APPENDIX B
4410-89-L-0070
13 pages

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US Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Dear Sirs:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Criticality Safety Evaluation for
Increasing the TMI-2 Safe Fuel Mass Limit

Attached for NRC review is the Criticality Safety Evaluation for Increasing the TMI-2 Fuel Mass Limit. This analysis demonstrates that the critical mass for TMI-2 fuel can be increased from the current administrative limit of 70 kg to 140 Kg.

The attached evaluation will be used as a baseline document in support of evaluations of future defueling activities and the Defueling Completion Report. It will be used to demonstrate subcriticality in the various areas of TMI-2 and that transition from Facility Mode 1 to Facility Mode 2, as defined by the TMI-2 Technical Specifications, can take place.

Sincerely,

/s/ R. E. Rogan for

M. B. Roche
Director, TMI-2

RDW/emf

Attachment

cc: D. M. Johnson - Acting Senior Resident Inspector, TMI
W. T. Russell - Regional Administrator, Region I
J. F. Stolz - Director, Plant Directorate I-4
L. H. Thonus - Project Manager, TMI Site

# SAFETY ANALYSIS

SA No. 4710-322?-89-?

Rev. No. 0

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# TITLE

CRITICALITY SAFETY EVALUATION FOR

INCREASING THE TMI-2 SAFE FUEL MASS LIMIT

Originator ____________ Date ?/?/89

CONCURRENCE

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Design Cognizant Engineer ____________ Date 1/31/89 Rad Con N/A Date ____________

APPROVAL

Mgr Eng. Section Paul J Korlin Date 2/8/89 Site Ops Director ____________ Date ?/?/?

**GPU Nuclear**

No. 4710-3220-89-1

Title: Criticality Safety Evaluation for Increasing the TMI-2 Safe Fuel Mass Limit



| Rev. | SUMMARY OF CHANGE | Approval | Date |
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| 0 | Initial submittal. | [illegible] | 2/89 |

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# CRITICALITY SAFETY EVALUATION FOR INCREASING THE TMI-2 SAFE FUEL MASS LIMIT

## 1.0 INTRODUCTION

### 1.1 Background

In the early stages of the TMI-2 cleanup activities, analyses were performed to establish limits on the amount of fuel debris that could collect in any plant component without posing a criticality safety concern (Reference 1). The significant assumptions used in the analysis included a fuel enrichment of 3% $U^{235}$, unborated water reflection and moderation and a maximum fuel rod diameter of 0.4 inches. The 3% enrichment corresponds to the unburned condition of the highest enriched batch 3 fuel. The unburned enrichments for the other fuel batches at TMI-2 were batch 1 (i.e., 1.98%) and batch 2 (i.e., 2.64%).

Based on the compilation of data presented in Reference 2, Reference 1 reported that the minimal critical mass for unborated water reflected and moderated 3% $UO_2$ fuel rods of a maximum diameter of 0.4 inches was 93 kg of $UO_2$. A factor of safety of approximately 75% was then applied, thus, establishing the criticality safe fuel mass for the TMI-2 defueling operations at 70 kg. This limit provided the criterion for the maximum amount of fuel which could collect in an isolated unit and remain subcritical regardless of what other parameters changed. This limit has been applied to the various defueling activities unless it was demonstrated by a specific evaluation that a larger mass would be maintained subcritical.

### 1.2 Purpose

The purpose of the present evaluation is to develop a refined safe fuel mass limit for use at TMI-2 during the remaining defueling activities and in evaluating long-term storage conditions (i.e., Post-Defueling Monitored Storage, Mode 4). This limit is developed based on more realistic and, consequently, less conservative assumptions than those used in the Reference 1 analyses. Justification for using these less conservative assumptions is provided by the significant data that have been collected from debris samplings, video inspections, and other defueling data which were unavailable at the time of the Reference 1 analyses. These data provide a better understanding of the accident scenario and the actual debris configuration and composition, thus, permitting a refined and more realistic modelling of the fuel debris.

### 1.3 Criterion for Allowable Fuel Mass

The criterion used to establish the acceptability of a quantity of fuel is that the calculated neutron multiplication ($K_{eff}$) did not exceed 0.99, including a computer code uncertainty bias. This acceptance criterion is consistent with the previous licensing basis for the RCS during defueling (References 3, 4, and 5).

## 2.0 MODELLING

### 2.1 Geometrical Considerations

The safe generic fuel mass limit model developed for this evaluation is shown in Figure 1. As noted from this figure, the innermost region of the model consisted of a mixture of unborated water and fuel debris. A spherical geometry was chosen in an effort to minimize the surface area to volume ratio, thus, maximizing the neutron multiplication. Surrounding the fuel region was an effectively infinitely thick (approximately 12 inches) unborated water reflector. The radius of the innermost region was varied until the calculated $K_{eff}$ (including a 2.5% $\Delta k$ uncertainty bias; see Section 3.2) reached the licensing limit of 0.99.

### 2.2 Fuel Model

As with previous criticality safety analyses for TMI-2 (References 3, 4, and 5), the fuel was represented as a homogeneous medium for which the neutronic data corresponded to a dodecahedral lattice structure of spherically shaped fuel pellets. The composition of the fuel was assumed to be TMI-2 average fuel (i.e., the homogeneous mixture of the three fuel batches). This homogeneous mixing of three fuel batches is considered conservative as defueling data indicates that most of the batch 3 fuel (at least approximately 65%) has been removed from the Reactor Vessel. Consequently, any remaining fuel is expected to consist primarily of batches 1 and 2 fuel. A more detailed justification for the homogeneous mixture is provided in Reference 5.

As with the Reference 5 analyses, burnup effects were considered in all three fuel batches. In each fuel batch, the effects of uranium depletion, fissionable plutonium generation, and rare earth fission product production were considered. The procedure used for the quantification of batches 1 and 2 burnup was similar to that previously used for the batch 3 fuel (see Reference 3) using the actual exposure histories for batches 1 and 2. The result of this incorporation of the burnup produced a net $U^{235}$ enrichment of 2.24% for the homogeneous mixture. The composition of the fuel used in the analysis is provided in Table 1.

The equivalent of standard full-sized fuel pellets were used for the fuel particle size. Additional evaluations were performed with smaller fuel particle sizes to assess the conservatism associated with assuming full pellets. It is recognized that fuel particle sizes greater than the standard pellets can exist due to fuel melting. However, sample data have shown that it is not credible that these particles will be pure $UO_2$ (References 6 and 7). The composition of this resolidified fuel material will also include impurities (e.g., zircaloy, iron, boron, etc.) Previous studies have shown that such impurities will result in a reduction in $K_\infty$ when compared to standard size fuel pellets (see Reference 5). Consequently, it was considered appropriately conservative to use standard size fuel pellets.

For conservatism, unborated water was assumed for the moderating medium. The fuel volume fraction (VF) used for all analyses in this evaluation corresponded to optimum moderation for an infinite lattice of the fuel pellets (VF=0.28). Additionally, no credit was taken for any impurities that exist in the fuel debris (e.g., control rod and structural material).

## 2.3 Conservatisms

In the development of the criticality safety model for this evaluation, conservative assumptions were utilized. These conservatisms include:

- Unborated water, in an optimal mixture with fuel debris, was assumed for the moderating medium.
- No credit was taken for the large amount of structural and solid poison materials existing in the debris.
- The equivalent of full standard sized fuel pellets was utilized.
- A spherical geometry, which minimizes the ratio of surface area to volume, thus maximizing $K_{eff}$, was utilized.
- The fuel was represented as TMI-2 average fuel (homogeneous mixture of all three fuel batches) which sample data has supported as being conservative.
- An effectively infinite water reflector was assumed.

# 3.0 RESULTS

## 3.1 Allowable Masses

The results of the analyses performed for this evaluation are shown in Table 2. Each of the reported masses represents the amount of $UO_2$ of the corresponding particle size which, when moderated with unborated water (VF=0.28), will result in a calculated $K_{eff}$ of 0.990 (including a 2.5% Δk uncertainty bias). These results are also provided graphically in Figure 2. Based on these results, a maximum allowable fuel mass of 140 kg is adopted.

The standard sized fuel particle case was performed by Oak Ridge National Laboratory (ORNL) using the computer program XSDRNPM (Reference 8) and was reported in Reference 9. The results presented for particle sizes less than the standard size pellets were developed by incorporating ORNL-provided $K_{\infty}$ data for smaller particles in near optimum moderation conditions into hand calculations employing the age-diffusion theory equations (Reference 10). Though these hand calculations are approximate, the results clearly indicate that the allowable fuel mass significantly increases as particle size decreases.

One of the most obvious results of the analyses is that the maximum allowable fuel limit (140 kg based on fuel pellet particle size) essentially doubles the 70 kg limit that was established in Reference 1. Although a different analytical technique was used to develop the initial

70 kg value, the main reason for the increase in the amount of allowable fuel in the current evaluation is that the net $U^{235}$ enrichment in the current evaluation (2.24%) was lower than the Reference 1 enrichment (3%). Two factors contributing to this lower enrichment were the assumed mixing of the three fuel batches (even though most of batch 3 fuel has been removed from the vessel) along with the incorporation of fuel burnup effects in all three fuel batches. As stated previously, the burnup effects incorporate selected fission products, some of which are strong neutron absorbers.

The refined analytical technique used in the present evaluation did not significantly contribute to the difference in the allowable mass. The $K_{eff}$ criterion established for the present evaluation (0.99 including a 2.5% Δk uncertainty bias) yields an allowable mass that is approximately 75% of the minimum critical mass in this case. The criterion for allowable mass in the former evaluation was 75% of the minimum critical mass for that case.

### 3.2 Computer Code Benchmarking

In Reference 3, an analytical uncertainty bias of 2.5% Δk, including the KENO V.a (Reference 11) statistical uncertainty, was established as an appropriate value for the highly borated systems being investigated in that report to define a safe boron concentration for the TMI-2 defueling program. Uncertainty values reported in the literature for unborated systems have been shown to be somewhat lower than this value (Reference 12). Consequently, the 2.5% Δk value is considered conservative for the criticality safety analyses provided in this evaluation. This bias is also considered acceptable and applicable for the XSDRNPM analyses performed in this evaluation since previous analyses (References 3 and 4) demonstrate the good agreement between the results generated by these codes.

## 4.0 CONCLUSIONS AND LIMITATIONS

The results of this evaluation have been utilized to develop the following fuel debris limit. For isolated accumulations of fuel debris (i.e., those accumulations for fuel that will remain physically and neutronically decoupled from other fuel accumulations) a maximum of 140 kg can exist without posing a criticality safety concern. Consequently, the safe fuel mass limit for these accumulations is increased to 140 kg. Fuel accumulations are considered neutronically decoupled if the equivalent of 12 inches of water separates the accumulations (Reference 13.)

The above conclusion is not considered applicable in cases where the fuel debris is surrounded by a thick lead reflector (e.g., the shipping cask), as under certain conditions lead can be a better neutron reflector than unborated water. In such cases, separate evaluations will be performed. Additionally, separate evaluations will be performed if it is determined that the Reactor Vessel contains areas that have fuel quantities that exceed the limitations of this report.

## 5.0 REFERENCES

1. Appendix to Technical Plan, "Ex-RCS Criticality Safety," TPO/TMI-132, Revision 1, November 1985.

2. H. K. Clark, "Critical and Safe Masses and Dimensions of Lattices of U and $UO_2$ Rods in Water," DP-1014, February 1966.

3. Criticality Report for the Reactor Coolant System, Revision 0, 15737-2-N09-001, October 1984.

4. Report on Limits of Foreign Materials Allowed in the TMI-2 Reactor Coolant System During Defueling Activities, Revision 1, 15737-2-N09-002, September 1985.

5. Criticality Safety Assessment for Using the Plasma Arc Torch to Cut the Lower Core Support Assembly, Revision 1, 15737-2-N09-004, November 1987.

6. Examination of Debris from the Lower Head, GEND-INF-084, January 1988.

7. TMI-2 H8A Core Debris Examination - Final, GEND-INF-060, Vol. 2, May 1985.

8. N. M. Greene and L. M. Petrie, "XSDRNPM-S: A One-Dimensional Discrete Ordinates Program for Transport Analysis," included as Sect. F3 in SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, Vols. 1-3, NUREG/CR-0200, U.S. Nuclear Regulatory Commission (originally issued July 1980; reissued January 1982; Revision 1 issued July 1982; Revision 2 issued June 1983; Revision 3 issued December 1984).

9. Letter, B. L. Broadhead (ORNL) to D. S. Williams (GPU Nuclear), September 29, 1988.

10. S. Glasstone and A. Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Ltd., 1967.

11. L. M. Petrie and N. F. Landers, "KENO V.a: An Improved Monte Carlo Criticality Program with Super-Grouping," included as Sect. F11 in SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation, Vols. 1-3, NUREG/CR-0200, U.S. Nuclear Regulatory Commission (originally issued July 1980; reissued January 1982; Revision 1 issued July 1982; Revision 2 issued June 1983; Revision 3 issued December 1984).

12. R. M. Westfall, et. al "TMI Criticality Studies: Lower Vessel Rubble and Analytical Benchmarking," GEND-071, May 1986.

13. Nuclear Safety Guide, TID-7016, Revision 2, J. T. Thomas Ed., June 1978 (Page 27).

# TABLE 1

## FUEL MODEL COMPOSITION

| ISOTOPE | NUMBER DENSITY (ATOMS/BARN-CM) |
|---|---|
| U-235 | 5.21 E-04 |
| U-238 | 2.25 E-02 |
| O-16 | 4.60 E-02 |
| Pu-239 | 4.01 E-05 |
| Pu-240 | 2.00 E-06 |
| Pu 241 | 2.49 E-07 |
| Sm-149 | 1.01 E-07 |
| Sm-151 | 1.79 E-07 |
| Eu-151 | 8.20 E-09 |
| Eu-153 | 1.32 E-07 |
| Eu-154 | 4.51 E-09 |
| Eu-155 | 6.12 E-09 |

NOTE: Only the more significant isotopes are listed above.

TABLE 2

ALLOWABLE FUEL MASSES FOR VARIOUS FUEL PARTICLE SIZES

| SPHERICAL FUEL PARTICLE DIAMETER (CM) | ALLOWABLE MASS (KG) |
|---|---|
| 1.07 (standard pellet) | 141 |
| 1.00 | 142 |
| 0.75 | 149 |
| 0.50 | 157 |
| 0.40 | 164 |
| 0.30 | 170 |
| 0.20 | 178 |
| 0.10 | 188 |
| 0.00 (fully homogenous) | 198 |

FIGURE 1

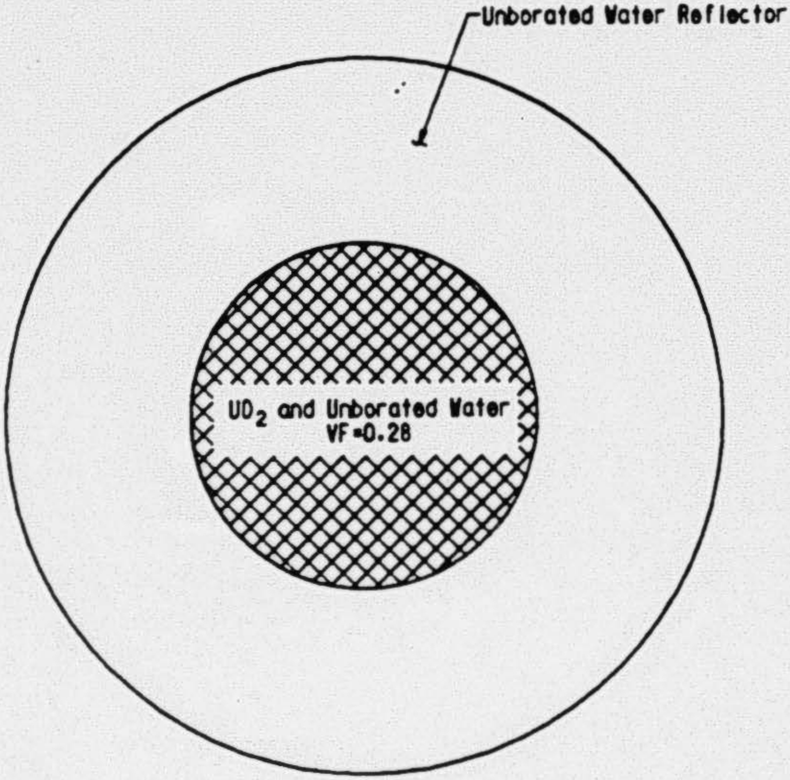


FIGURE 1: GENERIC SPHERE MODEL

Note:
For full pellet case the radius of inner fuel/water region is 22.7 cm, the outer radius is approximately 53 cm.

Figure 2

ALLOWABLE FUEL MASS (kg)