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A Three-Dimensional Operational Transient Simulation of the CANDU Core with Typical Reactor Regulating System

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Abstract

This paper describes the results of simulation of a CANDU operational transient problem (re-startup after short shutdown) using the Coupled Reactor Kinetics(CRKIN) code developed previously with CANDU Reactor Regulating System(RRS) logic. The performance in the simulation is focused on investigating the behaviours of neutron power and regulating devices in accordance with the changes of xenon concentration following the operation of the RRS.

1. Introduction

In General, full 3-D simulation of transient problems requires tremendous computing time even with modern high speed computer in large power reactors such as CANDU reactors. To reduce computing time, efforts have been directed toward the development of simple coarsh mesh methods requiring less computing time. The CRKIN computer code[1] using a coupled reactor kinetic theory belongs to such a category.

The objective of this work is to test the capability to simulate the CANDU reactor operational transient problems automatically by incorporating the typical RRS routine[2] into the CRKIN code. The major function of the RRS is to measure the reactor power and control to a specified setpoint, and to permit smooth automatic changes in reactor power. In this work, a program using a typical CANDU RRS logic has been written. It calculates the power error and set power and sends the signals to control devices for the necessary device movements to achieve the power set point. An interface routine between the main reactor kinetics and the RRS exchanges informations on control device positions, flux, and zonal neutron powers, etc.

The code is validated by testing with LMW benchmark problem[3]. The model problem chosen in this work is the one re-starting the reactor after short shutdown from the full power by the RRS logic.

2. Theory

The multi-point kinetics equation for calculating neutron behaviours in the core is given as follows;

$$l_{mn}(t)\frac{dS_m(t)}{dt} = -(1-\Delta k^f_m(t))S_m(t) + \sum_{n=1}^{N}\sum_i k^d_{imn}(t)\lambda_i C_{in}(t)$$
$$+\sum_{n=1}^{N}[\frac{1}{k_0}(1-\beta_{mn}(t))k^p_{mn}(t) - \Delta k^A_{mn}(t)]S_n(t), \qquad (1)$$

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

The equation for delayed neutron precursor densities is given,

$$\frac{dC_{im}(t)}{dt} = \frac{1}{k_0}\beta_{im}(t)S_m(t) - \lambda_i C_{im}(t). \qquad (2)$$

The Xe dynamic equations given as follows are also solved by implicit scheme to calculate Xe concentration following the power change,

$$\frac{dI_m(t)}{dt} = \gamma_I \Sigma_{fgm}\phi_{gm}(t) - \lambda_I I_m(t) \qquad (3)$$

$$\frac{dX_m(t)}{dt} = \gamma_I I_m(t) + \gamma_X \Sigma_{fgm}\phi_{gm}(t) - \lambda_X X_m(t) - \sigma_{aXg}\phi_{gm}(t). \qquad (4)$$

3. Test and Results

For evaluating the capability of CRKIN code in the transient problems, at first, the 3-D LMW test problem for LWR was used. Fig.1 and 2 show a view of the core at the start and the end of the transient. The transient is initiated by the withdrawl of the first group of control rods at a rate of 3 cm per second followed by insertion of the second control rods of opposite sites at a rate of 3cm per second. The resultant transient is advanced for 60 seconds.

The uniform directional mesh spacings of 22 X 22 X 10 meshes in the x, y and z directions, respectively were used and the 24 coupled regions in the core were employed for multi-point model. The control rods are modeled by increasing the thermal removal X-section at a rate consistent with their velocities of insertion. At any given solution time, the thermal removal X-section of the absorber is smeared over the cell into which it projects by volume averaging absorber and cell properties.

Fig.3 shows the behaviours of mean power versus time. The results are good agreement with the reference fine mesh solutions and the results by the coarse mesh code developed for CANDU simulator by CAE Eletronics Ltd. It is observed that the multi-point kinetic model yields accurate results in this kind of slow transient problem even carrying out assymetric perturbation insertions.

In CANDU reactors, there are control devices such as Liquid Zone Controllers(LZC), Adjusters, Mechanical Control Absorbers(MCA), and Shutoff Rods(SOR). The simulation is performed in connection with the typical RRS routine. The RRS logic used in this work is typical one used in the real CANDU core regulation and the program using its logics was written.

The layout of CANDU-600 core in x-z geometry is given in Fig.4. The 22 X 22 X 18 mesh spacings in the x, y and z directions, respectively are used to calculate the flux distribution for evaluating the time dependent coupling coefficients and kinetic parameters, and the 14 coupled regions in the core are used to calculate the typical CANDU 14 zonal powers by the multi-point model. The effective absorption cross section of each control device was calculated for simulating perturbation by control devices.

The simulation is performed by step-wise power increase to 100% full power before Xe override time after shutdown from the full power. All LZCs' levels are 50%. Demanded power rates are given in Table 1.

Time(sec)	Demanded Power(% F.P.)	Demanded Power Rate(Power/sec)
0	0	Shutdown
60 - 210	0	Withdrawl of shutoff rods
240 - 460	10	0.0067
460 - 640	80	0.0067
640 - 800	100	0.0014

Table 1. Demanded power and power rate in re-startup simulation

Fig.5 shows the total power and the positions of adjuster banks and LZCs versus time. At '0' second, the power following the insertion of the shutoff rods begins to decrease and xenon concentrations begin to increase. From 60 sec. to 210 sec., the power increases by the withdrawl of the shutoff rods and decreases after full withdrawl of the shutoff rods because there are no more positive reactivity in the core and because of negative reactivity due to xenon. After 240 sec., demanded power is 10% full power and the levels of LZCs begin to decrease and the positions of the adjuster banks begin to be withdrawn. The power behaviour shows oscillation before maintaining 10% steady state power. It is due to insuffiicient model of the RRS program for the rapid withdrawl of the adjuster banks and the direct method of Xe-concentration calculation. The Xe model in the CANDU design code CHEBXEMAX employes experimental values. After 460 sec., the power begins to increase with 80% demanded power. After 640 sec., the power begins to increase to initial 100% full power. The results were not quantitatively compared with the other simulation results because of the lack of data. However, the results represent reasonably the phenomena appearing during CANDU normal operation.

4. Conclusion

Using the computer code, CRKIN linked with typical CANDU RRS logic, a 3-D CANDU core regulating operational transient problem was tested. The results showed reasonable neutron power behaviours in accordance with the changes of xenon concentration following the operation of the RRS. This means to allow the applicability of the code to the 3-D CANDU core automatic regulating simulations.

References

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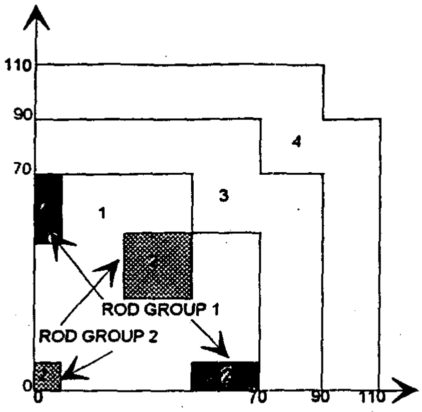

Fig.1 LMW Benchmark Horizontal cross-section

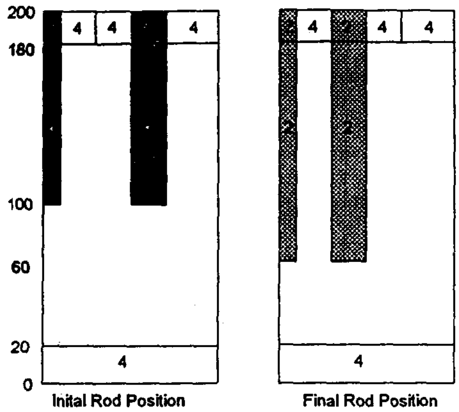

Fig.2 LMW Benchmark. :Vertical cross-sectioı

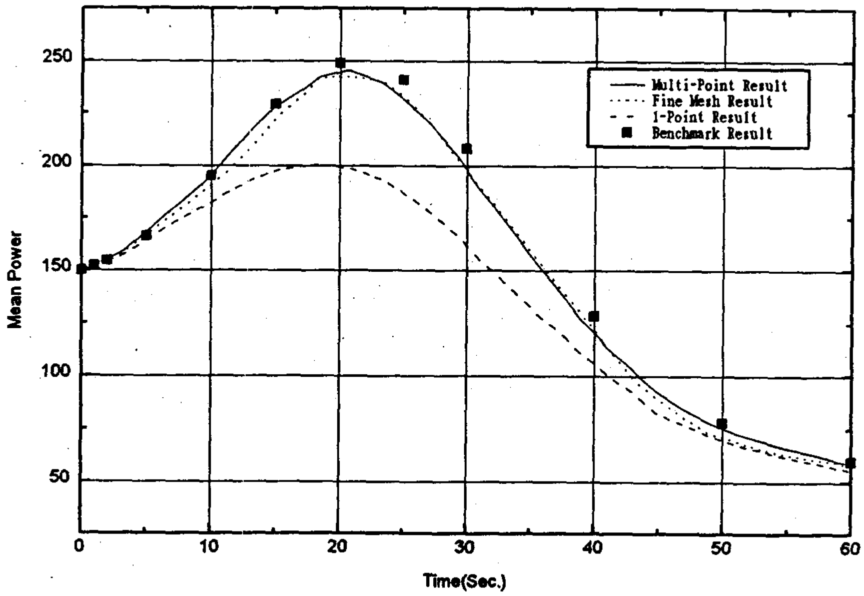

Fig. 3 Mean Power Behavior versus Time

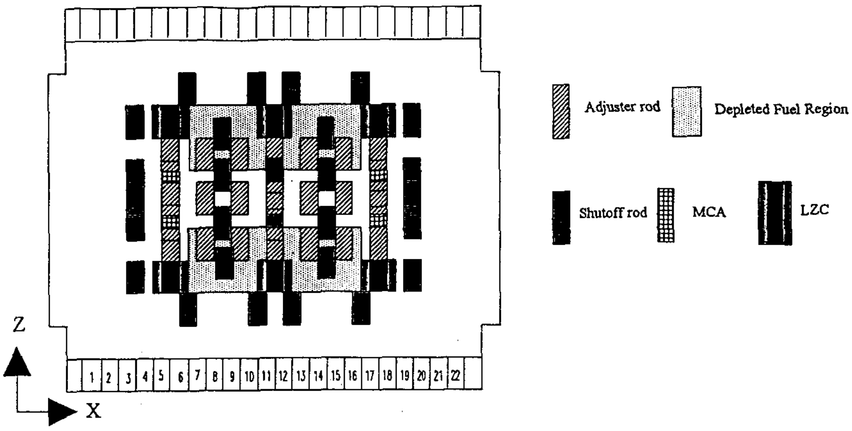

Fig. 4 CANDU-600 Layout in X-Z Geometry : Top View

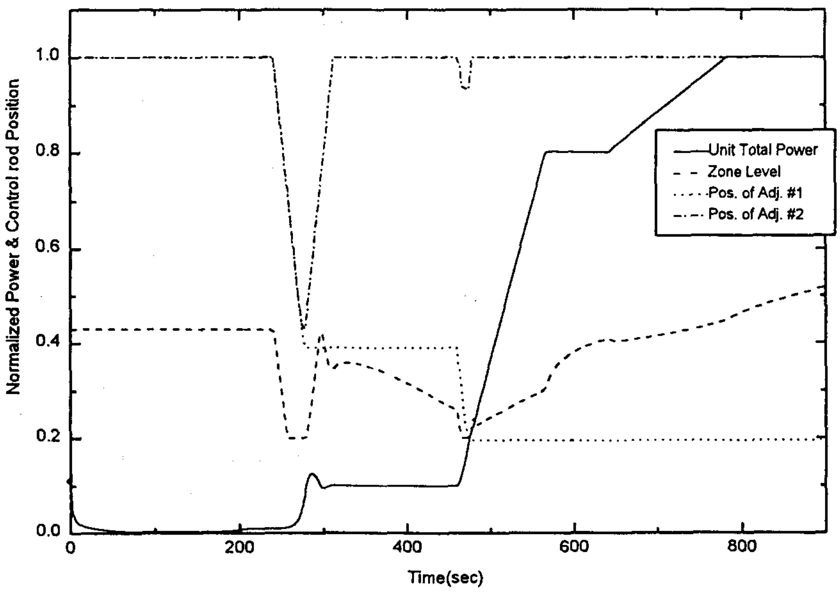

Fig. 5 Changes of Power & Positions of Control devices in re-startup following short shutdown