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Development of Reactivity Analysis Module for Virtual Reality Reactor Experiment Laboratory of AGN-201K Educational and Research Reactor

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1. Introduction

Educational Technology or EduTech indicates a wide range of tools and that platforms that facilitate teaching and learning, often leveraging digital devices, software, and online resources. Various Educational Technology contents that leverage its advantages such as accessibility, engagement, and personalization, have been developed by utilizing various technologies.

Recently, Kyung Hee University (KHU) and Unipola has been developing new EduTech contents that uses Virtual Reality (VR) technology to conduct reactor experiments with the AGN-201K zero power educational reactor. Currently, in the AGN-201K reactor experiments [1], the number of participants and the duration time of the experiment are strictly limited to manage the radiation exposure of the students. The new AGN-201K reactor experiment VR content will offer students with the vividness and interactivity of reactor experiments through VR technology, enabling them to overcome the limitations of space and time.

In a reactor experiment, the most important factor is accurately simulating neutron behaviors in a core in response to control rod movements. However, the current AGN-201K VR contents does not accurately represent the output changes caused by manipulating the control rods of the actual AGN-201K. Therefore, a reactivity analyzer that accurately represents the output changes is needed to improve training effectiveness.

In this study, we developed a reactivity analysis module using dynamic period equation for the AGN-201K VR contents and compared it with actual operation records.

2. VR Contents of AGN-201K Reactor Experiments

2.1 KHU Reactor Experiment Program

In the KHU, the reactor experiment program provides six experiments. Table I shows the contents of the reactor experiments. Exp #1 provides the practice to manipulate control rods to change the power level. In the Exp #2 and #4, students can measure reactor period and control rod worth by the positive period method, the compensation method, and the rod drop method. Exp #3 is the traditional criticality search method by an inverse multiplication (1/M) curve. Exp #5 is the measurement of thermal flux along the core by the neutron activation method (NAA) with gold-wire sample irradiations. Exp #6 is the measurement of the temperature coefficient and the effect of changes in reflector materials. These six reactor experiments are offered either as part of a regular semester course at KHU or as a one-week public short-term program.

Table I: Contents of KHU Reactor Experiment Program

No.	Experiments
1	Reactor Operation
2	Measurement of Reactor Period
3	Approach to Criticality
4	Control Rod Calibration
5	Thermal Flux Measurement
6	Effect of Temperature and Reflector

2.2 AGN-201K VR Contents

The reactor VR modeling has been completed using actual reactor measurements, and development of the content for the six experiments is currently underway. Figure 1 compares photos of the actual reactor (left) with their VR modeling (right).

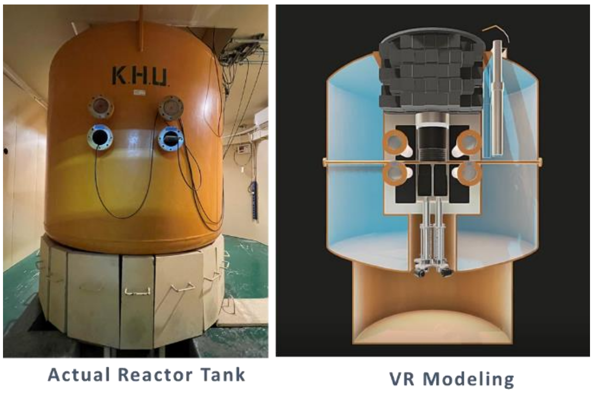

Figure 1. Comparison the actual reactor tank with its VR modeling for AGN-201K reactor

In the VR experiment content, the monitor of digital monitoring console (DMC), which allows users to clearly view measurement signals from the actual experiment, is prominently highlighted as shown in Figure 2.

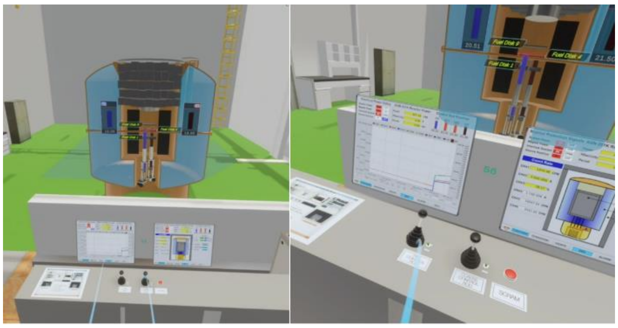

Figure 2. VR screen of digital monitoring console (DMC) for reactor operation and neutron detector signals

The Meta Quest 2 and Peripheral devices (VR headset, laptop, cable, Wi-Fi router) were used for the AGN-201K reactor experiment VR contents.

3. Development of Reactivity Analysis Module

3.1 Dynamic Period Equation

To create the VR content for realistic nuclear reactor core simulations, it is essential to have equations that represent the relationship between reactivity and reactor period in response to control rod movements. The "*Dynamic period equation*" is a fundamental equation in nuclear reactor physics used to describe the time-dependent behavior of a neutron population, particularly during transients. This equation gives the instantaneous reactor period as a function of reactivity, the rate of the delayed neutron precursors within the defined groups. The simplified *Dynamic period equation* can be expressed by the following equation [2,3].

$$\tau = \frac{l_p}{\rho} + \frac{\overline{\beta_{eff}} - \rho}{\lambda_{eff}\rho + \dot{\rho}}, \qquad (1)$$

where β_{eff} is the effective delayed neutron fraction in the reactor, and λ_{eff} is the effective decay constant of the precursor l_p is lifetime of prompt neutron. If the reactivity ρ is known, the reactor period τ can be determined using the *dynamic period equation*. By the definition of the reactor period, the time-dependent changes in reactor core power and neutron flux levels can be calculated using the following equation.

$$P(t) = P(0)\cdot e^{\frac{t}{\tau}}, \qquad (2)$$

$$P_1 = P_0 \frac{\beta_{eff} - \rho_0}{\beta_{eff} - \rho_1}, \qquad (3)$$

Eq. (2) shows the change in power P(t) over time when the reactivity is constant and the initial power is P(0), and Eq. (3) can be applied when the reactivity changes, resulting in a prompt jump or prompt drop.

3.2 AGN-201K Data for Dynamic Period Equation

To utilize *Dynamic period equation* in AGN-201K reactor simulations, various kinetic parameters and reactivity data in the AGN-201K reactor are required as input data. Figure 3 shows the control rod integral worth for fine rod (FR) from the experiments. [4,5]

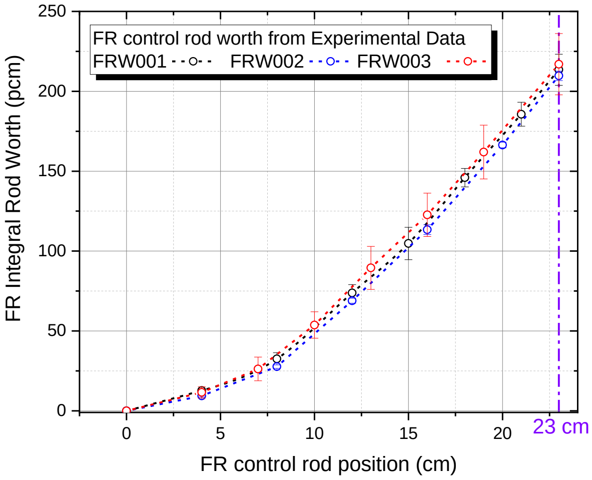

Figure 3. Integral worth curve of FR control rod from

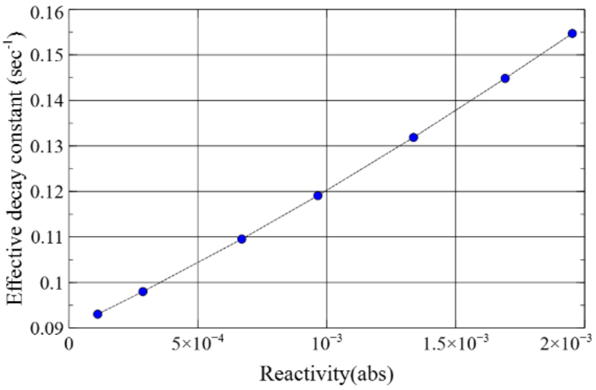

Figure 4. Relationship between effective decay constant and reactivity

The kinetic parameters such as effective delayed neutron fraction, decay constant, life time were input as the values calculated through McCARD [6] Monte Carlo (MC) analysis for same computational model. Meanwhile, the effective decay constant is a time-dependent parameter, represented by the following formula.

$$\lambda_{eff} = \frac{\sum \lambda_i C_i(t)}{\sum C_i(t)}, \qquad (4)$$

where $C_i(t)$ is the concentration of i-th precursor group. In this study, the purpose of this reactivity analysis module is to accurately reproduce the experimental results; therefore, the effective decay constants have been calibrated to ensure that the correct period is produced as shown in Eq. (5).

$$\lambda_{eff} \approx 3023.402\rho^2 + 27.314\rho + 0.0899\,, \qquad (5)$$

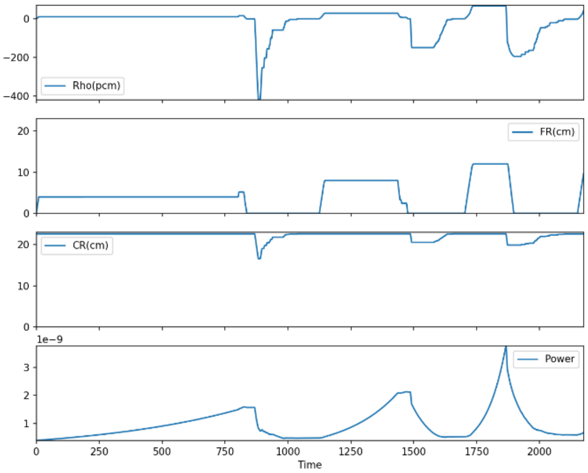

Figure 5. Example of running a reactivity analysis simulation

Figure 5 shows an example of a simulation run using the newly developed reactivity analysis module, specifically showing the temporal response of the reactor power to the movement of each control rod. This visual representation illustrates the dynamic behavior of the reactor in response to reactivity changes by clearly showing the relationship between the repositioning of the control rods and the resulting change in reactor power. It also effectively visualizes phenomena such as "prompt jump" or "prompt drop," which is the immediate response of the reactor power to reactivity changes.

3.3 Comparison with Experimental Operation Data

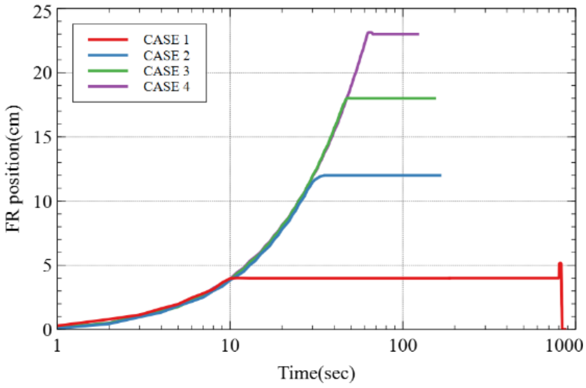

Figure 6. Operation data of AGN-201K

To verify the reactivity analysis module, the simulated powers are compared with actual one under the same control rod operation conditions from the AGN-201K operation data for the positive period method [4,5]. For the control rod worth measurement, the position of CR was fixed as about 23 cm. Figure 6 shows a record of a control rod operation.

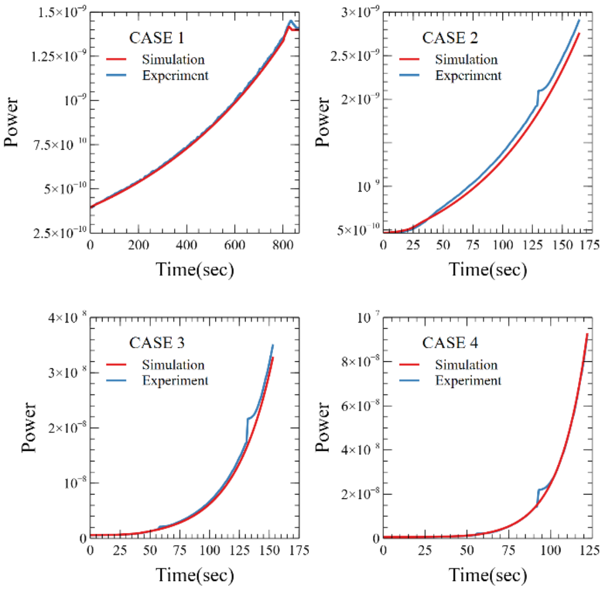

Figure 7. Compare between simulation results by the newly developed reactivity module and experimental data

Figure 7 compares the simulation results by the newly developed reactivity analysis module and the experimental data. It is observed that they are in excellent agreement considering the spike of the experimental value from the change in the detector signal scale.

4. Conclusion

In this study, a reactivity analysis module was newly developed to provide realistic results in the AGN-201K VR contents and it was seamlessly integrated within the AGN-201K VR contents. The reactivity analysis module provides the reactor period in response to the change in reactivity by control rod movements by the *Dynamic period equation*. The VR-based reactivity analysis module was validated by comparing the simulation results with the experimental one from the AGN-201K reactor operation, demonstrating a high level of accuracy in reproducing the experimental data. The incorporation of this module into a VR environment significantly enhances the educational experience of learners by offering a realistic and interactive simulation, while concurrently mitigating the limitations inherent to conventional reactor experiments, such as restricted access and safety concerns.

In the near future, numerical analytical methodologies to refine the accuracy of the simulations will be tested and applied to the VR reactivity analysis module.

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