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<u>THI-2 Criticality Analysis - Parametric Studies</u> and Overall-Results*

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<u>TMI-2 Criticality Analysis - Parametric Studies</u> <u>and Overail Results</u>

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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/k₁k₂ 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/k₁k₂. As a function of water-tofuel 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.

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The results of the multidimensional core analyses are summarized in Table 1. Comparison of the multiplication factor for the coldshutdown, 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.

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REFERENCES

and the foregoing

- 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).

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| Model | Čase No. | Case Description | Monte Carlo Code | Nultiplication Factor |
|------------------------------|-------------|---|---------------------|--|
| As-built. normal | 1a | Base configuration | KENO-IV | 0.737 ± 0.006 |
| core at cold | 1b | Base configuration | MORSE-SGC/S | 0.752 ± 0.007 |
| shutdown with | 2 | Case 1 with control rods out | NORSE-SGC/S | 0.805 ± 0.006 |
| 3180 wppm boron | 3 | Case 1 with LBP rods removed | MORSE-SGC/S | 0.778 ± 0.008 |
| | 4 | Control and LBP rods out | NORSE-SGC/S | 0.819 ± 0.007 |
| "Three Tump | 5 | Rese configuration ^d | NOPSE-SGC/S | 0 862 + 0 006 |
| Slumn ["] Discupted | 5 | Case 5 with control rode out | NORSE-SGC/S | 0.802 ± 0.000 |
| Core | 7 | Case 5 with JBD rode out | HORSE-SGC/S | 0.868 ± 0.006 |
| | 2 Q | Control rode and horony out | MORSE SUC/S | 1 070 + 0 012 |
| | 0 | IPD rode and haron ^b out | HORSE SOC/S | 1.079 ± 0.012 1.043 ± 0.010 |
| | 10 | Control rods in, boron ^b out | MORSE-SGC/S | 0.988 ± 0.011 |
| | | | | |
| Displaced-Fuel | 11 | Base configuration | KENO-IV | 0.845 ± 0.006 |
| Slump," Disrupted | 12 | Case 11 with control rods out | KENO-IV | 0.870 ± 0.006 |
| Core | 13 | Case 11 with boron ^D out | KENO-IV | 1.080 ± 0.006 |
| "In-Place Fuel | 14 | 25% swelling, d clad OD=1.179 cm | KENO-TV | 0.807 ± 0.006 |
| Slump," Disrupted | 15 | 50% swelling, clad OD=1.273 cm | KENO-IV | 0.845 ± 0.005 |
| Core | 16 | 75% swelling, clad $OD=1$ 360 cm | KENO-IV | 0.840 ± 0.006 |
| | 17 | 100% swelling alad $OD=1$ 442 cm | VENO_TV | 0.812 + 0.072 |
| | т <i>і</i> | TOOM SWOTTING, CIAU OD-1.445 CM | VTIAN-T A | 0.012 - 0.015 |

Table 1. Summary of TMI-2 Multidimensional Core Analyses

^a13.5% of upper middle core collapsed as $U_3O_6-UO_2-H_2O$ mixture, ZrO_2 distributed in coolant channels of lower core, fuel pins swollen by 30%.

^bBoron remaining in homogeneous, fueled portions of reactor.

^CUpper 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.

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^dFuel height reduced to conserve fuel volume, clad volume constant, base configuration is Case 1A.



Fig. 1. TMI Infinite Lattice Pitch Variation