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TMI-2 Criticality Analysis - Parametric Studies and Overall Results*

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Three hypothetical disrupted core models were analyzed for the President's Commission on the Accident at Three Mile Island Unit 2. The analytical models and methods applied in this study are described in a companion paper.[1] The purpose of this paper is to provide a summary of the results obtained from preliminary parametric studies and from the analyses of the disrupted core models. Hopefully, the implications from these results are useful in planning plant recovery operations. However, the scope of this study did not include a quantitative determination of the probable condition of the reactor core or, on the other end, the development of recommendations for specific actions to assure the criticality safety of the plant. A detailed description of this study is given in Ref. 2.

One-dimensional, discrete-ordinates analyses were performed to study the reactivity effects of geometric changes in the fuel pins and the interstitial coolant. The core disruptive mechanisms studied were:

1. Fuel pin lattice-pitch reduction,
2. Fuel pin swelling, and
3. Conversion from pin cell geometry to homogeneous $U_3O_8 + UO_2 + H_2O + B$ mixtures.

These geometry changes can be generally characterized as variations in the water-to-fuel volume ratio. One limit to this variation is the case of an infinite medium of dry $U(2.96)O_2$ which has a multiplication factor of 0.66. Thus, some content of water and its associated neutron moderation must be present for the system to be critical.

Pressurized water reactor fuel is normally considered to be undermoderated, that is, at less than an optimum water-to-fuel volume ratio for maximum reactivity. Undermoderation can be inferred for the unborated water case shown in Fig. 1. Reducing the lattive pitch from the design value lowers the multiplication factor. However, for the "cold borated" situation, the opposite effect is observed. The most reactive lattice pitch is significantly less than the design value. Eventually, the negative reactivity due to the loss of water overtakes the positive reactivity due to the loss of boron and the system multiplication factor comes back down.

The same behavior was observed with fuel swelling and coolant displacement by ZrO_2. The overall effect for the transition region of the "Three Jump Slump" model was +5.5% k/k_1k_2 with slightly more than half of the positive reactivity being due to fuel swelling. An even larger effect is seen in converting from the pin cell to the homogeneous fuel geometry. The water-to-fuel volume ratio went from 1.65 to 0.46 and the reactivity increased by 8.2% k/k_1k_2. As a function of water-to-fuel volume ratio, undermoderation sets in at a value less than 0.6 for systems with 2400 wppm boron and at a value less than 0.4 for systems with 3180 wppm.

The results of the multidimensional core analyses are summarized in Table 1. Comparison of the multiplication factor for the cold-shutdown, normal-core base case with those for the three disrupted core models led to the following conclusions for this heavily borated system.

1. Positive reactivity insertions due to the various core disruptive mechanisms increased the sytem multiplication factor from approximately 0.74 to 0.86.

2. To a first order approximation, the increase in reactivity for the three models can be correlated with a decrease in the borated water-to-fuel volume ratio.

3. The reactivity worths of the control rods and lumped burnable poison rods are significantly reduced by the high soluble boron content in the reactor.

4. Although the core disruptive mechanisms have introduced significant positive reactivity insertions, the disrupted core is still shut down by a substantial margin.

REFERENCES

1. J. T. West, et al., "TMI-2 Criticality Analyses-Analytical Methods and Models," Proceedings of this conference.

2. R. M. Westfall, et al., "Criticality Analyses of Disrupted Core Models of Three Mile Island Unit 2," ORNL/CSD/TM-106 (1979).

Table 1. Summary of TMI-2 Multidimensional Core Analyses

Model	Case No.	Case Description	Monte Carlo Code	Multiplication Factor
As-built, normal core at cold shutdown with 3180 wppm boron	1a	Base configuration	KENO-IV	0.737 ± 0.006
	1b	Base configuration	MORSE-SGC/S	0.752 ± 0.007
	2	Case 1 with control rods out	MORSE-SGC/S	0.805 ± 0.006
	3	Case 1 with LBP rods removed	MORSE-SGC/S	0.778 ± 0.008
	4	Control and LBP rods out	MORSE-SGC/S	0.819 ± 0.007
"Three Jump Slump," Disrupted Core	5	Base configuration[a]	MORSE-SGC/S	0.862 ± 0.006
	6	Case 5 with control rods out	MORSE-SGC/S	0.875 ± 0.006
	7	Case 5 with LBP rods out	MORSE-SGC/S	0.868 ± 0.006
	8	Control rods and boron[b] out	MORSE-SGC/S	1.079 ± 0.012
	9	LBP rods and boron[b] out	MORSE-SGC/S	1.043 ± 0.010
	10	Control rods in, boron[b] out	MORSE-SGC/S	0.988 ± 0.011
"Displaced-Fuel Slump," Disrupted Core	11	Base configuration[c]	KENO-IV	0.845 ± 0.006
	12	Case 11 with control rods out	KENO-IV	0.870 ± 0.006
	13	Case 11 with boron[b] out	KENO-IV	1.080 ± 0.006
"In-Place Fuel Slump," Disrupted Core	14	25% swelling,[d] clad OD=1.179 cm	KENO-IV	0.807 ± 0.006
	15	50% swelling, clad OD=1.273 cm	KENO-IV	0.845 ± 0.005
	16	75% swelling, clad OD=1.360 cm	KENO-IV	0.840 ± 0.006
	17	100% swelling, clad OD=1.443 cm	KENO-IV	0.812 ± 0.073

[a] 13.5% of upper middle core collapsed as U_3O_8-UO_2-H_2O mixture, ZrO_2 distributed in coolant channels of lower core, fuel pins swollen by 30%.

[b] Boron remaining in homogeneous, fueled portions of reactor.

[c] Upper 50% of core collapsed as U_3O_8-UO_2-H_2O mixture, upper portions of control and LBP rods missing, lower half of core normal.

[d] Fuel height reduced to conserve fuel volume, clad volume constant, base configuration is Case 1A.

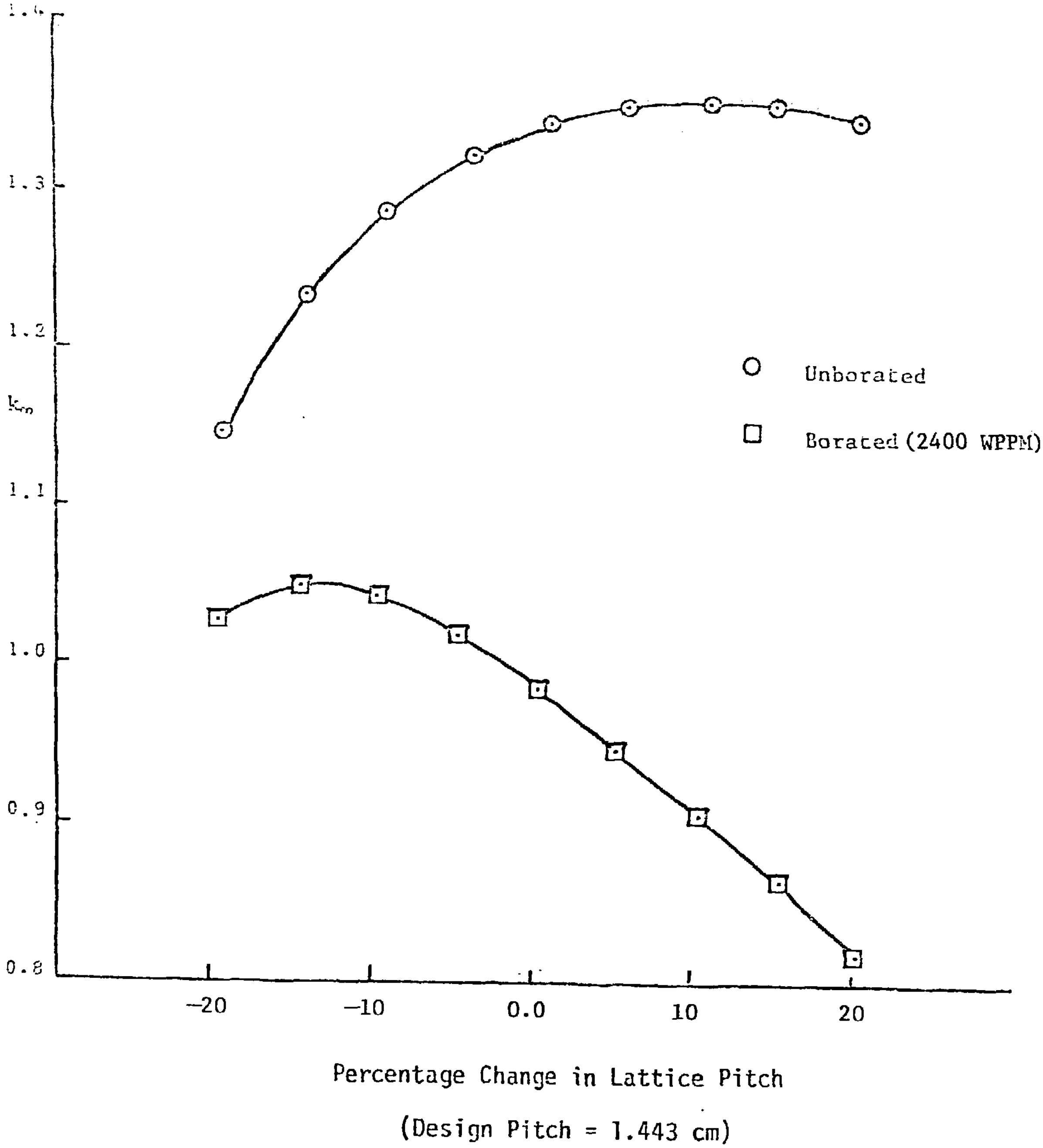

Fig. 1. TMI Infinite Lattice Pitch Variation