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TMI-2 Criticality Analysis - Analytical Models and Methods*

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The purpose of this paper is to describe the calculational models and analytical methods employed in a comprehensive study of reactivity effects due to hypothetical core disruptive mechanisms associated with the accident at Three Mile Island Unit 2. The TMI core design is described with regard to the heterogeneity arising from various fuel assembly configurations. Then the geometric lattice modeling capabilities of MORSE-SGC/S[1] and KENO-IV[2] are explained. After discussing the calculational difficulties and the analytical tools, the development of the disrupted core models is presented along with the procedure utilized in generating macroscopic cross sections. Verification of the analytical calculations includes a discussion on prior experience with the 27-neutron group cross section library[3] and results of a benchmark calculation of the reactor at the hot, zero-power start-up condition.

The TMI core (see Fig. 1) is a Babcock & Wilcox 177 fuel assembly plant containing three fuel enrichments; 1.98 wt %, 2.64 wt %, and 2.96 wt %. Each assembly may contain one of three types of lump burnable poison rods, two types of control rods, or stainless steel orifice rods. Preservation of the assembly loading pattern was considered to be essential in studying reactivity changes due to disruptive core mechanisms.

The multiple array lattice capability of MORSE-SGC/S with the new MARS geometry system and the single array capability of KENO-IV with the MIXED BOX geometry system allowed pin by pin modeling of the TMI design core and several postulated disrupted core models. The most complicated model was done with MARS geometry which allows multiple array modeling, unlimited array nesting, arbitrary vacancies in arrays, and array repetition by both translation and rotation. The simpler models were done with the KENO MIXED BOX geometry which allows modeling a single KENO array without repetition. The KENO analysis was performed to validate and back-up the MORSE-SGC/S effort. It also gave significant additional insights into the reactivity effects of specific core disruptive mechanisms.

The Three Jump Slump Model studied with MORSE-SGC/S was designed to incorporate all of the core disruptive mechanisms in an internally consistent manner; fuel swelling in lower half of core and conical fuel slumping in upper half of core with a transition region in the middle of the core. This model (see Fig. 2) contained 990 short assemblies of 15X15X1 pins each. The Three Jump Slump core was modeled as a 15X15X7 array of subarrays and bulk material regions using the MARS geometry system.

The Displaced Fuel Slump Model studied with KENO-IV features uniform fuel slumping without fuel swelling. The In-Place Fuel Slump Model features pin swelling without any fuel density changes or clad failure. The Displaced Fuel Slump Model and the In-Place Fuel Slump

Model were each based upon a 120X120X1 KENO MIXED BOX orientation array representing all pin lattice locations in the quarter core geometry of Fig. 1. The program MAKARAY was written to generate the KENO MIXED BOX input.

All of the analyses utilized the SCALE 27 neutron group cross section library based on ENDF-IV. The resonance isotopes were corrected for resonance self shielding via the Nordheim Integral treatment[4] in the NITAWL code. Prior criticality studies[5] using this library on several EPRI critical experiments[6] indicated that for the coolant to fuel volume ratio and corresponding lattice pitch of the TMI design core, the K-effective calculated would range from 0.98 and 0.99.

Pin by pin models of the TMI design core (as-built) were analyzed with MORSE-SGC/S and KENO-IV. As anticipated with the 27 group library, the MORSE computed K-effective was 0.987 ± 0.003 and the KENO computed K-effective was 0.983 ± 0.006. Calculated control rod worths agreed well with measured values. This hot, zero-power start-up benchmark analysis provided a verification of the analytical methods and modeling techniques for the subsequent disrupted core analyses.

References

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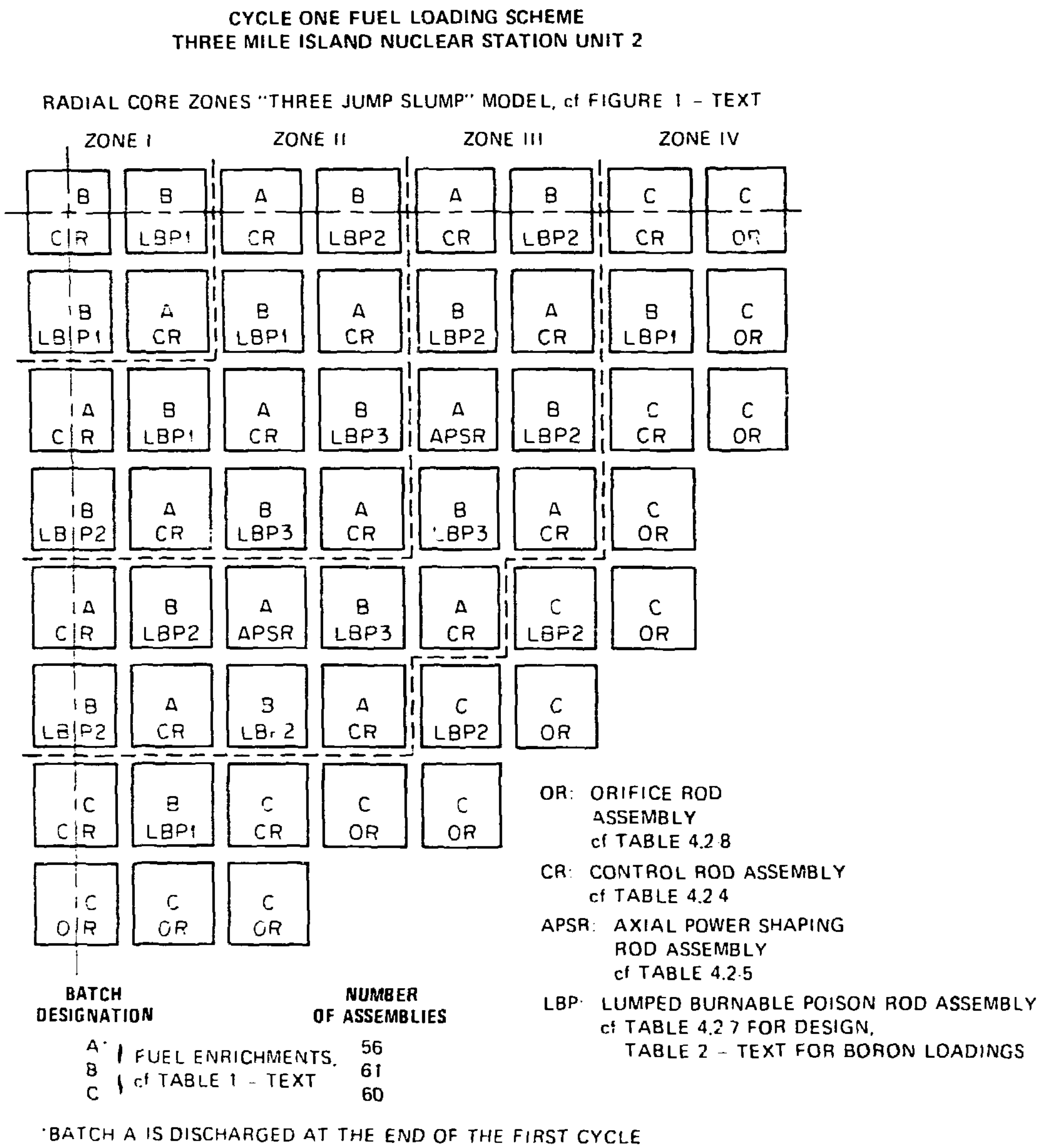

Fig. 1. Cycle One Fuel Loading Scheme
Three Mile Island Nuclear Station Unit 2

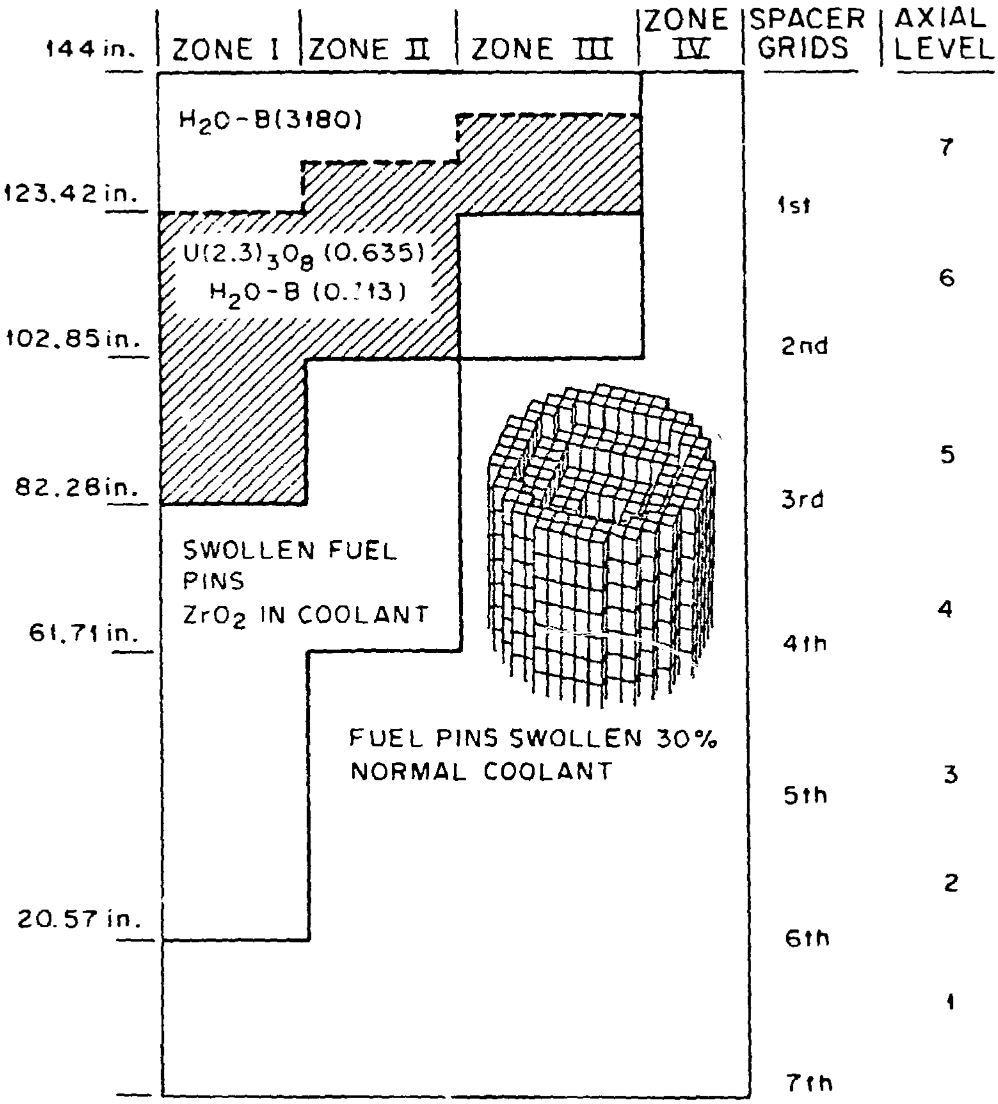

Fig. 2. MORSE-SGC/S Three Jump Slump Core Model