Application of Coupled Reactor Kinetics Method to a CANDU Reactor Kinetics Problem.

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ABSTRACT

A computer code for solving the 3-D time-dependent multigroup neutron diffusion equation by a coupled reactor kinetics method recently developed has been developed and for evaluating its applicability in CANDU transient analysis applied to a 3-D kinetics benchmark problem which reveals non-uniform loss of coolant accident followed by an asymmetric insertion of shutdown devices. The performance of the method and code has been compared with the CANDU design code, CERBERUS, employing a finite difference improved quasistatic method.

1. INTRODUCTION

The analysis of power distribution under transient operation in large power reactors with asymmetric reactivity insertions requires the use of detailed 3-D time-dependent neutron diffusion calculations. Effort has been directed toward the use and development of multi-dimensional few group transient diffusion programs. However, in large power reactors, full 3-D analysis by directly solving the neutron diffusion equation requires tremendous computing time even with modern high speed computer. Therefore, simple methods requiring less computing time has been tried and developed. The multi-point kinetics method[1] chosen in this work belongs to such category.

Principle objective of this work is to make a neutronic model for simulator which requires fast calculation time and aimed at developing a model providing reliable solutions to relevant problems. The coupled reactor kinetics method[1] recently developed, therefore, has been chosen and a program developed, and for evaluating its efficiency in simulator model tested with a 3-D CANDU kinetics problem[2].

Model equations are kinetic equations for multi-coupled regions with six

delayed neutron precursor groups. The benchmark problem chosen is typical CANDU fast transient problem with large asymmetric reactivity insertion requiring 3-D analysis.

2. THEORY

The time dependent multi-group diffusion equations for perturbed system with delayed neutrons .are introduced,

$$\frac{1}{v_g}\frac{\partial \Phi_g(r,t)}{\partial t} = (-A' + \frac{(1-\beta)}{k_0}B^{p'})\Phi_g(r,t)$$
$$+ \sum_i \chi_{ig}^b \lambda_i C_i(r,t) \tag{1}$$

Here A' is removal operator of cross section by perturbation and $B^{p'}$ is the fission operator for prompt neutrons.   The delayed neutron precursor density, $C_i(r,t)$, satisfies the following equation

$$\frac{\partial C_i(r,t)}{\partial t} = \frac{1}{k_0}\beta_i F' \Phi_g(r,t) - \lambda_i C_i(r,t)$$

In the coupled reactor kinetics method, Green's function, $G(r,g;r',g')$, for unperturbed system is used.   Using adjoint operator with Green's function introduced, we obtain the coupled reactor kinetics equation as follow;

$$l_{mn}(t)\frac{dS_m(t)}{dt} = -(1-\Delta k_m^F(t))S_m(t) + \sum_{n=1}^{N}\sum_i k_{imn}^d(t)\lambda_i C_{in}(t)$$
$$+ \sum_{n=1}^{N}[\ \frac{1}{k_0}(1-\beta_{mn}(t))k_{mn}^p(t) - \Delta k_{mn}^A(t)]\ S_n(t)$$

where k, l, Δk, β, and λ have the meanings of time-dependent coupling coefficients and kinetic parameters   The subscripts m and n are region indices for different coupled regions.   The N is the number of reactors or regions in a reactor, and the $S_m(t)$ and $C_{im}(t)$ are the fission and delayed neutron precursor densities in the region V_m.

3. BENCHMARK TEST PROBLEM

The problem is a 3-D benchmark based on realistic three-region (reflector, inner and outer fuels) CANDU reactor model with zero flux boundary conditions on external surfaces and steady-state initial conditions, and on reactivity transients that represent the effects of loss of coolant followed by subsequent insertion of shutdown reactivity devices.

The three dimensional configuration including dimensions and material assignments is detailed in Fig. 1 & 2. The concentration of the fissile components in the inner core is slightly less than that of the outer core. The loss of coolant is represented by linear decrease in the left-half core thermal removal cross section from time 0 to 0.4 seconds, followed by a decrease in same rate during the following 2.5 seconds. After a delay of 0.6 seconds, an incremental thermal removal cross section in upper left-half and down full core is added to simulate asymmetric insertion of shutdown devices at constant velocity in y-direction.

4. RESULTS AND CONCLUSION

Initial steady state is achieved by dividing the production cross sections by the fundamental eigenvalue, and initial precursor concentrations are in equilibrium with the initial flux. The shutdown devices are modeled by increasing the thermal removal cross section at a rate consistent with their top-to-bottom constant velocity insertion. At any given solution time, the tip of the absorber being inserted may or may not coincide with a mesh line. In the event that it does not, the effect of the portion of the absorber extending past the given mesh line is smeared over the cell into which it projects by volume averaging absorber and cell properties.

A non-uniform mesh consisting of 18, 18 and 10 mesh spacings in the x, y and z directions respectively was used in solving the flux distributions for evaluating the time dependent coupling coefficients and kinetic parameters. Spacings were either 30 cm or 60 cm. The 30 cm spacings were used in the vivinity of reflector core boundaries. The 72 coupled regions in the core were used for multi-point equations. For setting up coupled regions the core was divided by each one in left and right outer core and two in inner core for x-direction, number of meshes for y-direction, and two for z-direction.

Primary results obtained are the fundamental eigenvalue and relative region power, and total power versus time. The static eigenvalue and region relative powers obtained are compared in Table I. The results are in good agreement with the reference solutions. The small differences are due mainly to the different finite difference scheme employed.

Fig. 3 shows the behaviors of total power versus time. The power behaviors after shutdown devices insertion differ significantly from the reference solution by the 3-D CANDU detailed kinetics code, CERBERUS[3], employing the improved quasistatic method. It is assumed that the observed differences are associated with the use of different absorber insertion models or with the inadequacy of the present method using the reference core steady state flux distribution for evaluating the time-dependent coupling coefficients in large asymmetric reactivity

insertion transient. Further study is required. Having resolved these differences, it is concluded that the solutions by the present method are reliable for increasing power behaviors.

The results are also compared with those by point kinetics method. It is observed that the present multi-point kinetics model yields superior results to the point kinetics method.

Table 1. Comparison of Initial Power Fraction

Methods / Region	Reference Method	Multi-point method
1, 2, 3, 4 13, 14, 15, 16	0.0	0.0
6, 7, 9, 10 18, 19, 21, 22	0.03440	0.03424
5, 8, 17, 20	0.07764	0.07766
11, 12, 23, 24	0.10356	0.10386

The k-effectives of reference and present method are 1.00355 and 1.00224, resepectively.

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3. A. R. Dastur, et al., ''CERBERUS – A Computer Program for Solving the
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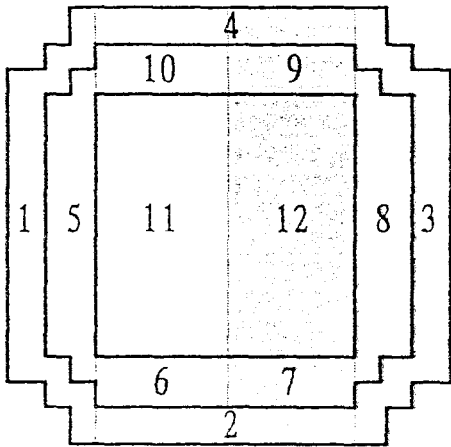   Atomic Energy of Canada Limited, 1979.

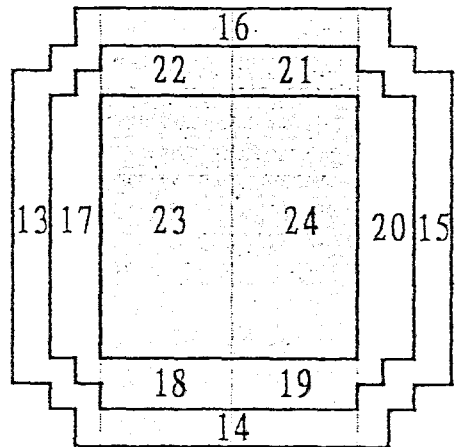Figure 1. Vertical Crossection at z=0 cm
Showing Region Assignment

Figure 2. Vertical Crossection at z=390cm
Showing Region Assignment

Fig. 3. Relative Power versus Time