Experiment of Feynman-alpha Method in AGN-201K

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1. Introduction

Measurement of criticality of the reactor has been a prime interest because there is no proper way of measuring sub-criticality. During power operation state, the critical state can be determined by observing the steady state. However, depth of sub-critical state can not be measureable with excore neutron detectors. Usually addition of soluble boron is done to provide sufficient negative reactivity for a newly loaded reactor core. Accurate sub-criticality measurement of the reactor can reduce over-conservatism and provide economic benefits. For the last decades, several methods have been studied for the measurement of the sub-criticality. In this paper, conventional noise analysis methods were tested to a zero power reactor.

In this study, noise analysis method was applied to AGN-201K research reactor of Kyung Hee University. Sub-criticality states were determined by the Feynman-alpha method. For comparative verification, we used the known control rod worth curve to estimate the sub-criticality.

2. Reactor AGN-201K

AGN-201K reactor is very safe reactor because of the very low excess reactivity and strong negative temperature feedback coefficient. The reactor core tank is sealed with the aluminum of 2mm thickness to keep the fission gas and its diameter is 32.2cm, height is 76cm. The reactor core is surrounded by the reflector of the high-density graphite with 20cm thickness. The gamma shield surrounding the reflector is the lead of 10cm thickness.

The reactor tank is comprised of core tank, reflector, lead shielding, control rod, Glory-Hole, Access Ports. There is the movable thermal column on the top of the reactor tank and reactor tank is surrounded by the light waters (about 1,000 gallon) of 55cm thickness except bottom part.

There are a total of six detectors in the reactor. It has 3 He-3 detectors, 3 BF3 ionization chambers, and 1 Fission chamber. Experiments were conducted using a BF3 ionization chamber, one of the portable detectors.

The AGN-201K is a small reactor with a total height of 280 cm and a diameter of 198 cm. Because of its small size, there is a lot of noise being measured on the detector. In this study, the Feynman-alpha method, one of the noise analysis methods to be applied, is highly worthy of experimentation.

3. Experiment with Feynman-alpha Method

3.1. .Feynman-alpha Method

This methodology was proposed by Feynman in 1956. The significant equation can be represented as [1],[2]:

$$\frac{\overline{Z^2}-\bar{z}^2}{z} \cong 1+\frac{\varepsilon D_v(1-\beta)^2}{(\beta-\rho)^2}\left[1-\frac{1-e^{-\alpha t}}{\alpha t}\right] = 1+a\left[1-\frac{1-e^{-\alpha t}}{\alpha t}\right]=1+Y \quad (1)$$

where Z is the count rate detected over time t, D_v is Diven Factor, β is the delayed neutron fraction and ρ is the reactivity. The effective multiplication factor can be calculated as:

$$k_{eff} = \frac{1}{1-\beta+\alpha\Lambda} \quad (2)$$

where α is the prompt decay constant, Λ is the neutron generation time. The effective multiplication factor can be calculated the prompt decay constant obtained from Eq. 1.

3.2. Experimental Process

Noise analysis is a method of analyzing the noise of detector signal under a sub-critical state and obtaining the criticality. Therefore, it has the advantage that no other equipment is needed. Generally, when applying the Feynman-alpha method, there should be sufficient measurement data to ensure statistical significance by increasing the gate time and sufficient number of measurements.

In order to obtain enough measurement data, KHNP-CRI developed a measuring device with a minimum gate time of 10 μsec. In this study, sub-criticality measurement experiment was performed using this measuring device.

The Feynman-alpha method experiment was conducted using a He-3 detector while changing the position of the Coarse Rod. The initial state of the reactor was critical at 20.25 cm for the position of the Coarse Rod. Feynman-alpha method.

The experiment data were acquired by measuring the minimum gate time at 10 μsec for about 5 minutes. At the end of the measurement, the coarse control rod positions were changed to 19.5 cm, 18.5 cm, 17.5 cm, and 0 cm, and data were acquired for 5 minutes in the same process. The data format consists of a set of neutrons, measured in 10 μsec continuously, in time and neutron numbers. That is, the data consists of about 30,000,000 bundles, assuming a measurement time of about five minutes.

As a result, sufficient data were obtained to apply the Feynman-alpha method. In addition, the obtained data can be selectively used according to the purpose. In this study, As can be seen in Fig 1, the data is selected by setting the Gate time, Initial time, Interval Time between the Gate Time.

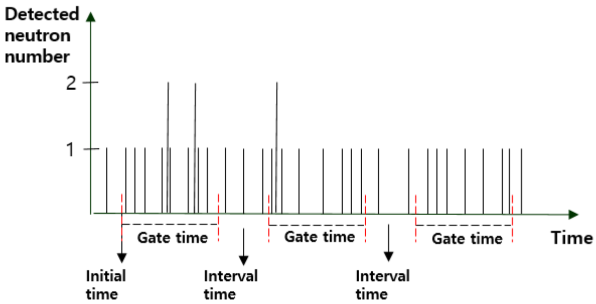

Fig. 1. Position of Initial time, Gate time and Interval time

In the selected data, a graph was drawn using the ratio of the average and the number of neutrons measured per gate time. Using the right-hand side of Equation 1, the appropriate alpha value was obtained by least squares fitting method. We proceeded to calculate the criticality by substituting the fraction of neutrons and neutron regeneration time in Equation 2.

4. Criticality Measurement with Feynmann-alpha Method

The Feynman-alpha experiment using AGN-201K was conducted through five experiments. A 5 minute measurement was performed for each experiment.

The code was programmed to proceed with data selection. When the user sets the gate time in the code, it substitutes an arbitrary time from 0 seconds to 1 second in the initial time, and assigns an arbitrary time from 0 seconds to 0.01 seconds to the interval time. The number of neutrons belonging to the gate time was selected and programmed to obtain mean and variance. The user can set the number of initial time and interval time to get the desired number of data per gate time.

In this study, we calculated average and variance ratios by setting about 10 data selections per average gate time. Fig. 2 is a graph of time for Y-1 obtained by subtracting 1 from the average and variance ratio of the measured neutron numbers of each gate time when the rough control rod is inserted at 18.25 cm.

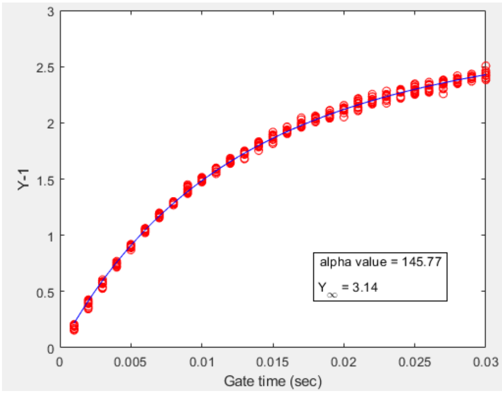

Fig. 2. Feynman-alpha curve in Coarse Rod Position: 18.25cm

To obtain the criticality using the Feynman-alpha method, we need to know the alpha value, which is the factor calculated from Equation 2. The alpha value can be calculated by the least square fitting method by applying Equation 1to the graph after creating Feynman-alpha graph of the selected data as shown in Fig. 2. Table I summarizes the alpha values and the criticality calculated for each experiment.

Table I The alpha value and the criticality for each experiments

Order	Inserted Rod Position (cm)		Alpha Value	k-value
	CR	FR		
1	20.25	12.56	125.39	0.99940
2	19.25	12.56	138.23	0.99844
3	18.25	12.56	145.77	0.99787
4	17.25	12.56	149.01	0.99763
5	0.0	12.56	168.00	0.99621

5. Criticality Estimation with Rod Worth Curves

To compare and verify the alpha values calculated by the Feynman-alpha method, we use the data obtained from the control rod worth measurement experiment to calculate the criticality according to the control rod position in the above five experiments. KHU Research Reactor AGN-201K has four control rods, one fine control rod, one coarse control rod, and two safety control rods.

By design, the control rods are the same in configuration and only differ in size. Since the control rod worth is known through the experiment, the coarse control rod is estimated through the fine control rod in order to calculate the criticality according to the reactor state. The fine control rod was measured using the Compensation method, one of the control rod worth measurement experiments. Experiments were conducted using DDRCS to obtain the integral rod worth of fine control rod. integral rod worth of the coarse control rod was calculated using the control rod design value (CR:

1250pcm, FR: 310pcm) [3]. This can be seen in Figure 3 below.

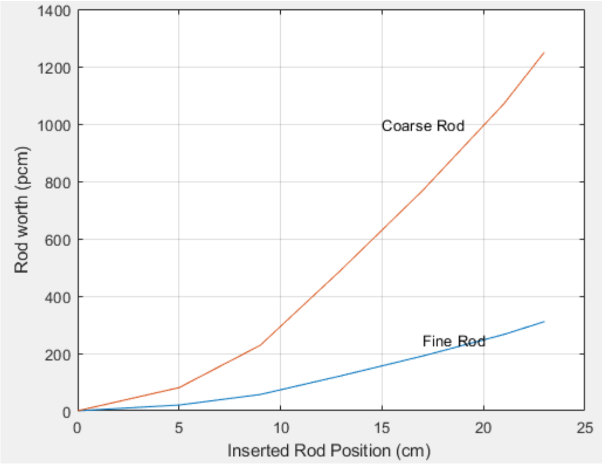

Fig. 3. Integral Rod Worth of Coarse Rod and Fine Rod

6. Criticality Estimation with Rod Worth Curves

We compared the criticality obtained from the experiment using the Feynman-alpha method and the estimated criticality using the control rod. Table Ⅱ shows the criticality calculated by substituting the alpha value obtained in the experiment using the Feynman-alpha method into Equation 2.

Using the integral rod worth of the coarse rod obtained from the fine rod worth, the criticality in five experiments according to the position of the coarse control rod was estimated and summarized in Table 2.

As a result of the comparison, the calculation errors of the two methods are within the range of 62pcm until the criticality reaches 0.997. However, we could see that the difference of the criticality was large in the experiments where the coarse control rod was all rod out state.

7. Conclusions

The sub-criticality measurement experiment using the Feynman-alpha method in the Research reactor AGN-201K of Kyung Hee University was carried out.

The data was collected using a device with a minimum gate time of 10 μsec, which was used by KHNP-CRI, and the code was programmed to select the desired data to obtain the sub-criticality.

In order to verify the calculated criticality, we used the control rod of the control rod of the reactor to estimate the criticality under the same experimental conditions.

As a result, it can be confirmed in that the comparisons of the criticality of the two methods were relatively good up to 0.997, and that the error of less than 0.989 was large. Since the experiments in the intermediate range have not been carried out, further experiments will be carried out. It is also considering how to perform verification calculation using MCNP calculation.

REFERENCES

[1] Juan Blazquez, Remarks on kinetics parameters of a sub-critical reactor for nuclear waste incieraation, NEA, 2001 pp826-829

[2] E. Lee, et al, A study of Ex-core detector characteristics for the estimation of effective multiplication factor in PWR, Korea Electric Power Corporation, 2009.

[3] KHU AGN-201K Technical Specification", Kyung Hee University, 2014.

Table Ⅱ Comparison of Multiplication Factor

Order	Estimation value using Rod worth			Feynman-alpha Method		Comparison
	CR	Alpha value	k-value (A)	Alpha value	k-value (B)	A-B (pcm)
1	20.25	125.47	0.99939	125.39	0.99940	-1
2	19.25	133.84	0.99876	138.23	0.99844	32
3	18.25	147.07	0.99777	145.77	0.99787	-10
4	17.25	157.31	0.99701	149.01	0.99763	-62
5	0.0	265.10	0.98904	168.00	0.99621	-717