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Measurements of the Isothermal Temperature Reactivity Coefficient of KUCA C-Core with a D_2O Tank

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1. Introduction

The Kyoto University Critical Assembly (KUCA) [1] is a multi-core type critical assembly consisting of three independent cores in the Kyoto University Research Reactor Institute. The light-water-moderated core (C-core) is a tank type reactor, and the experiments of the isothermal temperature reactivity coefficient (ITRC) of C-core with a D_2O tank were carried out with the use of six 10 kW heaters and a radiator system in a dump tank, one 10 kW heater in a core tank, and one 5 kW heater in the D_2O tank.

The ITRCs of the C-core with the D_2O tank immersed in the core tank are considered important to investigate the mechanism of moderation and reflection effects of H_2O and D_2O in the core on the evaluation by numerical simulations. The objectives of this paper are to report the ITRC measurements for C-core with D_2O tank ranging between 26.7℃ and 58.5℃, and to examine the accuracy of the numerical simulations by the Seoul National University Monte Carlo code, McCARD [2], through the comparison between measured and calculated results.

2. Description of Experiments

2.1 Core Configuration

Grid plates are located in the core tank of diameter and depth of 2,000 mm to place fuel frames, control and safety rods, and detectors. Fuel plates each of which length, width, and thickness are 600 mm, 62 mm, and 1.5 mm, respectively, are inserted in the fuel frames corresponding to the critical mass. In the fuel plate, a fuel meat made of the 93%-enriched U-Al alloy fuel is cladded with two aluminum layers of thickness of 0.5mm.

The experiments were conducted in the core configuration of C35R80D2O as shown in Fig. 1 where a square grid size is 71mm and two grid plates are separated by 26.2mm to place the D_2O tank. The maximum number of fuel plates to be inserted in the C35 fuel frame type is 40 with the coolant thickness of 1.99mm. The D_2O tank made of aluminum is 420mm wide, 820mm long and 1120mm high. The purity of heavy water is 99.5%.

In the experiments, the total number of fuel plates in the core was set to 384 with 40 plates for each of the frame 3501~3508 and 16 plates for each of the frame 3509~3512.

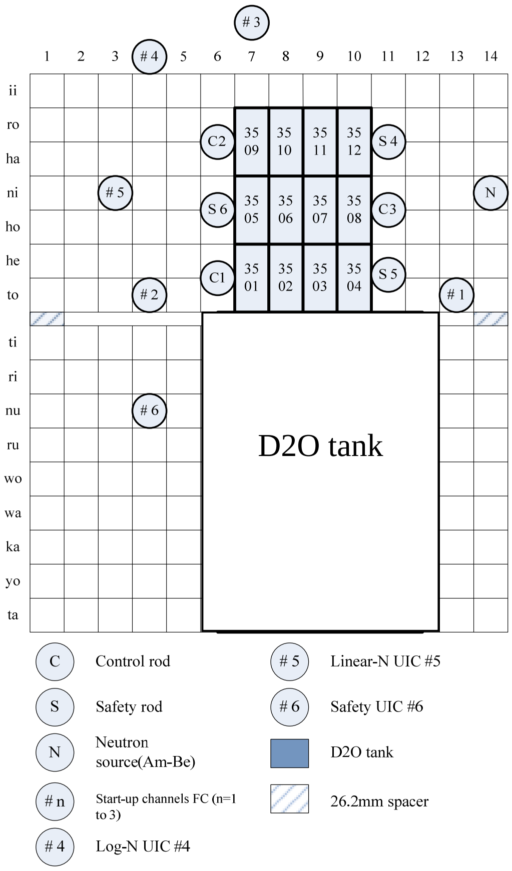

Fig. 1. Configuration of C35R80D2O core

2.2 Procedure of Experiments

The experiments were conducted in the power-level less than 0.01W so that the fuel and cladding temperatures are considered to be identical to the light water coolant temperature. The temperatures of light water in the core tank were measured by two thermometers located at 630mm and 1438mm from the bottom of the tank and those of heavy water in the D_2O tank were measured for center and upper positions.

The desired temperature of light water was achieved in the dump tank with the use of the heaters or radiator, and the heated or cool-downed water was fed into the core tank. The criticalities were adjusted by the C3 rod in the condition that the other control rods and all the safety rods were withdrawn to the upper limit by changing the system temperature as shown in Table 1. From the tendency shown in Table 1, the maximum difference of the regional temperatures was found within 0.8℃.

Table 1. Measured temperatures (℃) of the criticality experiments

Case	CT 5[a)]	CT 6[a)]	DT center[b)]	DT upper[b)]
27	26.7	26.7	27.3	27.5
38	38.1	38.1	38.0	38.0
40	40.1	40.2	39.9	40.2
45	44.9	45.0	44.9	45.1
50	50.4	50.4	50.1	50.3
55	55.2	55.1	54.6	54.8
58	58.5	58.4	58.2	58.6

a) The CT 5 and 6 are the light water temperatures of lower and upper positions, respectively, of the core tank.

b) The DT center and upper are temperatures of the heavy water in the D_2O tank.

The reactivity worth of the inserted C3 rod was measured by withdrawing the rod and timing the reactor period. From the inhour equation, the excess reactivity ρ_{ex} corresponding to the measured reactor period P can be calculated by

$$\rho_{\text{ex}} = \frac{\ell}{P+\ell} + \frac{P}{P+\ell}\sum_{i=1}^{6}\frac{\beta_{i,eff}}{1+\lambda_i P}\,. \tag{1}$$

ℓ is the prompt neutron life time. $\beta_{i,eff}$ and λ_i are the delayed neutron fraction and the decay constant, respectively, of the ***i***-th group delayed neutron precursor.

Then from the excess reactivities measured at the different temperatures T_1 and T_2, the ITRC at the mid-temperature point, α_{iso}, can be directly calculated by

$$\alpha_{\text{iso}}\left(\frac{T_1+T_2}{2}\right) \cong \frac{\rho_{ex}(T_2)-\rho_{ex}(T_1)}{T_2-T_1}\,. \tag{2}$$

To enhance the smoothness of the ITRC estimations, the excess reactivity can be fitted to a quadratic curve [3,4]:

$$\rho_{\text{ex}}(T) \cong aT^2 + bT + c\,, \tag{3}$$

where a, b, and c are constants. Then α_{iso} can be determined by

$$\alpha_{\text{iso}}(T) \cong 2aT + b\,. \tag{4}$$

3. Experimental and Numerical Results

Table 2 and Figure 2 show the measured excess reactivities in the seven temperature cases of Table 1 and the fitting constants of Eq. (3). From the results in Table 2, the measurements are observed fairly well fitted by the quadratic polynomial of Eq. (3).

For the cases 27 and 58, the McCARD eigenvalue calculations were executed with the use of 200 active cycles on 100,000 histories per cycle and the continuous cross section libraries processed from the ENDF/B-VII.1 nuclear libraries. From the two McCARD results, the ITRC was estimated by Eq. (2), and Figure 3 reveals the comparison between the results in the measured and calculated α_{iso}. From Fig. 3, the ITRC estimated by McCARD is observed to get in good agreement with the measurements.

Table 2. Temperature dependent excess reactivities

Case	C3 Position[a)]	ρ_{ex}	Fitting const.
27	345.15	330.0	a=-1.929×10^{-1}, b= 6.323×10^{0}, c= 2.979×10^{2}
38	377.33	255.7	
40	389.31	242.6	
45	420.50	191.1	
50	461.20	129.7	
55	516.17	60.7	
58	-	6.9	

a) The withdrawal length (mm) of the control rod from the grid plate

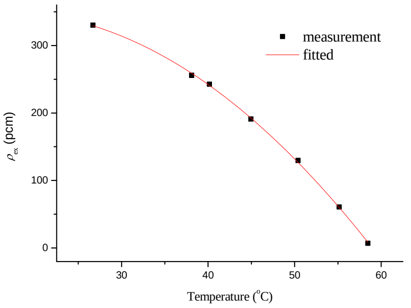

Fig. 2. Temperature effects on the excess reactivities

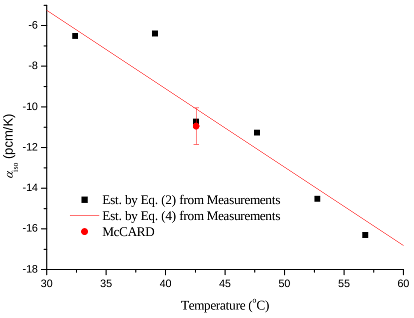

Fig. 3. Calculated and Measured temperature coefficients

4. Conclusions

The temperature reactivity coefficient is one of the most important safety parameters of nuclear reactors. The ITRC measurements in the KUCA C-core with D_2O tank could be utilized for the validations of nuclear system design and analysis codes.

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