reactor physics. Preceding that publication, a textbook translated into Korean[6] was published from Dongguk University in Korea on March 2010.

Table I. Number of participants in reactor physics programs for students at KUCA from 1975 to 2014

Country	Japan	Korea	Sweden	China	Total
# of students	3,630	179	42	9	3,860

2. KUCA Facility

KUCA (**Figure 1** and **Table II**), a multi-core-type critical assembly established in 1974 as a facility for joint studies on reactor physics by researchers at all universities in Japan, comprises three independent cores: A, B and C (**Figure 2**). Solid polyethylene and graphite moderators are used in the A- and B-cores, whereas a light-water one in the C-core. In KUCA, however, only one core can attain critical state at a time because the assembly is equipped with a single control mechanism.

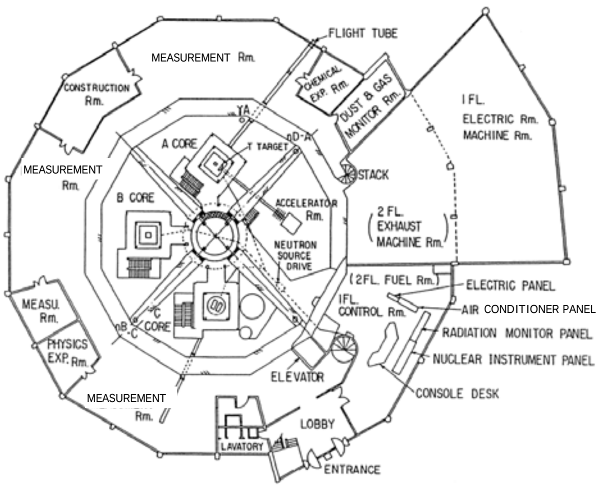
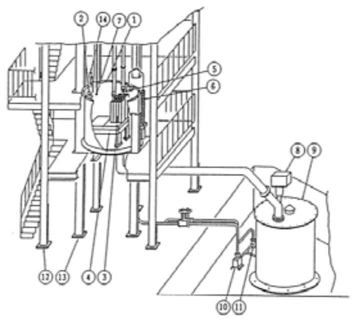


Fig. 1. Horizontal cross section of the KUCA building

There are two types of highly-enriched uranium fuels; a coupon-type fuel plate 2” square and 1/16” thick with a thin metallic coating for the A- and B-cores; a plate-type one 60×600 mm and 1.5 mm thick with aluminum (Al) cladding 0.5 mm thick for the C-core. Moreover, the C-core has two types (highly- and intermediate-enriched) 650 mm long and 1.4 mm thick with Al cladding of 0.45 mm thick, with thirty-two kinds of different curvatures and widths.

In the A- and B-cores, a fuel element or a reflector element is assembled by piling up plates of various materials, 2" square and various thicknesses, in an Al sheath 55.3 mm square (inner dimension), 1.5 mm thick and approximately 1,500 mm high. These elements are arranged vertically on a grid plate to construct the critical assembly. Various neutron spectra are attained by changing (1) the combination of fuel and moderator plates in the fuel element and (2) the thickness of the moderator plate and the number of fuel plates in the unit cell of the fuel region. Reactor physics studies on thorium-loaded cores, criticality safety, tight pitch lattice cores, and such, have been carried out in these cores.



1. Core tank
2. Handle for the core separation mechanism
3. Core assembly
4. Core separation mechanism
5. Float switch to detect the core overflow
6. Overflow tube
7. Water level switch
8. Dump valve
9. Dump tank
10. High-flow fee pump
11. Low-flow feed pump
12. Supporting structure of the scaffold
13. Supporting structure of the core tank
14. Water feed tank for precision control

Fig. 2. Overall structure of the KUCA light-water-moderated core (C-core)

Table II. Specification of A, B and C cores in KUCA

Core	Moderator (Reflector)	Fuel	SCRAM	Attached
A	Poly. (C, Al, Fe, Be, Pb, Pb-Bi)	Coupon (HEU, LEU & Th)	Center core drop	14 MeV-n 100 MeV-p
B	Poly. (C, Al, Fe, Be, Pb, Pb-Bi)	Coupon (HEU, LEU & Th)	Center core drop	-
C	H_2O (D_2O)	Plate (HEU & MEU)	Water dump	-

Poly.: polyethylene, Th: thorium, n: neutrons, p: protons

Fuel plates of three pitches are set in the C-core to change the neutron spectrum in the core region. A fuel element is assembled by inserting fuel plates one by one vertically between two Al side plates of a fuel frame along grooves approximately 3.0, 3.5 and 4.5 mm pitch. The fuel elements are arranged on a grid plate in an Al core tank; light water is pumped up into the core tank to set up a critical assembly. Reactor physics studies on coupled-cores, research reactor cores of reduced enrichment uranium fuel, criticality safety, and safety features of reactor core, and such, have been conducted in the C-core. The core has been used in the education courses, since the handling of plate-type fuel with Al cladding is easier and safer than that of coupon-type fuel with metallic coating.

3. Reactor Physics Experiments

3.1 Approach to criticality

Approach to criticality is the most fundamental procedure in nuclear reactor experiments. Preparation and adjustment of the critical assembly as an experimental apparatus are completed by the approach to criticality. When a reactor is first loaded with fuel, the amount of fuel needed to make the reactor critical is not very accurately. Prediction of critical mass through neutronic calculations based on the theory of reactor physics is requisite for safely loading the fuel. The physical characteristics of a nuclear reactor as well as the validity of calculation methods and nuclear data used should also be well understood through a comparison between the predicted and the measured critical mass. The reactor is controlled by three control rods, which are installed in addition to three safety rods. Three fission chambers and three uncompensated ionization chambers are used for nuclear instrumentation.

3.2 Control rod calibration

Determination of various reactivity effects in nuclear reactors is usually conducted by compensating the given reactivity with control rods to maintain the critical state. Calibration of control rods (determination of reactivity worth per unit movement of control rod) is thus essential when they are used as reactivity standards to measure the reactivity changes caused by other perturbation in the reactor. With control rod calibration data (also important for the reactor operation), the operator estimates the reactivity caused by control rod movement and operates the reactor safely. Furthermore, determination of excess reactivity and the shut-down margin of a reactor is one of the strictest requirements for safe reactor operation. Thus, calibration of the control rods of newly built core is the most crucial task to be accomplished immediately after the approach to criticality and before conducting the other experiments.

3.3 Measurement of reaction rates

When a thermal reactor is operated at constant power, its thermal neutron flux forms a unique distribution that is determined by reactor characteristics. Since the magnitude of this flux distribution is proportional to the reactor power, the latter is determined by measuring the relative flux distribution (**Figure 3**) in the reactor and the absolute flux level at a certain location in the reactor core. Compared with the neutron detectors comprising ionization chambers and fission chambers, activation detectors that detect the neutrons through saturated activity are insensitive to γ-ray and are used in locations where other detectors could not be used because of their large size.

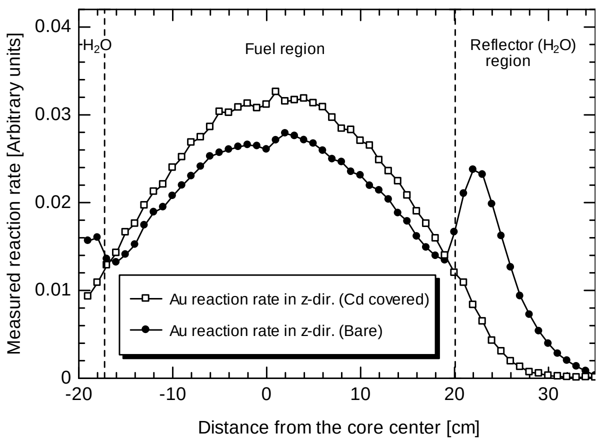


Fig. 3. Measured ^{197}Au reaction rates in z-direction

4. Concluding Remarks

The reactor laboratory course for graduate and undergraduate students has been successfully conducted at KUCA in Japan. A total number of 3,860 students both in domestic and overseas majoring in nuclear engineering have taken part in the course from 1975 to 2014. Especially, the courses of foreign students in Korea, Sweden and China were a big challenge for the KUCA side; nonetheless, fruitful accomplishments and valuable experiences were gained in terms of experimental nuclear education and international collaboration, for both students and professors from Korea, Sweden, China and Japan. Based on these experiences, future reactor laboratory courses could be initiated for students from other countries for international promotion of reactor physics education and international collaboration programs with KURRI. In conclusion, the course was highly conducive to the development of personal friendships among foreign students during their stay at KUCA. Many of the students who joined the course are engaged in the nuclear engineering field in Korea, Sweden, China and Japan have studied the nuclear engineering overseas, and have pursued their professional careers in government, industry and at educational research institutes.

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