BNL-NUREG-32105

BNL-NUREG--32105

CONF-830304--8

DE83 003609

Paper Submitted to the Topical Meeting on Advances in Reactor Computations

Salt Lake City, Utah

March 28-31, 1983

THE EFFECT OF SHAPE REACTIVITY ON THE ROD-EJECTION ACCIDENT*

P. Neogy and J.F. Carew

BROOKHAVEN NATIONAL LABORATORY

Department of Nuclear Energy
Upton, New York 11973

September 1982

*Work performed under the auspices of the U.S. Nuclear Regulatory Commission.

THE EFFECT OF SHAPE REACTIVITY ON THE ROD-EJECTION ACCIDENT

Detailed three-dimensional MEKIN-B[1] calculations of the PWR control rod ejection accident (REA) are being performed as part of the BNL/NRC evaluation of methods currently used to analyze PWR REA events. Of particular interest are the point kinetics and one-dimensional methods in which spatial dimensions are eliminated by making simplifying assumptions concerning the temporal behavior of the flux shape. A principal objective of these calculations has been to evaluate in three dimensions the effect of flux redistribution on the core transient reactivity and hence on transient core power level.

The core reactivity is expressed in terms of the net neutron production operator, $\mathcal{L}$, and the shape function, ψ, as[2]

$$\rho = \frac{1}{N}\left\{(W,\mathcal{L}_0\psi_0) + (W,\delta\mathcal{L}\psi_0) + (W,\mathcal{L}_0\delta\psi) + (W,\delta\mathcal{L}\delta\psi)\right\} \tag{1}$$

where

$$\mathcal{L} = \left\{\nabla.D\nabla - A + \sum_j\left[(1-\beta_j)\,\chi_p^j + \sum_{i=1}^{6}\beta_i^j\,\chi_i\right]F^{j^T}\right. \tag{2}$$

$$N = (W,\mathcal{F}\psi) \tag{3}$$

$$\mathcal{F} = \sum_j\left[(1-\beta_j)\,\chi_p^j + \sum_{i=1}^{6}\beta_i^j\chi_i\right]F^{j^T} \tag{4}$$

In equations (1) through (4), W is an arbitrary weight function, and the symbols D,A,F, β and χ have their usual meaning. $\mathcal{L}_0$ and ψ_0 denote the steady state values of the net production operator and the shape function, respectively. By choosing an initially critical reactor, $W=\psi_0^*$, and applying equation (1) to a component, ρ_c, of the total reactivity, we find

$$\rho_c = \frac{1}{N}\left\{(\psi_0^*,\delta\mathcal{L}_c\psi_0) + (\psi_0^*,\delta\mathcal{L}_c\delta\psi)\right\} \tag{5}$$

The first term is the usual perturbation theory expression for ρ_c. The second term gives the contribution of the change in the shape function, $\delta\psi$, to the reactivity, and is the subject of the present paper.

A three-dimensional MEKIN-B quandrant symmetric model of a typical four-loop PWR at the beginning of life was constructed for the REA calculations. The reactor core consisted of 193 fuel assemblies, containing fuel rods in 15x15 arrays, and arranged in a typical first core checkerboard pattern. The standard loading pattern was slightly altered near the center of the core to ensure that a center rod worth of approximately 1% was obtained at hot zero power with the control banks D and C fully inserted. Nominal design values were used for the coolant flow rate, inlet temperature and the system pressure. The initial power level was taken to be 3.25 MW, or 0.1% of the rated power. A quadrant of the reactor core was partitioned into 56 thermal-hydraulic channels and 17 thermal-hydraulic planes. The thermal hydraulic regions were further partitioned to yield neutronic mesh spacings of 7.2 cm horizontally and vertically. Cross-sections were generated at reference and off-reference conditions using the CASMO[3] code.

In this configuration, the central control rod was found to have a static worth of 1.02% $\Delta k/k$. The rod was ejected out of the core with uniform velocity in 0.1 seconds and the transient was followed out to 0.48 seconds. A neutronic time step of .001 seconds was used for the first 0.2 seconds, and a time step of .002 seconds thereafter. In Figure 1, the total, control, Doppler and moderator density reactivities are presented versus time. Out to 0.1 seconds, the total reactivity is determined almost entirely by the reactivity due to the ejecting control rod. The Doppler reactivity makes a significant contribution beyond $\sim$0.12 seconds. The moderator density reactivity is small and negative throughout the transient. Between 0.11 seconds and 0.19 seconds, the total reactivity is seen to decrease by 0.90% $\Delta k/k$ and the transient is reversed. Of this decrease, the Doppler reactivity contributes 0.42%, while the change in control reactivity (which is entirely a shape reactivity during this period) contributes as much as 0.48%, establishing the importance of the flux shape reactivity in determining the course of this transient.

In Figure 2, the core thermal power is presented versus time. As in earlier analyses[4] of the hot zero power rod ejection accident, the core thermal power is seen to exhibit oscillations. Comparison with Figure 1 indicates that they are clearly associated with the oscillations in the control reactivity. These variations in control reactivity are brought about by radial flux oscillations in which the flux alternately moves between the relatively high reactivity central and the low reactvity peripheral regions of the core. These flux oscillations contribute to oscillations in the Doppler reactivity as well. The oscillations in the Doppler reactivity are less developed, however, because of its weaker spatial dependence (as compared to that of the control reactivity). Also, the Doppler reactivity oscillations are out of phase with the control reactivity oscillations, since a flux peak at the ejected rod location leads to a negative Doppler contribution and a positive control reactivity contribution.

In summary, the shape reactivity has a significant influence on the rod ejection accident. After the control rod is fully ejected from the core, the neutron flux undergoes a large reduction at the ejected rod location. The corresponding effect on the control reactivity is comparable in magnitude to the Doppler reactivity, and makes a significant contribution to limiting the power excursion during the transient. The neglect of this effect in point kinetics and space time synthesis analyses of the rod ejection accident may account in part for the large degree of conservatism usually associated with these analyses.[5]

References

1. A.L. Aronson, H.S. Cheng, D.J. Diamond, and M.S. Lu, "MEKIN-B: The BNL Version of the LWR Core Dynamics Code MEKIN," BNL-NUREG 28071, June 1980.

2. J.B. Yasinsky, "Notes on Nuclear Reactor Kinetics" WAPD-TM-960 July 1970.

3. A. Ahlin, M. Edenius, H. Haggblom, "CASMO, A Fuel Assembly Burnup Program," Studsvik Report AE-RF-76-4158, June 1978.

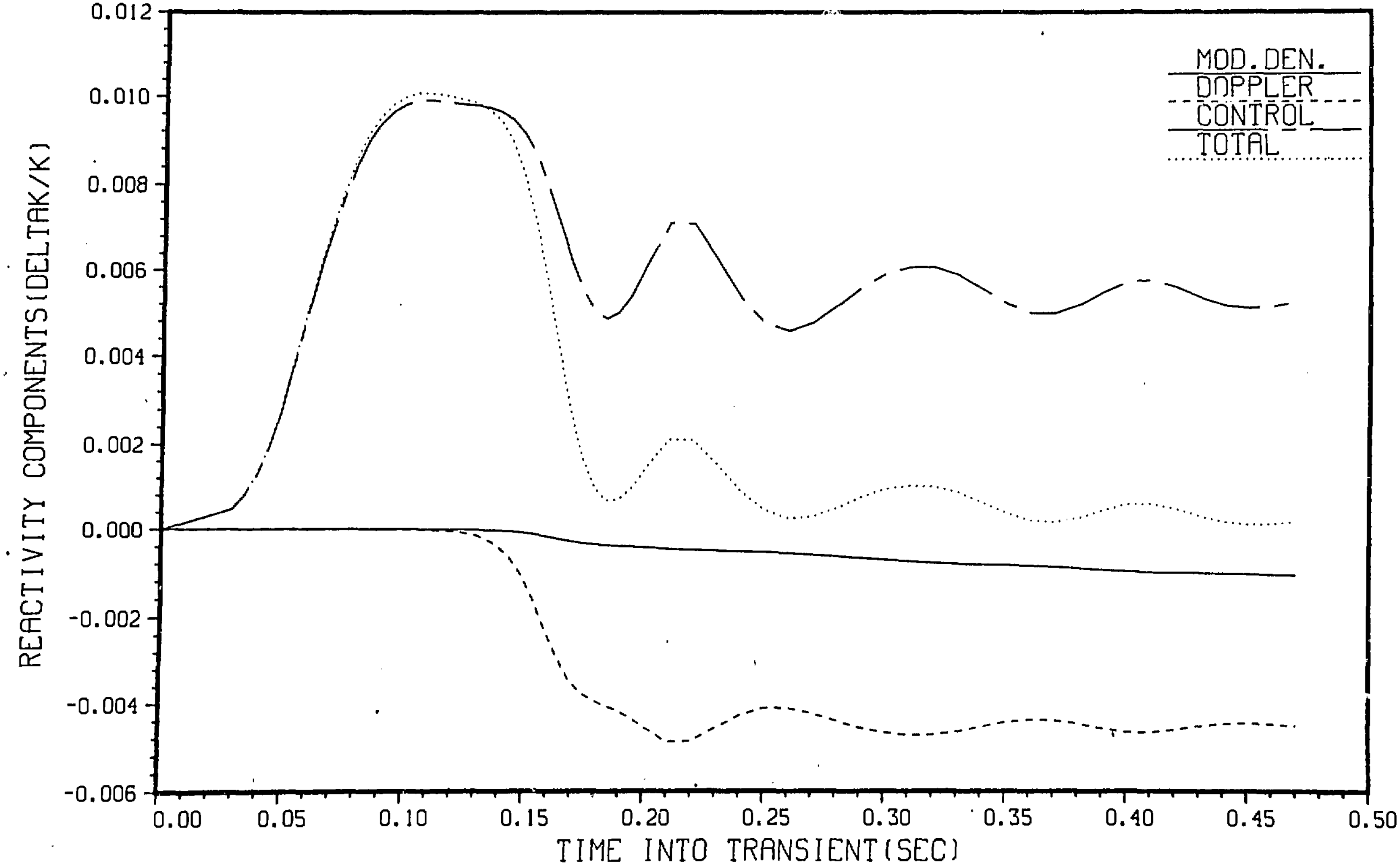
4. J.B. Yasinsky, "On the Use of Point Kinetics for the Analysis of the Rod Ejection Accident," Nuclear Science & Engineering 39, 241 (1970).

5. D.H. Risher, "An Evaluation of the Rod Ejection Accident in Westinghouse Pressurized Water Reactors Using Spatial Kinetic Methods," WCAP-7588, January 1975.

PWR REA ANALYSIS AT HZP

REACTIVITY COMPONENTS VS. TIME

FIGURE 1



PWR REA ANALYSIS AT HZP
CORE THERMAL POWER VS. TIME
FIGURE 2