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March 15, 1985

Docket No. 50-320

Mr. F. R. Standerfer
Vice President/Director
Three Mile Island Unit 2
GPU Nuclear Corporation
P.O. Box 480
Middletown, PA 17057

Dear Mr. Standerfer:

By letter (4410-84-L-0199) dated November 8, 1984, you forwarded the "Reactor Coolant System Criticality Report." This report provides the criteria and rationale used for the selection of a boron concentration for the reactor coolant system (RCS) which will ensure that the fuel in the RCS will remain subcritical with a shutdown margin of at least one percent ($K_{eff} \leq 0.99$) for any conceivable core configuration. The report concludes that an RCS boron concentration of 4350 ppm will provide the stated shutdown margin (i.e., at least one percent) throughout all reactor disassembly and defueling activities.

The "Criticality Report" was reviewed by the NRC Core Performance Branch (CPB) and the CPB evaluation is enclosed. As discussed in the enclosure, the staff concludes that an RCS boron concentration of 4350 ppm will assure at least one percent shutdown margin for the hypothetical conservative fuel model assumed in your analysis. We note that your maintenance of an "operating" RCS boron concentration of approximately 5000 ppm will provide a significantly larger real shutdown margin, and a corresponding degree of enhanced safety, as you conduct reactor disassembly and defueling operations.

Sincerely,

Original signed by
B. J. Snyder

Bernard J. Snyder, Program Director
Three Mile Island Program Office
Office of Nuclear Reactor Regulation

Enclosure:
As stated

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ENCLOSURE

A REVIEW OF A CRITICALITY REPORT FOR TMI-2

A letter from F. Standerfer, TMI-2, GPU Nuclear, to B. Snyder, NRC, dated November 8, 1984 enclosed a report, "Criticality Report for The Reactor Coolant System at TMI-2", October 1984. The purpose of the report was to "explain the criteria and rationale used for establishing a boron concentration for the RCS which supports a shutdown margin of at least one percent under any conceivable core configuration". This is a brief review of that report by the Core Performance Branch, NRR.

The report presents in reasonable detail discussions in the following areas involved in developing a selection of a moderator boron level to be specified for future TMI-2 operations (including defueling).

1. A bounding approach ("infinite poison") to maintain subcriticality for all achievable configurations

2. A criterion for a suitable boron concentration; one percent subcritical for "bounding" model with uncertainty

3. "Bounding" physical model which is conservative compared to achievable configurations

4. Calculation methods and cross sections

5. Search for and calculation of relevant nuclear experiments to check methods

6. Uncertainty determination for calculations from experimental comparisons

7. Determination of suitable fuel burnup and fission product characteristics

8. Calculations for selected "bounding" model and other models for sensitivity studies

9. Results

We have examined the material presented in these areas and conclude (in brief) that appropriate and conservative approaches, criteria, physical models, calculational methods and data, experiments, uncertainty analyses and sensitivity analyses have been considered, selected and used, and the results and conclusions are acceptable. A brief elaboration or comment on these areas follows.

1. The approach selected is to use a sufficiently high boron level in the moderator ("infinite poison") to meet a subcritical criterion (see 2.) for any "reasonably" conceivable ("bounding", see 3.) fuel configuration. This is certainly a conservative approach (although somewhat dependent on the nature of the "bounding" configuration). The resulting "reasonably" conceivable configuration does not go as far as an infinite array of geometrically optimized, unburned, high enrichment fuel, but the "bounding" model does use all of the fuel in an appropriately maximized, conservative configuration (3). There will be more comments on the relation to an infinite array when we discuss results (9).

2. The shutdown criterion, i.e., sufficient boron to assure one percent shutdown for any state and fuel configuration (and specifically based on a "bounding" configuration) and including allowance for uncertainty in calculations, is somewhat arbitrary but reasonable and appropriate considering usual shutdown margin requirements. The "bounding" and uncertainty requirements should provide a much larger shutdown margin in any real condition. In the boron range of interest (4000-5000 ppm) the boron worth is about 300 ppm/%Δk and any boron dilution event would have to be extensive (from the criterion level of 4350 or the expected normal operating level of 5050 ppm) to reach critical.

3. The physical "bounding" model involving a lenticular core comprising all of the fuel, optimized fuel particle size and shape, optimized fuel/moderator ratio, no structure or solid poison, a central core containing all of the high enrichment fuel with appropriate burnup (no burnup for other fuel) and an optimized stainless steel reflector is certainly highly conservative compared to any reasonably achievable configuration. It was the product of an extensive geometry and material reactivity sensitivity analysis. Our review indicates that it can be considered an appropriate "bounding" model, and it does not differ greatly in reactivity from other more conservative models, e.g., spherical or infinite (see 9. for some quantitative comparisons to other configurations.

4. The computer codes used for calculations of reactivity or multiplication, primarily the Monte Carlo code KENO along with the transport code XSDRN (for sensitivity studies and parallel checks), and the cross section sets, are basic state of the art methodology with considerable background of use at ORNL (and elsewhere) for various criticality studies, and are fully acceptable.

5. Although the methods had been used for many criticality studies, it was felt that additional confirmation of the methodology for high density boron and close packed fuel arrays was needed. Extensive searches were done for relevant experiments and comparison calculations were made to develop additional confidence and quantitative uncertainty levels. Our review indicates that an impressive investigation of relevant experiments was conducted and a suitable analysis and confirmation of the methodology and uncertainty was carried out. Our review did not involve specific check calculations (e.g., by our BNL consultants), but we did compare some previous BNL results in this area (see reference 4 of the report) with some results from the report, using some of the sensitivity studies for extrapolation. They were in reasonable agreement. We expect

the calculation results given in the report to be reasonably correct.

6. The results of the specific experiment calculations and previous relevant calculations were examined and a conservative uncertainty of 2.5 percent delta k to be applied to results was determined. This process was discussed in detail in the report. Our review concludes that a suitably conservative uncertainty factor was determined and the result seems reasonable based on other similar work we have seen.

7. Credit was taken in the model for fuel burnup only for the central region high enrichment fuel. Other fuel was assumed unburned. (There was, of course, no burnable poison in the model.) Some fission product poison for the burned fuel was also used, but only after an extensive investigation of which isotopes would still be with the fuel. Also included were plutonium buildup and the decay of various isotopes since the event. We have concluded that a thorough study of burnup effects was done and a conservative model was used.

8. An extensive set of calculations was done to explore material configurations and the sensitivity of results to parameters such as boron level, fuel/moderator ratio, fuel burnup and isotopes present, temperature, and reflector. Our review indicates that, given the approach and model used, a complete and useful exploration was performed.

9. The "bounding" model (3.) meets the criterion (2.) with a boron content of 4350 ppm. The present TMI-2 boron content is about 5050 ppm and this is expected to continue during the defueling operations. The following table gives multiplication values (for the most part our estimates using report values and sensitivities) at 4350 and 5050 ppm for several configurations beginning with an ultimate maximum (an infinite array of high enrichment, optimum fuel pellets, at optimum moderator ratio), and leading by steps to the "bounding" model. This presents, briefly, some concept of sensitivities and margins involved.

Some steps have no listed k values since the information is not available, but are included to indicate full progression from maximum to chosen state.

		Calculated (or estimated) nominal k with B@	
		4350 ppm	5050 ppm
1.	infinite array of high enrichment, unburned, optimized fuel and moderator	1.007	0.985
2.	sphere of (from center) high, medium, low enrichment fuel, SS reflector, with radially "non uniform" optimized fuel and moderator	-	-
3.	2. with uniform optimized rubble	-	-
4.	3. with medium and low enrichment mixed	0.984	0.962
5.	4. with high enrichment burned	0.968	0.946
6.	5. with lenticular shape	0.965	0.943
7.	6. with 2.5% uncertainty added	0.990	0.968

We can note from the table that the change from sphere to lenticular is only 0.3 percent so that the "bounding" shape is not significantly far from optimum (in addition to being justifiably conservative). The use of burned high enrichment fuel is worth about 1.6 percent (about 500 ppm B), a significant amount, but is a known to exist phenomenon, conservatively calculated.

The change from the "bounding" type spherical geometry to an infinite array of high enrichment, about 2 percent, while significant, is sufficiently small to indicate no great importance to a radially non uniform moderator ratio (potential) problem. Even for an infinite array the system would be (nominally) subcritical with the expected 5050 boron level. To go from the "bounding" model to a "real" model would involve changes providing less optimum conditions (probably simultaneously) for the gross geometrical configuration, fuel enrichment geometrical arrangement, fuel amount, fuel particle size, moderator ratio, structural material present and solid poison present. Our review indicates that the "bounding" model is indeed satisfactory and conservative and that 4350 ppm boron should maintain subcriticality with sufficient margin.

We conclude that the work described in the report represents an excellent job in exploring the problems of criticality for TMI-2 defueling, including the areas of geometry selection, parameter selection, calculation methodology and uncertainty analysis. The resulting analysis leading to a selection of 4350 ppm boron as a minimum level for operation is fully satisfactory and should "ensure subcriticality through all reactor disassembly and defueling operations". In particular it should "assure at least one percent shutdown margin for an appropriate design basis fuel model."