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SHAPE REACTIVITY EFFECTS IN THE ROD EJECTION ACCIDENT*

P. Neogy and J.F. Carew

BROOKHAVEN NATIONAL LABORATORY

Department of Nuclear Energy
Upton, New York 11973

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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. 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

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

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

and

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

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 quadrant symmetric model of a typical four-loop PWR at the beginning of life was constructed for the REA calculations. 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. Cross-sections were generated at reference and off-reference conditions using the CASMO[3] code.

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. 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 ~ 0.12 seconds. 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.

The variation of the core thermal power with time is presented in Figure 2. The core thermal power exhibits oscillations which are clearly seen here to be associated with oscillations in the control reactivity. These control reactivity oscillations are also a shape reactivity effect, produced by flux shape oscillations that follow the ejection of the control rod. The shape oscillations influence the Doppler reactivity also, although the oscillations are less developed, and the phase is opposite to that of the control reactivity oscillations.

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 due to Doppler feedback. 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.

References

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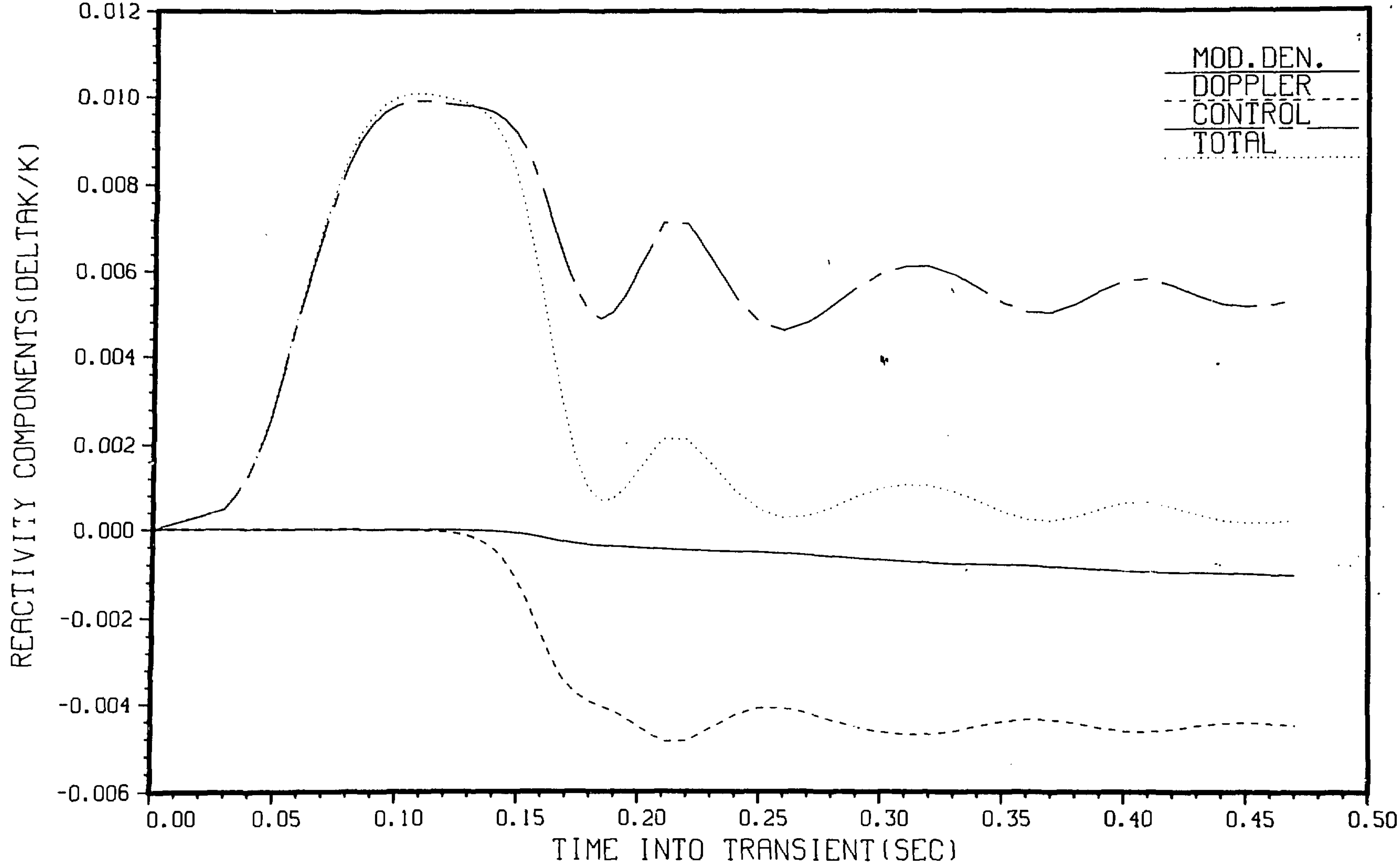
PWR REA ANALYSIS AT HZP
REACTIVITY COMPONENTS VS. TIME
FIGURE 1



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