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Dynamic Behavior of a Subcooled BWR Core During a Rod-Drop Accident

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The techniques and models used in the study of rapid reactivity insertion in a BWR have ranged from approximate conservative methods with simple feedback models[1] to detailed representations of coupled neutronic thermal-hydraulic mechanisms[2]. In a recent paper Cheng and Diamond[3] presented a detailed evaluation of the control rod drop accident (CRDA). Their calculations suggested that the effect of inlet subcooling and rod drop speed may play an important role in determining the severity of the rod drop accident. The purpose of the work summarized in this paper has been to determine in detail the dynamic behavior of a BWR core as the inlet moderator temperature and the speed of the dropped rod are varied.

Knowledge of the effects of increased inlet subcooling is of interest since, during the approach to a hot standby condition from cold critical, a BWR core may be highly subcooled. On the other hand, an increase in the speed of the dropped rod, as expected, will result in a faster transient and lead to higher peak power and peak fuel enthalpy. A quantitive evaluation of these effects is necessary in establishing the severity of the CRDA.

Using a BWR-4 model at hot zero power (HZP) conditions a set of BNL-TWIGL[4] CRDA calculations has been carried out for inlet subcoolings ranging from saturation to 100°F for the case of a 5 ft/sec rod speed. In all cases moderator feedback was included and the dropped rod was taken to be the center rod with a static rod worth of $\sim 2\% \Delta k/k$. The core power response to a reactivity insertion of this magnitude at HZP is a large rapid power excursion at ~0.5 sec. which, in this case, is immediately terminated by Doppler and/or void feedback. In Fig. 1 the transient behavior of the reactivity components at saturation and at 50°F inlet subcooling are presented. The void, and to a lesser degree the Doppler reactivity can be seen to increase rapidly at ~0.5 sec. in order to reverse the rising power in the saturated case. However, in the 50°F subcooled case, the power rise is reversed almost entirely by the much stronger Doppler reactivity with the void reactivity being almost inconsequential in the mitigation of the accident due to the subcooled state of the core.

The variation of the peak fuel enthalpy and power as a function of subcooling is given in Fig. 2. The rapid rise in both these parameters, in the range between saturation and an inlet subcooling of 20°F is due to the decrease in the void feedback with the Doppler feedback becoming the dominant mechanism for limiting the power excursion as subcooling increases. It is important to note that in all cases the CRDA peak fuel enthalpy is well below the 280 cal/gm criterion.

In order to evaluate the effect of the rod drop speed on the CRDA peak fuel enthalpy and power BNL-TWIGL calculations were also performed with an increased rod drop speed of 15 ft/sec at saturation and an inlet subcooling of 20°F. It should be noted that a rod drop speed of 15 ft/sec is more than four times the average measured speed and represents an extreme case. Increasing the rod drop speed from 5 ft/sec to 15 ft/sec resulted in an ~140% increase in power for both the saturated and the 20°F subcooled cases. The corresponding increase in peak fuel enthalpy is ~30% and ~22%, respectively, for the two cases.

In summary, the dependence of the CRDA peak power and fuel enthalpy on the core inlet subcooling and rod drop speed have been determined. Both the peak power and fuel enthalpy are found to increase rapidly as a function of subcooling up to a subcooling of ~20°F and are relatively insensitive at higher subcoolings. The peak fuel enthalpy increased by $\lesssim$30% as the rod speed was increased from 5 ft/sec to 15 ft. sec. In all cases the peak fuel enthalpy was well below the 280 cal/gm criterion.

References

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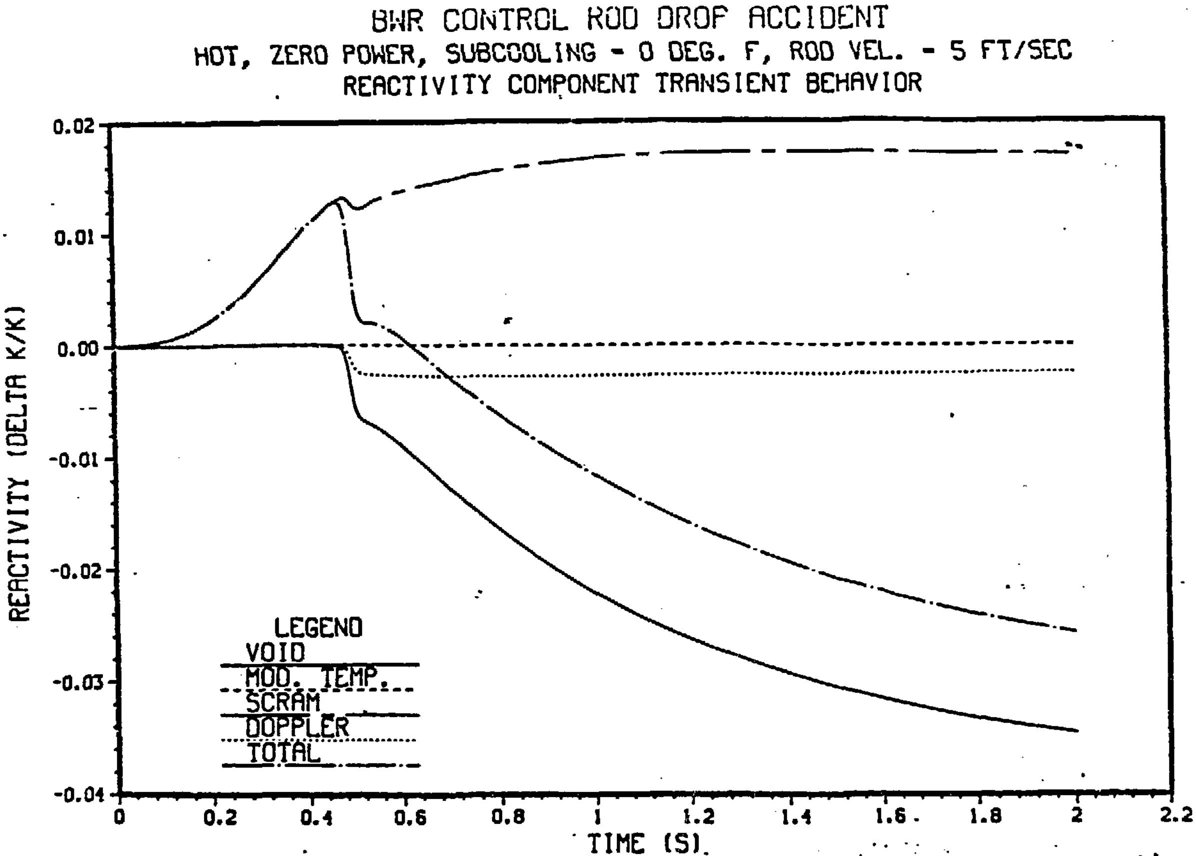

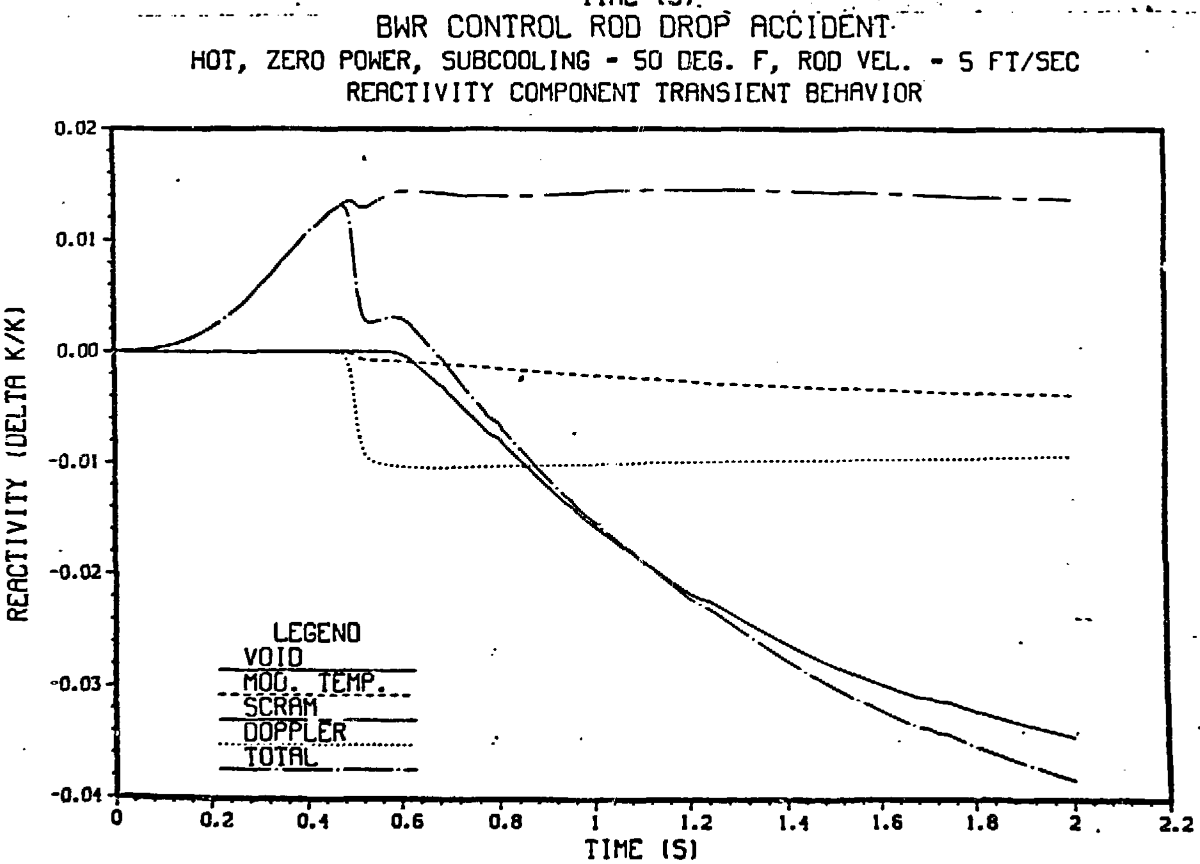

Fig. 1 Transient Behavior of the CRDA Reactivity Components at Saturation and at an Inlet Subcooling of 50°F

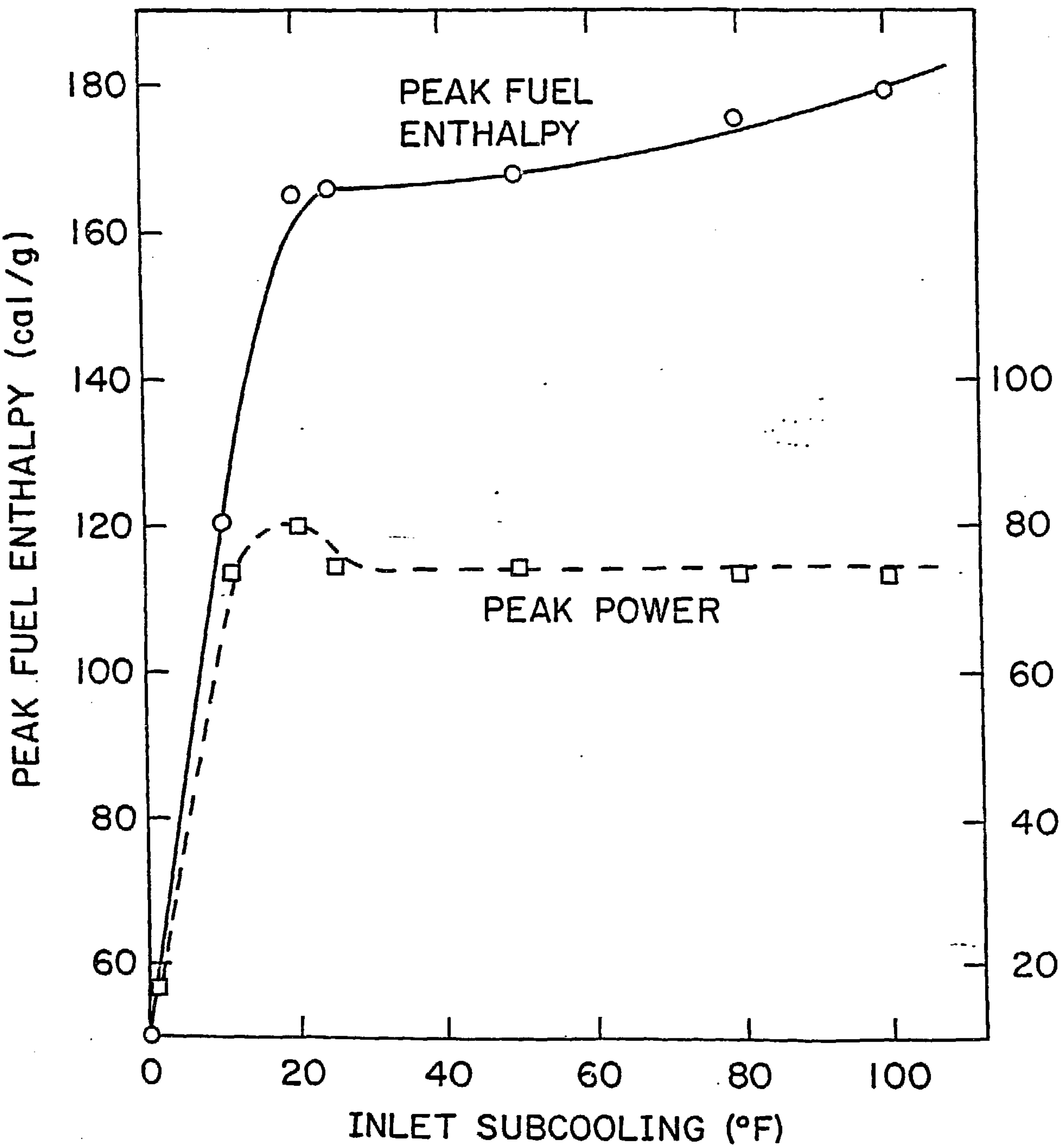
PEAK FUEL
ENTHALPY
PEAK POWER
PEAK FUEL ENTHALPY (cal/g)
PEAK POWER (GW)
INLET SUBCOOLING (°F)
180
160
140
120
100
80
60
100
80
60
40
20
0
20
40
60
80
100

Fig. 2