Subcriticality Evaluation of AGN-201 Reactor Using Modified Neutron Source Multiplication Method

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1. Introduction

One of the main issues in nuclear criticality safety is to measure subcriticality accurately at nuclear facility containing fissile materials. In order to verify the feasibility and safety of reactor, reactor physics test is performed in the commercial reactor. Among these test items, the measurement of control rod worth is taken most of period of reactor physics test. For that reason, the new methods have been introduced for subcriticality measurement to reduce the test period from the economic point of view: for example, pulse neutron method, neutron noise analysis method, Neutron Source Multiplication (NSM) method and so on. In 1980's, the research for subcriticality measurement methodology was performed about accelerator driven system, fast breeder reactor and critical experiment reactor. In this study, subcritcality is evaluated by modified NSM method. It is based on the conventional NSM method adding two correction processes: (1) extraction of the fundamental mode from measuring neutron count rate data that contains not only fundamental mode but also higher modes in real situation and (2) spatial corrections for perturbation induced by a reactivity addition in the distributions of the fundamental mode and a neutron importance field. In the previous studies, the verification of this method has been firstly performed for the subcriticality measurement of critical assembly of Kyoto University Critical Assembly (KUCA) at Kyoto University Research Reactor Institute in Japan. Recently subcriticality measurement study for the Pressurized Water Reactor (PWR) has been carried out. In the present study, the subcriticality was evaluated for Aerojet General Nucleonics (AGN)-201 reactor by the modified NSM method with two correction processes. The AGN-201 reactor is the graphite moderated homogeneous type research reactor and is used for reactor experiments such as critical mass approach, control rod calibration, measurement of neutron flux and so on. For subcriticality evaluation by modified NSM method, three kinds of the neutron flux distributions such as forward, adjoint, fixed source neutron fluxes, which are solution in both eigenvalue and fixed source problems are needed. These flux distributions were calculated by using MCNP-4c2 and DANTSYS simulation codes. It was found that the modified NSM method could be applied for various subcriticality states of AGN-201 reactor based on these flux distributions. [1]

2. Basic Theory

Generally, the conventional NSM method is the simplest method for subcriticality measurement. This method is measured reactivity through amplification phenomenon of neutrons. However, it is impossible to measure subcriticality accurately because conventional NSM method is not considered neutron source and detector position. Therefore, in order to evaluate the subcriticality accurately, a new neutron source multiplication method called modified NSM method was proposed from Hokkaido University in Japan.

2.1 Modified NSM method

In modified NSM method, the extraction of fundamental mode in neutron count rates is mainly considered. Based on this solution, the perturbation of neutron importance field and spatial effect were modified by three-correction factors that aim to evaluate subcriticality accurately. The modified NSM method was defined as follows:

$$\rho_l^s = \rho_{ref}^s C_l^{ext} C_l^{im} C_l^{sp} \left(\frac{M_{ref}}{M_l} \right) \quad (1)$$

where ρ_l^s is the evaluated subcritcality of the specific l-th state, ρ_{ref}^s is the subcriticality of the reference state, M is the neutron count rates and C_l^{ext}, C_l^{im} and C_l^{sp} are extraction correction factor, importance field correction factor and spatial correction factor. ρ_{ref}^s is subcriticality of a reference state that is nearest to the critical state.

2.2 Correction factors

C_l^{ext} is extraction coefficient ratio of specific state and reference state. C_l^{im} is the ratio of neutron source intensity weighted by the neutron importance for a specific state to that for the reference state. C_l^{sp} is the ratio of normalized contained in the neutron count rate for a specific state to that for a reference state. The three correction factors are expressed symbolically as follows:

$$C_l^{im} = \left[\frac{\phi_{1,l}^{*c}, S}{\phi_{1,ref}^{*c}, S} \right], \quad (2)$$

$$C_l^{sp} = \left[\frac{\int_V W_d(r) \overset{-c}{\phi}_{1,l}(r) dr}{\int_V W_d(r) \overset{-c}{\phi}_{1,ref}(r) dr} \right], \tag{3}$$

and

$$C_l^{ext} = \left[\frac{C_{1,ref}}{C_{1,l}} \right], \tag{4}$$

where, $C_{1,x} = \left[\frac{\int_V W_d(r) \overset{-c}{\phi}_1(r) dr}{\int_V W_d(r) \overset{-s}{\phi}(r) dr} \right],$

$C_{1,x}$ is the extraction factor that was expressed ratio of eigenvalue problem neutron flux to fixed source problem neutron flux. [2]

2.4 Correction of Gamma effect

In the practical application of subcriticality measurement, it is necessary to taken into account γ-ray background noise that can be contained in detector signal. Gamma ray is originated from γ-decay of fission production in burnt fuels. In this case, the contamination of γ-ray can be edited using γ correction factor. Hence the subcritialtiy of a specific state in modified NSM method and γ-ray correction factor become as follows:

$$\rho_l^s = \rho_{ref}^s C_l^{ext} C_l^{im} C_l^{sp} C_l^{\gamma} \left(\frac{M_{ref}}{M_l} \right), \tag{5}$$

$$where \;\; C_l^{\gamma} = \frac{\frac{M_l}{M_{ref}}}{(1 + A_{ref}) \frac{M_l}{M_{ref}} - A_{ref}},$$

$$A_{ref} = \frac{\gamma}{n_{ref}} = gamma \;\; fraction,$$

The γ-ray correction factor aforementioned is not always necessary if we can set appropriate discrimination level in the instrumentation system. [3]

3. Calculation Model

The AGN-201 reactor is used for reactor experiments of reactor physics. Therefore it is easy to get the neutron count rate and neutron fluxes through the experiments. The AGN-201 reactor consists of core, graphite reflector, lead shield, water reflector and four control rods. The neutron flux distributions of various subcriticality states in AGN-201 reactor were calculated by using two simulation code systems described in the above to apply in modified NSM method. Finally, the control rod worth measurement through subcriticality measurement could be evaluated.

4. Results and Conclusion

Figure 1 shows the forward fast neutron flux distributions for three control rod loading patterns. It was found that the neutron flux distribution do not change in the outer region of core. Table 1 gives theoretical control rod worth for each control rod loading pattern. The reactivity difference between the All-Rod-In (ARI) state and All-Rod-Out (ARO) state is 1.321%Δ k/k. In order to evaluate subcriticality more accurately, it is necessary to correct the gamma background noise effect in low power level.

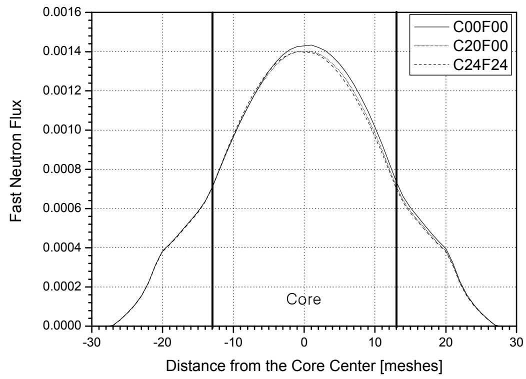

Figure 1. Forward fast neutron distribution

Rod Insertion patterns		Control Rod Worth
Coarse Rod	Fine Rod	(%Δ k / k)
0 cm	0 cm	1.971
20 cm	0 cm	2.777
24 cm	24 cm	3.292

Table 1. Theoretical Control rod worth for control rod patterns

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