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Validation of AGN-201K Design Data with Combination of Numerical Analysis and Experiments

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1. Introduction

Since 1982 Zero-Power reactor AGN-201K of Kyung Hee University has been operating by relocating the reactor operated by Colorado State University in 1967. In addition, the reliability of the design data prepared in the 1960s had to be validated as the maximum allowable heat power was increased from 0.1Watt to 10Watt and the facility was reinforced. And there was a discrepancy between the actual measurement data and the design data[1] through the repair and additional installation of the measurement system. In this study, the results of verifying various operation and design data through numerical analysis and related experiments by using MCNP6 code are summarized.

2. Design Data of AGN-201K

The design data verified in this study is the FSAR of AGN-201K. Design data and actual measurement data of AGN-201K are also attached to the report. The study was conducted using these data.

AGN-201K is a nuclear reactor in which the core is surrounded by the graphite reflector, the lead shield, and a water shield. At the top of the reactor, a thermal column covers the core, and consists of a 2.38cm diameter Glory hole that penetrates all the reactors to the core, and four 10.16cm diameter access ports that pass through the shield and reflector.

The core of the reactor is composed of a structure in which nine nuclear fuel disks are vertically stacked in a circular cylinder. Nuclear fuel consists of a mixture of uranium and polyethylene with a concentration of 19.5w/o.

The control rod system of the AGN-201K is composed of the same mixture as nuclear fuel, and consists of two safety control rods, a fine control rod and a coarse control rod.

3. Validation of AGN-201K Design Data

Design data and actual measurement data of AGN-201K were used to design the MCNP6 code input data, and the input data were validated by comparing it with the experimental results. First, evaluation of criticality was performed to verify the input data, and kinetic parameters were compared through experiments. Finally, the criticality and kinetic parameters were compared using the noise analysis method.

3.1 Design Data Verification Using MNCP6 Code

In proceeding with the verification using the MCNP6 code, the important thing was to determine the discrepancy between the design data and the actual measurement data. For example, it is described that there is a difference in the measured thickness between nuclear fuel disks within about 2mm in the actual data, but the design document differs in that each disk is designed to have the same thickness. In this case, the disks of the same size were designed to be the same without error. This is because the amount of U-235 loaded as a zero-power reactor is very small, 690g, so even a small error in design shows a big difference in core characteristics. In designing the input data of the code, actual data were used as the basis, but when there was a difference, the design data was used. Fig 1 is a schematic daigram of AGN-201K simulated with MCNP6 code.

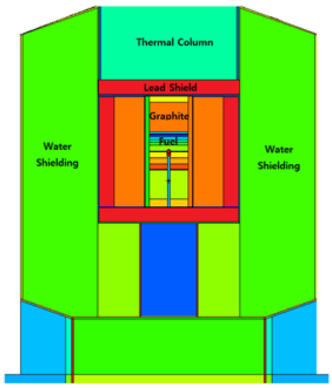


Fig. 1. Schematic diagram of AGN-201K

When performing the verification of the input data of the code, the calculation was performed using the design data and the actual measurement data, but the criticality was not satisfied at the position of the control rod in the critical condition obtained through the experiment, so adjustment of the composition of the core was required. The composition of the fuel was adjusted because there was no significant influence on the criticality other than the composition of nuclear fuel. The mass of U-235 was confirmed to be 690g in the Criticality Approach Experiment. By controlling the mass of polyethylene, the calculation was performed so that the criticality was achieved at the position of the control rod in the critical condition obtained through the experiment. Table 1 shows this, and it is the result of adjusting the mass of polyethylene so that the supercritical condition is satisfied in the All Rod In state and the critical condition is satisfied in the critical condition. When the mass of polyethylene was 0.949 times, the condition was satisfied, and the fuel composition at this time was used for design.

Table I: MCNP6 Code Calculation Result by Controlling The Polyethylene Mass

ARI		Critical state	
(C2H4)n Mass Control (Multiply)	Keff	(C2H4)n Mass Control (Multiply)	Keff
0.990	1.01569	0.990	1.01343
0.970	1.00944	0.970	1.00706
0.950	1.00281	0.950	1.00045
0.949	**1.00241**	**0.949**	**0.99997**
0.947	1.00185	0.947	0.99928
0.940	0.99931	0.940	0.99694

To further verify the design of the core composition, experimental data with different control rod positions in critical condition were used. Code calculation was performed based on a total of 10 experimental data with a reactor temperature of about 20°C. The result satisfies the critical condition as shown in Table 2 below.

Table II: MCNP6 Code Calculation Result at Critical State

Control Rod Position (cm)				**Reactor Temp. (°C)**	**Keff**	**STD**
CR	**FR**	**SR**	**SR**			
20.92	18.78	24	24	20.1	1.00066	0.00014
20.52	17.73	24	24	20.2	1.00031	0.00014
20.54	17.1	24	24	20.2	1.00039	0.00014
20.94	14.57	24	24	19.6	1.00017	0.00014
19.98	19.85	24	24	19.9	1.00044	0.00015
21.0	13.98	24	24	19.8	1.00021	0.00014
20.27	19.88	24	24	20.4	1.00072	0.00013
20.07	15.01	24	24	19.8	0.99940	0.00015
21.25	15.91	24	24	20.3	1.00058	0.00014
21.13	16.2	24	24	20.2	1.00041	0.00015

Using the designed code input data, comparison with the design value of the rod worth of AGN-201K was performed. The control rod of the reactor consists of a coarse control rod, two safety control rods and a fine control rod. The rod worth of the coarse rod and safety rods are 1250pcm and the fine rod worth is 310pcm. Table 3 shows the comparison of the result of the MCNP6 code calculation and the design value.

Table III: Comparison of Design Value with Rod Worth in MCNP6 Code Calculation

	k-eff	STD	ρ	Δρ (pcm)	Reference
ARI	1.00241	0.00011	0.002404		
CRO	0.99020	0.00010	-0.009897	**1230.12**	1.25% Δρ
FRO	0.99931	0.00010	-0.000690	**309.468**	0.31% Δρ
Critical state	0.99997	0.00010			

Table 4 shows the composition ratio of each nuclide of fuel used as code input data.

Table IV: Nuclide Mass Ratio In Nuclear Fuel

U235 %mass	U238 %mass	O16 %mass	C12 %mass	H1 %mass
0.049697	0.205161	0.034334	0.608583	0.102224

3.2 Design Data Verification Through Rod Worth Measurement Experiment

In order to verify the design data, kinetic parameter was compared with the calculation result of MCNP6 code through the experiment [2] for measuring the fine rod worth. In the rod worth measurement experiment, it was calculated using the Inhour equation.
The rod worth measurement experiment in AGN-201K is performed using a fine control rod. The experiment used the Compensation method and the Positive Period Method. The locations of the detectors inside the reactor are as shown in Figure 2, and the detectors used in the experiment are Channel 2, Ch3, Ch4 and Ch7.

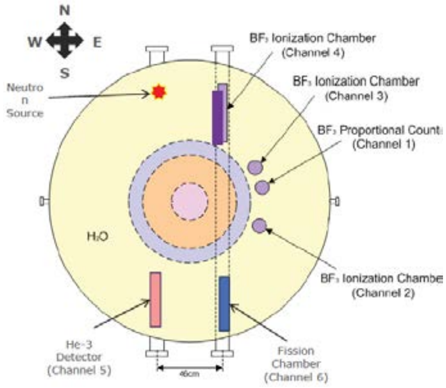


Fig2. Location of the detector in AGN-201K

The kinetic parameter used for the calculation of the rod worth was performed by using the value obtained through the calculation of the eigenvalue of the MCNP6 Code. When the calculation value of the code was applied, the fine rod worth did not satisfy the design value of 310pcm, so it was adjusted and inserted. The code calculation values and the values used in the experiment are shown in Table 5, and the experimental value of the fine rod wroth are shown in Table 6.

Table V : Kinetic Parameter in MCNP6 and Experiment

Precursor	Delayed neutron fraction		Decay Constant	
	MCNP6	Experiment	MCNP6	Experiment
1	0.00027	0.00029	0.01334	0.01128
2	0.00133	0.00193	0.03273	0.02776
3	0.00137	0.00173	0.12079	0.10101
4	0.00298	0.00350	0.30293	0.27391
5	0.00121	0.00102	0.85006	1.02830
6	0.00049	0.00041	2.85509	2.73000
sum	0.00765	0.00887		

Table VI : Rod Worth Measurement Experiment Result

	Case 1				
Method	Positive Period	Compensation			
Detector	Ch3	Ch2	Ch3	Ch4	Ch7
Rod Worth (pcm)	307	314	320	314	308
	Case 2				
Method	Positive Period		Compensation		
Detector	Ch2	Ch7	Ch2	Ch4	Ch7
Rod Worth (pcm)	314	298	314	316	310

3.2 Design Data Verification Through Noise Analysis

In this study, design data analysis through criticality analysis was performed using the Feynman-alpha method, one of the noise anlayis. The methodology, proposed by Feynman in 1956, is a method of measuring the criticality by analyzing neutron pulses collected from the detectors. The relational expression of the neutron pulse and the relational expression according to the neutron behavior can be expressed by the following equation. [3][4]

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

Z is the count rate of the detector during a specific time t, β is the delayed neutron fraction, ε is the detector's efficiency, Dv is the Diven Factor, and ρ is the reactivity.

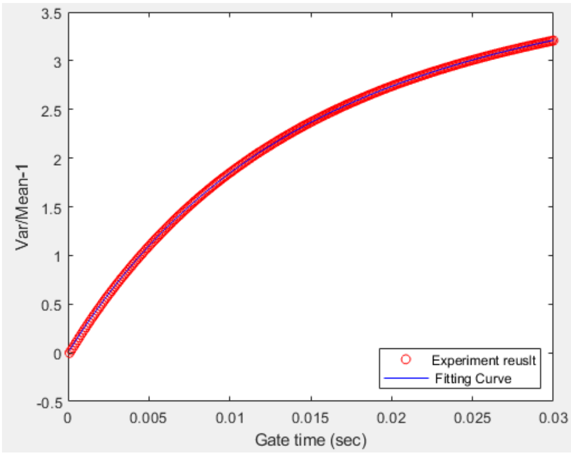
Using the alpha obtained in the above equation and the kinetic parameter obtained in Section 3.2, the effective multiplication factor can be calculated with Equation 2.

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

Table 7 shows the Feynman-alpha curve obtained using Equation 1 and 2 at the criticality of 0.99954 (MCNP6).

Table VII : Feynman-alpha Experiment Results (MCNP6 Keff :0.99954)

Variance/mean-1	Alpha	Keff
4.38	120	0.99930



The AGN-201K operates with 4 control rods, and the criticality in all rod out state was 0.96202 when calculated using the MCNP6 code. The experiment was carried out using a data measurement device with a minimum gate time of 10 μsec (KHNP), and the processing was performed using the Moving Bunching Technique. In this study, noise analysis was performed from the critical condition to the deepest subcritical state, 0.96202, and the results were compared. This is shown in Figure 3 and Table 8.

Table VIII : . Comparison of the Criticality between MCNP6 Code Results and Feynman-alpha Experiment Results

#	MCNP6 Result		Experiment Result		Difference (A-B)
	Keff (A)	STD	alpha	Keff (B)	
1	0.99954	0.00015	120	0.99930	24
2	0.99724	0.00014	152	0.99731	-7
3	0.99552	0.00015	185	0.99487	65
4	0.99288	0.00014	207	0.99269	19
5	0.99064	0.00015	229	0.99106	-42
6	0.98950	0.00015	279	0.98743	207
7	0.98902	0.00015	275	0.98772	130
8	0.98848	0.0015	278	0.98741	107
9	0.98819	0.00014	278	0.98769	50
10	0.98786	0.00015	255	0.98933	-147
11	0.98768	0.00015	265	0.98856	-88
12	0.98753	0.00014	270	0.98829	-76
13	0.98737	0.00014	275	0.98788	-51
14	0.98712	0.00013	301	0.98599	113

15	0.98707	0.00015	274	0.98799	-92
16	0.98372	0.00015	355	0.98159	213
17	0.98184	0.00014	371	0.98003	181
18	0.97974	0.00014	429	0.97573	401
19	0.97764	0.00016	397	0.97771	-7
20	0.97651	0.00014	422	0.97562	89
21	0.97544	0.00014	321	0.98260	-716
22	0.97484	0.00014	458	0.97265	219
23	0.97147	0.00015	546	0.96499	648
24	0.96942	0.00015	543	0.96525	417
25	0.96711	0.00016	477	0.96910	-199
26	0.96551	0.00014	548	0.96356	195
27	0.96378	0.00015	535	0.96380	-2
28	0.96278	0.00015	489	0.96760	-482
29	0.96202	0.00016	715	0.95018	1184

3. Conclusions

In this study, design data and actual measurement data were validated based on FSAR. The numerical analysis and related experiments were performed and verified through the MCNP6 Code.

First, the input data of the MCNP6 code was prepared using the actual measurement data and design data. To verify the input data, the experimental value in the criticality measurement experiment and the design value of the control rod were compared. The comparison of the criticality at the different control rod positions was within 72pcm, and the comparison of the control rod worth showed a difference within 20pcm for both the coarse rod and the fine rod.

To verify the kinetic parameter, the rod worth measurement experiment was performed. The kinetic parameter was calculated through the calculation of the eigenvalue of the MCNP6 code, and was inserted into the Inhour equation. It was confirmed that the differences of the fine rod worth between the design value of 310pcm and obtained through the compensation method and the positive period method was within 12pcm.

Finally, noise analysis was performed to additionally valdiate the criticality and kinetic parameter. The difference was within 200pcm up to the criticality of 0.98707, but the difference was up to 1184pcm in the deeper subcritical state..

In addition, to verify the design data by performing noise analysis and delayed neutron fraction measurement experiments will be performed.

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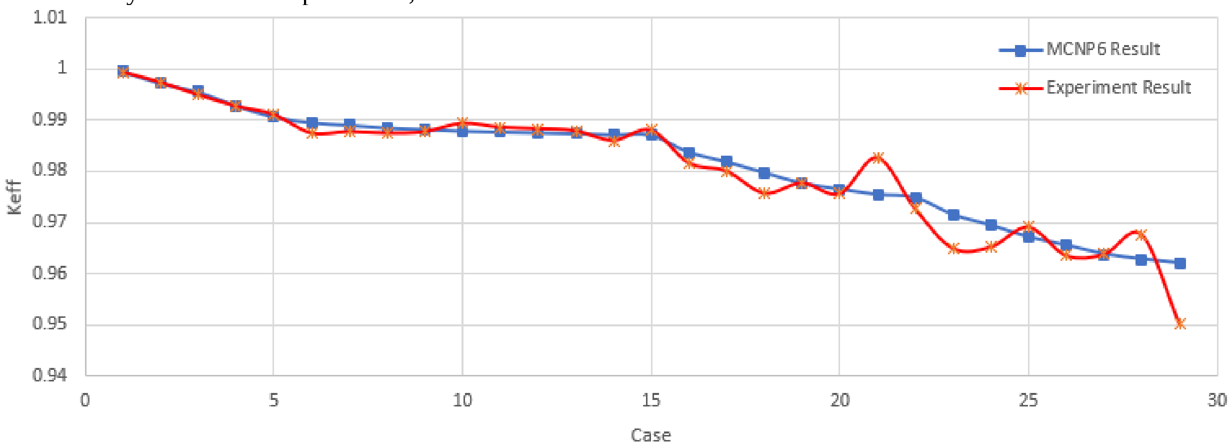

Fig3. Criticality curve of Feynman-alpha experiment result and MCNP6 code results