Time-dependent problems of Subcritical System

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1. Introduction

Recently year, accelerator-driven system (ADS) has been recognized in the world as a highly safety of the core characteristics and in the use of transmutation of very large amount of radioactive wastes and miner actinides.
Although, it is subcritical system (=ADS) with such a big advantage, the characteristic still has inadequate investigation. Therefore, the analysis technique of the characteristic is also various. The feature of ADS is that the system is operated by subcriticality. These cores are characterized by a very low fraction of delayed neutrons and by a low Doppler reactivity coefficient. Therefore, it differs from the characteristic in the conventional critical state.
In this study, the following analyses were proposed among those characteristics taking into account of the dynamics for subcritical system. For example, it is generally difficult to analyze three-dimensional space-time dependent kinetics by using a Monte Carlo method since the sampling of the neutron becomes in a region whose characteristics changes with time. Here, we investigated the method of solving this problem using the general kinetic equation. In this study, we try to this method which is static method for ADS.

2. Theory

In this study, the behavior of neutrons is considered spontaneous in the subcritical system. It means a neutron is absorbed or leaks in a short period after being born by fission, while the region characteristics do not change. Therefore they are treated by steady state calculation. (Eqs (1)) On the other hand the densities of delayed neutron precursors changes slowly, and the region characteristics change. (Eqs (2))

$$\Omega\cdot\nabla\Phi+\sigma\Phi=\iint\sum_{\chi\neq f}\sigma_\chi f_\chi\Phi'\,d\Omega'\,dE'$$
$$+\iint\chi_p(1-\beta)\nu\sigma_f\Phi'\,d\Omega'\,dE'+\sum_j\chi_d\lambda_jC_j(r,t_{index})+Q \qquad (1)$$

$$\frac{\partial C_j(r,t)}{\partial t}+\lambda_jC_j=\iint\beta_j\nu\sigma_f\Phi'\,d\Omega'\,dE' \qquad (2)$$

The definition of the Boltzmann equation of a subcriticality stationary state with the source of a neutron follows the definition of Salvatores etc. (Ref.1, 2)

Therefore we are calculated by using conventional time-dependent precursor equation. In the newly developed method, the neutrons are calculated by using steady state equation at each time point for a neutron, and the delayed neutron precursors are calculated by using time dependent equation.

$$\frac{d\Phi}{dt}=\frac{\rho-\beta}{\Lambda}\Phi+\sum_i\lambda_iC_i+Q \qquad (3)$$

$$\frac{dC_j(t)}{dt}=\frac{\beta_j}{\Lambda}\Phi-\lambda C_j(t) \qquad (4)$$

3. Calculation method

We tried to inspect the accuracy of this method by using a simple point reactor Eqs (3), (4). We obtained strict solution Φ* as a reference solution, Φ1 as a solution by the present method and Φ2 as the solution where both neutrons and delayed neutron precursors are treated by using static equations. Here, ε_p Eqs (5) and ε_d Eqs (6) is approximation accuracy both Φ* and Φ1, and Φ2. We investigate whether time constant assumption can apply to the subcritical state of how large.

$$\varepsilon_p=\frac{(\Phi^*-\Phi1)}{\Phi^*} \qquad (5)$$
$$\varepsilon_d=\frac{(\Phi^*-\Phi2)}{\Phi^*} \qquad (6)$$

Calculation definitions are summarized in Table.1. Here, we investigate both approximation accuracy using ε_p and ε_d. The calculation condition was conducted for the fast critical assembly that consists of enriched uranium (93%), Stainless Steel and Cf neutron source at the center fuel region. (Table.2) Reactivity was introduced by drawing out a fuel control rod. Where, we assumed the reactivity insertion speed of -0.0125$/sec. Finally, the reactivity of about $ -6 is supplied. This is very slow reactivity insertion case. In addition, we consider to Trangent as a high speed reactivity insertion case.

Table.1. Calculation definitions

	dΦ/dt	dCi(t)/dt
Φ*	Considered	Considered
Φ1	= 0	Considered
Φ2	= 0	= 0

Table.2. Calculation conditions and calculation cases

	CASE1	CASE2	CASE3	CASE4
Initial subcriticarity keff	0.95	0.95	0.9	0.97
External source	exist	exist	exist	exist
Reactivity insertion	fuel rod	fuel rod	fuel rod	fuel rod
Insertion speed	-0.0125$/sec	-0.5/sec	-0.5/sec	-0.5/sec
Insertion method	slow	trangent	trangent	trangent
Total reactivity	6$	0.5$	0.5$	0.5$

Here, we explain about calculation cases. First, CASE1 means a slow reactivity insertion. Same time, the insertion speed and approximation accuracy of the reactivity in ε_p and ε_d are compared.On the other hand, other CASE's (2-4) are Trangent. We want to research the relation both the system subcriticality and the approximation accuracy on the CASE (2-4). Physically, if the system subcriticality becomes small, the effect of the delayed neutron becomes large.

4. Calculation Results

Fig.1 shows the effect of a delayed neutron at the slow insertion of the reactivity. The obtained results show a good agreement between Φ1 and Φ* with less than 1% of accuracy.

On the other hand, Φ2 and Φ* produces the error of 60% or more.

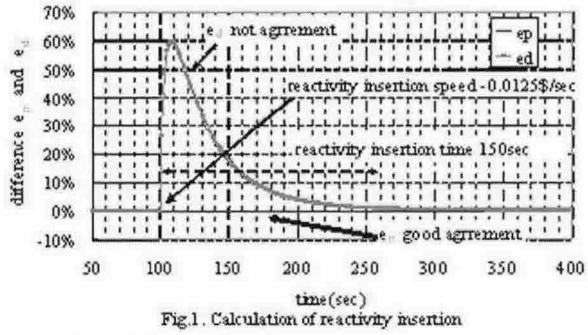

Fig.1. Calculation of reactivity insertion

Next, we showed the results of Trangent cases.
All cases reactivity was negative reactivity.Fig.2-4 showed CASE2-4. In this calculation, any case's p is very small compare with d . Therefore, only d which affects change of a neutron level here is expressed to graph. If it compares numerically, it differs to an orders level. Same time, we will inspect a result according to the difference in the subcriticality of this system.
If it considers from all figures, the approximation error of k= 0.9 is 3.5% and K= 0.97 is 0.7%. The difference of about 5 or more times had error each other. These figures showed that the error was expanded, when a system was close to criticality. If the error acquired this time is taken into consideration to an experimental order, it will be the thing of the range which can fully acquire accuracy. The insertion reactivity is about 0.5$, the influence for a time differentiation terms (dN/dt, dC/dt) is not large in this system. Moreover, the more system subcriticalty is large, the more it turns out that it is ineffective. From these results, we assumed to the various intensity of reactivity and investigated the effective range in which theory is materialized.

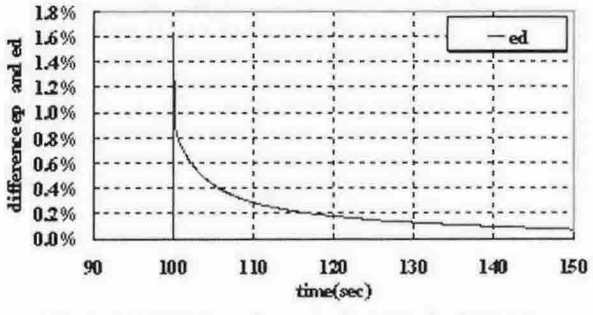

Fig.2. CASE2 Result$_d$εonly (system keff=0.95)

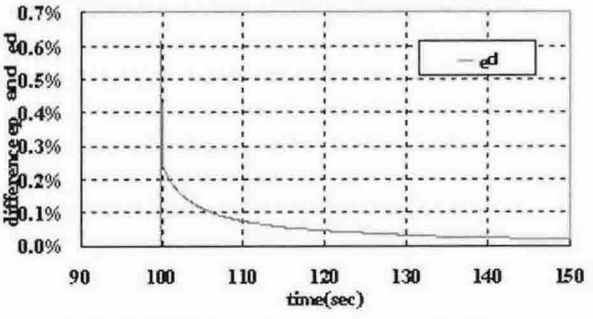

Fig.3. CASE3 Result$_d$εonly (system keff=0.9)

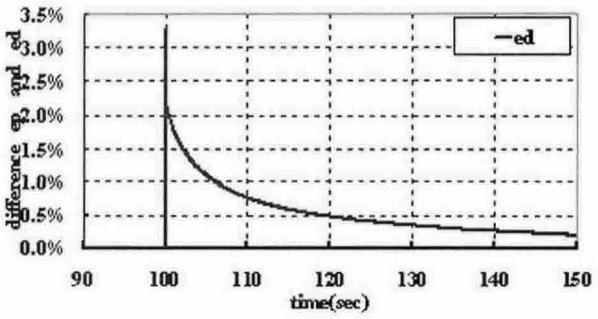

Fig.4. CASE4 Result$_d$εonly (system keff=0.97)

Here, from the reactivity from -1$ to 10$, five insertion intensity was chosen and it supplied to system keff=0.95. The result is shown in Fig. 5.
From Fig. 5, if larger reactivity than -2$ is added, for keff=0.95 system, the approximation error is over 5%.
When the reactivity more than 2$ is supplied to the system of keff=0.95, 20% or more of approximation error is produced. Therefore, it turns out that the time differentiation terms (dN/dt, dC/dt) of a delayed neutron cannot be approximated.

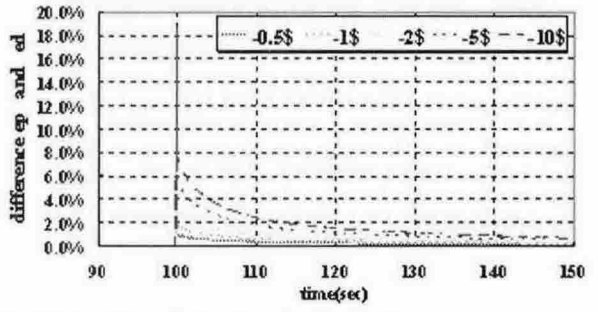

Fig.5. Result$_d$εonly (system keff=0.95)

5. Conclusions

This result indicated that Φ2's approximation is not realized. And we researched that this error was expanded, when a system was close to criticality. Therefore, although the approximation which disregarded the time differentiation terms of a neutron was possible. But it turns out that the ranges are limited. Therefore, it remains in use on the limited conditions. In other words, the delayed neutron precursor density should be calculated with the information at that time step together with previous step.
It is important for the time dependent kinetics simulation by using a Monte Carlo method. It turned out that it is necessary to argue about the detail handling of a delayed neutron.

References

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2.K.Kobayashi, K.Nishihara, Nucl.Sci.Eng. 136,272 (2000)