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Comparison of a Center and Off-Center BWR Control Rod Drop Accident*

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A BWR control rod drop accident (RDA) induces a rapid core power transient involving strong neutronic/thermal-hydraulic coupling, which requires a detailed multi-dimensional spatial kinetics analysis. Typical two-dimensional (r,z) RDA calculations require that the dropped rod be a center rod, as a result of geometric limitations,[1-4] while in three-dimensional (x,y,z) calculations the dropped rod is generally taken to be the center rod in order to allow a quarter-core representation and limit computer running times.[4-5] However, for typical BWR core loadings, the highest worth rod is not necessarily the center rod and it is not known, a priori, what effect this difference in spatial location has on the RDA dynamics. In order to evaluate the effects of this simplification, three-dimensional RAMONA-3B[6] calculations have been performed for both a center and off-center control rod drop accident.

The RAMONA-3B model used in these calculations is based on a generic 764-bundle 3293 MW_t BWR/4 beginning-of-life core. The core is assumed to be at hot-zero-power (HZP) conditions, with the core flow at 25% of nominal and zero subcooling.[4] The calculation was carried out using a 1-1/2 group nodal flux solution with six delayed neutron groups, and a multi-channel thermal-hydraulics description employing a non-equilibrium two-phase flow model.

The center RDA calculations were performed in quarter-core geometry, while the off-center calculations were performed in half-core geometry. The control rods were arranged in a checkerboard pattern with approximately 50% control density, with the off-center rod located on the core axis, in the second outermost ring of control rods on the core flats. Due to the increased leakage at the off-center rod location, the local control rod density was reduced in this case in order to obtain increased flux peaking and the required 1.2% $\Delta k/k$ rod worth.

The transient calculations were initiated by "dropping" a rod, having a static worth of 1.2% $\Delta k/k$, from the fully inserted position at a constant speed of 5 ft/sec. The control rod reactivity insertion results in a rapid and large core power transient which is ultimately reversed by the Doppler and void feedback reactivities. Due to the large local peaking factors ($F_Q \sim 40$-50) in the RDA, the feedback reactivity is dominated by the contribution from the dropped rod location.

The peak fuel enthalpy is presented in Figure 1 for the center and off-center RDA calculations. The peak fuel enthalpy is, to a good approximation, determined by the requirement that when the core power is maximum (i.e., at $\dot{P}=0$) the local reactivity feedback balances the inserted 1.2% $\Delta k/k$ control rod reactivity. Since the feedback requirement is the same in both the center and off-center calculations, the calculated peak fuel enthalpies should be in good agreement. In fact, the calculations yielded 79.5 cal/g and 80.4 cal/g in the center and off-center RDA, respectively.

The core power transient is presented in Figure 2 and the peak core power during the transient is seen to decrease from $P_O{}^C = 19.1$ GW in the center rod calculation to $P_O{}^{OC} = 16.4$ GW in the off-center calculation. While P_O decreases in the off-center calculation, it is noteworthy that the product $P_O F_Q$ (evaluated at $\dot{P}_O = 0$) remains essentially unchanged, as suggested by the invariance of the peak fuel enthalpy:

$$P_O{}^{OC} F_Q{}^{OC} = 16.4 \times 48 = 787 \sim P_O{}^C F_Q{}^C = 19.1 \times 40 = 764.$$

In summary, both a center and off-center rod drop calculation have been performed and, to within the assumptions and approximations implicit in the calculational model, it may be concluded that for equal rod worths, the differences between the transients are small compared to the margin to the fuel damage threshold. These results suggest that two-dimensional (r,z) center rod drop calculations adequately describe the major features of the off-center rod drop event as well.

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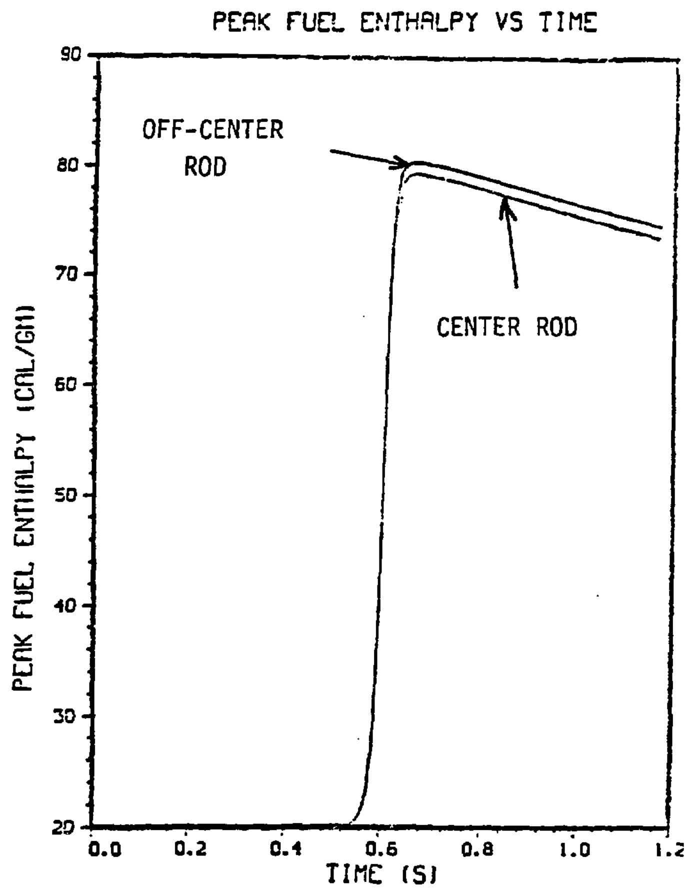

Figure-1. Comparison of the Peak Fuel Enthalpy for the BWR Center and Off-Center Control Rod Drop Accidents.

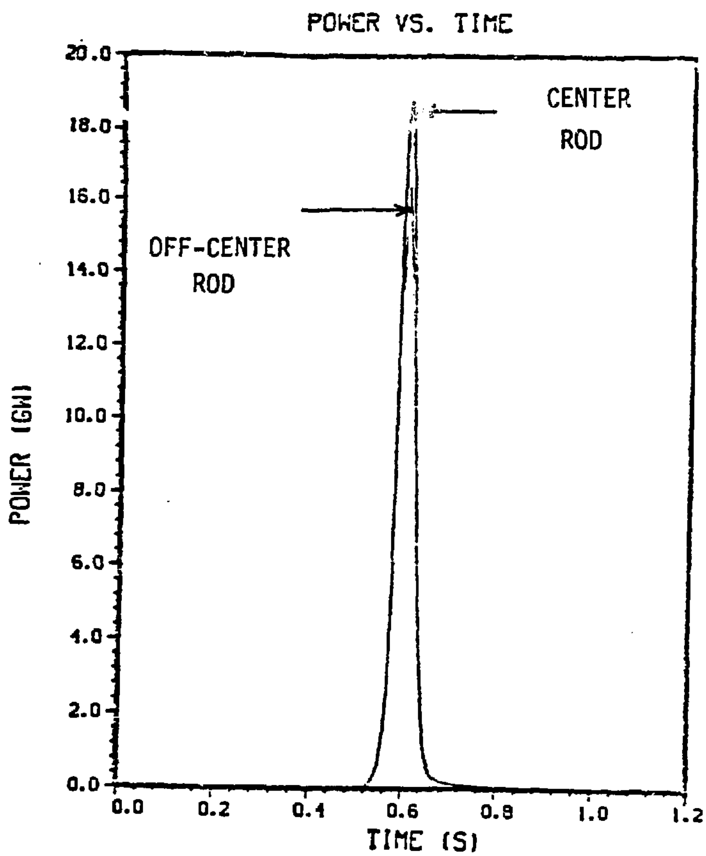

Figure-2. Comparison of the Core Power Transient for the BWR Center and Off-Center Control Rod Drop Accidents.