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EFFECTS OF ROD WORTH AND DROP SPEED ON  
THE BWR OFF-CENTER ROD DROP ACCIDENT\*

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In recent years several multi-dimensional coupled neutronic/thermal-hydraulic calculations of the BWR control rod drop accident (RDA) have been performed. Typically, two dimensional (r,z) RDA calculations require that the dropped rod be a center rod, as a result of geometric limitations, while in three dimensional 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.<sup>4</sup> However, for typical BWR core loadings the center rod is not necessarily the highest worth rod, and in a recent series of calculations the transient dynamics for the center and off-center RDA have been compared.<sup>5</sup> In the present study, these calculations are extended in order to determine the effect of increasing the control rod worth and the rod drop speed. An increase in either of these parameters results in an increase in peak core power and fuel enthalpy, and the objective of this study is to determine the margin to the fuel damage threshold.

The RAMONA-3B<sup>6</sup> model used in these calculations is based on a generic 764-bundle 3293 MW<sub>e</sub> 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.<sup>4</sup> The calculations were carried out in half-core geometry using a multi-channel thermal-hydraulics description employing a non-equilibrium two-phase flow model. The control rods were arranged in a checkerboard pattern with an approximately 50% control density. The off-center rod was located on the core axis in the second outermost ring of control rods. Due to the increased leakage at the off-center rod location, the local control rod density was reduced in order to obtain increased flux peaking and the required 1.2%  $\Delta k/k$  and 1.7%  $\Delta k/k$  rod worths.

In Figures 1 and 2 the calculated core power and peak fuel enthalpy are presented for the base case, in which a control rod having a static worth of 1.2%  $\Delta k/k$  is dropped from the fully inserted position at a constant speed of 5 ft/sec. The reactivity insertion results in a rapid power transient of ~ 16 GW which is ultimately reversed by doppler and void feedback. The peak fuel enthalpy increases from ~ 20 cal/g to a transient peak of ~ 80 cal/g.

In order to determine the effect of increased rod worth, the control rod pattern was adjusted to increase the rod worth to ~ 1.7%  $\Delta k/k$ . The core power and fuel enthalpy transients resulting from the ~ 1.7%  $\Delta k/k$  rod drop are shown in Figures 1 and 2, respectively. The peak fuel enthalpy is, to a good approximation, determined by the requirement that the local reactivity feedback balances the inserted control rod reactivity when the core power (P) is maximum (i.e., at  $P=0$ ). Consequently, increasing the inserted rod worth from 1.2%  $\Delta k/k$  to 1.7%  $\Delta k/k$  results in an increase in peak fuel enthalpy from ~ 80 cal/g to ~ 130 cal/g (and a corresponding increase in doppler fuel temperature), and an increase in core power from ~ 16 GW to ~ 37 GW. The increased rod worth results in a more rapid reactivity insertion, a shorter period, and an earlier and stronger transient.

To determine the effect of increased rod drop speed, the rod speed was increased to 15 ft/sec (an extreme value of more than four times the average measured speed). The resulting core power and peak fuel enthalpy

transients are presented in Figures 1 and 2. The increased rod speed results in a faster reactivity insertion, a shorter period, and an earlier and stronger transient. The calculated peak core power and fuel enthalpy are ~ 25 GW and ~ 96 cal/g, respectively.

In summary, BWR off-center RDA calculations have been performed for selected control rod worths and drop speeds. While in all cases the peak fuel enthalpy was well below the 280 cal/g fuel criterion, a substantial sensitivity to control rod worth and rod drop speed was observed.

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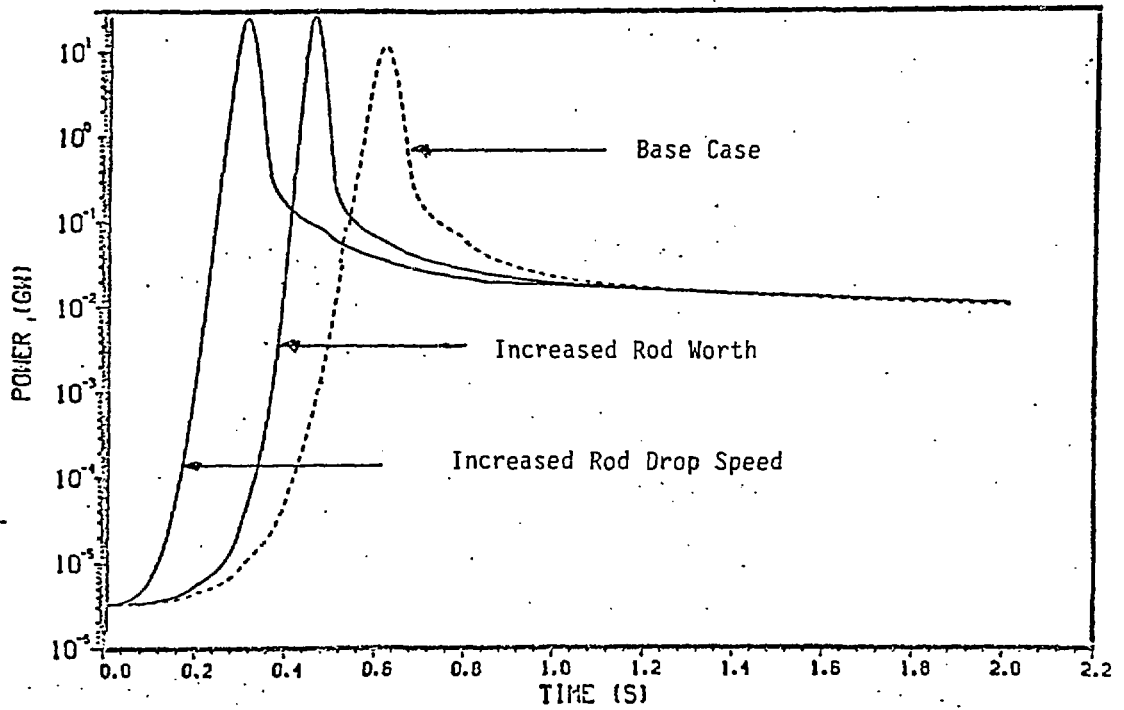


Figure 1. Core Power Transients for the BWR Off-Center RDA

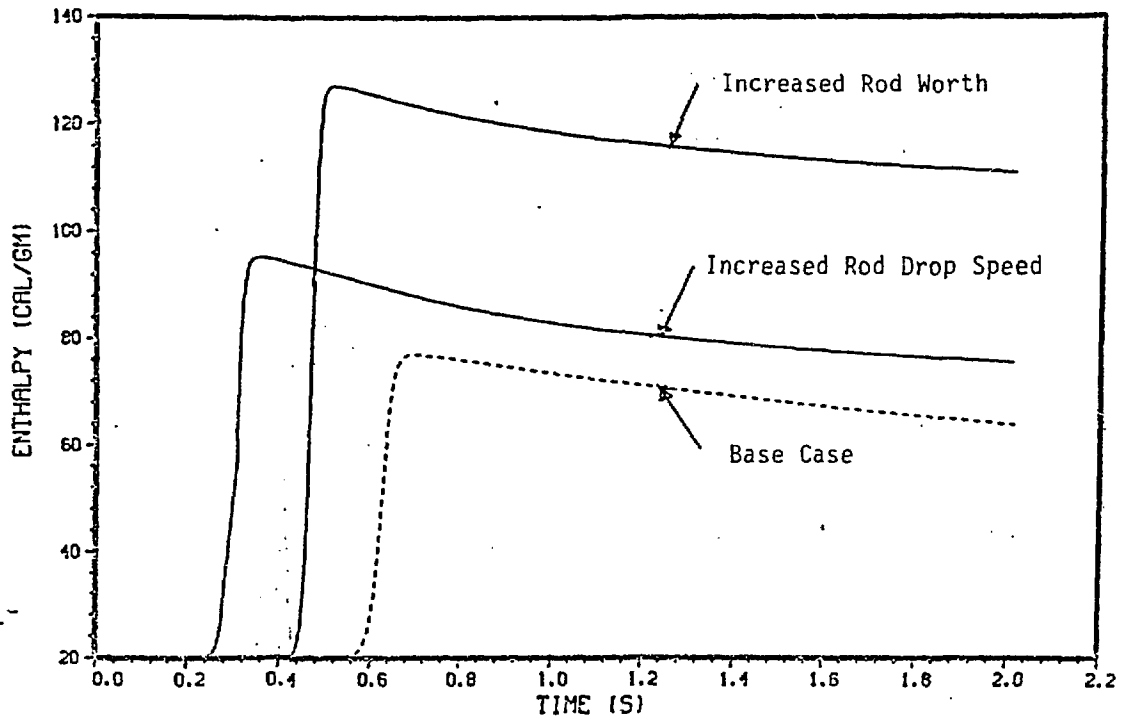


Figure 2. Peak Fuel Enthalpy Transients for the BWR Off-Center RDA